Prepared in cooperation with the South Carolina Department of Transportation

Characterization of Stormwater at Selected South Carolina Department of Transportation Maintenance Yard and Section Shed Facilities in Ballentine, Conway, and North Charleston, South Carolina, 2010–2012

Scientific Investigations Report 2013–5175

U.S. Department of the Interior
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SALLY JEWELL, Secretary

U.S. Geological Survey
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Excel files available for download at http://pubs.usgs.gov/sir/2013/5175/

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic inch (in^3)	16.39	cubic centimeter (cm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon per day per square mile [(gal/d)/mi^2]	0.001461	cubic meter per day per square kilometer [(m^3/d)/km^2]
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallons per day per square mile [(Mgal/d)/mi^2]	1,461	cubic meter per day per square kilometer [(m^3/d)/km^2]

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:

$$°C=(°F-32)/1.8$$

The vertical geodetic datum used is the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83), Universal Transverse Mercator projection, zone 17.

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

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

Characterization of Stormwater at Selected South Carolina Department of Transportation Maintenance Yard and Section Shed Facilities in Ballentine, Conway, and North Charleston, South Carolina, 2010–2012

By Celeste A. Journey and Kevin J. Conlon

Abstract

The South Carolina Department of Transportation operates section shed and maintenance yard facilities throughout the State. The U.S. Geological Survey conducted a cooperative investigation with the South Carolina Department of Transportation to characterize water-quality constituents that are transported in stormwater from representative maintenance yard and section shed facilities in South Carolina. At a section shed in Ballentine, S.C., stormwater discharges to a retention pond outfall (Ballentine). At the Conway maintenance yard, stormwater in the southernmost section discharges to a pipe outfall (Conway1), and stormwater in the remaining area discharges to a grass-lined ditch (Conway2). At the North Charleston maintenance yard, stormwater discharges from the yard to Turkey Creek through a combination of pipes, ditches, and overland flow; therefore, samples were collected from the main channel of Turkey Creek at the upstream (North Charleston1) and downstream (North Charleston2) limits of the North Charleston maintenance yard facility.

The storms sampled during this study had a wide range of rainfall amounts, durations, and intensities at each of the facilities and, therefore, were considered to be reasonably representative of the potential for contaminant transport. At all facilities, stormwater discharge was significantly correlated to rainfall amount and intensity. Event-mean unit-area stormwater discharge increased with increasing impervious surface at the Conway and North Charleston maintenance yards. The Ballentine facility with 79 percent impervious surface had a mean unit-area discharge similar to that of the North Charleston maintenance yard (62 percent impervious surface). That similarity may be attributed, in part, to the effects of the retention pond on the stormwater runoff at the Ballentine facility and to the greater rainfall intensities and amounts at the North Charleston facility.

Stormwater samples from the facilities were analyzed for multiple constituents and characteristics. Concentrations of sediment and concentrations of nutrients and fecal indicator bacteria, which are commonly transported with the sediment in stormwater, were measured. Total and dissolved concentrations of six trace metals were determined in the samples. Stormwater samples also were analyzed for organic compounds including 10 herbicides, 18 organochlorine pesticides, 7 Aroclor or polychlorinated biphenyl congeners, 44 volatile organic compounds, and 16 polycyclic aromatic hydrocarbons.

Stormwater often transports large quantities of sediment and sediment-bound contaminants, including nutrients and fecal indicator bacteria. Median event-mean concentrations of suspended sediment in stormwater at these facilities ranged from 54 milligrams per liter in Turkey Creek at North Charleston2 to 147 milligrams per liter in stormwater discharging from the Ballentine retention pond outfall. In general, event-mean concentrations of total nitrogen consisted mainly of total Kjeldahl nitrogen (organic nitrogen plus ammonia) rather than nitrate plus nitrite in stormwater, and the median event-mean concentrations of total nitrogen ranged from 1.59 milligrams per liter at the Conway1 pipe outfall to 2.00 milligrams per liter at the Ballentine retention pond outfall. Median event-mean concentrations of total phosphorus in stormwater ranged from 0.15 milligram per liter at the Conway1 outfall to 0.42 milligram per liter in Turkey Creek at North Charleston1.

Escherichia coli and enterococcus concentrations often varied by 3 to 4 orders of magnitude in grab samples collected during the “first flush” of stormwater discharging to the sampled outfalls of Turkey Creek. Additionally, enterococcus concentrations consistently were greater than the corresponding *Escherichia coli* concentrations in stormwater. Specifically, median “first-flush” *Escherichia coli* concentrations ranged from 30 colonies per 100 milliliters at the Conway1 outfall to 4,359 colonies per 100 milliliters in Turkey Creek

at North Charleston2, whereas enterococcus concentrations ranged from 512 colonies per 100 milliliters at the Conway1 outfall to 6,329 colonies per 100 milliliters in Turkey Creek at North Charleston2. In comparison to the proposed South Carolina Department of Health and Environmental Control primary and secondary body contact criterion of 349 colonies per 100 milliliter, stormwater had *Escherichia coli* concentrations that were greater than the criterion in 4 of the 9 storms at Ballentine retention pond outfall, 1 of the 8 storms at the Conway1 pipe outfall, 5 of the 7 storms at the Conway2 grass-lined ditch outfall, 2 of the 8 storms at North Charleston1 on Turkey Creek, and 8 of the 8 storms at North Charleston2 on Turkey Creek.

Of the six trace metals measured in stormwater, only copper and zinc had event-mean concentrations greater than the hardness-dependent South Carolina Department of Health and Environmental Control aquatic life criteria maximum concentrations. Measured dissolved copper event-mean concentrations in stormwater were greater than the criterion in 5 of the samples at the Ballentine facility, 1 of the samples at Conway1, 2 of the samples at Conway2, and 1 of the samples at North Charleston2. Measured dissolved zinc event-mean concentrations in stormwater were greater than the criterion in 3 of the samples at the Ballentine facility, 1 of the samples at Conway1, 2 of the samples at Conway2, and 0 of the samples at North Charleston2. At North Charleston1 upstream from the North Charleston maintenance yard, the measured dissolved trace-metal concentrations were all less than the criterion maximum concentrations.

Among the three facilities, Conway1 outfall had the greatest range in event-mean yields in stormwater for total phosphorus, total nitrogen, total suspended solids, and suspended sediment, and both Conway outfalls tended to have median event-mean yields greater than those of the Ballentine and North Charleston yard facilities. “First-flush” yields of *Escherichia coli* in stormwater were not statistically different among the three facilities.

Median event-mean yields of suspended sediment, total nitrogen, total phosphorus, total copper, and total zinc in stormwater demonstrated a strong linear relation to impervious surface at the three facilities. However, median ”first-flush” fecal indicator bacterial yields did not have a linear relation to impervious surface.

Introduction

Increased impervious surfaces (driveways, parking lots, and buildings) and human activities (residential, industrial, and commercial) have been linked to significant changes in both the quality and quantity of stormwater on a watershed scale (Brabec and others, 2002; Pitt and Maestre, 2005). Smaller-scale storage and equipment repair facilities increase impervious surface that prevent infiltration of stormwater and accommodate activities that can introduce trace metals, organic compounds, and other contaminants to the facility’s grounds. So, ultimately, these smaller facilities may contribute pollutants to the environment during storm events (U.S. Environmental Protection Agency, 1992).

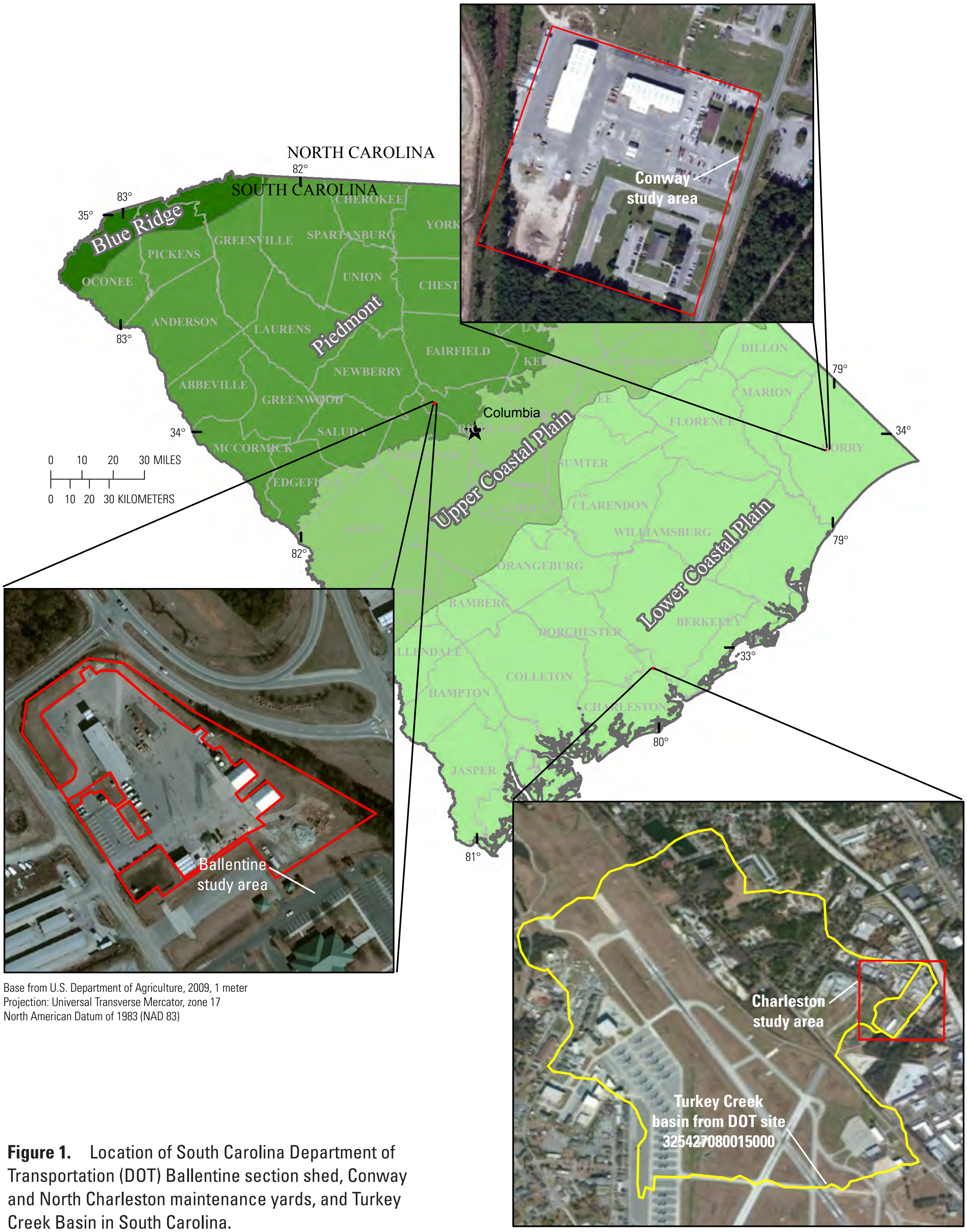
The South Carolina Department of Transportation (SCDOT) operates section shed and maintenance yard facilities throughout the State. Prior to this investigation, the SCDOT had no data to define the quality of stormwater leaving these facilities. To provide these data, the U.S. Geological Survey (USGS), in cooperation with SCDOT, conducted an investigation to identify and quantify constituents that are transported in stormwater from two maintenance yards and a section shed in three different areas of South Carolina. The two maintenance yards, in North Charleston and Conway, S.C., were selected because they represent facilities where equipment and road maintenance materials are stored and complete equipment repair operations are conducted (fig. 1; table 1). The section shed, in Ballentine, S.C., was selected because it is a facility that stores equipment and road maintenance material, including road salt and gravel, in enclosed buildings (fig. 1; table 1). Characterization of the constituents that were transported in stormwater from these representative SCDOT maintenance facilities may be used by the SCDOT in the development of stormwater management plans for similar section shed and maintenance yard facilities throughout the State to improve stormwater quality.

Purpose and Scope

The purpose of this report is to characterize the concentration, load, and yield of selected water-quality constituents transported by stormwater from SCDOT section shed and maintenance yard facilities. From March 2010 to January 2012, storm samples were collected at five locations that received stormwater discharge from the Ballentine (1 outfall), North Charleston (2 locations on Turkey Creek), and Conway (2 outfalls) facilities and analyzed for nutrients, fecal indicator bacteria, trace metals, suspended sediment, and synthetic and semivolatile organic compounds. The water-quality data are presented in tables and figures.

Description of the Study Area

The section shed in Ballentine is in the Piedmont Physiographic Province in Richland County, South Carolina (fig. 1). The Piedmont Province is characterized by relatively low, rolling hills cut by or bounded by valleys of steeper slope and greater depth. The Ballentine section shed is a facility that stores equipment and road maintenance material. The drainage area of the study site is 12,133 square meters (m^2; 0.0047 square mile (mi^2)) and 79 percent of the area is composed of impervious surface (table 1; fig. 2). Stormwater drainage from the study area is surficial sheet flow that is diverted by a curb-and-gutter system to a retention basin or pond that is dry except during storms. Stormwater enters the



Base from U.S. Department of Agriculture, 2009, 1 meter
Projection: Universal Transverse Mercator, zone 17
North American Datum of 1983 (NAD 83)

Figure 1. Location of South Carolina Department of Transportation (DOT) Ballentine section shed, Conway and North Charleston maintenance yards, and Turkey Creek Basin in South Carolina.

Table 1. Description of South Carolina Department of Transportation maintenance yard and section shed facilities in North Charleston, Conway, and Ballentine, South Carolina.

[m^2, square meters; mi^2, square miles; ft^3/s, cubic feet per second; ND, not determined; NS, not sampled; SCDOT, South Carolina Department of Transportation; S.C., South Carolina; NWIS, National Water Information System database of the U.S. Geological Survey; ID, identification]

NWIS station identification number	NWIS station name	Site ID	Drainage area		Impervious surface, in percent	Number of samples collected	Mean event-mean stormwater discharge (ft^3/s)	Mean event-mean unit-area stormwater discharge ($ft^3/s-mi^2$)
			m^2	mi^2				
340801081142000	SCDOT maintenance yard outfall near Ballentine, S.C.	Ballentine	12,133	0.005	79	9	0.33	70.2
335444079024500	Outfall 1 from SCDOT maintenance yard, Conway, S.C.	Conway1	1,200	0.000	100	9	0.16	348
335448079024500	Outfall 2 from SCDOT maintenance yard, Conway, S.C.	Conway2	9,912	0.004	100	8	0.67	176
ND		Conway maintenance yard	41,207	0.016	70	NS	NS	NS
021720646	Turkey Creek at SCDOT maintenance yard, North Charleston, S.C.	North Charleston1	3,909,680	1.510	ND	8	3.06	2.0
325427080014600	Turkey Creek below SCDOT maintenance yard, North Charleston, S.C.	North Charleston2	3,995,679	1.543	ND	8	5.39	3.5
ND		North Charleston maintenance yard	85,999	0.033	62	NS	2.35	71.2

retention pond through drainage pipes. Stormwater accumulates in the retention pond until there is enough water depth and flow to exit the retention pond through the main outfall that then directs the stormwater off the facility to a roadside ditch. If an adequate quantity of stormwater was produced during the storm, stormwater leaving the section shed in the roadside ditch may eventually empty to Metz Branch, which flows into Hollinshead Creek, a tributary to the Broad River. The closest impaired water body to the Ballentine section shed is 30.9 kilometers (km; 19.2 miles (mi)) downstream at the Broad River at U.S. 176 (Broad River Road) in Columbia, S.C. The South Carolina Department of Health and Environmental Control (SCDHEC) is required by Section 303(d) of the Clean Water Act to develop a list of water bodies that do not meet water-quality standards and submit that list to U.S. Environmental Protection Agency (EPA) every 2 years. The Broad River at this location is on the SCDHEC 303(d) list for copper concentrations elevated above background levels (South Carolina Department of Health and Environmental Control, 2010).

The Conway and North Charleston maintenance yards are in the lower Coastal Plain Physiographic Province in Horry and Charleston Counties, respectively, near the Atlantic Coast of South Carolina. The Coastal Plain Province is characterized by gently sloping topography drained by low-gradient streams that are often tidally influenced near the coast (fig. 1). Stormwater in this part of the study area flows to non-tidal and tidal, freshwater to brackish water systems.

The Conway maintenance yard is a facility where equipment and road maintenance materials are stored and complete (vehicular and small engine) equipment repair operations are conducted. The Conway maintenance yard has a drainage area of 41,207 m^2 (0.01590 mi^2) with a curb-and-gutter system to capture stormwater as it runs off the facility (fig. 3). The total impervious surface of the facility is 70 percent. Water drainage from the study area is surficial sheet flow that discharges to two outfalls within the study site. The Conway1 outfall, near the fuel island at the southern end of the property, was modified by installing a 6-inch polyvinyl chloride (PVC) pipe to sample the stormwater discharge (fig. 3). This outfall has a drainage area of 1,329 m^2 (0.00051 mi^2), and the area is almost entirely (88 percent) composed of impervious surface (table 1). The Conway2 outfall is at the beginning of a grass-lined ditch that drains the northern part of the site (fig. 3). Stormwater was captured and directed to this outfall by a curb-and-gutter system. The drainage area is 9,659 m^2 (0.0037 mi^2) with 78 percent impervious surface (table 1). Both outfalls discharge stormwater from the facility to an unnamed creek that flows into Grier Swamp. The Conway maintenance yard facility is 10.7 km (6.65 mi) upstream from an impaired water body, Kingston Lake near Pump Station on Lakeside Drive, Conway, S.C.; it is on the SCDHEC 303(d) list for low dissolved oxygen levels and elevated fecal coliform concentrations (South Carolina Department of Health and Environmental Control, 2010).

Stormwater discharges from the North Charleston maintenance yard to Turkey Creek, a perennial stream, through a combination of pipes, ditches, and overland flow. To completely sample all stormwater from the yard, samples were collected from the main channel of Turkey Creek at the upstream (North Charleston1) and downstream (North Charleston2) limits of the North Charleston maintenance yard facility (fig. 4). Drainage area of the maintenance yard is 85,999 m^2 (0.033 mi^2), and the total impervious surface is 62 percent (table 1). Stormwater constituents in the water samples at the upstream site (North Charleston1) represent stormwater contributions from the headwater drainage area above the North Charleston property. Turkey Creek is 6.15 km (3.82 mi) upstream from Goose Creek at S-08-136 Bridge, Hanahan, S.C., an impaired water body which is on the SCDHEC 303(d) list for elevated fecal coliform concentrations (South Carolina Department of Health and Environmental Control, 2010).

The climate of the study areas is characterized by hot, humid summers and moderate winters. The monthly mean temperature ranges from about 10 degrees Celsius (°C) (50 degrees Fahrenheit (°F)) in January to about 28 °C (83 °F) in July (National Oceanic and Atmospheric Administration, National Climatic Data Center, *http://www.noaa.gov/climate.html*, accessed December 13, 2012). Precipitation in the study area averages about 132 centimeters per year (cm/yr) (52 inches per year (in/yr)) (National Oceanic and Atmospheric Administration, National Climatic Data Center, *http://www.ncdc.noaa.gov/oa/climate/climateinventories.html*, accessed December 13, 2012). In 2010 and 2011, annual precipitation ranged from 90.2 centimeters (cm) (35.5 inches (in.)) to 93.0 cm (36.6 in.), respectively, in Columbia, S.C.; from 106.4 cm (41.9 in.) to 85.1 cm (33.5 in.), respectively, in North Myrtle Beach, S.C.; and from 146.3 cm (57.6 in.) to 94.0 cm (37.0 in.), respectively, in North Charleston, S.C. (National Oceanic and Atmospheric Administration, National Climatic Data Center, *http://www.ncdc.noaa.gov/oa/climate/climateinventories.html,* accessed December 13, 2013).

Approach and Methods

This investigation included an initial data-collection period followed by the final data compilation and analysis. From January 2010 through January 2012, the USGS operated data-collection stations at the five sites (table 1). The data-collection effort included monitoring the quantity of rainfall and the collection of stormwater-quality samples. Established guidelines and protocols were used to ensure the data were of the highest quality. Additional details of analytical methods are provided in subsequent sections.

Drainage-area delineation at each site was accomplished by the standard delineation process, using automated tools within a geographic information system (GIS) (Djokic and others, 1997; Esri, 1997). A 10-meter Digital Terrain Model (DEM) from the National Elevation Dataset (NED) (Gesch, 2007) and available Light Detection and Ranging (lidar) data were used (*http://www.dnr.sc.gov/GIS/lidar.html*) for the North Charleston, Ballentine, and Conway SCDOT drainage areas. Further editing and accuracy were provided by ground truthing and visual verification at each maintenance yard.

Rainfall and Stormwater-Flow Data Collection

The surface-water data consist of stage or stormflow measurements (appendix 1A). Flow measurements were made with appropriate current meter, using the methods described in Rantz and others (1982) or using indirect methods. At the North Charleston facility, a continuous-record water-level gage was established on Turkey Creek at the upstream site (North Charleston1) and a stage-flow relation (rating curve) was established for the upstream and downstream sites (station 021720646; table 1; fig. 4). At the Ballentine section shed facility, stormwater enters a retention pond before leaving the facility. The retention pond is dry, and there is no flow in the outfall pipe except during storms. During storms, flow measurements were made with a current meter in the outfall pipe that drains the retention pond (fig. 2). At the Conway facility, flow measurements were made with a current meter in the grass-lined ditch where stormwater leaves the paved area of the Conway maintenance yard facility (Conway2 outfall)

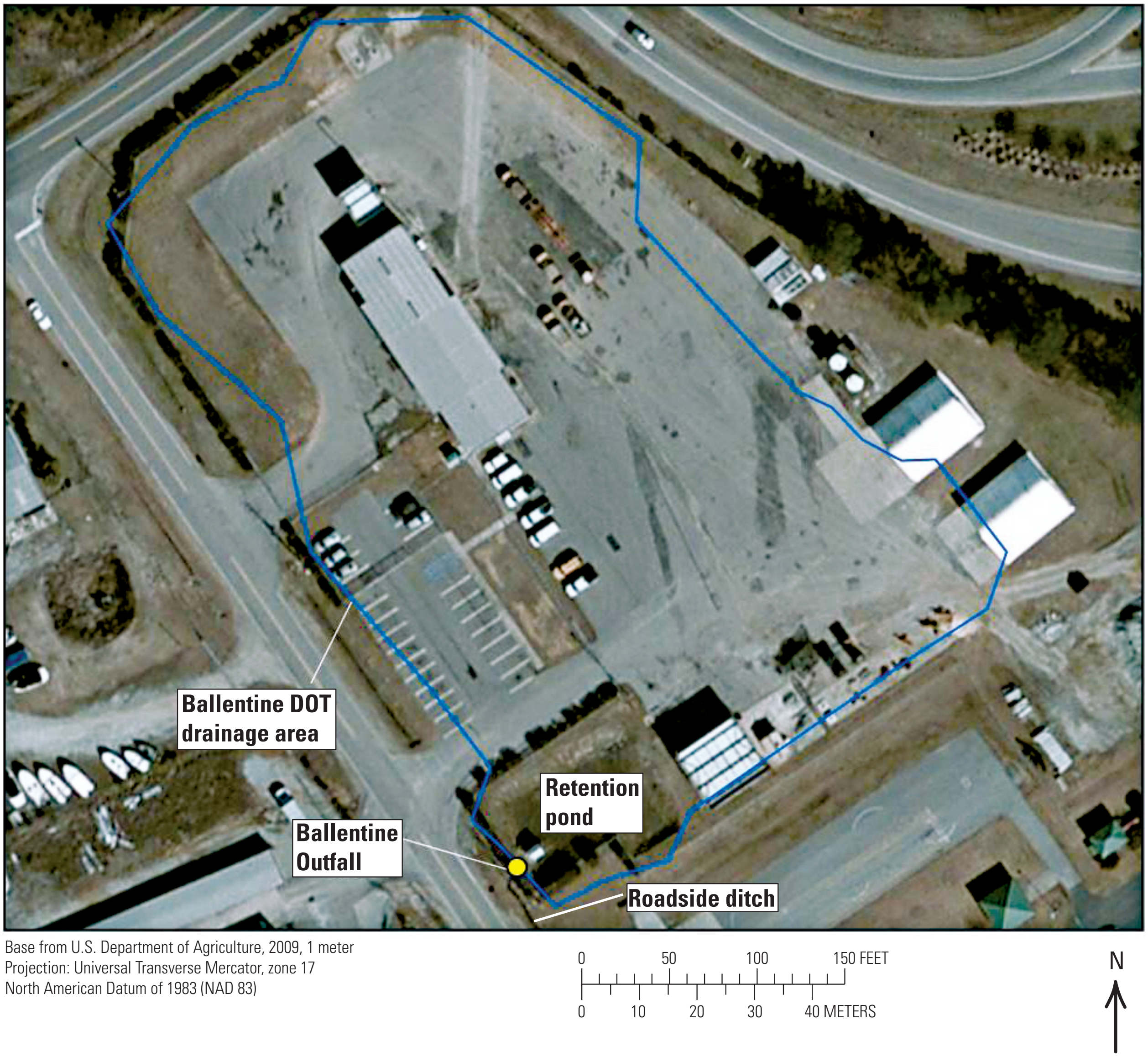


Figure 2. Aerial photograph of drainage area delineation of the South Carolina Department of Transportation (DOT) section shed and outfalls, Ballentine, South Carolina.

(fig. 3). At the Conway1 outfall, stormwater flow discharging from the pipe outfall was estimated by indirect methods by using the Culvert Analysis Program (CAP) (Fulford, 1998).

Mean and peak stormwater discharges for each storm (event-mean discharge or EMQ) were computed and used in the data analysis (appendix 1A). Rainfall data were collected with a tipping bucket raingage at each site (appendix 1A). Data were collected at 5-minute intervals and stored in a data logger on site. Satellite telemetry was used to transmit data every 4 hours to the USGS South Carolina Water Science Center (SCWSC) office in Columbia, S.C. Procedures outlined in the USGS SCWSC Surface Water Quality-Assurance Plan (Cooney, 2001) were used to ensure that proper data handling, review, and approval procedures were followed. Surface-water data are stored in the USGS National Water Information System (NWIS) database, and approved surface-water data are available for retrieval on the internet at *http://waterdata.usgs.gov/sc/nwis/sw.*

Water-Quality Data Collection

Stormwater runoff samples were collected during 8 to 9 selected storms over a 23-month period (from March 2010 to January 2012) that represent a range of seasons and rainfall intensities. The National Pollution Discharge Elimination System (NPDES) permit requirements established by EPA and adopted by SCDHEC for target storms stipulate that rainfall is greater than (>) 0.10 in. and less than (<) 0.10 in. in the 72 hours prior to the sampled storm (South Carolina Department of Health and Environmental Control, 2001). Of the

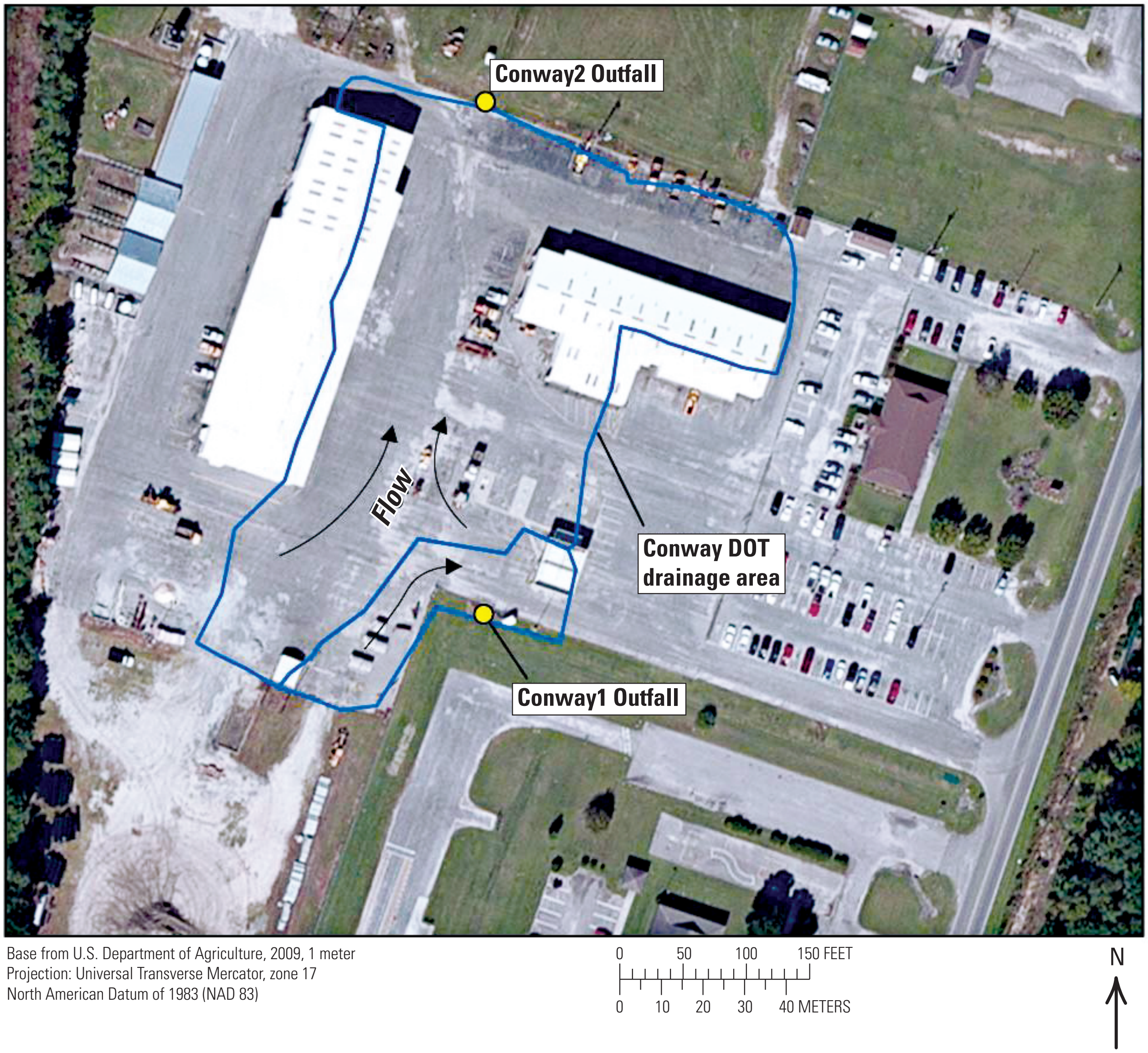


Figure 3. Aerial photograph of drainage area delineation of the South Carolina Department of Transportation (DOT) maintenance yard and outfalls, Conway, South Carolina.

9 sampled storms at all facilities, 2 storms at the Ballentine (March 2 and 10, 2010) and Conway facilities had <0.10 in. of rainfall (appendix 1A). All sampled storms met the 72-hour prior rainfall criterion, except for a storm on September 27, 2011, at the Ballentine facility (appendix 1A) .

Over the 23-month data collection period, sample collection consisted of 1 sample per season (winter, spring, summer, and fall) at each site as a flow-weighted composite until a total of 8 to 9 samples were collected at each location (appendix 1B–F). For this investigation, seasons were based on the summer and winter solstice and vernal and autumnal equinoxes. Sample collection methods are described in the USGS and EPA protocols (U.S. Environmental Protection Agency, 1992; U.S. Geological Survey, variously dated; 2006). Nine samples were collected at Ballentine and Conway1 outfalls, and 8 samples were collected at North Charleston1, North Charleston2, and Conway2 outfalls (table 1; appendix 1B–F).

Two types of samples (grab and flow composite) were collected for water-quality analysis using point sampling methods at each site (U.S. Environmental Protection Agency, 1992; U.S. Geological Survey, 2006). Sampling equipment was cleaned prior to use according to appropriate inorganic and organic constituent procedures described in Wilde (2004). Samples for compositing were collected automatically throughout time of the stormwater hydrograph by using a programmed sampler with pre-cleaned tubing and sample bottles at the North Charleston and Ballentine sites. At the Conway maintenance yard, samples for compositing were collected manually throughout the stormwater hydrograph at each

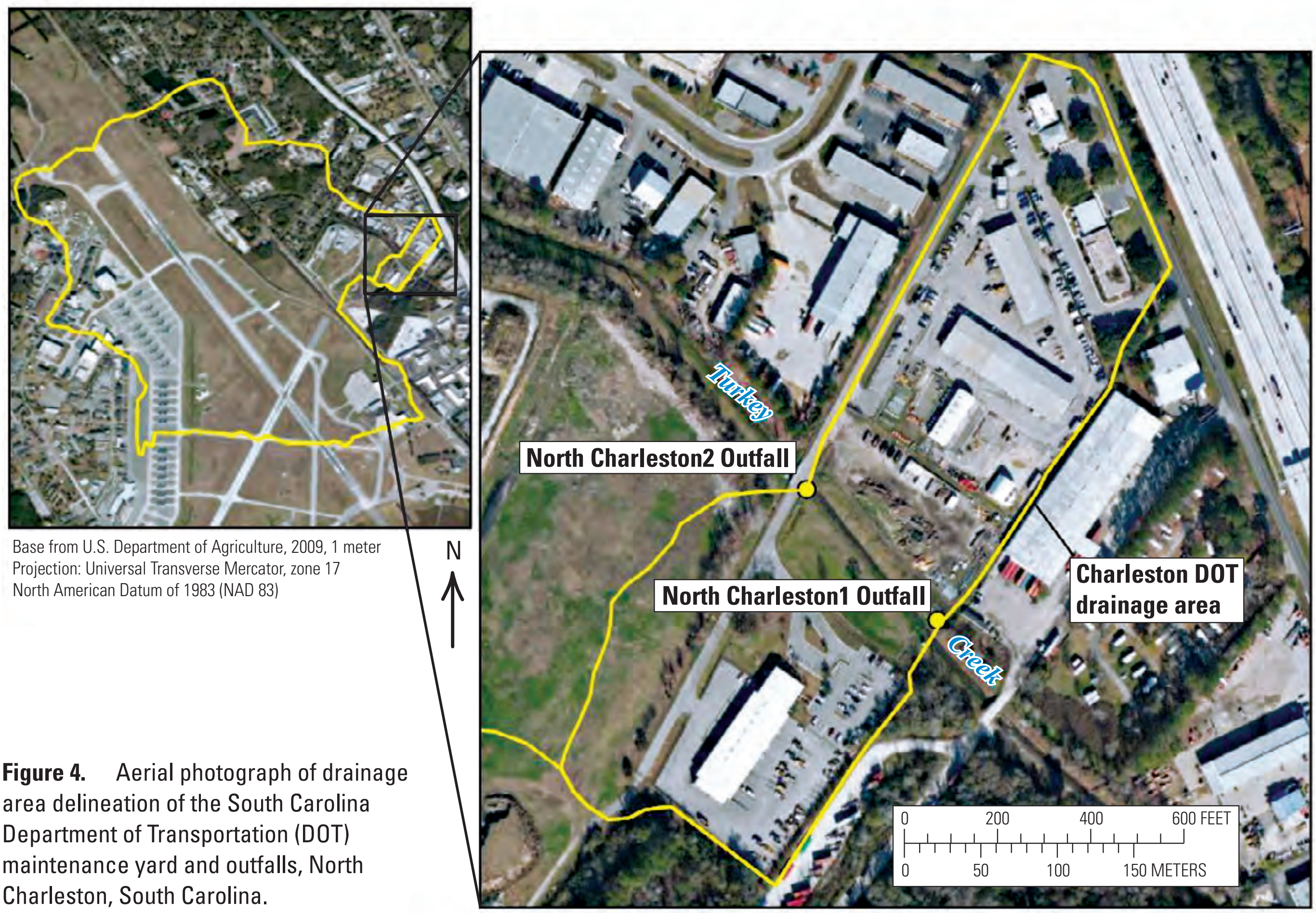


Figure 4. Aerial photograph of drainage area delineation of the South Carolina Department of Transportation (DOT) maintenance yard and outfalls, North Charleston, South Carolina.

outfall by on-site personnel using pre-cleaned sample bottles. In addition to flow-composited samples, grab samples were collected in dedicated bottles during the first 15 to 30 minutes of a storm that represented the initial “first-flush” of stormwater and that was considered to contain maximum accumulations of the constituents discussed below. Two grab samples were collected in sterilized 300-milliliter (mL) glass bottles for analysis of 5-day biochemical oxygen demand (BOD_5), *Escherichia coli* (*E. coli*), enterococci, fecal coliform, and total coliform (table 2; U.S. Geological Survey, 2006; Myers and others, 2007). A third grab sample was collected in three 40-mL pre-baked amber glass bottles for the analysis of volatile organic compound concentrations (table 2; U.S. Geological Survey, 2006).

Flow-weighted volumes of each fixed-time-interval sample were computed and placed in a compositing device to produce a flow-weighted composite sample. The individual samples were processed in the USGS SCWSC water-quality laboratory within 12 hours of collection. Sample processing consists of the measures taken to prepare (for example, compositing and filtering) and preserve (for example, acidification) the final flow-composite sample (Wilde and others, 2004). Procedures followed are specific to the constituent being analyzed and are described in Wilde and others (2004). Pre-cleaned, acid-rinsed 8-liter (L) plastic churns were used as the compositing devices. For analysis of dissolved constituents (nutrients, major ions, and trace elements), samples were filtered using 0.45-micron capsule filters that were conditioned with 1 L of deionized water. These samples were analyzed for suspended sediment, total suspended solids, turbidity, trace metals, biochemical oxygen demand, nutrients, organochlorine insecticides, polychlorinated biphenyls (PCBs), herbicides, and semivolatile compounds, including polycyclic aromatic hydrocarbons (PAHs) (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).

All water-quality samples, except for sub-samples for suspended sediment and bacterial analyses, were analyzed by a National Environmental Laboratory Accreditation Program (NELAP) certified TestAmerica laboratory. Total organic nitrogen and ammonia (total Kjeldahl nitrogen (TKN)) and total phosphorus (TP) concentrations were determined according to EPA methods 351.2 and 365.4, 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). Pesticide and herbicide

Table 2. Types of constituents and analytical methods for sampled stormwater collected from selected outfalls at the South Carolina Department of Transportation section shed or maintenance yard facilities in North Charleston, Conway, and Ballentine, South Carolina.

[EPA, U.S. Environmental Protection Agency; SM, Standard Methods; ASTM, American Society for Testing and Materials]

Constituents	Type of sample	EPA or other method
pH	In situ	150.2
Specific conductance	In situ	120.1
Dissolved oxygen	In situ	SM 4500-G
Turbidity	Flow-composited	180.1
Total suspended solids	Flow-composited	SM 2540D
Biochemical oxygen demand	Grab	405.1 (SM 5210B)
Nutrients (total and dissolved phosphorous, nitrate, total Kjeldahl nitrogen, and nitrate+nitrite)	Flow-composited	365.4, 365.1, 352.3, 351.2, 350.1,
Total and dissolved calcium, magnesium, lead, zinc, copper, nickel, and cadmium	Flow-composited	200.7 Rev. 4.4, 200.8
Suspended sediment	Flow-composited	USGS
Base/neutral extractable organic compounds (including polycyclic aromatic hydrocarbons)	Flow-composited	610
Volatile organic compounds	Grab	624
Pesticides	Flow-composited	608
Fecal coliform, enterococci bacterial analysis, and *Escherichia coli*	Grab	SM 9223B, ASTM D6503-99

concentrations were determined according to EPA method 608 (U.S. Environmental Protection Agency, 1999). Concentrations of volatile organic compounds were determined according to EPA method 624 (U.S. Environmental Protection Agency, 1999). Semivolatile organic compound concentrations were determined according to EPA method 610 (U.S. Environmental Protection Agency, 1999). The EPA method 405.1 (Standard Methods 5210B; Clesceri and others, 1998) for whole-water samples was used to determine BOD_5 for the study. Whole-water samples were analyzed for turbidity according to EPA method 180.1 (U.S. Environmental Protection Agency, 1999).

Whole-water samples were analyzed for suspended-sediment (SS) 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 SS concentrations at the USGS Sediment Laboratory are described in Knott and others (1993) and Shreve and Downs (2005). Total suspended solids (TSS) were analyzed at TestAmerica using Standard Method 2540D (Clesceri and others, 1998). Analytical methods to determine SS and TSS were used to quantify concentrations of suspended organic and inorganic particles in surface waters. Concentrations of SS and TSS were 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 SS analytical method is considered to produce more reliable results; however, the TSS method is often the method adopted for regulatory monitoring. Therefore, both methods were considered in this investigation. Generally, a bias in relation to SS and TSS is observed when sand-sized material is greater than 25 percent of the sediment dry weight, such that the SS values tend to exceed their paired TSS values (Gray and others, 2000). On the basis of past research by Gray and others (2000), this bias indicates TSS was a poor measure of suspended particles in stormwater when the dominant fraction was sand size or coarser. High SS and TSS concentrations can adversely affect surface waters by reducing visibility and absorbing light, which can increase stream temperatures and cause limited aquatic plant growth.

Whole-water samples were analyzed by USGS SCWSC personnel for fecal indicator bacteria using the Colilert-18 and Enterolert defined substrate technology (DST) methods within 6 hours of collection (Edberg and Edberg, 1988). The Colilert-18 method has been approved by the EPA for drinking water and ambient water and is proposed for use by the NPDES. The DST microbiological methods are described in Standard Methods for Examination of Water and Wastewater, 20th edition, (Clesceri and others, 1998) and USGS National Field Manual (Myers and others, 2007).

Data Analysis

For each outfall, water-quality data were compiled (appendixes 1B–F) and summarized statistically in tables further on in the report (tables 8–12). Corresponding parameter codes for selected water-quality data are provided in the appendixes and tables to simplify retrieval of data from the publicly accessible NWIS Web interface (http://waterdata.usgs.gov/sc/nwis/qw). Selected constituent EMCs were compared to existing NPDES criteria or other screening levels and to reported median values from National Stormwater Quality Database (Pitt and Maestre, 2005; South Carolina Department of Health and Environmental Control, 2012). The EMCs are appropriate for comparing constituent concentrations in stormwater runoff with established water-quality criteria and standards (Shipp and Cordy, 2001). The EMCs for the constituents in the flow-weighted composite samples were used to calculate storm loads by multiplying the EMC by the mean runoff flow for the storm, then applying a correction factor to convert the units to kilograms per event or grams per event. Constituent loads in stormwater runoff can be an important tool in assessing the effect on the water-quality impairment of a particular surface-water body. 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 load is a function of the constituent concentration and the flow for the storm (Rasmussen, 1998). For the sampled outfalls at the SCDOT facilities, the event-mean load (L_i) in kilograms per event resulting from stormwater runoff for an individual storm was calculated by multiplying the event-mean concentration (EMC_i) in milligrams per liter (for major ions, BOD_5, sediment, nutrients) or micrograms per liter (for trace elements) by the mean stormwater discharge (Q_i) in cubic feet per second of water passing the sampling site during the storm ($_i$) by the event duration (ED_i) in minutes per event:

$$L_i = a\ EMC_i\ Q_i ED_i, \tag{1}$$

where

a = 1.669, the unit conversion factor.

Units of measurement for loads varied by constituent. For constituents with concentrations in milligrams per liter the constituent loads were expressed in kilograms per event. For trace-metal constituents with concentrations in micrograms per liter, loads were expressed in grams per event. For enterococci and *E. coli,* concentrations and loads were expressed in colonies per 100 mL and million colonies per event, respectively.

For the purpose of this study, the ranges of constituent EMCs and loads were evaluated. EMCs were compared to established freshwater criteria for screening purposes, where available, and EMCs were evaluated for correlation to other water-quality constituents and six hydrologic characteristics (rainfall amount, duration, and intensity; days since last rainfall; and peak and mean stormwater discharges) Water-quality data were censored below the laboratory reporting level (LRL) for several constituents, including trace metals and orthophosphate. For data with censored values, descriptive statistics, including mean and median values, were computed by the robust Regression on Order Statistics (ROS) method using the USGS plug-in program incorporated into the Tibco Spotfire S+® 8.1 software (Childress and others, 1999; Helsel, 2005). Exceptions to this approach were *E. coli* and enterococcus concentrations that were above the maximum quantification level of the methods used. For most samples, a 1:100 dilution was used that translates to a laboratory reporting limit (LRL) of 24,196 colonies per 100 mL (col/100mL), and the results would be censored as greater than 24,196 col/100 mL. For data analysis, the censored value of 24,196 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 reported concentrations. Median values were used for comparison because they dampen the effects of outliers on the data (Helsel and Hirsch, 1992). For plotting and event-load computation purposes, censored values (less than the LRL) were replaced with one-half the detection limit (Childress and others, 1999). An exception was made in the substitution method for censored PAH concentrations, which were replaced with zero for computation of acute potency ratios (method described later in this section).

Kendall tau-b correlation analysis was applied to water-quality and hydrologic data from the different SCDOT sites to evaluate the strength of the association among selected water-quality and hydrologic constituents (appendixes 3A–E; Helsel and Hirsch, 1992). Kendall tau is a nonparametric statistical analysis of ranked data that measures the observed co-variation and the strength of the monotonic relation between two variables; its large sample approximation produces p-values very near exact values, even for small sample sizes (Helsel and Hirsch, 1992). Prior to analysis, censored values were given the same rank and ranked below estimated and quantitative values (detections above the LRL) (Childress and others, 1999; Helsel, 2005). Estimated values are semi-quantitative detections and were ranked above censored values but below detected values (Childress and others, 1999; Helsel, 2005). The coefficient for this analysis is called tau (τ). A τ ranges from 0 to 1; the closer the τ is to 1, the stronger the correlation. A probability value (or p-value) is computed during the analysis. A correlation resulting in a p-value less than the alpha level of 0.05 (p-value <0.05) is considered significant in this report. Caution is needed in interpreting correlation analysis results, as a significant correlation proves only co-variation, not cause-and-effect.

Comparison tests were applied to the stormwater constituent concentration data for the 2 outfalls at Conway and the 2 locations on Turkey Creek in North Charleston. An alpha level of 0.05 (translates to a 95-percent confidence that the statistical finding was correct) was used to determine statistically significant differences. Because most of the datasets were not normally distributed, the test was performed on ranks of the data. The Wilcoxon Two-Sample (Rank-Sum) test was applied to the Conway1 and Conway2 outfall data to determine whether the medians of the stormwater-quality data were statistically different from each other (appendix 3F; Helsel and Hirsch, 1992). This comparison method was selected instead of the signed-rank for comparing stormwater at the two Conway outfalls because the drainage characteristics of the outfalls did not fit an inflow-outflow design. The Wilcoxon Rank-Sum test produces a W-statistic that was used to compute the p-value when no ties in the data existed, and Z-scores were used to compute the p-value when ties existed in the data. The Wilcoxon Signed-Rank test also was applied to the stormwater data collected at the North Charleston1 and North Charleston2 locations on Turkey Creek to determine whether stormwater contributions from the maintenance yard to Turkey Creek produced a statistically significant downstream change in the EMCs of selected constituents (table 13; Helsel and Hirsch, 1992). The Wilcoxon Signed-Rank test evaluated whether the difference between the EMCs at the upstream (inflow) and downstream (outflow) locations for each storm was equal to zero (that is, no significant difference in EMCs) (Helsel and Hirsch, 1992). The exact distribution of the test statistic V was used to compute the p-value when no ties in the data existed. However, if ties existed, a Z-score was used to compute the p-value.

For comparison of yields among outfalls at the three facilities, the multiple comparison analysis was used (appendix 3G; Helsel and Hirsch, 1992). 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 determine whether a statistical difference existed for at least one of the medians of the groups of data. A significant difference was determined at an alpha level of 0.05, which means that if the probability value (p-value) of the ANOVA test was <0.05, a significant difference existed among the analyzed data group with a 95-percent confidence that the statistical finding was correct. The Kruskal-Wallis test is a robust test that determines only whether a difference exists among the outfalls; it does not identify which outfalls were different from the others. Therefore, a second test was conducted to identify the actual differences. If the more robust Kruskal-Wallis test indicated 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 than the others. However, the Tukey's test is not as robust as the Kruskal-Wallis test and may not be able to determine differences among groups for datasets with high variability and small sample sizes (results were labeled as "not determined" when this occurred; appendix 3G). A significant difference was determined at an alpha level of 0.05, which means that if the p-value of the ANOVA test is <0.05, a significant difference exists among the analyzed data group with 95-percent confidence that the statistical finding is correct.

Nutrients

The amount of biologically available nutrients, mainly nitrogen and phosphorus compounds, in stormwater that enters nearby water bodies can accelerate the process of eutrophication. Eutrophication from nutrient enrichment related to long-term contributions to water bodies during storms can result in high biochemical oxygen demand, depletion of dissolved oxygen, and nuisance or even harmful algal blooms in the receiving water bodies. Although the SCDHEC has not established narrative or numeric nutrient criteria for rivers and streams, the EPA has established recommended nutrient criteria for rivers and streams (U.S. Environmental Protection Agency, 2000; South Carolina Department of Health and Environmental Control, 2012). The sites in this study are in the Southeastern Plains aggregated nutrient ecoregion, and the EPA has recommended criteria whereby concentrations of total phosphorus in rivers and streams are not to exceed 0.04 milligram per liter (mg/L) and concentrations of total nitrogen are not to exceed 0.9 mg/L (U.S. Environmental Protection Agency, 2000). The SCDHEC has established numeric nutrient criteria for lakes in the southeastern Coastal Plain and Piedmont Physiographic Provinces in South Carolina; total phosphorus concentrations are not to exceed 0.06 mg/L, and total nitrogen concentrations are not to exceed 1.50 mg/L (South Carolina Department of Health and Environmental Control, 2012).

For this study, nutrients were evaluated on the basis of the dominant form of nitrogen (total organic nitrogen plus ammonia (total Kjeldahl nitrogen or TKN) versus nitrate plus nitrite), comparison of the total nitrogen (TN) and total phosphorus (TP) concentrations in stormwater runoff relative to criteria, and correlation between nutrient concentrations and other measured constituents (for example, rainfall amount and intensity, suspended sediment, and other nutrients). The TKN form of nitrogen represents the particulate and dissolved forms of organically bound nitrogen and ammonia. Nitrate plus nitrite represents the dissolved inorganic form of nitrogen. The total amount of all forms of nitrogen is accounted for in TN concentrations. The TP form of phosphorus is the total amount of phosphate in water, which also includes the particulate and dissolved forms. Additionally, temporal change in the associated nutrient enrichment characteristic, BOD_5, was evaluated. The BOD_5 represents the amount of oxygen that is consumed by biological organisms that are actively degrading organically bound nitrogen in a body of water. However, BOD_5 does not include the oxidation of ammonia in the TKN to nitrate or nitrite, a process that also consumes oxygen. In this investigation, grab samples of stormwater discharging from the outfall were collected during the "first flush" period of a storm for analysis of BOD_5.

Bacteria

Fecal 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 fecal indicator bacteria signifies that other disease-causing or pathogenic organisms also may be present. Prior to 1986, the EPA recommended that criteria be based on fecal coliforms to protect human health. In 1986, the EPA recommended the use of criteria based on *E. coli* levels for freshwater systems and enterococci levels for freshwater and marine water systems rather than fecal coliform (U.S. Environmental Protection Agency, 1986). The EPA recommended this change in the use of bacteria indicator organisms because the EPA 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). The SCDHEC uses enterococci as saltwater indicator bacteria with a single-sample maximum criterion (SSM) of 104 colonies per 100 milliliters (col/100 mL) for primary and secondary contact in recreational coastal waters; however, the EPA recommends a criterion of 151 col/100 mL for freshwater where infrequent full-body contact takes place. Therefore, we compared the stormwater “first-flush” enterococcus concentrations to the EPA infrequent full-body contact criterion for this study (U.S. Environmental Protection Agency, 1986; South Carolina Department of Health and Environmental Control, 2012). The recommended criterion for waters with infrequent body contact established by the EPA for *E. coli* is a SSM of 575 col/100 mL. However, the SCDHEC has established a slightly more stringent SSM of 349 most probable number (MPN) of colonies per 100 mL for primary and secondary contact in freshwater and for NPDES permit effluent limitations (South Carolina Department of Health and Environmental Control, 2012).

In this report, only enterococci and *E. coli* concentrations are discussed and, for screening purposes, compared to the EPA enterococci SSM for infrequent body contact and to the SCDHEC *E. coli* SSM for secondary and primary contact in freshwater. In this study, the “first flush” fecal indicator bacteria concentrations collected at the facilities during storms represent potentially the greatest concentrations in the stormwater during a single storm and, therefore, overcompensate for impacts to receiving waters. Additionally, research has indicated that *E. coli* and enterococci can survive for several days in aquatic sediment in situ, indicating that fecal indicator bacteria in water may not always represent 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). One study reported that fecal indicator bacteria can survive in bed sediments of streams and lakes for up 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 affecting bacterial contamination, primarily in sediments at or near storm-sewer outfalls (Cinotto, 2005).

Total and Dissolved Metals

For this study, storm samples were analyzed for total (particulate and dissolved forms of the metal) and dissolved metal concentrations. Concentrations of the particulate forms of the metals were computed by subtracting dissolved from the total concentrations. The total metal concentrations in the samples from maintenance yard outfalls were compared to existing aquatic life criteria to provide a relative screening tool. Acute and chronic aquatic life criteria were established for metal concentrations by the U.S. Environmental Protection Agency and adopted by the SCDHEC for receiving waters (U.S. Environmental Protection Agency, 2006; South Carolina Department of Health and Environmental Control, 2012). Criteria established by the EPA 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 (appendix 2A). These hardness-dependent criteria represent the combined effects of different water-quality variables, such as pH and alkalinity that tend to be correlated with hardness. Two generalized criterion levels exist for metals—criteria maximum concentration (CMC) and criteria continuous concentration (CCC)—based on hardness of 25 mg/L (table 3). Both levels of criteria are different for freshwater and saltwater. The freshwater CMC was selected as the criterion used in this investigation rather than the CCC because stormwater contributions of metals to receiving water represent the more acute or maximum contribution for freshwater.

Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are a subset of semivolatile organic compounds that are ubiquitous in the environment and are derived from natural and manmade sources (Van Metre and others, 2000; Mahler and others, 2005; Hwang and Foster, 2006; Stein and others, 2006; Mahler and others, 2012). Natural sources of PAHs include coal, plant debris, and forest and grassland fires (pyrogenic source), whereas manmade sources include leakage of petroleum-based fossil fuel (petrogenic source), fuel combustion (pyrogenic source), and coal-tar sealant used on asphalt parking lots (petrogenic source). Polycyclic aromatic hydrocarbons are common stormwater contaminants and are suspected carcinogens and mutagens for humans and aquatic biota. Sediment and water PAH compositions help distinguish between natural and anthropogenic sources (Van Metre and others, 2000; Yunker and others, 2002; Hwang and Foster, 2006; Stein and others, 2006; Selbig, 2009; Watts and others, 2010; Mahler and others, 2012). Pyrogenic (combustion origin) PAH mixtures are generally enriched in high molecular weight (HMW) compounds, whereas petrogenic PAH mixtures are generally enriched in low molecular weight (LMW) compounds (Hwang and Foster, 2006) (table 4). Preferential volatilization and leaching of the more soluble LMW PAHs also can affect PAH compound ratios (Mahler and others, 2005).

Table 3. South Carolina Department of Health and Environmental Control established aquatic life criteria for metals in freshwater and saltwater, based on a hardness of 25 milligrams per liter as calcium carbonate.

[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					
CMC	0.53	3.8	14	150	75
CCC	0.1	2.9	0.54	16	8.3
Saltwater aquatic life					
CMC	43	5.8	220	37	95
CCC	9.3	3.7	8.5	37	86

The EPA has established "benchmarks," lower threshold values for PAHs of concern to biota, primarily in sediment (not monitored in this study). The SCDHEC has established ambient-water PAH criteria, aquatic life consumption of fish, for adverse human health effects from consumption of tainted fish (South Carolina Department of Health and Environmental Control, 2012). Although these criteria concentrations do not completely reflect the potential for stormwater PAH contamination of surface-water receptors, they were used here as preliminary screening tools for stormwater PAH contamination at the Ballentine and Conway outfalls.

The EPA recommends cumulative assessment of oil-related organic compounds, including PAHs, because these compounds have similar, additive effects on aquatic organisms (U.S. Environmental Protection Agency, 2003; 2008; appendix 2B). Potency divisors for individual PAHs have been developed to estimate the aggregate toxicity of sample-specific, aqueous PAH mixtures (appendix 2B). In addition, alkyl constituents not captured by the analytical method are estimated using established "alkylation multipliers." The potential hazard to aquatic organisms is estimated by comparing the sum of the potency-adjusted values to a hazard index of 1 with values greater than 1, indicating the potential for acute or chronic effects on aquatic life (for example, fish, crabs, and clams) (Dave Mount, U.S. Environmental Protection Agency Office of Research and Development, Duluth, Minnesota, written commun., accessed online on July 16, 2013, at *http://www.epa.gov/bpspill/water/explanation-of-pah-benchmark-calculations-20100622.pdf*)). These criteria and potency approach are stipulated by SCDHEC and were employed in this study.

Published median and mean concentrations of selected individual and total concentrations of all 16 PAHs ($\sum PAH_{16}$) in stormwater were compiled for sites with similar land use, including urban, commercial, and industrial sites with commercial roofs and parking lots (Ngabe and others, 2000; Menzie and others, 2002; Selbig, 2009; Watts and others, 2010; Mahler and others, 2012) (table 5). The median PAH concentrations are for sealed parking lots, including those treated with asphalt-based and coal-tar-based sealants, and unsealed lots. Sealed parking lots, especially those sealed with coal-tar-based sealants, contribute significantly greater PAHs during storms than unsealed lots (Selbig, 2009; Watts and others, 2010; Mahler and others, 2012; table 5).

Quality Assurance and Quality Control

Water-quality data from each sampled runoff 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 NWIS. Collection and analysis of quality-control (QC) samples also were an integral part of the quality-assurance procedures 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 be scientifically defensible (U.S. Geological Survey, 2006). Of the 50 samples analyzed for this study, 6 (12 percent) were QC samples, including 3 equipment blanks and 3 replicates. Prior to collection of the equipment blank, the inorganic-free and organic-free blank water (from the USGS National Water Quality Laboratory (NWQL)) to be used for the equipment blank was poured directly into the sample bottles, preserved, then analyzed by the laboratory and considered a source solution blank. The source solution blank represented the bottle, blank water, and laboratory performance and was analyzed by the laboratory only if significant detectable levels of constituents were present in the equipment blank. Equipment blanks were analyzed to ensure that the sampler, intake lines, churns, and bottles did not contaminate samples. Replicates were analyzed to document the reproducibility of laboratory results.

Of the approximately 148 water-quality constituents (the number varied by site and sampling event), only 8 of those constituents were detected in the equipment blanks. Total Kjeldahl nitrogen and total nitrogen were detected once in the 3 equipment blanks (34 percent) at a level of 0.30 and estimated (E) 0.32 mg/L, respectively, on March 17, 2010

Table 4. Summary of whole-water polycyclic aromatic hydrocarbons properties (modified from Yunker and others, 2002).

[NWIS, U.S. Geological Survey National Water Information System; HMW, high molecular weight; LMW, low molecular weight; SCDHEC, South Carolina Department of Health and Environmental Control; µg/L, micrograms per liter; --, no criterion]

Whole-water polycyclic aromatic hydrocarbons	NWIS parameter code	Molecular weight	Number of rings	Group by weight	Common abbreviations	SCDHEC aquatic life consumption of fish (µg/L)
Benzo[a]anthracene	P34526	228	4	HMW	BaA	0.018
Benzo[a]pyrene	P34247	252	5	HMW	BaP	0.018
Benzo[b]fluoranthene	P34230	252	5	HMW	BbF	--
Benzo[ghi]perylene	P34521	276	6	HMW	Bghi	--
Benzo[k]fluoranthene	P34242	252	5	HMW	BkF	0.018
Chrysene	P34320	228	5	HMW	Ch	0.018
Dibenzo[a,h]anthracene	P34556	278	5	HMW	DhA	0.018
Fluoranthene	P34376	202	4	HMW	Fl	140
Pyrene	P34469	202	4	HMW	Py	4,000
Indeno[1,2,3-cd]pyrene	P34403	276	6	HMW	IP	0.018
Anthracene	P34220	178	3	LMW	An	40,000
Phenanthrene	P34461	178	3	LMW	Pn	--
Naphthalene	P34696	128	2	LMW	Na	--
9H-Fluorene	P34381	166	3	LMW	F	5,300
Acenaphthene	P34205	154	2	LMW	Aen	990
Acenaphthylene	P34200	152	3	LMW	Ayl	--

(appendix 1G). The March 17, 2010, equipment blank also had detectable, but estimated, concentrations of nitrate plus nitrite (E0.02 mg/L) and total phosphorus (E0.08 mg/L). The analysis of the corresponding source solution blank indicated even greater detectable concentrations of nitrate plus nitrite (E0.04 mg/L) and total phosphorus (0.51 mg/L) were present. As requested by the contract laboratory, the laboratory-provided, pre-acidified sample bottles were not rinsed prior to collection of the source solution blank. However, preparation and processing of the equipment blank required additional rinsing of the bottles and may explain the lower concentrations for those constituents in that sample. It was determined that bottles and acid preservatives would be obtained from the NWQL immediately (May 2010) and used to replace the contract laboratory-provided supplies. The subsequent blank samples collected on November 21, 2011, had a source solution blank with elevated total phosphorus concentrations and detectable TKN concentrations; however, detectable concentrations were greatly reduced in the equipment blank for total phosphorus (E0.003 mg/L) and absent for total nitrogen and total Kjeldahl nitrogen (appendix 1G). Detectable total phosphorus concentrations represented <5 percent of the median environmental sample constituent concentrations in the November 21, 2011, equipment blank compared to 41 percent in the March 1, 2010, equipment blank. A detectable nitrate plus nitrite concentration (0.07 mg/L) still was observed in the March 19, 2012, equipment blank after the bottle replacement process.

Total ammonia was detected once in the three blanks at a level of 0.100 mg/L on November 21, 2011, (compared to less than the LRL of 0.026 in the two other blanks) (appendix 1G). The ammonia concentration of 0.100 mg/L in the blank produced a potential contamination of environmental samples (based on median EMCs) at the sampled outfalls of between 21 (North Charleston1) and 118 percent (Conway1) at the sampled facilities (appendix 1G). Because of the high level of potential contamination, total ammonia data were rejected as unreliable for this study and were not used in the data analysis. The average concentration of nitrate plus nitrite in the equipment blank represents between 9 and 20 percent of the median concentration in the environmental samples from the outfalls. At this level of potential contamination, environmental nitrate and nitrite concentrations were considered reliable and used in the data analysis (appendix 1G). Total nickel concentrations were at detectable levels (E3.1 micrograms per liter (µg/L)) in the November 21, 2011, equipment blank. That blank concentration represents between 50 and 157 percent and an average of 94 percent of the median total nickel concentration in the environmental samples (appendix 1G). Therefore, total nickel data were rejected as unreliable for this study and were not used in the data analysis. Chemical oxygen demand (COD) was detected in both the source solution and equipment blank of November 21, 2011, at concentrations of 28 and 25 mg/L, respectively (appendix 1G). A cleaning step that included methanol rinsing of the equipment is the suspected contamination source. Therefore, COD data were rejected as

Table 5. Median or mean polycyclic aromatic hydrocarbon concentrations in stormwater runoff in Madison, Wisconsin, Columbia, South Carolina, Massachusetts, University of New Hampshire Stormwater Center, New Hampshire, and Los Angeles, California.

[<, less than; ND, not determined; --, no data. Units are in micrograms per liter]

Polycyclic aromatic hydrocarbon (PAH)	[1]Madison, Wisconsin				[2]Columbia, South Carolina	[3]Coastal area of Massachusetts		[4,5]New Hampshire		[6]Los Angeles, California		
	Parking lots, sealed	Parking lots, not sealed	Commecial roof	Mixed use, strip mall	Urban stormwater	Urban residential-commercial, suburban	Urban residential-commercial	Parking lots, coal-tar sealed	Parking lots, asphalt, sealed or not sealed	Commer-cial	Indus-trial	Trans-portation
9H-Fluorene	< 0.52	< 0.52	< 0.52	< 0.52	0.06	0.055	0.075	--	--	--	--	--
Acenaphthene	< 0.064	< 0.064	< 0.064	< 0.064	ND	0.032	0.166	--	--	--	--	--
Acenaphthylene	< 0.11	< 0.11	< 0.11	< 0.11	ND	0.016	0.031	--	--	--	--	--
Anthracene	0.25	< 0.031	< 0.031	< 0.031	0.056	0.102	0.079	--	--	--	--	--
Naphthalene	< 0.042	< 0.042	< 0.042	< 0.042	ND	0.066	0.046	--	--	--	--	--
Phenanthrene	5.2	0.31	0.28	0.36	0.48	0.821	0.302	--	--	--	--	--
Benzo[a]anthracene	1.1	0.17	0.1	0.15	0.28	0.15	0.163	--	--	--	--	--
Benzo[a]pyrene	3.6	0.35	0.21	0.32	0.42	0.183	0.133	--	--	--	--	--
Benzo[b]fluoranthene	5.2	0.54	0.24	0.6	0.98	0.473	0.346	--	--	--	--	--
Benzo[ghi] perylene	4.1	0.53	0.24	0.56	0.46	0.187	0.163	--	--	--	--	--
Benzo[k]fluoranthene	2.4	0.24	< 0.12	0.21	ND	0.169	0.146	--	--	--	--	--
Chrysene	4.7	0.43	0.19	0.52	0.62	0.517	0.353	--	--	--	--	--
Dibenzo[a,h] anthracene	< 0.12	< 0.034	< 0.060	< 0.034	ND	0.028	0.033	--	--	--	--	--
Fluoranthene	13	1.1	0.53	1.2	0.64	1.29	0.56	--	--	--	--	--
Indeno[1,2,3-cd] pyrene	3.8	0.43	0.21	0.55	0.39	0.185	0.164	--	--	--	--	--
Pyrene	9.2	0.77	0.42	0.82	0.47	0.67	0.421	--	--	--	--	--
Total (ΣPAH_{16})	**52.3**	**4.76**	**2.40**	**5.72**	**5.59**	**13.2**	**13.8**	**71**	**2**	**1.2**	**1.5**	**0.48**

[1]Selbig, 2009.
[2]Ngabe and others, 2000.
[3]Menzie and others, 2002.
[4]Watts and others, 2010.
[5]Mahler and others, 2012.
[6]Stein and others, 2006.

unreliable for this study and were not used in the data analysis. Phenanthrene was the only organic compound detected at an estimated concentration in 1 of the 3 equipment blanks from March 19, 2012. A similar concentration was detected in the associated source solution blank, indicating that the laboratory was the likely source of contamination.

The replicate samples from the sampled outfalls had relative percent differences (RPDs) ranging from zero to 76.7 percent (appendix 1H). For some of these constituents, RPDs greater than 20 percent were observed but only once for the three replicates. Overall, the single replicate analyzed for two organic constituents (dieldrin and pp-DDD) on March 17, 2010, had average RPDs greater than 100 percent, much higher than for inorganic constituents. Therefore, the evaluations for these organic constituents were provided in a semi-qualitative context. In the same March 17, 2010, replicate sample, benzo[a]pyrene and benzo[ghi]fluoranthene had RPDs of 120 and 88 percent (appendix 1H). However, further evaluation indicated that the concentrations were near or at the censoring levels, which produce high RPDs, but actual differences were acceptable for the evaluation of PAHs. Specifically, the benzo[a]pyrene concentration in the environmental sample was <0.041 µg/L and in the replicate sample, E0.011 µg/L. The benzo[ghi]perylene concentration in the environmental sample was 0.07 µg/L and in the replicate sample, 0.18 µg/L.

Characterization of Stormwater

The amount, intensity, and duration of rainfall during a storm can affect stormwater runoff and the quantity of the contaminants it transports off the facility grounds. For this study, the duration of a runoff event was considered to be the time between the start of the rainfall and the end of stormwater runoff discharging at the outfalls. The intensity of the storm was computed as the amount of rainfall that fell during the duration of the runoff event (typically inches per hour). The range and extremes of the stormwater discharge and associated rainfall characteristics at each outfall or facility were evaluated to provide a foundation to assess the water-quality conditions.

Stormwater runoff often transports large quantities of sediment and sediment-bound contaminants, including nutrients, fecal indicator bacteria, trace metals, and organic compounds. The event-mean concentrations and loads of sediment-related, water-quality constituents are summarized for each facility further on. Elevated concentrations of trace metals in water potentially can cause impairment of the aquatic biota; therefore, aquatic life criteria have been established to protect the aquatic ecosystem. Although these criteria were developed for application to ambient concentrations in receiving waters, not stormwater, in this study, the criteria were used as a screening tool to assess potential impairment to the receiving water body. Additionally, the relation of hydrologic conditions to water-quality constituents was assessed using correlation analysis. Finally, discussions related to the occurrence of organochlorine insecticide, herbicide, polychlorinated biphenyls (PCBs), volatile organic compounds (VOCs), and PAH compounds and comparison of their concentrations to existing aquatic life criteria are presented in the section “Occurrence of Synthetic and Semivolatile Organic Compounds” of this report.

Stormwater Discharge and Rainfall

The storms sampled during this study cover a wide range of rainfall amounts, durations, and intensities at each of the facilities and, therefore, are considered to be reasonably representative of the potential for contaminant transport (fig. 5; appendix 1A). At all three facilities, the duration of the sampled rainfall event was not correlated significantly to mean or peak stormwater discharge, but rainfall amount and intensity were correlated (table 6). At Ballentine retention pond outfall and the Conway1 pipe outfall, the rainfall intensity and amount had similar significant correlation to event-mean stormwater discharge (table 6). In Turkey Creek at the North Charleston2 location and at the grass-lined ditch outfall at Conway2, the rainfall amount was correlated more strongly to event-mean stormwater discharge during storm events than intensity (table 6). Stormwater discharge in Turkey Creek at North Charleston1 was not correlated to either rainfall amount or intensity (table 6).

Among all three locations, rainfall intensity ranged from 0.02 (Ballentine) to 1.73 (North Charleston) inches per hour (in/h), and rainfall duration ranged from 25 (Ballentine) to 360 (Conway2) minutes (min) (fig. 5; table 7). Rainfall intensity varied the least at the Ballentine facility, with a range of 0.02 to 0.38 in/h during the study period, whereas the North Charleston facility, near the coast, had the greatest range of 0.08 to 1.73 in/h. Values for the Conway facility are intermediate to those of the other two facilities.

At the Ballentine location, rainfall intensity greater than 0.2 in/h occurred during the October 25, 2010 (fall), September 5, 2011 (summer), and September 27, 2011 (fall), sampling events (fig. 5*A*; appendix 1A). Rainfall amounts at this location were greater than 0.2 in. during these three high rainfall intensity sampling events and during the April 8, 2010 (spring), January 25, 2011 (winter), and April 5, 2011 (spring), events (fig. 5*A*: appendix 1A).

Rainfall intensity ranged from 0.03 to 1.22 in/h at the Conway outfalls, with averages of 0.26 in/h for 9 storms at the Conway1 outfall and 0.29 in/h for 8 storms at the Conway2 outfall (October 10, 2011, storm not sampled at Conway2) (fig. 5*B*, *C*; appendix 1A). Rainfall intensities of greater than 0.2 in/h occurred at the Conway sites on November 4, 2010 (fall), February 28, 2011 (winter), and September 20, 2011 (summer), storm sampling events. Rainfall amounts of greater than 0.2 in. were measured during the above three high intensity sampling events and on September 6, 2011 (summer), November 28, 2011 (fall), and January 11, 2012 (winter), sampling events.

Table 6. Kendall tau correlation coefficients (τ) and probability values (p) for selected stormwater discharge and rainfall measurements made during sampled storm events at outfall sites in Conway, Ballentine, and North Charleston, South Carolina, 2009 to 2011.

[τ, Kendall tau correlation coefficients; p, probability value; probability values less than 0.05 constituted a significant relation]

Stormwater discharge	Correlation statistic	Rainfall														
		Ballentine outfall			Conway1 outfall			Conway2 outfall			North Charleston1 location			North Charleston2 location		
		Intensity	Amount	Duration	Intensity	Amount	Duration	Intensity	Amount	Duration	Intensity	Amount	Duration	Intensity	Amount	Duration
Event-mean	τ	0.611	0.611	–0.197	0.667	0.667	–0.254	0.714	0.786	–0.036	0.286	0.357	0	0.571	0.929	–0.286
	p	0.022	0.022	0.463	0.012	0.012	0.345	0.013	0.007	0.901	0.322	0.216	1	0.048	0.001	0.322
Peak	τ	0.648	0.592	–0.229	0.611	0.611	–0.197	0.786	0.714	–0.109	0.286	0.357	0	0.714	0.786	–0.429
	p	0.016	0.028	0.399	0.022	0.022	0.463	0.007	0.013	0.708	0.322	0.216	1	0.013	0.007	0.138

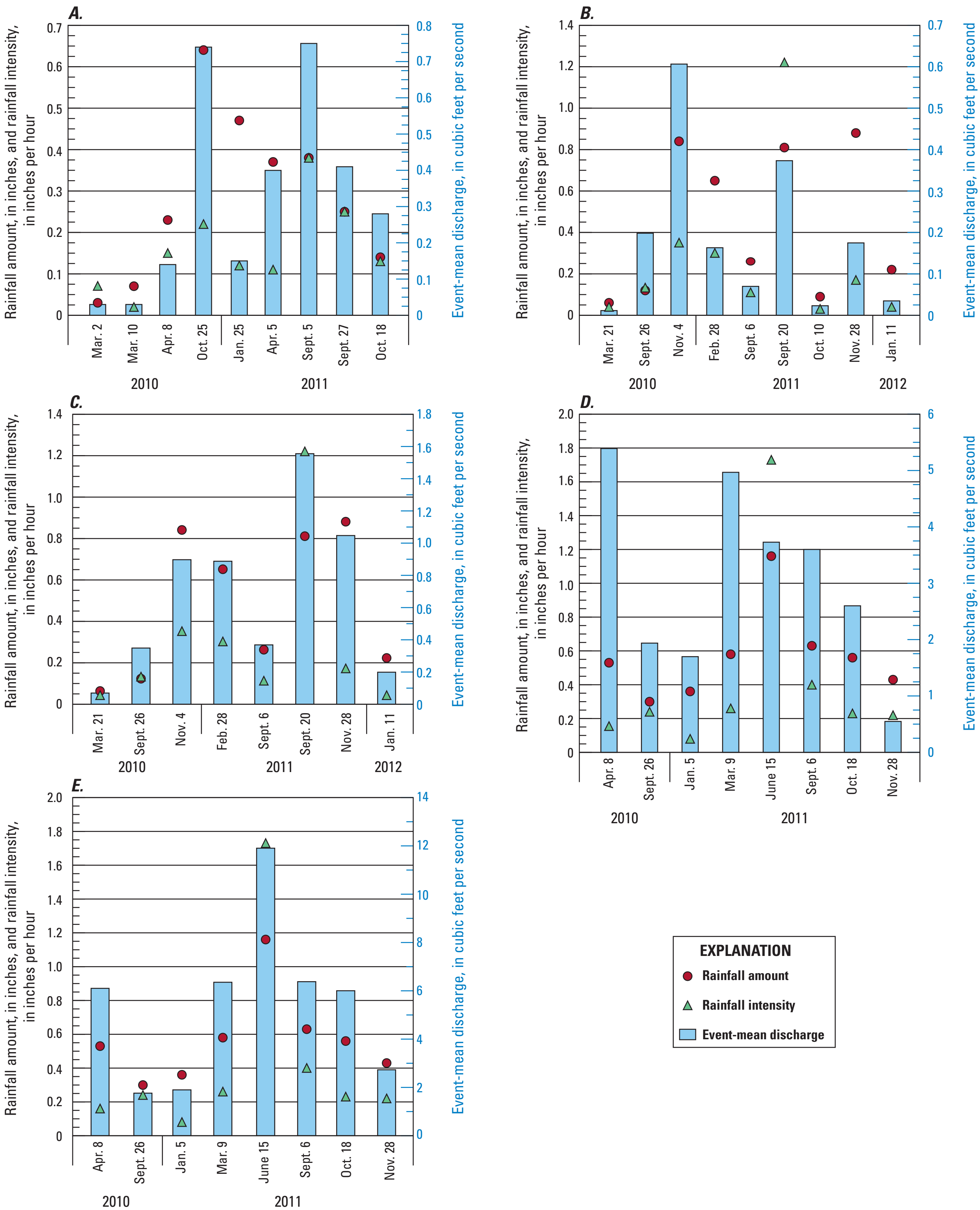


Figure 5. Event-mean stormwater discharge, rainfall, and rainfall intensity of sampled storms at *A*, Ballentine outfall, *B*, Conway1 outfall, *C*, Conway2 outfall, *D*, North Charleston1 outfall, and *E*, North Charleston2 outfall, South Carolina, 2010–2012.

Table 7. Summary statistics for stormwater discharge and rainfall for sampled storm events at the South Carolina Department of Transportation section shed near Ballentine (Ballentine retention pond outfall), maintenance yard at Conway (Conway1 pipe and Conway2 grass-lined ditch outfalls), and maintenance yard at North Charleston (North Charleston1 upstream and North Charleston2 downstream locations on Turkey Creek), South Carolina, 2010 to 2012.

[StDev, standard deviation; 25th Q, twenty-fifth quartile; 75th Q, seventy-fifth quartile; Min, minimum; Max, maximum; ft^3/s, cubic feet per second, r - based on ACGill comment]

Constituent	Number	Units	Mean	StDev	Median	25th Q	75th Q	Min	Max
Ballentine retention pond outfall									
Event-mean stormwater discharge	9	ft^3/s	0.33	0.27	0.28	0.14	0.41	0.03	0.75
Peak stormwater discharge	9	ft^3/s	0.71	0.65	0.43	0.29	1.06	0.04	1.72
Rainfall amount	9	inches	0.29	0.20	0.25	0.14	0.38	0.03	0.64
Rainfall intensity	9	inches per hour	0.16	0.11	0.13	0.11	0.22	0.02	0.38
Rainfall duration	9	minutes	130	88	90	60	195	25	255
Conway1 pipe outfall									
Event-mean stormwater discharge	9	ft^3/s	0.16	0.17	0.14	0.03	0.17	0.01	0.52
Peak stormwater discharge	9	ft^3/s	0.39	0.46	0.25	0.1	0.51	0.03	1.47
Rainfall amount	9	inches	0.44	0.35	0.26	0.12	0.81	0.06	0.88
Rainfall intensity	9	inches per hour	0.26	0.37	0.13	0.04	0.3	0.03	1.22
Rainfall duration	9	minutes	159	107	145	85	165	40	345
Conway2 grass-lined ditch outfall									
Event-mean stormwater discharge	8	ft^3/s	0.67	0.51	0.63	0.31	0.94	0.07	1.56
Peak stormwater discharge	8	ft^3/s	7.85	1.5	1.53	0.84	2.56	0.15	4.78
Rainfall amount	8	inches	0.48	0.35	0.46	0.2	0.82	0.06	0.88
Rainfall intensity	8	inches per hour	0.29	0.39	0.15	0.09	0.31	0.04	1.22
Rainfall duration	8	minutes	160	118	138	78	189	40	360
North Charleston1 upstream location on Turkey Creek									
Event-mean stormwater discharge	8	ft^3/s	3.06	1.67	3.1	1.88	4.04	0.55	5.39
Peak stormwater discharge	8	ft^3/s	9.87	5.15	11.8	6.73	13.8	1.04	14.8
Rainfall amount	8	inches	0.57	0.26	0.55	0.41	0.59	0.30	1.16
Rainfall intensity	8	inches per hour	0.41	0.54	0.24	0.21	0.29	0.08	1.73
Rainfall duration	8	minutes	136	76	125	90	159	40	280
North Charleston2 downstream location on Turkey Creek									
Event-mean stormwater discharge	8	ft^3/s	5.39	3.33	6.05	2.52	6.36	1.76	11.9
Peak stormwater discharge	8	ft^3/s	14.1	10.7	13.5	6.49	15.8	3.7	37.5
North Charleston maintenance yard									
Event-mean stormwater discharge	8	ft^3/s	2.35	2.64	1.78	0.58	2.94	0	8.17
Peak stormwater discharge	8	ft^3/s	4.46	8.92	1.41	0.25	2.9	0	26.3

At the North Charleston location, rainfall intensity ranged from 0.08 to 1.73 in/h with an average of 0.43 in/h (fig. 5*D*, *E*; appendix 1A). Rainfall intensities greater than 0.2 in/h were common at this location; only two sampling events (April 8, 2010, and January 5, 2011) had intensities below 0.2 in/h. All sampling events had rainfall amounts of greater than 0.3 in.

At the Ballentine facility, mean stormflow ranged from 0.03 to 0.75 cubic foot per second (ft^3/s) with a mean of 0.33 ft^3/s (fig. 5*A*; table 7). The maximum event mean stormwater discharge occurred on September 5, 2011 (summer), when the maximum rainfall intensity (0.38 in/h) also occurred, but not the maximum rainfall amount (fig. 5*A*; appendix 1A). Additionally, the mean event-mean stormwater discharge was normalized for the differences in drainage area by computing the mean unit-area stormwater discharge (mean event-mean stormwater discharge divided by drainage area) (table 1). At the Ballentine outfall at the retention pond, the mean unit-area discharge was 70.2 cubic feet per second per square mile ((ft^3/s)/mi^2) (table 1).

At the Conway facility, stormwater discharges in the two outfalls differed during storms (appendix 3F; Wilcoxon rank-sum W-statistic = 54; p-value = 0.008). Mean stormwater discharges at Conway1 outfall (smaller drainage area than Conway2) ranged from 0.01 to 0.52 ft^3/s with an average value of 0.16 ft^3/s. For the same storms, Conway2 outfall had greater mean stormwater discharges that ranged from 0.07 to 1.56 ft^3/s and averaged 0.67 ft^3/s (table 7; appendix 3F). At the Conway1 outfall, the greatest mean stormwater discharge of 0.52 ft^3/s occurred on November 4, 2010 (fig. 5*B*; appendix 1A). However, at the Conway2 outfall, the greatest mean stormwater discharge of 1.56 ft^3/s occurred on the September 20, 2011 (fig. 5*C*; appendix 1A). A comparison of the mean unit-area stormwater discharges at the Conway1 and Conway2 outfalls determined that the Conway1 outfall had almost twice the storm runoff per unit area (348 $(ft^3/s)/mi^2$) than the Conway2 outfall (176 $(ft^3/s)/mi^2$; table 1).

Stormwater runoff from the North Charleston facility drains to Turkey Creek, a perennial stream. Flow measurements during storms were made for Turkey Creek at the upstream (North Charleston1) and downstream (North Charleston2) limits of the SCDOT property. Event-mean stormflow discharge at North Charleston1 site ranged from 0.55 to 5.39 ft^3/s with a mean of 3.06 ft^3/s. At the North Charleston2 site, event-mean stormflow ranged from 1.76 to 11.90 ft^3/s with a mean of 5.39 ft^3/s (table 7). The maximum stormwater discharge occurred during different sampling events at the North Charleston1 (April 8, 2010) and North Charleston2 (June 15, 2011) sites on Turkey Creek (fig. 5*D*, *E*; appendix 1A). An estimate of the actual stormwater runoff contribution from the SCDOT property can be computed by subtracting the North Charleston1 stormwater discharge from North Charleston2 stormwater discharge for each sampling event. The estimated event-mean stormwater discharge for this location ranged from 0 (+/– 0.2 due to measurement error) to 8.17 ft^3/s with a mean of 2.35 ft^3/s (table 7). Average event-mean unit-area stormwater discharge for the North Charleston maintenance yard, which had the least amount of impervious surface (62 percent) of the three locations, was estimated to be about 71.2 $(ft^3/s)/mi^2$ (table 1). The mean unit-area discharge at the North Charleston facility was similar to that at the Ballentine facility, although the Ballentine outfall drained over 15 percent more impervious surface (table 1). That similarity may be attributed, in part, to the effects of the retention pond on the stormwater runoff at the Ballentine facility and the greater rainfall intensities and amounts at the North Charleston facility.

General Water-Quality Conditions

Stormwater runoff often transports large quantites of sediment and sediment-bound contaminants, including nutrients and fecal indicator bacteria. The event-mean concentrations and loads of the following water-quality constituents are summarized for each facility: (1) suspended sediment (SS) and total suspended solids (TSS), (2) nutrients (TKN, nitrate plus nitrite, and TP), and (3) fecal indicator bacteria. Turbidity also was described because it has been used as a surrogate measure of suspended sediment or particulates in water. While numeric criteria for turbidity, SS, or TSS have not been established for stormwater in South Carolina, the SCDHEC has established a narrative permit effluent limitation whereby stormwater runoff cannot “significantly concentrate or contribute to additional turbidity to the discharged water” (South Carolina Department of Health and Environmental Control, 2012, p. 21). For use in this report, the SCDHEC freshwater water-quality criterion for turbidity was adopted as a conservative screening limit, although it was developed for receiving waters, not stormwater. For the turbidity criterion established by the SCDHEC, receiving waters are considered impaired if more than 25 percent of the turbidity measurements over a 5-year period are greater than 50 nephelometric turbidity units (NTUs) (South Carolina Department of Health and Environmental Control, 2012). For a comparison of the turbidity levels in stormwater to this criterion, it was assumed that the stormwater would contribute 100 percent of the turbidity with no dilution to the receiving water.

Potential sources of nutrients in stormwater runoff include fertilizers applied to grassways, septic or sewage leakage, and plant debris. Nitrogen can be present as an organic form that is accounted for in the TKN value or inorganic form of ammonia, nitrate, or nitrite which are more biologically available to the aquatic biota than the organic form. Total nitrogen includes TKN and nitrate plus nitrite in dissolved and particulate phases. Phosphorus also can be present in the more biologically available inorganic form of orthophosphate, whereas total phosphorus comprises inorganic and organic forms, and dissolved and particulate phases. The BOD_5 is a measure of the biologically mediated organic decay processes that are capable of removing dissolved oxygen from the water column. Elevated BOD_5 concentrations tend to occur in water that is organically enriched from manmade or natural sources.

Ballentine Section Shed

Stormwater drainage from the Ballentine section shed area is surficial sheet flow that is diverted by a curb-and-gutter system to a retention basin. Stormwater runoff enters the basin through two outfalls. The stormwater accumulates in the basin until there is enough flow to exit the property through an outfall to a roadside ditch. Therefore, the potential exists for reduction in suspended sediment and sediment-bound contaminant concentrations in stormwater runoff at this facility before reaching the outfall.

Suspended Sediment and Total Suspended Solids

At the Ballentine site, stormwater samples from 6 of the 9 sampled storms were analyzed for SS concentrations (fig. 6; appendix 1B). For the sampled events, event-mean concentrations of SS in stormwater ranged from 37.0 to

252 mg/L, with a median value of 147 mg/L (fig. 6*A*, table 8). The maximum event-mean SS concentration occurred during the April 8, 2010, sampling event (fig. 6*A*, appendix 1B) with a mean stormwater discharge of 0.14 ft^3/s and rainfall intensity of 0.15 in/h (fig. 5*A*; appendix 1A). During the September 5, 2011, sampling event when the maximum event-mean stormwater discharge and rainfall intensity occurred at the Ballentine site, the SS EMC was 136 mg/L, which was below the median value (appendix 1*B*; table 8). Although TSS and SS EMCs were not correlated to each other at this outfall (appendix 3A), TSS EMCs at the Ballentine site had a temporal pattern similar to that of SS, except for the April 5, 2011, sampling event (fig. 6*B*) with the maximum TSS EMC of 290 mg/L occurring during the same April 8, 2010, sampling event as the maximum SS EMC (fig. 6*A*). At the Ballentine site, the TSS EMCs ranged from 30 to 290 mg/L, with a median value of 110 mg/L (fig. 6*B*; table 8). During the September 5, 2011, sampling event when the maximum event-mean stormwater discharge and rainfall intensity occurred at the Ballentine site, the TSS EMC was 170 mg/L, which was above the median value (fig. 6*B*; table 8). Greater SS and TSS EMCs were not correlated to greater mean stormwater discharge, rainfall amount, or intensity, but TSS EMCs were correlated to a greater number of days since last rainfall event (antecedent conditions) (appendix 3A).

Turbidity in the sampled events was not correlated to TSS or SS EMCs at the retention pond outfall at the Ballentine section shed facility (appendix 3A). Event-mean turbidity in stormwater runoff at the Ballentine site ranged from 16 to 160 NTUs with a median (50th percentile) of 51 (fig. 6*C*; table 8). For screening purposes, the values of turbidity in the stormwater were compared to the SCDHEC turbidity criterion of 50 NTUs that was established for ambient conditions in freshwater streams and rivers (not stormwater) to assess the potential of the stormwater to impair the receiving water. Stormwater discharging at the retention pond outfall had turbidity greater than the 50-NTU criterion for 5 of the 9 sampled storms at the Ballentine facility (fig. 6*C*; appendix 1B). Greater turbidity was not correlated to greater mean stormwater discharge, rainfall amount, or intensity but was correlated to a greater number of days since last rainfall event (antecedent conditions) (appendix 3A).

Event-mean loads and yields for individual storm events were computed for SS and TSS at the Ballentine section shed site (fig. 7*A*, *B*). Stormwater at the sampled outfall had SS loads that ranged from 1.55 to 34.5 kilograms per event (kg/event) and a median of 7.97 kg/event (fig. 7*A*; table 8). The greatest SS event-mean loads occurred during the October 2010 (34.5 kg/event) and September 2011 (23.5 kg/event) sampling events during maximum peak mean stormwater discharge (1.72 ft^3/s), not when maximum SS EMCs were measured (fig. 7*A*; appendix 1A). Event-mean loads of TSS tended to be less than SS loads, with the exception of the September 2011 sampling event (fig. 7*A*). TSS event-mean loads ranged from 0.140 to 26.4 kg/event with a median value of 6.38 kg/event

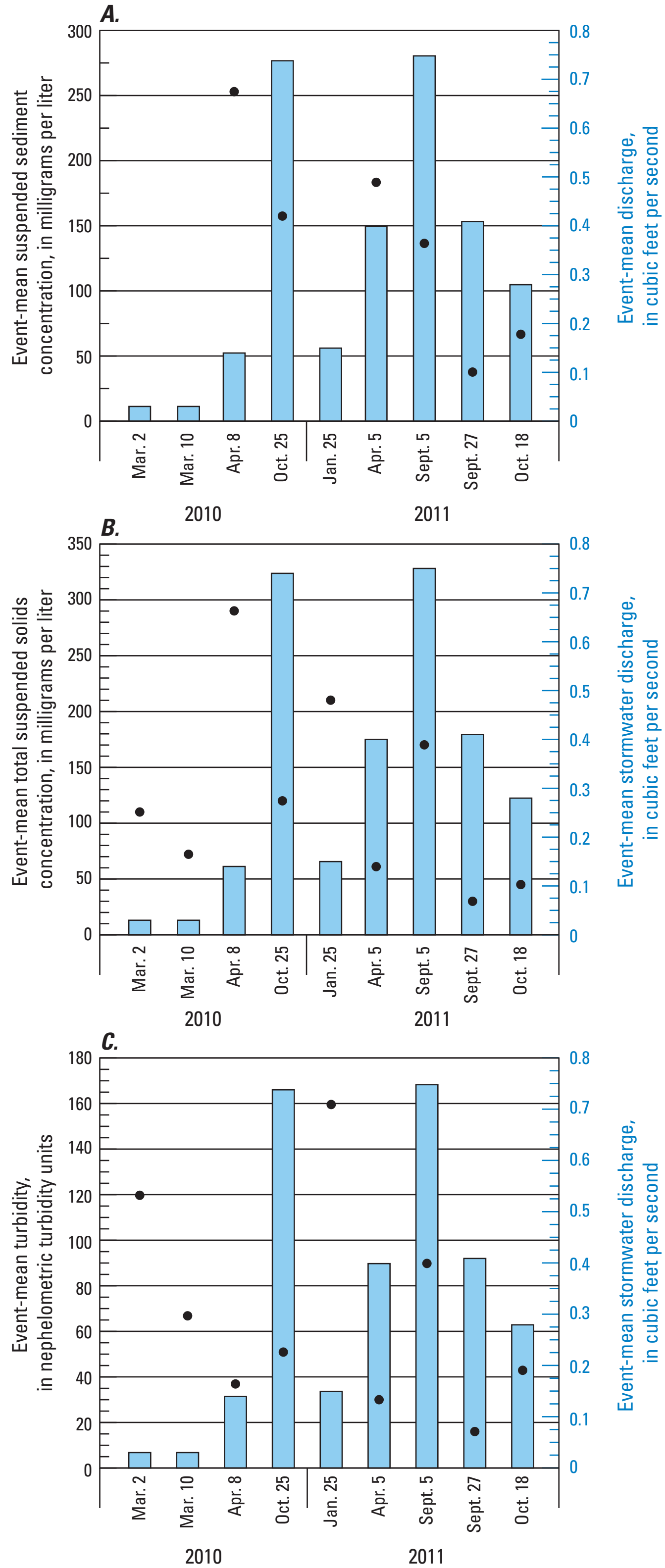


Figure 6. Event-mean concentrations of *A*, suspended sediment, *B*, total suspended solids, and *C*, turbidity in relation to event-mean stormwater discharging at the Ballentine outfall, Ballentine, South Carolina, 2010–2012.

Table 8. Summary statistics for selected constituent concentrations, loads, and yields in stormwater collected at the South Carolina Department of Transportation section shed outfall in Ballentine, South Carolina, (station 340801081142000), 2010 to 2012.

[Number, number of samples; StDev, standard deviation; 25th Q, twenty-fifth quartile; 75th Q, seventy-fifth quartile; Min, minimum; Max, maximum; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; col/100 mL, colonies per 100 milliliters; <, less than the laboratory reporting level; mg/L, milligrams per liter; µg/L, micrograms per liter; kg/event, kilograms per event; Mcol/event, million colonies per event; g/event, grams per event; (kg/event)/ha, kilograms per event per hectare; (mg/event)/ha, milligrams per event per hectare; (g/event)/ha, grams per event per hectare; (Mcol/event)/ha, million colonies per event per hectare; ND, not applicable; E, estimated value; Statistics in bold italics were computed using the Regression on Order Statistics for datasets with censored values]

Constituent	Number (censored)	Units	Mean	StDev	Median	25th Q	75th Q	Min	Max
Ballentine retention pond outfall event-mean concentrations									
Water temperature	9 (0)	°C	18.7	6.4	20.0	14.6	23.3	6.5	27.3
pH	9 (0)	standard units	6.7	0.4	6.8	6.7	7.0	6.1	7.2
Specific conductance	9 (0)	µS/cm	1,382	2,364	108	64.4	873	42	6,313
Dissolved oxygen	7 (0)	mg/L	8.0	1.6	7.7	6.8	8.3	6.7	11.2
Hardness	7 (0)	mg/L	55	66	21	11	83	E 6.3	194
Turbidity	9 (0)	NTU	68	47	51	37	90	16	160
Total Kjeldahl nitrogen	9 (0)	mg/L	1.76	1.57	1.5	0.92	1.8	0.73	5.80
Total nitrogen	9 (0)	mg/L	2.41	1.61	2.00	1.25	2.60	0.97	6.30
Nitrate plus nitrite	9 (0)	mg/L	0.66	0.49	0.50	0.30	0.93	0.19	1.6
5-day biochemical oxygen demand	8 (0)	mg/L	24.0	20.1	15.5	10.7	31.8	5.2	58.0
Total phosphorus	9 (0)	mg/L	0.26	0.32	0.15	0.15	0.20	0.049	1.1
Orthophosphate	***9 (5)***	***mg/L***	***0.022***	***0.027***	***< 0.016***	***< 0.016***	*0.028*	***< 0.016***	***0.086***
Enterococcus	9 (0)	col/100 mL	1,957	3,208	1,017	91	1,437	41	10,130
Escherichia coli	9 (0)	col/100 mL	538	746	110	41	754	10	2,070
Suspended sediment	6 (0)	mg/L	139	78.4	147	83.5	177	37	252
Suspended Sediment finer than 63 micron	6 (0)	percent	98.5	0.84	99	98	99	97	99
Total suspended solids	9 (0)	mg/L	123	85.9	110	61	170	30	290
Total cadmium	***9 (5)***	***µg/L***	***0.16***	***0.18***	***<0.13***	***< 0.13***	***0.17***	***< 0.13***	***0.54***
Dissolved cadmium	***8 (7)***	***µg/L***	***ND***	***ND***	***< 0.095***	***< 0.095***	***ND***	***< 0.095***	***E 0.26***
Total chromium	***9 (3)***	***µg/L***	***8.27***	***4.01***	***8.00***	***5.43***	***11.0***	***< 2.50***	***15.0***
Dissolved chromium	***9 (9)***	***µg/L***	***< 2.50***	***ND***	***< 2.50***	***< 2.50***	***< 2.50***	***< 2.50***	***< 2.50***
Total copper	9 (0)	µg/L	12.7	6.7	10	7.1	19	4.9	22
Dissolved copper	9 (0)	µg/L	6.5	3.3	6.4	4.0	9.6	E 2.4	12
Total lead	9 (0)	µg/L	5.3	3.0	5.1	3.8	6.2	1.9	12
Dissolved lead	***9 (4)***	***µg/L***	***0.58***	***1.2***	***0.21***	***< 0.20***	***0.27***	***< 0.20***	***3.7***

Table 8. Summary statistics for selected constituent concentrations, loads, and yields in stormwater collected at the South Carolina Department of Transportation section shed outfall in Ballentine, South Carolina, (station 340801081142000), 2010 to 2012. —Continued

[Number, number of samples; StDev, standard deviation; 25th Q, twenty-fifth quartile; 75th Q, seventy-fifth quartile; Min, minimum; Max, maximum; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; col/100 mL, colonies per 100 milliliters; <, less than the laboratory reporting level; mg/L, milligrams per liter; µg/L, micrograms per liter; kg/event, kilograms per event; Mcol/event, million colonies per event; g/event, grams per event; (kg/event)/ha, kilograms per event per hectare; (mg/event)/ha, milligrams per event per hectare; (g/event)/ha, grams per event per hectare; (Mcol/event)/ha, million colonies per event per hectare; ND, not applicable; E, estimated value; Statistics in bold italics were computed using the Regression on Order Statistics for datasets with censored values]

Constituent	Number (censored)	Units	Mean	StDev	Median	25th Q	75th Q	Min	Max
Ballentine retention pond outfall event-mean concentrations —Continued									
Dissolved nickel	***8 (2)***	***µg/L***	***2.5***	***0.78***	***2.3***	***1.9***	***3.2***	***< 2.0***	***3.7***
Total zinc	9 (0)	µg/L	77.9	30.8	85	64	97	34	130
Dissolved zinc	***8 (0)***	***µg/L***	***39.8***	***28.4***	***27.0***	***19.5***	***54.5***	***17.0***	***99.0***
Ballentine retention pond outfall event-mean loads									
5-day biochemical oxygen demand	8 (0)	kg/event	2.2	3.9	0.53	0.20	1.8	0.02	11.4
Hardness	8 (0)	kg/event	1.8	2.0	1.1	0.49	2.4	0.10	6.1
Total Kjeldahl nitrogen	9 (0)	kg/event	0.087	0.073	0.062	0.028	0.14	0.002	0.20
Total nitrogen	9 (0)	kg/event	0.12	0.089	0.14	0.038	0.16	0.038	0.26
Nitrate plus nitrite	9 (0)	kg/event	0.031	0.032	0.015	0.011	0.042	0.002	0.10
Total phosphorus	9 (0)	kg/event	0.013	0.012	0.012	0.002	0.020	0.000	0.033
Orthophosphate	***9 (5)***	***kg/event***	***0.002***	***0.003***	***0.000***	***0.000***	***0.002***	***< 0.00002***	***0.008***
Enterococcus	9 (0)	Mcol/event	1,333	1,525	731	39.9	2,268	0.64	4,074
Escherichia coli	9 (0)	Mcol/event	370	558	130	9.7	355	0.15	1,671
Suspended sediment	6 (0)	kg/event	13.1	13.4	7.97	2.92	20.8	1.55	34.5
Total suspended solids	9 (0)	kg/event	7.86	8.60	6.38	1.25	13.0	0.140	26.4
Total cadmium	***9 (5)***	***g/event***	***0.0044***	***0.0072***	***0.0012***	***0.00074***	***0.0037***	***< 0.0002***	***0.022***
Dissolved cadmium	***8 (7)***	***g/event***	***ND***	***ND***	***< 0.006***	***ND***	***ND***	***< 0.00012***	***E 0.016***
Total chromium	***9 (3)***	***g/event***	***0.45***	***0.63***	***0.11***	***0.021***	***0.76***	***< 0.077***	***1.87***
Dissolved chromium	***9 (9)***	***g/event***	***ND***	***ND***	***ND***	***< 0.011***	***ND***	***< 0.003***	***< 0.055***
Total copper	9 (0)	g/event	0.70	0.71	0.48	0.20	1.2	0.027	2.2
Dissolved copper	9 (0)	g/event	0.30	0.20	0.21	0.17	0.49	0.012	0.53
Total lead	9 (0)	g/event	0.37	0.43	0.14	0.062	0.68	0.00025	0.28
Dissolved lead	***9 (4)***	***g/event***	***0.043***	***0.091***	***0.0065***	***0.0013***	***0.036***	***< 0.00025***	***0.28***
Dissolved nickel	***8 (2)***	***g/event***	***0.084***	***0.069***	***0.054***	***0.049***	***0.12***	***< 0.27***	***0.22***
Total zinc	9 (0)	g/event	5.1	5.1	2.2	1.2	8.1	0.11	15
Dissolved zinc	8 (0)	g/event	2.2	2.6	0.96	0.52	3.3	0.036	7.6

Table 8. Summary statistics for selected constituent concentrations, loads, and yields in stormwater collected at the South Carolina Department of Transportation section shed outfall in Ballentine, South Carolina, (station 340801081142000), 2010 to 2012. —Continued

[Number, number of samples; StDev, standard deviation; 25th Q, twenty-fifth quartile; 75th Q, seventy-fifth quartile; Min, minimum; Max, maximum; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; col/100 mL, colonies per 100 milliliters; <, less than the laboratory reporting level; mg/L, milligrams per liter; µg/L, micrograms per liter; kg/event, kilograms per event; Mcol/event, million colonies per event; g/event, grams per event; (kg/event)/ha, kilograms per event per hectare; (mg/event)/ha, milligrams per event per hectare; (g/event)/ha, grams per event per hectare; (Mcol/event)/ha, million colonies per event per hectare; ND, not applicable; E, estimated value; Statistics in bold italics were computed using the Regression on Order Statistics for datasets with censored values]

Constituent	Number (censored)	Units	Mean	StDev	Median	25th Q	75th Q	Min	Max
Ballentine retention pond outfall event-mean yields									
5-day biochemical oxygen demand	8 (0)	(kg/event)/ha	1.8	3.2	0.43	0.16	1.5	0.017	9.3
Hardness	7 (0)	(kg/event)/ha	1.45	1.60	0.902	0.400	1.94	0.0803	4.95
Total Kjeldahl nitrogen	9 (0)	(kg/event)/ha	70.5	59.3	50.7	23.1	112	1.86	162
Total nitrogen	9 (0)	(kg/event)/ha	95.3	72.5	113	30.7	132	3.11	211
Nitrate plus nitrite	9 (0)	(kg/event)/ha	24.8	25.9	12.4	8.93	34	1.24	81.2
Total phosphorus	9 (0)	(kg/event)/ha	10.4	9.54	10.1	1.72	16.2	0.176	26.8
Orthophosphate	***9 (5)***	***(kg/event)/ha***	***1.78***	***2.45***	***0.278***	***0.278***	***1.72***	***< 0.017***	***6.62***
Enterococcus	9 (0)	(Mcol/event)/ha	1,084	1,240	593.9	32.45	1,843	0.518	3,310
Escherichia coli	9 (0)	(Mcol/event)/ha	301	454	106	7.92	288	0.125	1,366
Suspended sediment	6 (0)	(kg/event)/ha	10.6	10.9	6.48	2.37	16.9	1.26	28.1
Total suspended solids	9 (0)	(kg/event)/ha	6.39	6.99	5.18	1.02	10.6	0.114	21.5
Total cadmium	***9 (5)***	***(mg/event)/ha***	***3.55***	***5.83***	***0.936***	***0.600***	***3.04***	***< 3.27***	***18.3***
Dissolved cadmium	***8 (7)***	***(mg/event)/ha***	***ND***	***ND***	***< 4.56***	***ND***	***ND***	***< 0.135***	***E 13.2***
Total chromium	***9 (3)***	***(mg/event)/ha***	***365.7***	***515.5***	***92.54***	***17.18***	***613.8***	***< 62.82***	***1520***
Dissolved chromium	***9 (9)***	***(mg/event)/ha***	***ND***	***ND***	***< 84.9***	***ND***	***ND***	***< 2.59***	***< 447***
Total copper	9 (0)	(mg/event)/ha	569.2	577.5	393.1	166.4	964	21.75	1,752
Dissolved copper	9 (0)	(mg/event)/ha	239.8	160.7	171.5	137.3	398	9.94	430.8
Total lead	9 (0)	(mg/event)/ha	304.3	350.1	110.8	50.26	549.2	6.42	1,019
Dissolved lead	***9 (4)***	***(mg/event)/ha***	***34.79***	***74.10***	***5.277***	***1.055***	***29.08***	***< 0.2071***	***229.9***
Dissolved nickel	***8 (2)***	***(mg/event)/ha***	***68.32***	***55.89***	***43.51***	***39.93***	***98.53***	***< 215.4***	***180.2***
Total zinc	9 (0)	(mg/event)/ha	4,106	4,162	1,787	972.6	6,596	88.02	12,516
Dissolved zinc	8 (0)	(mg/event)/ha	1,767	2,074	779.1	418.7	2,663	28.99	6,151

(table 8). Greatest TSS event-mean loads occurred during the same sampling events as the greatest SS event-mean loads and is attributed to maximum stormwater discharge (fig. 7*A*). The SS event-mean yields ranged from 1.26 to 28.1 kilograms per event per hectare ((kg/event)/ha) with a median of 6.48 (kg/event)/ha. The TSS event-mean yields ranged from 0.114 to 21.5 (kg/event)/ha with a median of 5.18 (kg/event)/ha (table 8).

Nutrients and Biochemical Oxygen Demand

Predominant species and concentrations of nutrients varied among the sampled storms at the retention pond outfall at the Ballentine location (fig. 8*A*, *B*; appendix 1B). In general, total nitrogen concentrations consisted mainly of TKN rather than nitrate plus nitrite, with the exception of the January 2011 storm, in which nitrate plus nitrite EMC was more prevalent (fig. 8*A*; table 8). The maximum nitrate plus nitrite EMC (1.6 mg/L), which was more than 3 times the median of 0.5 mg/L, occurred during the January 2011 storm with a high amount (0.47 in.) and long duration (4.1 h) rainfall that produced a low rainfall intensity (0.12 in/h) and a relatively low mean stormwater discharge (0.15 ft^3/s) from the retention pond (fig. 8*A*; appendix 1A). In contrast, the January 2011 storm did not produce the greatest TKN or TN EMCs. Maximum TKN and TN EMCs of 5.80 and 6.30 mg/L (table 8), respectively, co-occurred during the April 2010 storm, which also had a relatively low rainfall intensity (0.15 in/h) and mean stormwater discharge (0.14 ft^3/s) (table 8; appendix 1A; appendix 1B). For most storms, nitrogen EMCs in stormwater leaving the sampled outfall at the retention pond tended to fall close to the median concentrations of 2.00 mg/L for TN, 1.50 mg/L for TKN, and 0.50 mg/L for nitrate plus nitrite (table 8; fig. 8*A*). For screening purposes, total nitrogen EMCs were compared to EPA recommended criteria related to ambient conditions in freshwater streams and rivers, and in all nine stormwater runoff events, TN EMCs exceeded the 0.90 mg/L EPA recommended criterion for rivers and streams (U.S. Environmental Protection Agency, 2000). However, it is likely that the concentrations in the sampled stormwater would have sufficient mixing with the receiving water to be reduced below the recommended level.

Maximum total phosphorus EMC of 1.1 mg/L occurred during the same April 2010 storm that produced the maximum TKN and TN concentrations in stormwater at the Ballentine retention pond (fig. 8*B*; table 8). For all other storms, total phosphorus EMCs in stormwater leaving the sampled outfall at the retention pond were an order of magnitude less than the maximum and tended to fall close to the median concentration of 0.15 mg/L (fig. 8*B*; table 8). Total phosphorus EMCs for all nine sampled storms exceeded the 0.04 mg/L EPA recommended criterion for rivers and streams (fig. 8*B*; U.S. Environmental Protection Agency, 2000). However, it is likely that the concentrations in the sampled stormwater would have sufficient mixing with the receiving water to be reduced below the recommended level. Orthophosphate EMCs constituted only a small portion of the TP EMCs for most sampled storms. For the September 5, 2011 and September 27, 2011 storms, however, orthophosphate was a significant portion of TP, and the orthophosphate EMCs were greater than the median orthophosphate concentration of <0.016 mg/L and were a significant portion (36 and 57 percent) of the TP (fig. 8*B*; table 8). The greatest orthophosphate EMCs, which were more than 4 to 7 times the median, occurred during storms with the greatest rainfall intensities (0.22–0.38 in/h) and mean stormwater discharges (0.41–0.75 ft^3/s) from the retention pond (fig. 5*A*; appendix 1A).

The EMCs for BOD_5 ranged from 5.20 to 58.0 mg/L with a median of 15.5 mg/L (table 8; fig. 8*C*). The maximum BOD_5 EMC of 58.0 mg/L occurred on April 2010, concurrent with the maximum TN, TKN, and TP EMCs. The April 8, 2010, storm had relatively low rainfall intensity (0.15 in/h) and mean stormwater discharge (0.14 ft^3/s) (table 8; figs. 5*A*, 8*C*).

Event-mean loads and yields of nutrients in samples collected at the outfall of the retention pond at the Ballentine facility during storms demonstrated variability over time (fig. 7*C*, *D*). Stormwater leaving the retention pond at the sampled outfall had a median TN event-mean load of 0.12 kg/event with a range of 0.038 to 0.26 kg/event (fig. 7*C*; table 8). TKN event-mean loads ranged from 0.0023 to 0.20 kg/event with a median of 0.062 kg/event (fig. 7*C*; table 8). In general, nitrate plus nitrite event-mean loads (range of 0.0015 to 0.10 kg/event) were lower than TKN event-mean loads by about half (fig. 7*C*; table 8). The median event-mean load for TP in the stormwater was 0.012 kg/event, and event-mean loads for TP ranged from 0.00022 to 0.033 kg/event (fig. 7*C*; table 8). Event-mean yields, in grams per hectare per event, for all nutrients were computed and statistically summarized (fig. 7*D*; table 8). At the Ballentine facility, maximum nutrient event-mean loads and yields of TN, TKN, and TP occurred during the September 5, 2011 storm, which had the maximum mean storm discharge of 0.75 ft^3/s (figs. 5*A*, 7*C*, *D*). Median event-mean yields were 113 grams per event per hectare ((g/event)/ha) for TN, 50.7 (g/event)/ha for TKN, and 10.1 (g/event)/ha for TP (fig. 7*B*, *D*; table 8). Median event-mean yield for nitrate plus nitrite was 12.4 (g/event)/ha (fig. 7*B*, *D*; table 8).

Fecal Indicator Bacteria

The *E. coli* and enterococcus concentrations varied by 3 orders of magnitude in grab samples collected during the first flush of stormwater from the Ballentine outfall at the retention pond (fig. 9; appendix 1B). Additionally, enterococcus concentrations consistently were greater than the corresponding *E. coli* concentrations in stormwater at the outfall (fig. 9; appendix 1B). Specifically, *E. coli* concentrations ranged from 10 to 2,070 col/100 mL with a median of 110 col/100 mL, whereas enterococcus concentrations ranged from 41 to 10,130 col/100 mL, with a median of 1,017 col/100 mL (fig. 9*A*; table 8). As described above, these

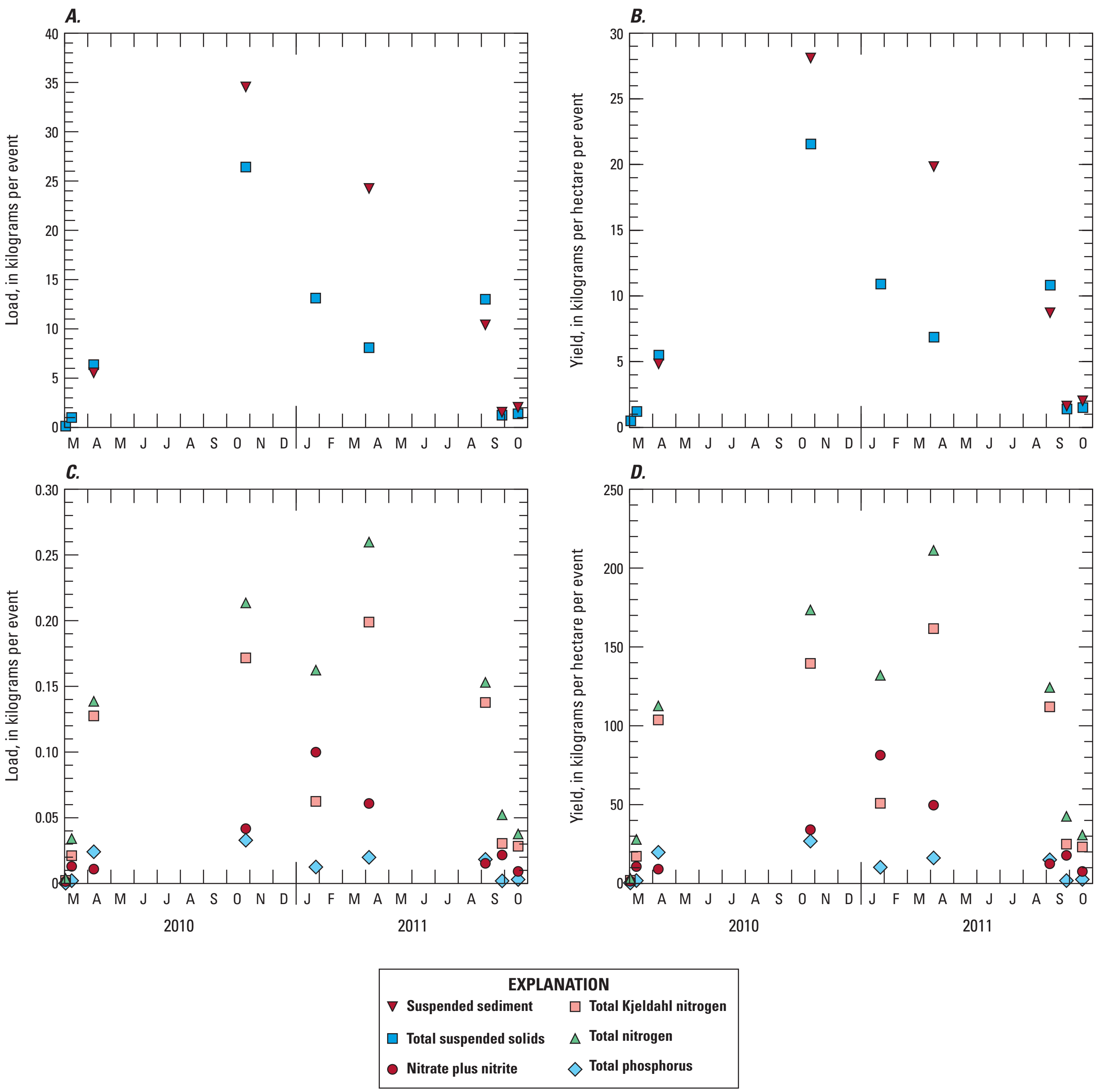


Figure 7. Temporal variation in total suspended solids and suspended sediment *A*, event-mean loads and *B*, event-mean yields and in nutrient *C*, event-mean loads and *D*, event-mean yields in stormwater discharging at the Ballentine outfall, Ballentine, South Carolina, 2010–2011.

"first flush" fecal indicator bacteria concentrations represent potentially the greatest concentrations in the stormwater during a single storm and, therefore, overcompensate for the effects on receiving waters. Notwithstanding, the "first flush" *E. coli* concentrations in the stormwater at the Ballentine outfall were compared to the SCDHEC newly adopted SSM for *E. coli* of 349 col/100 mL for recreational waters to screen the bacteria data for potential effects on receiving waters. Even though the *E. coli* concentrations likely overestimated potential effects on receiving water, only 4 of the 9 sampled storms (44 percent) had *E. coli* concentrations that exceeded the SCDHEC criterion (fig. 9*A*; appendix 1B). Additionally for screening purposes, the "first flush" enterococcus concentrations in the stormwater at the Ballentine facility were compared to the EPA SSM of 151 col/100 mL for waters where infrequent body contact occurs. At the Ballentine facility, 6 (67 percent) of the 9 sampled storms had enterococcus concentrations that exceeded the EPA SSM of 151 col/100 mL (fig. 9*A*; appendix 1B). The data screening indicated some potential for effects on receiving waters, but it is likely that the concentrations in the sampled stormwater would have sufficient mixing with additional stormwater and the receiving water to be reduced below the criterion level. The maximum concentration for *E. coli* and enterococci in the "first-flush" grab sample occurred during the April 8, 2010, storm that had a peak stormwater discharge of 0.41 ft^3/s and rainfall intensity at 0.15 in/h (fig. 9; appendix 1A). Minimum concentrations for *E. coli* and enterococci occurred during the January 25, 2011, storm that had a peak stormwater discharge of 0.15 ft^3/s and rainfall intensity of 0.12 in/hr (fig. 9; appendix 1A).

Escherichia coli and enterococcus loads in stormwater discharging from the retention pond at the Ballentine facility varied by 4 and 3 orders of magnitude, respectively, among the nine sampled storms (table 8; fig. 9*B*). "First-flush" loads of *E. coli* ranged from 8.96 to 15,700 million colonies per event (Mcol/event) with a median of 120 Mcol/event at the Ballentine outfall (fig. 9*B*). Enterococcus loads were greater than the *E. coli* loads, ranging from 36.4 to 65,193 Mcol/event with a median of 17,542 Mcol/event (fig. 9*B*). Maximum *E. coli* and enterococcus loads did not occur during the same storm (fig. 9*B*). The maximum *E. coli* load occurred during the October 2011, storm, which is attributed to relatively high "first flush" stormwater discharge and long rainfall duration (fig. 9*B*; appendix 1A). The maximum enterococcus load occurred during the April 8, 2010, storm when maximum enterococcus concentrations were present. The April 2010 storm had less "first flush" stormwater discharge and shorter rainfall duration than the October 2011 storm (fig. 9*B*; appendix 1A).

Relations Among Water-Quality Constituents and Hydrologic Characteristics

Of the six hydrologic characteristics at the Ballentine site, which include rainfall amount, intensity, and duration; peak stormwater discharge; mean stormwater discharge; and antecedent conditions, the hydrologic characteristic most frequently and significantly correlated to water-quality EMCs was stormwater discharge (peak and mean) (appendix 3A). The EMCs for hardness (calcium and magnesium), nitrate, pH, and specific conductance were correlated negatively to peak and mean stormwater discharges (appendix 3A). Total and dissolved copper and total nickel EMCs were correlated negatively to mean stormwater discharge only at this site. The negative correlation indicates decreasing concentrations with increased stormwater discharge, commonly attributed to dilution type processes. One exception was a positive correlation between stormwater discharge and orthophosphate EMCs at this site, which indicates increasing concentrations with

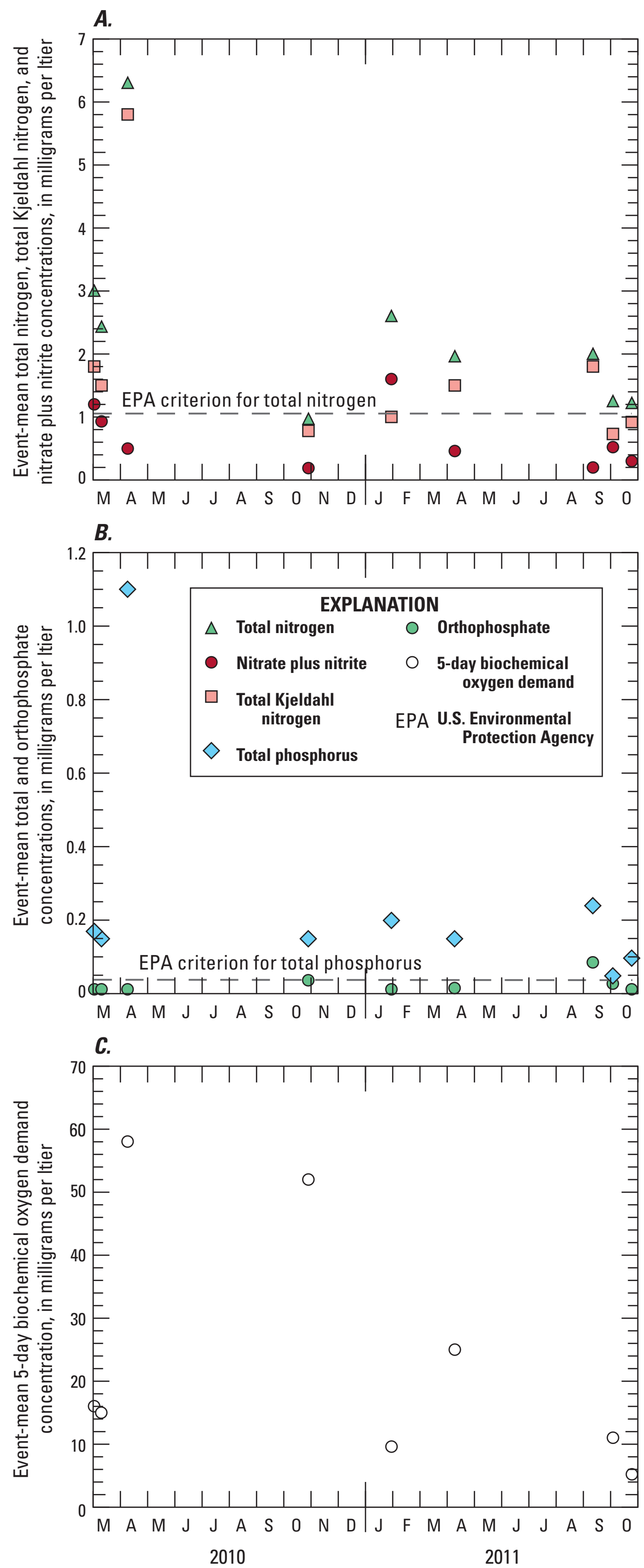


Figure 8. Event-mean concentrations of *A*, nitrogen species, *B*, phosphorus species, and *C*, 5-day biochemical oxygen demand in stormwater discharging at the Ballentine outfall, Ballentine, South Carolina, 2010–2012.

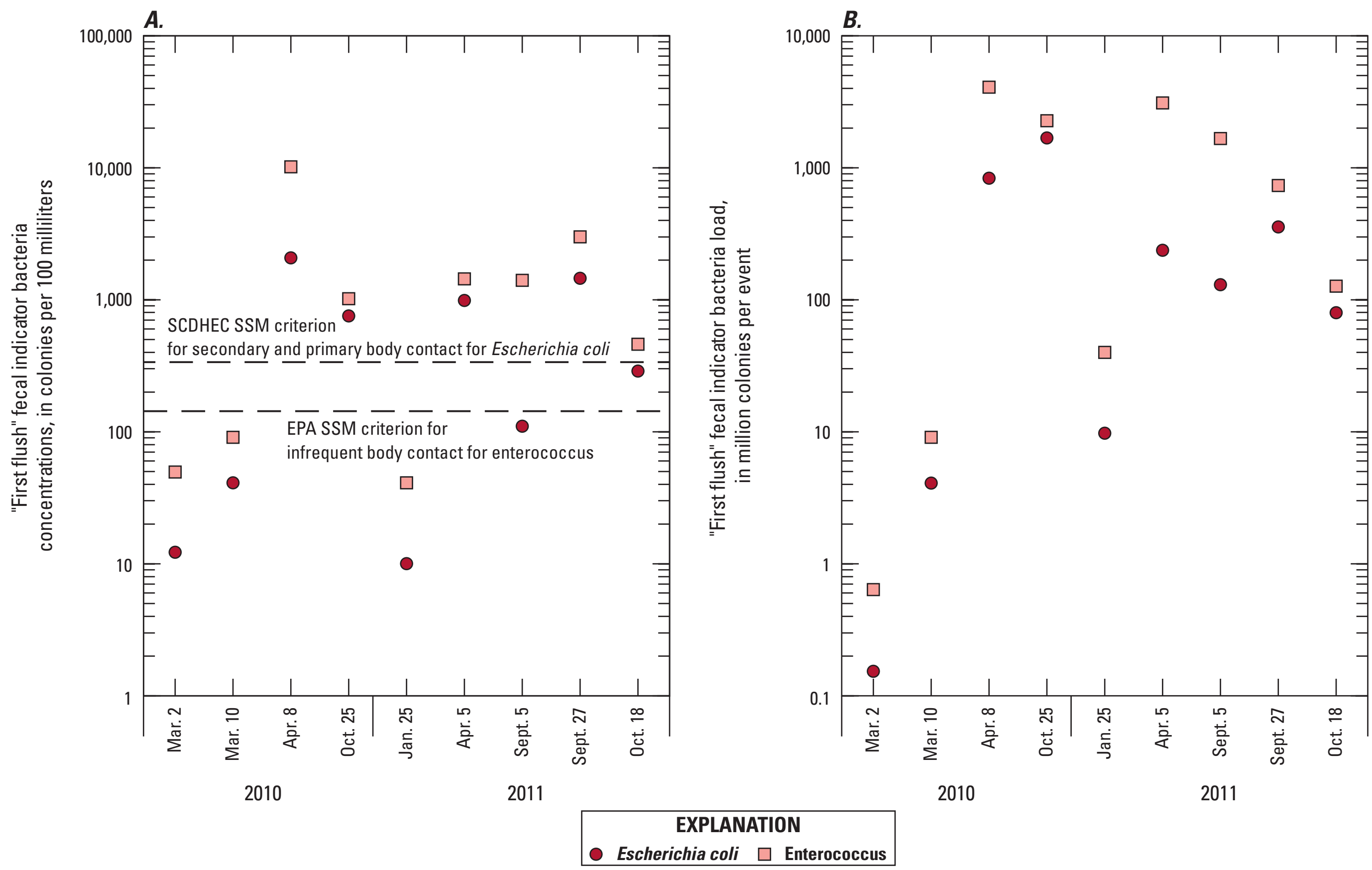


Figure 9. Temporal variation of *Escherichia coli* and enterococcus *A*, concentrations and *B*, loads in "first flush" grab samples collected in stormwater discharging at the Ballentine outfall, Ballentine, South Carolina, 2010–2012. [SCDHEC, South Carolina Department of Health and Environmental Control; SSM, single sample maximum; EPA, U.S. Environmental Protection Agency]

increased stormwater. A similar positive relation was identified between rainfall intensity, which co-varied with stormwater discharge, and orthophosphate. For the sediment-based constituents, the antecedent condition, days since last rainfall, was the main hydrologic characteristic that displayed a statistically significant positive relation with TSS EMCs and turbidity, which indicates greater TSS EMCs and turbidity occurred during storms that were preceded by long dry periods. The EMCs of TSS and SS were not correlated to each other or to turbidity. Total phosphorus EMCs were correlated positively with TSS, total nitrogen, and TKN EMCs. "First flush" enterococcus and *E. coli* concentrations were negatively correlated to turbidity in stormwater at the Ballentine facility (appendix 3A).

Conway Maintenance Yard

At the Conway maintenance yard facility, stormwater discharges at the Conway1 outfall (PVC pipe outlet) or the Conway2 outfall (grass-lined ditch). Event-mean concentrations, loads, and yields of the suspended sediment, nutrients, biochemical oxygen demand, and fecal indicator bacteria in stormwater samples from the two outfalls are summarized in tables 9 and 10. Differences in median EMCs in samples from the outfalls are based on the Wilcoxon Rank-Sum Test results (appendix 3F).

Suspended Sediment and Total Suspended Solids

Event-mean concentrations of SS and TSS produced by the transport of sediment in stormwater runoff at the Conway maintenance yard were not statistically different in stormwater discharging at Conway1 and Conway2 outfalls, but turbidity was greater in stormwater at the Conway1 outfall than at Conway2 outfall (appendix 3F). Event-mean concentrations of SS in the stormwater runoff at the Conway1 outfall ranged from 33.0 to 263 mg/L with a median value of 105 mg/L (fig. 10*A*; table 9). The SS EMCs in the stormwater discharging at Conway2 outfall ranged from 40 to 260 mg/L with a median of 94 mg/L (fig. 10*B*; table 10). Maximum SS EMCs occurred during the February 28, 2011, storm at both Conway1 and Conway2 outfall with rainfall intensity of 0.30 in/h and mean stormwater discharge of 0.14 and 0.89 ft^3/s, respectively (appendix 1A, 1C, 1D). One excursion from the similar temporal patterns of SS EMCs at the two outfalls occurred during the November 2010 storm when the SS EMC (254 mg/L) was near maximum at the Conway1 outfall but near the minimum EMC at Conway2 outfall (50 mg/L) (fig. 10*A*, *B*; appendixes 1C, 1D). During this event, a greater percentage (3%) of the suspended sediment consisted of sand-sized particles than silt- and clay-sized particles (appendix 1C, 1D).

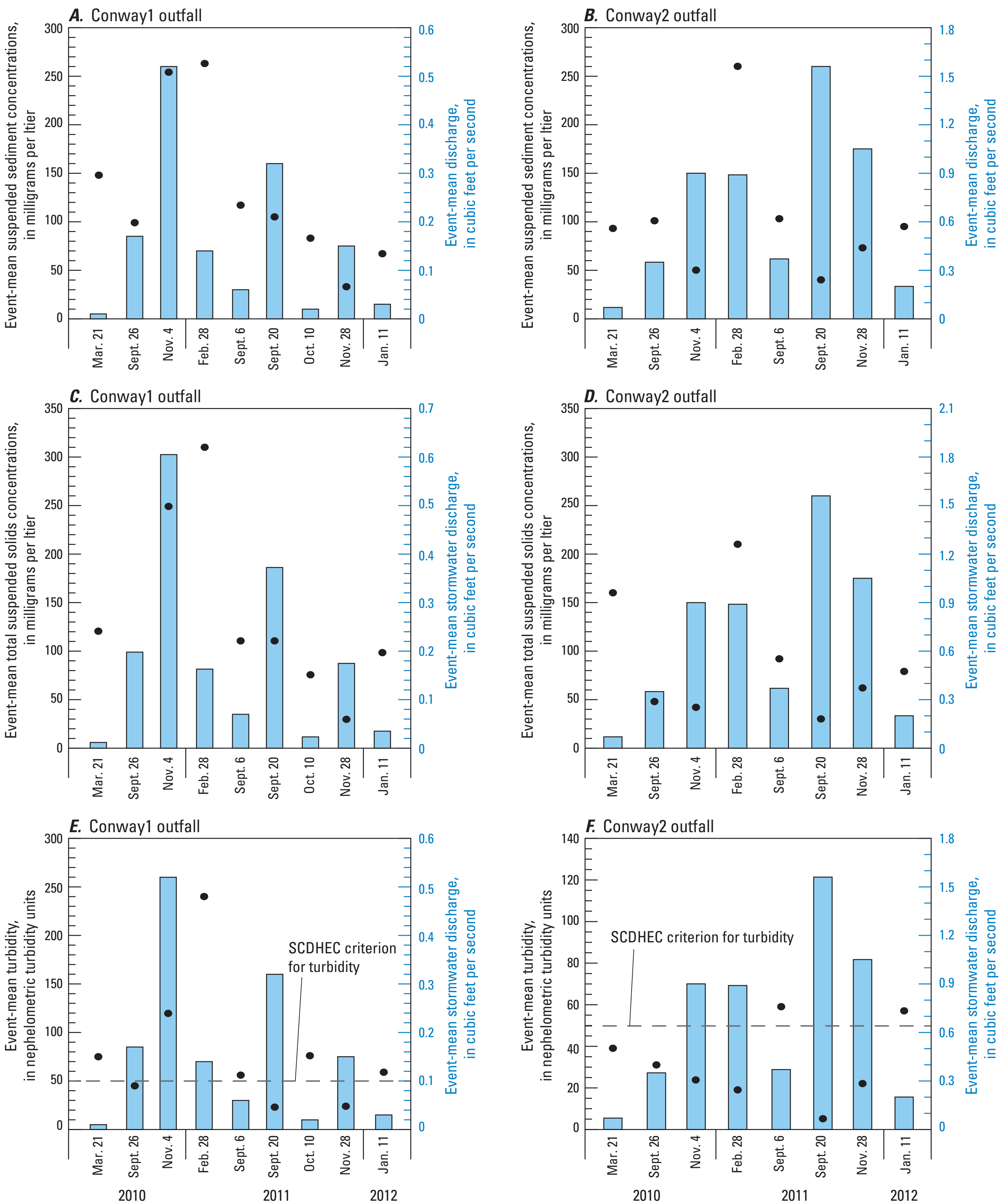


Figure 10. Event-mean concentrations of *A*, suspended sediment, *C*, total suspended solids, and *E*, turbidity in stormwater discharging at the Conway1 outfall and of *B*, suspended sediment, *D*, total suspended solids, and *F*, turbidity in stormwater discharging at the Conway2 outfall, Conway, South Carolina, 2010–2012. [SCDHEC, South Carolina Department of Health and Environmental Control]

Table 9. Summary statistics for selected constituent concentrations, loads, and yields in stormwater collected at the pipe outfall (Conway1; station 3354440790245000) at the southern boundary of the South Carolina Department of Transportation maintenance yard near Conway, South Carolina, 2010 to 2012.

[Number, number of samples; StDev, standard deviation; 25th Q, twenty-fifth quartile; 75th Q, seventy-fifth quartile; Min, minimum; Max, maximum; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; col/100 mL, colonies per 100 milliliters; <, less than the laboratory reporting level; mg/L, milligrams per liter; µg/L, micrograms per liter; kg/event, kilograms per event; g/event, grams per event; (kg/event)/ha, kilograms per event per hectare; (mg/event)/ha, milligrams per event per hectare; (g/event)/ha, grams per event per hectare; Mcol/event, million colonies per event; (Mcol/event)/ha, million colonies per event per hectare; ND, not applicable; E, estimated value; Statistics in bold italics were computed using the Regression on Order Statistics for datasets with censored values]

Constituent	Number (censored)	Units	Mean	StDev	Median	25th Q	75th Q	Min	Max
Conway1 pipe outfall event-mean concentrations									
Water temperature	8 (0)	°C	20.9	4.7	19.9	18.6	21.8	16.2	31.4
pH	8 (0)	Standard units	8.4	0.8	8.1	8.0	8.5	7.6	10.1
Specific conductance	8 (0)	µS/cm	118	71	89	70	145	60	260
Dissolved oxygen	8 (0)	mg/L	8.8	0.9	8.8	8.4	9.6	7.1	9.8
Hardness	9 (0)	mg/L	49	31	42	31	72	13	105
Turbidity	9 (0)	NTU	80	67	59	45	76	23	240
Total Kjeldahl nitrogen	9 (0)	mg/L	1.64	1.39	1.30	0.76	2.10	0.36	4.80
Total nitrogen	9 (0)	mg/L	1.93	1.44	1.59	0.79	2.78	0.50	4.96
Nitrate plus nitrite	9 (0)	mg/L	0.28	0.21	0.24	0.16	0.38	0.034	0.74
5-day biochemical oxygen demand	9 (0)	mg/L	10	8.3	5.0	4.6	20	2	23
Total phosphorus	***9 (1)***	***mg/L***	***0.20***	***0.11***	***0.15***	***0.12***	***0.29***	***< 0.024***	***0.36***
Orthophosphate	***9 (3)***	***mg/L***	***0.024***	***0.016***	***0.021***	***< 0.016***	***0.025***	***< 0.016***	***0.055***
Enterococcus	9 (0)	col/100 mL	3,567	7,869	512	145	1,467	41	>24,196.0
Escherichia coli	9 (3)	col/100 mL	624	1,544	30	< 10	262	< 10	4,725
Suspended sediment	9 (0)	mg/L	130	79.6	105	83	148	33	263
Total suspended solids	8 (0)	mg/L	138	93.7	110	92.3	153	29	310
Suspended sediment finer than 63 micron	9 (0)	percent	97	2.18	97	97	99	92	99
Total cadmium	***9 (8)***	***µg/L***	***ND***	***ND***	***< 0.13***	***ND***	***ND***	***< 0.13***	***E 0.19***
Dissolved cadmium	***8 (8)***	***µg/L***	***ND***	***ND***	***< 0.095***	***ND***	***ND***	***< 0.095***	***< 0.095***
Total chromium	***9 (2)***	***µg/L***	***15.7***	***21.1***	***7.8***	***3.3***	***18***	***< 2.5***	***68***
Dissolved chromium	***8 (5)***	***µg/L***	***9.2***	***16.5***	***< 2.5***	***< 2.5***	***12.1***	***< 2.5***	***46***
Total copper	9 (0)	µg/L	7.5	5.2	5.7	4.1	11	E 1.4	17
Dissolved copper	***6 (2)***	***µg/L***	***3.5***	***3.9***	***2.1***	***< 1.1***	***4.6***	***< 1.1***	***11***
Total lead	9 (0)	µg/L	6.3	4.0	4.7	3.8	8.1	1.6	14
Dissolved lead	***8 (6)***	***µg/L***	***ND***	***ND***	***< 0.2***	***ND***	***ND***	***< 0.2***	***1.7***
Dissolved nickel	***8 (5)***	***µg/L***	***2.9***	***2.0***	***2.3***	***<2.0***	***3.9***	***<2.0***	***6.8***
Total zinc	9 (0)	µg/L	121	53.9	110	69	160	56	210
Dissolved zinc	***8 (2)***	***µg/L***	***25.1***	***24.1***	***17.5***	***8.8***	***35***	***< 8.3***	***75***

Table 9. Summary statistics for selected constituent concentrations, loads, and yields in stormwater collected at the pipe outfall (Conway1; station 3354440790245000) at the southern boundary of the South Carolina Department of Transportation maintenance yard near Conway, South Carolina, 2010 to 2012. —Continued

[Number, number of samples; StDev, standard deviation; 25th Q, twenty-fifth quartile; 75th Q, seventy-fifth quartile; Min, minimum; Max, maximum; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; col/100 mL, colonies per 100 milliliters; <, less than the laboratory reporting level; mg/L, milligrams per liter; µg/L, micrograms per liter; kg/event, kilograms per event; g/event, grams per event; (kg/event)/ha, kilograms per event per hectare; (mg/event)/ha, milligrams per event per hectare; (g/event)/ha, grams per event per hectare; Mcol/event, million colonies per event; (Mcol/event)/ha, million colonies per event per hectare; ND, not applicable; E, estimated value; Statistics in bold italics were computed using the Regression on Order Statistics for datasets with censored values]

Constituent	Number (censored)	Units	Mean	StDev	Median	25th Q	75th Q	Min	Max
Conway1 pipe outfall event-mean loads									
5-day biochemical oxygen demand	9 (0)	kg/event	0.248	0.250	0.100	0.040	0.365	0.027	0.649
Hardness	9 (0)	kg/event	1.63	2.94	0.616	0.325	1.15	0.162	9.40
Total Kjeldahl nitrogen	9 (0)	kg/event	0.031	0.021	0.027	0.015	0.046	0.0032	0.062
Total nitrogen	9 (0)	kg/event	0.037	0.025	0.028	0.022	0.063	0.0044	0.074
Nitrate plus nitrite	9 (0)	kg/event	0.0066	0.0085	0.0043	0.0012	0.0072	0.00090	0.028
Total phosphorus	***9 (1)***	***kg/event***	***0.0061***	***0.0098***	***0.0022***	***0.00087***	***0.0046***	***< 0.0020***	***0.031***
Orthophosphate	***9 (3)***	***kg/event***	***0.00038***	***0.00030***	***0.00024***	***0.00014***	***0.00064***	***< 0.000028***	***0.00087***
Enterococcus	9 (0)	Mcol/event	388	499	148	39	669	12	1,347
Escherichia coli	***9 (3)***	***Mcol/event***	***73***	***112***	***18***	***2***	***77***	***< 2***	***317***
Suspended sediment	6 (0)	kg/event	5.65	10.4	1.73	1.18	2.69	0.229	32.5
Total suspended solids	9 (0)	kg/event	6.29	10.8	2.04	1.32	4.19	0.185	32.0
Total cadmium	***9 (8)***	***g/event***	***ND***	***ND***	***< 0.002***	***ND***	***ND***	***<0.0002***	***E 0.006***
Dissolved cadmium	***8 (8)***	***g/event***	***ND***	***ND***	***< 0.002***	***ND***	***ND***	***< 0.0001***	***< 0.012***
Total chromium	***9 (2)***	***g/event***	***1.1***	***2.9***	***0.071***	***< 0.054***	***0.12***	***< 0.054***	***8.7***
Dissolved chromium	***8 (5)***	***g/event***	***0.76***	***2.1***	***0.0043***	***0.0036***	***0.062***	***< 0.040***	***5.9***
Total copper	9 (0)	g/event	0.27	0.49	0.089	0.035	0.16	0.026	1.5
Dissolved copper	***6 (2)***	***g/event***	***0.069***	***0.10***	***0.026***	***0.017***	***0.062***	***< 0.024***	***0.27***
Total lead	9 (0)	g/event	0.26	0.45	0.085	0.062	0.13	0.013	1.4
Dissolved lead	***9 (4)***	***g/event***	***ND***	***ND***	***< 0.005***	***ND***	***ND***	***< 0.001***	***E 0.015***
Dissolved nickel	***8 (5)***	***g/event***	***0.026***	***0.034***	***0.014***	***0.012***	***0.020***	***< 0.035***	***0.11***
Total zinc	9 (0)	g/event	5.1	8.4	2.2	0.98	5.3	0.17	27
Dissolved zinc	8 (0)	g/event	0.67	0.70	0.33	0.21	1.1	0.062	2.0
Conway1 pipe outfall event-mean yields									
5-day biochemical oxygen demand	9 (0)	(kg/event)/ha	1.9	1.9	0.75	0.61	2.7	0.20	4.9
Hardness	9 (0)	(kg/event)/ha	12.3	22.1	4.63	2.45	8.66	1.22	70.8
Total Kjeldahl nitrogen	9 (0)	(g/event)/ha	230	157	203	110	347	24.4	466
Total nitrogen	9 (0)	(g/event)/ha	280	191	209	164	475	33.0	559

Table 9. Summary statistics for selected constituent concentrations, loads, and yields in stormwater collected at the pipe outfall (Conway1; station 3354440790245000) at the southern boundary of the South Carolina Department of Transportation maintenance yard near Conway, South Carolina, 2010 to 2012. —Continued

[Number, number of samples; StDev, standard deviation; 25th Q, twenty-fifth quartile; 75th Q, seventy-fifth quartile; Min, minimum; Max, maximum; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; col/100 mL, colonies per 100 milliliters; <, less than the laboratory reporting level; mg/L, milligrams per liter; µg/L, micrograms per liter; kg/event, kilograms per event; g/event, grams per event; (kg/event)/ha, kilograms per event per hectare; (mg/event)/ha, milligrams per event per hectare; (g/event)/ha, grams per event per hectare; Mcol/event, million colonies per event; (Mcol/event)/ha, million colonies per event per hectare; ND, not applicable; E, estimated value; Statistics in bold italics were computed using the Regression on Order Statistics for datasets with censored values]

Constituent	Number (censored)	Units	Mean	StDev	Median	25th Q	75th Q	Min	Max
Conway1 pipe outfall event-mean yields —Continued									
Nitrate plus nitrite	9 (0)	(g/event)/ha	49.4	64.0	32.3	8.84	54.2	6.75	212
Total phosphorus	***9 (1)***	***(g/event)/ha***	***46.0***	***73.8***	***16.7***	***6.53***	***34.7***	***< 14.7***	***231***
Orthophosphate	***9 (3)***	***(g/event)/ha***	***2.86***	***2.27***	***1.84***	***1.05***	***4.78***	***2.12***	***6.57***
Enterococcus	9 (0)	(Mcol/event)/ha	2,920	3,754	1,116	290	5,030	87	10,139
Escherichia coli	***9 (3)***	***(Mcol/event)/ha***	***546***	***842***	***132***	***12.6***	***576***	***< 12***	***2,387***
Suspended sediment	6 (0)	(kg/event)/ha	42.5	77.9	13.0	8.87	20.3	1.72	245
Total suspended solids	9 (0)	(kg/event)/ha	47.3	81.3	15.4	9.97	31.5	1.40	241
Total cadmium	***9 (8)***	***(mg/event)/ha***	***ND***	***ND***	***< 17***	***ND***	***ND***	***< 1.5***	***E 44.2***
Dissolved cadmium	***8 (8)***	***(mg/event)/ha***	***ND***	***ND***	***< 14***	***ND***	***ND***	***< 1.1***	***< 92***
Total chromium	***9 (2)***	***(mg/event)/ha***	***8,146***	***21,561***	***536***	***367***	***932***	***< 409***	***65,547***
Dissolved chromium	***8 (5)***	***(mg/event)/ha***	***5,678***	***15,625***	***32.2***	***27.1***	***470***	***< 300***	***44,341***
Total copper	9 (0)	(mg/event)/ha	2,007	3,659	671	265	1,195	198	11,567
Dissolved copper	***6 (2)***	***(mg/event)/ha***	***518***	***749***	***198***	***128***	***465***	***< 180***	***2024***
Total lead	9 (0)	(mg/event)/ha	1,943	3,383	638	463	982	94.2	10,603
Dissolved lead	***9 (4)***	***(mg/event)/ha***	***ND***	***ND***	***< 39***	***ND***	***ND***	***< 8.44***	***E 115***
Dissolved nickel	***8 (5)***	***(mg/event)/ha***	***193***	***254***	***103***	***87.8***	***154***	***< 265***	***813***
Total zinc	9 (0)	(mg/event)/ha	38,472	63,084	16,683	7,410	39,554	1,279	202,425
Dissolved zinc	8 (0)	(mg/event)/ha	5,029	5,274	2,503	1,579	8,242	464	15,341

Unlike stormwater discharging at the retention pond outfall at the Ballentine section shed facility, TSS EMCs in stormwater discharging from the Conway1 and Conway2 outfalls correlated positively with SS EMCs (appendixes 3B, 3C). TSS EMCs ranged from 29.0 to 310 mg/L for Conway1 outfall and from 30.0 to 210 mg/L for Conway2 outfall with a median values of 110 and 71 mg/L, respectively (fig. 10*C*, *D*; tables 9, 10). The maximum TSS EMC occurred during the same February 2011, storm as the maximum SS EMC for Conway1 and Conway2 outfalls, (fig. 10*C*, *D*; appendix 1D).

Event-mean turbidity values in stormwater runoff at the Conway1 outfall were significantly greater than the event-mean turbidity values in stormwater at the Conway2 outfall for the sampled storms (appendix 3F). Additionally, event-mean turbidity was not significantly correlated with SS or TSS EMCs at the Conway1 outfall (appendix 3B) or at the

Table 10. Summary statistics for selected constituent concentrations, loads, and yields in stormwater collected at the outfall at the grass-lined ditch (Conway2; station 335448079024500) on the northern boundary of the South Carolina Department of Transportation maintenance yard near Conway, South Carolina, 2010 to 2012.

[Number, number of samples; StDev, standard deviation; 25th Q, twenty-fifth quartile; 75th Q, seventy-fifth quartile; Min, minimum; Max, maximum; ºC, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; col/100 mL, colonies per 100 milliliters; <, less than the laboratory reporting level; mg/L, milligrams per liter; µg/L, micrograms per liter; kg/event, kilograms per event; g/event, grams per event; (kg/event)/ha, kilograms per event per hectare; (g/event)/ha, grams per event per hectare; Mcol/event, million colonies per event; (Mcol/event)/ha, million colonies per event per hectare; ND, not applicable; E, estimated value; Statistics highlighted in bold italics were computed using the Regression on Order Statistics for datasets with censored values]

Constituent	Number (censored)	Units	Mean	StDev	Median	25th Q	75th Q	Min	Max
Conway2 grass-lined ditch outfall event-mean concentrations									
Water temperature	8 (0)	ºC	21.7	5.86	19.3	17.7	24.4	16	31.7
pH	6 (0)	standard units	6.7	1.4	7.1	6.9	7.4	3.8	7.7
Specific conductance	8 (0)	µS/cm	77	63	64	32	93	17	214
Dissolved oxygen	8 (0)	mg/L	8.6	1.2	9.3	7.9	9.4	6.7	9.7
Hardness	7 (0)	mg/L	23	19	17	8.3	33	4.5	53
Turbidity	8 (0)	NTU	32	19	28	21	44	5.1	59
Total Kjeldahl nitrogen	8 (0)	mg/L	1.38	1.02	1.45	0.38	1.85	0.28	3.10
Total nitrogen	8 (0)	mg/L	1.67	1.22	1.80	0.47	2.24	0.31	3.54
Nitrate plus nitrite	8 (0)	mg/L	0.30	0.26	0.23	0.10	0.46	0.032	0.77
5-day biochemical oxygen demand	***8 (1)***	***mg/L***	***13***	***9.2***	***13***	***6.4***	***20***	***< 2***	***25***
Total phosphorus	***8 (1)***	***mg/L***	***0.17***	***0.114***	***0.16***	***0.066***	***0.26***	***< 0.024***	***0.35***
Orthophosphate	***8 (3)***	***mg/L***	***0.056***	***0.044***	***0.049***	***0.017***	***0.100***	***< 0.016***	***0.110***
Enterococcus	7 (0)	col/100 mL	10,233	10,533	3,441	2,807	19,166	50	> 24,196
Escherichia coli	7 (0)	col/100 mL	4,983	8,890	1,178	247	4,508	1	> 24,196
Suspended sediment	8 (0)	mg/L	102	68	94	67	102	40	260
Total suspended solids	8 (0)	mg/L	90	63	71	47	109	30	210
Suspended sediment finer than 63 micron	8 (0)	percent	90	7	92	88	94	77	97
Total cadmium	***8 (5)***	***µg/L***	***< 0.13***	***0.07***	***< 0.13***	***< 0.13***	***0.15***	***< 0.13***	***E 0.25***
Dissolved cadmium	***7 (6)***	***µg/L***	***ND***	***ND***	***< 0.095***	***ND***	***ND***	***< 0.095***	***E 0.15***
Total chromium	***8 (2)***	***µg/L***	***7.4***	***4.5***	***5.5***	***3.9***	***12***	***< 2.5***	***14***
Dissolved chromium	***7 (4)***	***µg/L***	***2.9***	***2.2***	***2.3***	***< 2.5***	***4.2***	***< 2.5***	***46***
Total copper	***8 (1)***	***µg/L***	***7.1***	***4.7***	***6***	***3.1***	***11.5***	***< 1.1***	***14***
Dissolved copper	4 (0)	µg/L	3.8	4.1	2	1.5	4.3	1.3	10
Total lead	***8 (1)***	***µg/L***	***4.8***	***2.9***	***4.1***	***3.0***	***5.8***	***< 0.5***	***11***
Dissolved lead	***6 (5)***	***µg/L***	***ND***	***ND***	***< 0.2***	***ND***	***ND***	***< 0.2***	***E 0.39***
Dissolved nickel	***7 (5)***	***µg/L***	***ND***	***ND***	***< 2***	***ND***	***ND***	***< 2.0***	***8.2***
Total zinc	8 (0)	µg/L	133	102	103	64.5	188	E 14	330
Dissolved zinc	6 (0)	µg/L	65	106	21.5	12.3	43.5	E 9.5	280

Table 10. Summary statistics for selected constituent concentrations, loads, and yields in stormwater collected at the outfall at the grass-lined ditch (Conway2; station 335448079024500) on the northern boundary of the South Carolina Department of Transportation maintenance yard near Conway, South Carolina, 2010 to 2012. —Continued

[Number, number of samples; StDev, standard deviation; 25th Q, twenty-fifth quartile; 75th Q, seventy-fifth quartile; Min, minimum; Max, maximum; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; col/100 mL, colonies per 100 milliliters; <, less than the laboratory reporting level; mg/L, milligrams per liter; µg/L, micrograms per liter; kg/event, kilograms per event; g/event, grams per event; (kg/event)/ha, kilograms per event per hectare; (mg/event)/ha, milligrams per event per hectare; (g/event)/ha, grams per event per hectare; Mcol/event, million colonies per event; (Mcol/event)/ha, million colonies per event per hectare; ND, not applicable; E, estimated value; Statistics in bold italics were computed using the Regression on Order Statistics for datasets with censored values]

Constituent	Number (censored)	Units	Mean	StDev	Median	25th Q	75th Q	Min	Max
Conway2 grass-lined ditch outfall event-mean loads									
5-day biochemical oxygen demand	8 (1)	mg/L	1.6	1.5	0.97	0.68	2.1	< 0.21	4.3
Hardness	7 (0)	kg/event	1.9	1.4	1.9	0.97	2.1	0.47	4.6
Total Kjeldahl nitrogen	8 (0)	kg/event	0.133	0.1	0.124	0.072	0.163	0.024	0.334
Total nitrogen	8 (0)	kg/event	0.16	0.112	0.147	0.091	0.213	0.032	0.372
Nitrate plus nitrite	8 (0)	kg/event	0.026	0.019	0.024	0.013	0.036	0.003	0.062
Total phosphorus	***8 (1)***	***kg/event***	***0.015***	***0.013***	***0.014***	***0.006***	***0.017***	***< 0.014***	***0.045***
Orthophosphate	***8 (3)***	***kg/event***	***0.004***	***0.004***	***0.003***	***0.001***	***0.007***	***< 0.002***	***0.01***
Enterococcus	7 (0)	Mcol/event	46,673	61,718	8,957	7,456	66,495	9.39	169,851
Escherichia coli	7 (0)	Mcol/event	14,093	20,649	2,654	657	19,324	< 1	> 56,032
Suspended sediment	7 (0)	kg/event	16.7	18.9	10.2	4.01	19.1	0.98	51.1
Total suspended solids	8 (0)	kg/event	13.8	15.6	8.85	2.81	16.1	1.57	41.3
Total cadmium	***8 (5)***	***g/event***	***0.006***	***0.003***	***0.006***	***0.006***	***0.007***	***< 0.014***	***0.012***
Dissolved cadmium	***7 (6)***	***g/event***	***ND***	***ND***	***< 0.012***	***ND***	***ND***	***< 0.0010***	***E 0.005***
Total chromium	***8 (2)***	***g/event***	***0.76***	***0.88***	***0.45***	***0.26***	***0.88***	***< 0.27***	***2.75***
Dissolved chromium	***7 (3)***	***g/event***	***0.16***	***0.11***	***0.13***	***0.095***	***0.23***	***< 0.27***	***0.38***
Total copper	***8 (1)***	***g/event***	***0.8***	***0.72***	***0.62***	***0.27***	***1.2***	***< 0.12***	***2.2***
Dissolved copper	4 (0)	g/event	0.42	0.26	0.41	0.29	0.54	0.11	0.74
Total lead	***8 (1)***	***g/event***	***0.72***	***0.75***	***0.53***	***0.12***	***1.1***	***< 0.053***	***2.2***
Dissolved lead	***7 (5)***	***g/event***	***ND***	***ND***	***< 0.039***	***ND***	***ND***	***< 0.002***	***0.19***
Dissolved nickel	***7 (5)***	***g/event***	***ND***	***ND***	***< 0.44***	***ND***	***ND***	***< 0.21***	***0.27***
Total zinc	8 (0)	g/event	16.1	12.7	14.2	8.47	22.5	1.01	35.4
Dissolved zinc	6 (0)	g/event	4.5	3.5	4.3	2.1	7	0.32	9.2

Table 10. Summary statistics for selected constituent concentrations, loads, and yields in stormwater collected at the outfall at the grass-lined ditch (Conway2; station 335448079024500) on the northern boundary of the South Carolina Department of Transportation maintenance yard near Conway, South Carolina, 2010 to 2012. —Continued

[Number, number of samples; StDev, standard deviation; 25th Q, twenty-fifth quartile; 75th Q, seventy-fifth quartile; Min, minimum; Max, maximum; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; col/100 mL, colonies per 100 milliliters; <, less than the laboratory reporting level; mg/L, milligrams per liter; µg/L, micrograms per liter; kg/event, kilograms per event; g/event, grams per event; (kg/event)/ha, kilograms per event per hectare; (mg/event)/ha, milligrams per event per hectare; (g/event)/ha, grams per event per hectare; Mcol/event, million colonies per event; (Mcol/event)/ha, million colonies per event per hectare; ND, not applicable; E, estimated value; Statistics in bold italics were computed using the Regression on Order Statistics for datasets with censored values]

Constituent	Number (censored)	Units	Mean	StDev	Median	25th Q	75th Q	Min	Max
Conway2 grass-lined ditch outfall event-mean yields									
5-day biochemical oxygen demand	8 (1)	(kg/event)/ha	1.64	1.57	1.00	0.703	2.19	< 0.22	4.43
Hardness	7 (0)	(kg/event)/ha	1.95	1.43	1.94	1.01	2.22	0.493	4.77
Total Kjeldahl nitrogen	8 (0)	(g/event)/ha	138	103	128	74.8	169	25.1	346
Total nitrogen	8 (0)	(g/event)/ha	165	116	152	94.6	221	33.5	385
Nitrate plus nitrite	8 (0)	(g/event)/ha	27.2	19.7	24.9	13.3	38.0	3.51	64.6
Total phosphorus	***8 (1)***	***(g/event)/ha***	***15.7***	***13.7***	***14.1***	***6.54***	***17.4***	***< 14.2***	***46.8***
Orthophosphate	***8 (3)***	***(g/event)/ha***	***4.06***	***3.94***	***2.72***	***1.03***	***6.89***	***< 2.03***	***10.4***
Enterococcus	7 (0)	(Mcol/event)/ha	48,322	63,897	9,273	7,719	68,842	9.72	175,847
Escherichia coli	7 (0)	(Mcol/event)/ha	14,590	21,378	2,748	680	20,006	0.19	58,010
Suspended sediment	7 (0)	(kg/event)/ha	17.3	19.6	10.6	4.15	19.8	1.02	52.9
Total suspended solids	8 (0)	(kg/event)/ha	14.3	16.1	9.16	2.91	16.7	1.63	42.7
Total cadmium	***8 (5)***	***(mg/event)/ha***	***6.35***	***3.00***	***5.66***	***5.66***	***7.06***	***< 14.3***	***12.3***
Dissolved cadmium	***7 (6)***	***(mg/event)/ha***	***ND***	***ND***	***< 10.2***	***ND***	***ND***	***< 1.04***	***E 5.08***
Total chromium	***8 (2)***	***(mg/event)/ha***	***783***	***906***	***463***	***268***	***910***	***< 274***	***2,849***
Dissolved chromium	***7 (3)***	***(mg/event)/ha***	***170***	***114***	***139***	***98.8***	***237***	***< 274***	***393***
Total copper	***8 (1)***	***(mg/event)/ha***	***824***	***748***	***637***	***280***	***1,206***	***< 121***	***2,239***
Dissolved copper	4 (0)	(mg/event)/ha	433	274	428	303	558	109	768
Total lead	***8 (1)***	***(mg/event)/ha***	***743***	***776***	***552***	***119***	***1,159***	***< 54.9***	***2,239***
Dissolved lead	***7 (5)***	***(mg/event)/ha***	***ND***	***ND***	***< 40.7***	***ND***	***ND***	***< 2.18***	***198***
Dissolved nickel	***7 (5)***	***(mg/event)/ha***	***ND***	***ND***	***< 215***	***ND***	***ND***	***< 220***	***278***
Total zinc	8 (0)	(mg/event)/ha	16,651	13,150	14,656	8,765	23,285	1,048	36,633
Dissolved zinc	6 (0)	(mg/event)/ha	4,710	3,584	4,417	2,139	7,283	327	9,481

Conway2 outfall (appendix 3C). Event-mean turbidity values at the Conway1 outfall ranged from 23 to 240 NTUs with a median value of 59 NTUs (fig. 10*E*; table 9). Stormwater from the Conway2 outfall had event-mean turbidity values that ranged from 5.1 to 59 NTUs with a median of 28 NTUs (fig. 10*F*; table 10). Maximum turbidity co-occurred with the maximum SS and TSS EMCs during the February 28, 2011, storm in stormwater discharging at Conway1 outfall (fig. 10*A*, *C*, *E*), but maximum turbidity did not co-occur with maximum SS and TSS EMCs in stormwater discharging at Conway2 outfall (fig. 10*B*, *D*, *F*). At the Conway2 outfall during the February 28, 2011, storm, an increase in sand-size fraction of the SS (SS finer than 63 microns was reduced to 77 percent) that can produce rapid settling of the suspended particles was observed, and the increase resulted in a turbidity measurement of only 19 NTUs (appendix 1D; Anderson, 2005). Maximum event-mean turbidity of 59 NTU in stormwater discharging at the Conway2 outfall was measured during the September 6, 2011, storm at TSS and SS EMCs of 92 and 103 mg/L, respectively (appendix 1D). For screening purposes, the turbidity values in the stormwater runoff were compared to the SCDHEC turbidity criterion of 50 NTUs that was established for ambient conditions in freshwater streams and rivers (not stormwater) to assess the potential of the stormwater runoff to affect the receiving water. Six of the 9 storms sampled (67 percent) at Conway1 outlet pipe outfall produced stormwater with turbidity values greater than the 50-NTU criterion for freshwater (fig. 10E; appendix 1C). At the Conway2 grass-lined ditch outfall, 2 of the 8 storms sampled (25 percent) produced stormwater runoff with turbidity of 57 and 59 NTUs that exceeded the turbidity criterion for freshwater (fig. 10*F*; appendix 1D). However, these event-mean turbidity values were near the criterion of 50 NTUs and had minimal likelihood of impairing the ambient conditions in the receiving water body (fig. 10F; appendix 1D). The greater number of exceedances at Conway1 compared to Conway2 might be explained by storage of road maintenance materials in the drainage area of Conway1 outfall and by the sediment-removal potential of the grass-lined ditch at Conway2 outfall.

Event-mean loads and yields were computed for sampled storms at the Conway facility outfalls. Stormwater discharging at the Conway1 outfall had event-mean SS loads ranging from 0.229 to 32.5 kg/event with a median of 1.73 kg/event (fig. 11*A*; table 9). At Conway1 outfall, the event-mean TSS loads ranged from 0.185 to 32.0 kg/event with a median of 2.04 kg/event (fig. 11*A*; table 9). The maximum SS and TSS loads occurred during the November 2010 storm and were an order of magnitude higher than the next greatest SS and TSS loads at Conway1 outfall (fig. 11*A*). Event-mean SS loads in stormwater runoff discharging at Conway2 outfall ranged from 0.980 to 51.1 kg/event with a median of 10.2 kg/event (fig. 12*A*; table 10). At the Conway2 outfall, event-mean TSS loads in stormwater runoff ranged from 1.57 to 41.3 kg/event with a median of 8.85 kg/event (fig. 12*A*; table 10). The maximum SS and TSS loads occurred during the February 2011 storm at the Conway2 outfall and did not represent dramatic outliers (fig. 12*A*). Event-mean SS and TSS yields (adjusted event-mean SS and TSS loads for differences in drainage areas) indicated relatively uniform contributions of suspended sediment during stormwater runoff throughout the Conway facility, with the exception of the maximum SS yield at Conway1 (figs. 11*B*, 12*B*). Stormwater discharging at the Conway1 outfall had event-mean SS yields ranging from 1.72 to 245 (kg/event)/ha with a median of 13.0 (kg/event)/ha (fig. 11*B*; table 9). At Conway1 outfall, the event-mean TSS yields ranged from 1.40 to 241 (kg/event)/ha with a median of 15.4 (kg/event)/ha (fig.11*B*; table 9). Event-mean SS yields in stormwater runoff discharging at Conway2 outfall ranged from 1.02 to 52.9 (kg/event)/ha with a median of 10.6 (kg/event)/ha (fig. 12*B*; table 10). At the Conway2 outfall, event-mean TSS yields in stormwater runoff ranged from 1.63 to 42.7 (kg/event)/ha, with a median of 9.16 (kg/event)/ha (fig. 12*A*; table 10).

Nutrients and Biochemical Oxygen Demand

Stormwater discharging at the Conway1 outfall had nutrient EMCs statistically similar to those in stormwater discharging at the Conway2 outfall (appendix 3F). Although TKN and nitrate-plus-nitrate forms of nitrogen were present in the stormwater runoff, total nitrogen (TN) was composed predominantly of TKN in samples from both outfalls (figs. 13*A*, 14*A*; appendixes 1C, 1D). For the nine sampled storms, stormwater discharging at the outfall of Conway1 had a median TKN EMC of 1.30 mg/L and an EMC range of 0.36 to 4.80 mg/L; the median TN EMC was 1.59 mg/L with a nearly identical EMC range of 0.50 to 4.96 mg/L (fig. 13*A*; table 9). During most storms, nitrate-plus-nitrite EMCs in stormwater at Conway1 were about 7 times less than TN EMCs (fig. 13*A*; table 9). Maximum TN and TKN EMCs in stormwater runoff discharging at the Conway1 outfall occurred during the October 2011 storm (fig. 13*A*; appendix 1C). Similar to the Ballentine facility, the October 2011 storm at the Conway facility produced low mean stormwater discharge (0.02 ft^3/s) and the minimum rainfall intensity at that facility (0.03 in/h) (appendix 1A; fig. 5*B*). Of the nine storms sampled at Conway1 outfall, all but the October 2011 storm were sampled at the Conway2 outfall (fig. 11*A*). Stormwater discharging at the Conway2 outfall during those eight storms had TKN EMCs ranging from 0.28 to 3.10 mg/L with a median EMC of 1.45 mg/L and nearly identical TN EMCs ranging from 0.31 to 3.54 mg/L but with a median of 1.80 mg/L (fig. 14*A*; table 10). The maximum TN EMC in stormwater at the Conway2 outfall occurred during the September 26, 2010, storm that also had relatively low mean stormwater discharge (0.35 ft^3/s) and rainfall intensity (0.13 in/h) (appendixes 1A, 1D; figs. 5*C*, 14*A*) During most storms, nitrate-plus-nitrite EMCs in stormwater at Conway2 were about 5 times less than TN EMCs (fig. 14*A*; table 10). For screening purposes, the TN EMCs at both outfalls were compared to the EPA recommended criterion for total nitrogen concentrations for ambient (non-storm) conditions in freshwater streams and rivers of 0.90 mg/L because no SCDHEC-established numeric criteria exist for nutrients in South Carolina. Total nitrogen EMCs in stormwater discharging from the Conway maintenance yard exceeded the 0.90 mg/L EPA recommended criterion for rivers and streams in 6 of 9 storms at the Conway1 outfall and in 5 of 8 storms at the Conway2 outfall, indicating some likelihood that stormwater affected the chemistry of the receiving water during storms (figs. 13*A*, 14*A*).

At the Conway maintenance yard facility, stormwater discharging to the sampled outfalls had median TP EMCs of 0.15 mg/L for Conway1 and 0.16 mg/L for Conway2 (tables 9, 10). Nearly identical ranges of TP EMCs were observed in stormwater discharging at the Conway1 (<0.024 to 0.36 mg/L) and Conway2 (<0.024 to 0.35 mg/L) outfalls (figs. 13*B*, 14*B*; tables 9, 10). However, maximum TP EMCs did not occur in stormwater runoff during the same storm at both outfalls. At the Conway1 outfall, the maximum TP EMC occurred in stormwater during the February 2011 storm that was characterized by relatively low mean stormwater discharge (0.14 ft^3/s) and average rainfall intensity (0.30 in/h) (appendixes 1A, 1C;

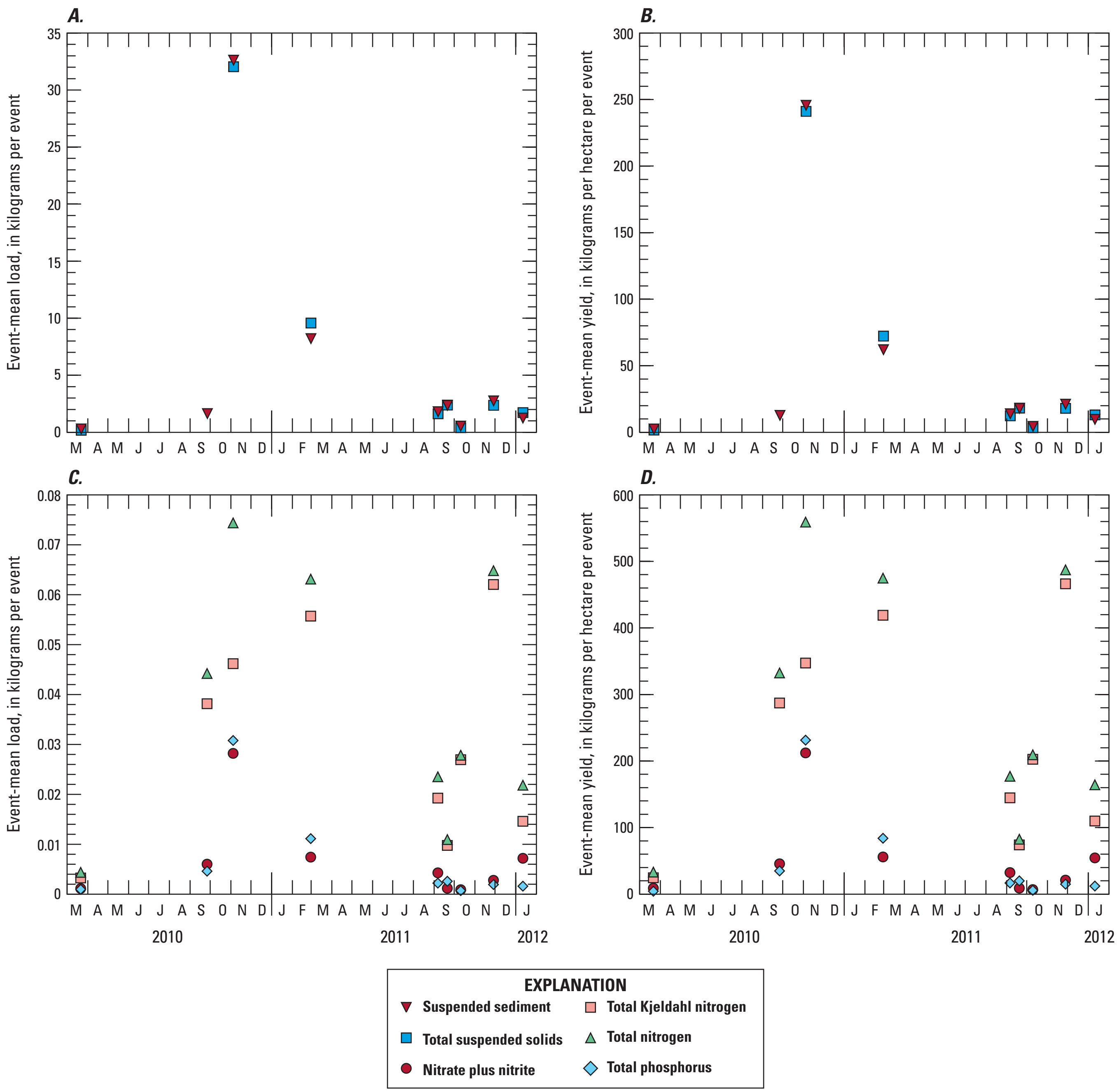


Figure 11. Temporal variation in *A*, event-mean loads and *B*, event-mean yields of total suspended solids and suspended sediment, and *C*, event-mean loads and *D*, event-mean yields of nutrients in stormwater discharging at the Conway1 outfall, Conway, South Carolina, 2010–2011.

fig. 13*B*). Stormwater discharging at the Conway2 outfall had the maximum TP EMC during the September 26, 2010, storm that was characterized by greater mean stormwater discharge (0.35 ft^3/s) but lower rainfall intensity (0.13 in/h) than the February 2011 storm (appendixes 1A, 1D; fig. 14*B*). TP EMCs in stormwater runoff from all but 1 of the 9 sampled storms at Conway1 outfall and all but 1 of the 8 sampled storm at Conway2 outfall exceeded the EPA recommended criterion of 0.04 mg/L for ambient conditions in freshwater rivers and streams, often by a large margin, indicating the likelihood that stormwater affected the chemistry of the receiving water during storms (figs. 13*B*, 14*B*). The EMCs of the inorganic form of phosphorus in stormwater ranged from <0.016 to 0.055 mg/L (median of 0.021 mg/L) at Conway1 outfall and from <0.016 to 0.110 mg/L (median of 0.049 mg/L) at Conway2 outfall (tables 9, 10).

Organic enrichment in stormwater runoff was evaluated by measuring the BOD_5 in stormwater discharging at the outfalls at the Conway facility (figs. 13*C*, 14*C*). At the Conway1 outfall, BOD_5 EMCs ranged from 2 to 23 mg/L with a median

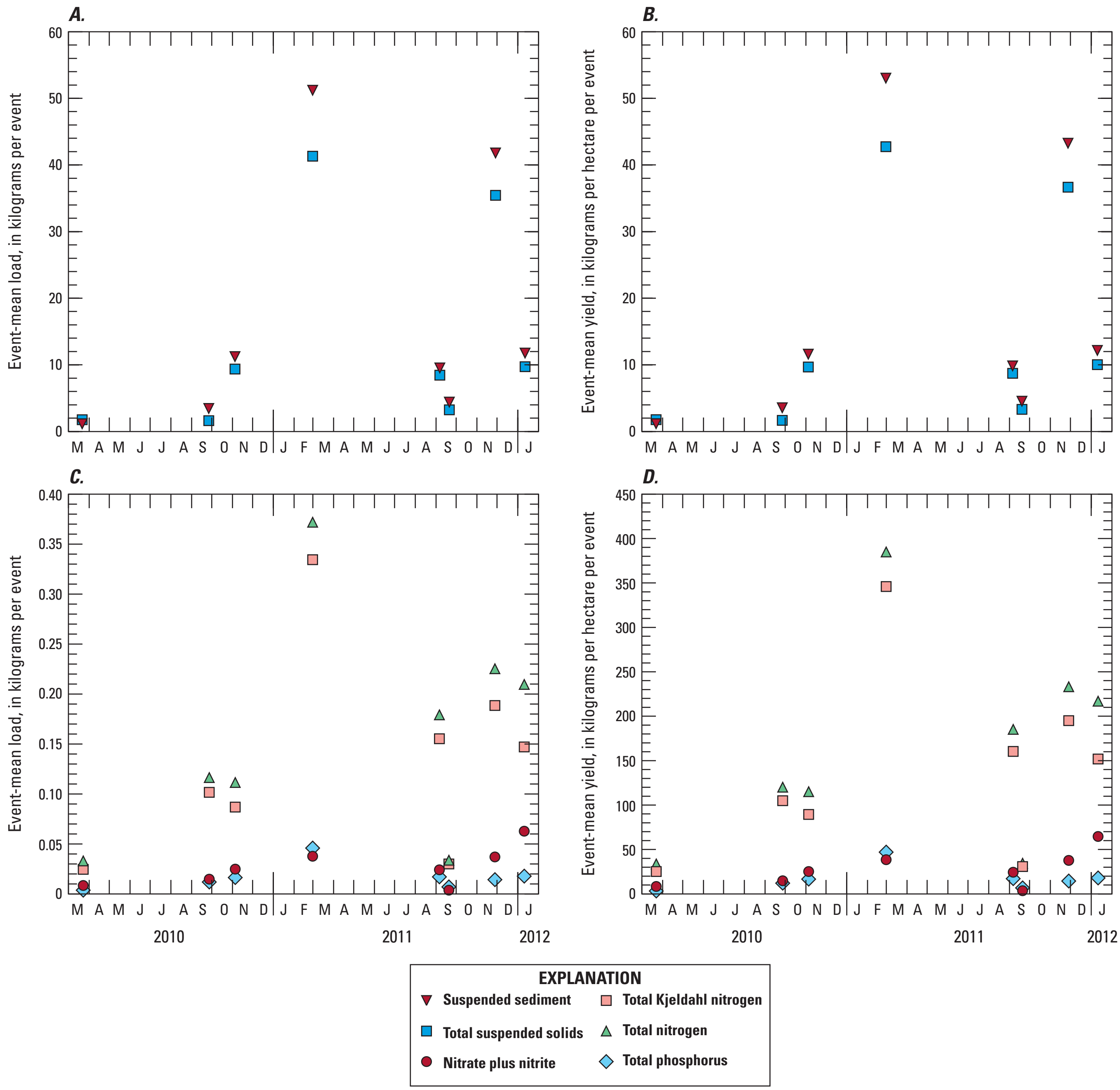


Figure 12. Temporal variation in *A*, event-mean loads and *B*, event-mean yields of total suspended solids and suspended sediment and *C*, event-mean loads and *D*, event-mean yields of nutrients in stormwater discharging at the Conway2 outfall, Conway, South Carolina, 2010–2011.

of 5.0 mg/L (fig. 13*C*, table 9). Stormwater discharging at the Conway2 outfall had a BOD_5 median that was statistically similar to the Conway1 median (13 mg/L) with a nearly identical range (<2 to 25 mg/L) (fig. 14*C*, table 10). Maximum BOD_5 EMCs at both outfalls occurred during the September 26, 2010, storm, which had relatively low mean stormwater discharge and rainfall intensity (appendixes 1A, 1C, 1D; figs. 5*B*, *C*, 14*C*).

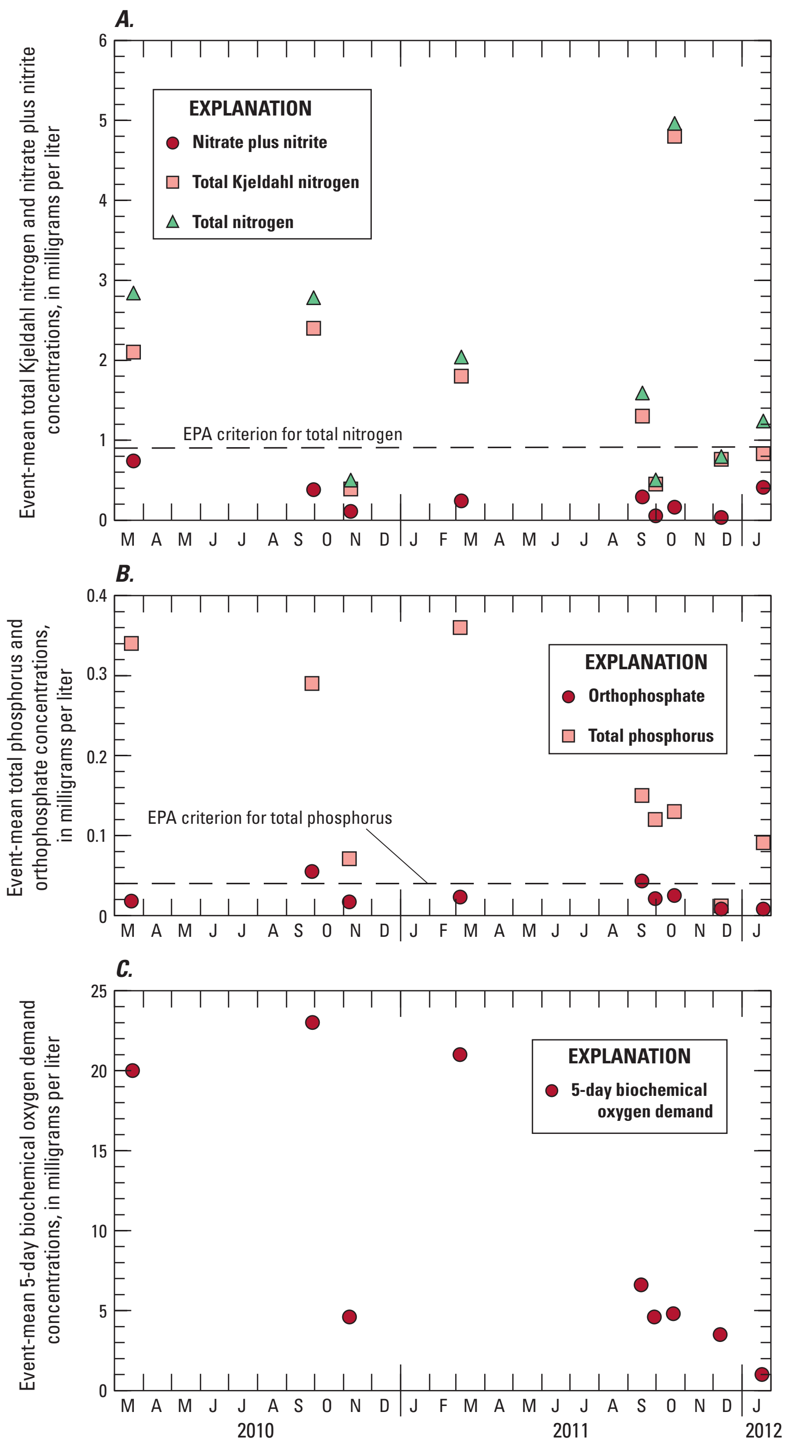


Figure 13. Event-mean concentrations of *A*, nitrogen species, *B*, phosphorus species, and *C*, 5-day biochemical oxygen demand in stormwater discharging at the Conway1 outfall, Conway, South Carolina, 2010–2012.

Event-mean loads and yields of nutrients in stormwater discharging at the two outfalls during the sampled storms were computed for the Conway facility (figs. 11*A–D*, 12*A–D*; tables 9, 10). Stormwater discharging at the Conway1 outfall had TN loads ranging from 0.0044 to 0.074 kg/event (median of 0.028 kg/event); TN was primarily composed of the TKN form of nitrogen (fig. 11*C*; tables 9, 10). Because of statistically greater discharge, TN loads in stormwater at the Conway2 outfall were approximately 5 times greater than TN loads at the Conway1 outfall. Event-mean TN loads at the Conway2 outfall ranged from 0.032 to 0.372 kg/event (median of 0.147 kg/event) and were composed mainly of the TKN form (fig. 12*C*, tables 9, 10; appendix 3F). Event-mean loads of TP in stormwater at the Conway1 outfall ranged from <0.0020 to 0.031 kg/event, and event-mean loads of TP at the Conway2 outfall ranged from <0.014 to 0.45 kg/event (figs. 11*C*, 12*C*; tables 9, 10). Additionally, Conway2 had a median TP load an order of magnitude greater than the median TP load (0.014kg/event) at Conway1 (0.0022 kg/event) (fig. 12*C*; tables 9, 10).

Event-mean yields of nutrients indicated relatively uniform contributions of nutrients and biodegradable organics were present in stormwater runoff throughout the Conway facility (figs. 10, 11*D*, 12*D*; appendix 3C). Event-mean yields of TN in stormwater at Conway1 outfall ranged from 33.0 to 559 (g/event)/ha with a median of 209 (g/event)/ha (fig.11*D*; table 9). Stormwater at the Conway2 outfall had event-mean yields of TN that ranged from 33.5 to 385 (g/event)/ha with a median of 152 (g/event)/ha (fig. 12*D*; table 10). Stormwater at the Conway1outfall had event-mean TP yields ranging from <14.7 to 231 (g/event)/ha with a median of 16.7 (g/event)/ha (fig. 11*D*; table 9). Event-mean yields of TP in stormwater at the Conway2 outfall ranged from <14.2 to 46.8 (g/event)/ha with a median of 14.1 (g/event)/ha (fig. 12*D*; table 10).

Fecal Indicator Bacteria

Stormwater discharging at the Conway1 outfall had *E. coli* and enterococcus “first flush” concentrations that were statistically similar to *E. coli* and enterococcus concentrations in the stormwater discharging at the Conway2 outfall (appendix 3F). For each storm, enterococcus concentrations consistently were greater than the *E. coli* concentrations in stormwater discharging from Conway1 and Conway2 outfalls (appendix 1C, 1D). “First-flush” *E. coli* concentrations in samples collected from stormwater at the Conway1 outfall varied by 4 orders of magnitude with a range of <10 to 4,725 col/100 mL and a median of 30 col/100 mL (fig. 15*A*; table 9). As described earlier, the *E. coli* "first flush" concentrations collected during the nine storms were compared to the SCDHEC proposed SSM of 349 col/100 mL for screening purposes. At the Conway1 outfall, the *E. coli* concentration in stormwater was greater than the SCDHEC SSM for primary and secondary body contact for the March 21, 2010, storm only (fig. 15*A*; appendix 1C). One of the 3 lowest stormwater discharges (both peak and mean) and rainfall intensities of the 9 storms sampled at this facility occurred during the March 21, 2010, storm (appendix 1A). At Conway2 outfall, the *E. coli* concentrations ranged from 1 to greater than 24,196 col/100 mL with a median value of 1,178 col/100 mL (fig. 16*A*; table 10). Unlike stormwater discharging at the Conway1 pipe outfall, stormwater discharging at the grass-lined ditch outfall at Conway2 had *E. coli* concentrations greater (often much greater) than the SCDHEC SSM of 349 col/100 mL for secondary and primary body contact during 5 of the 7 storms (fig. 16*A*).

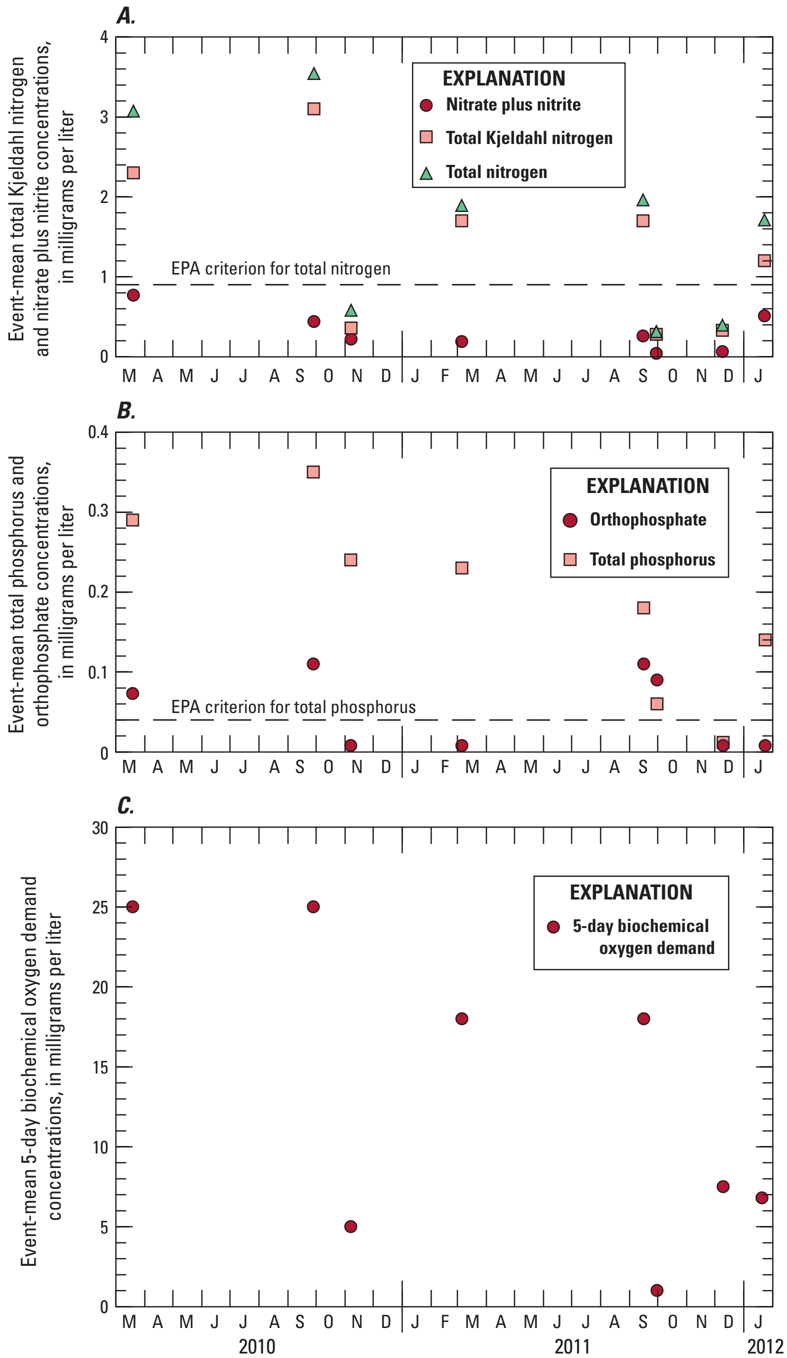


Figure 14. Event-mean concentrations of *A*, nitrogen species, *B*, phosphorus species, and *C*, 5-day biochemical oxygen demand in stormwater discharging at the Conway2 outfall, Conway, South Carolina, 2010–2012.

Enterococcus concentrations in the "first flush" samples ranged from 41 to greater than 24,196 col/100 mL with a median of 512 col/100mL for Conway1 outfall (fig. 15*A*; table 9). Of the 9 storms sampled at Conway1 outfall, enterococcus concentrations in 6 of the samples were greater than the EPA SSM of 151 col/100 mL for infrequent body contact (fig. 15*A*; appendix 1C). For Conway2, concentrations ranged from 50 to greater than 24,196 col/100 mL with a median of 3,441 col/100mL (fig. 16*A*; table 10). Stormwater from all but one of the sampled storms at the Conway2 outfall had enterococcus concentrations that were greater than the EPA SSM of 151 col/100 mL (fig. 16*A*; appendix 1D).

During the nine storms at the Conway1 outfall, *E. coli* loads ranged from <2 to 317 Mcol/event with a median of 18 Mcol/event (fig. 15*B*; table 9). During the same storms at the Conway2 outfall, *E. coli* loads ranged from <1 to greater than 56,032 Mcol/event with a median of 2,654 Mcol/event, which was 2 orders of magnitude greater than the median *E. coli* load at Conway1 (fig. 16*B*; tables 9, 10). Enterococcus loads in stormwater discharging at the Conway1 outfall ranged from 12 to 1,347 Mcol/event with a median of 148 Mcol/event during the nine storms (fig. 15*B*; table 9). During the same storms at the Conway2 outfall, enterococcus loads ranged from 9.39 to 169,851 Mcol/event with a median of 8,957 Mcol/event (fig. 16*B*; table 10). All maximum *E. coli* and enterococcus loads occurred during different storms with different hydrologic characteristics at the two outfalls (figs. 15*B*, 16*B*). At Conway1 outfall, the maximum *E. coli* load occurred during the "first flush" of the November 4, 2010, storm, which was characterized by having some of the greater stormwater discharges, rainfall intensities, and durations at the facility (fig. 15*B*; appendix 1A). In contrast, the maximum enterococcus load at the Conway1 occurred during the September 20, 2011, storm, which was characterized by having one of the greater stormwater discharges and the maximum rainfall intensity of the nine sampled storms (fig. 15*B*; appendix 1A). For stormwater discharging at the Conway2, the maximum *E. coli* load occurred during the "first

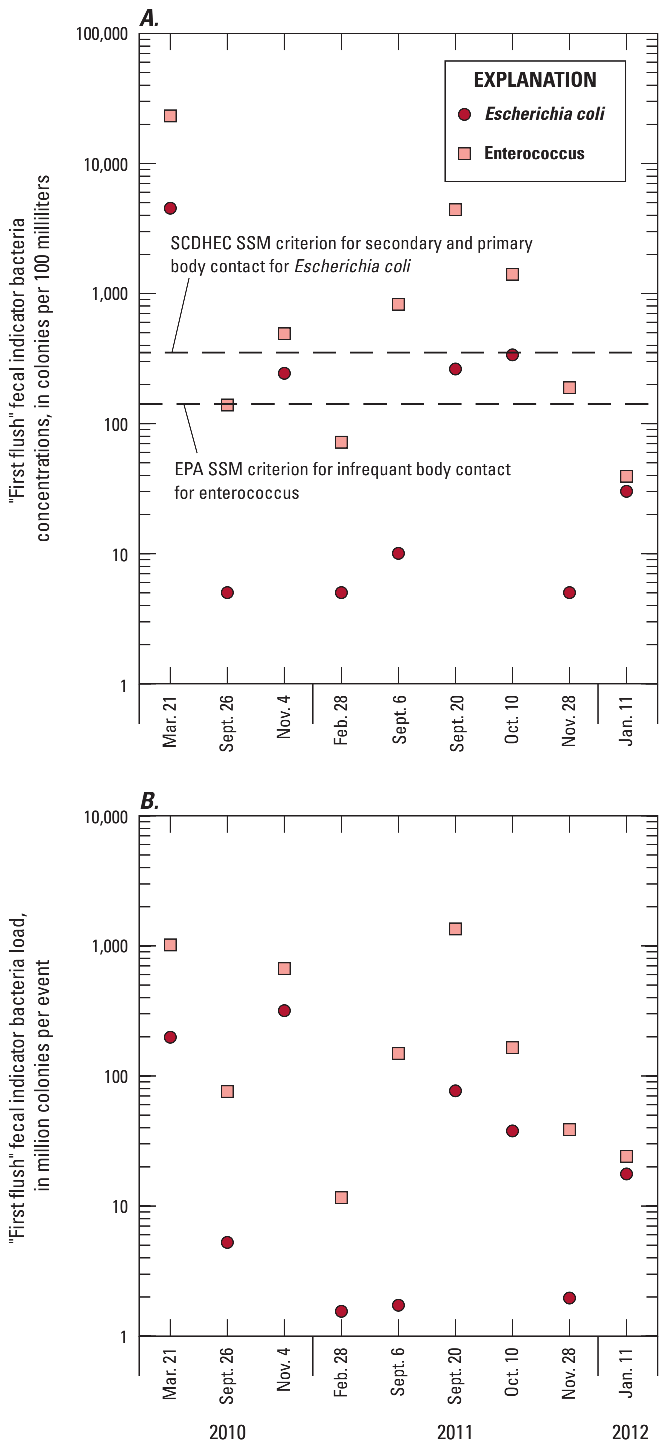


Figure 15. Temporal variation in *Escherichia coli* and enterococcus *A*, concentrations and *B*, loads in "first flush" grab samples collected in stormwater from the Conway1 outfall, Conway, South Carolina, 2010–2012. [SCDHEC, South Carolina Department of Health and Environmental Control; SSM, single sample maximum; EPA, U.S. Environmental Protection Agency]

flush" of the September 6, 2011, storm, which was characterized by relatively less stormwater discharge and rainfall intensities than other sampled storms (fig. 16*B*; appendix 1A). The maximum enterococcus load at Conway2 occurred during the November 28, 2011, storm, which had greater stormwater discharge, but intermediate to low rainfall intensity, when compared to the other sampled storms (fig. 16*B*; appendix 1A).

Relations Among Water-Quality Constituents and Hydrologic Characteristics

In general, EMCs for the commonly associated sediment constituents TSS, SS, and turbidity in the sampled stormwater at Conway1 and Conway2 outfalls were not correlated to hydrologic characteristics (appendixes 3B, 3C). One exception was event-mean turbidity in stormwater at the Conway2 outfall that correlated negatively with peak stormwater discharge and rainfall intensity (appendix 3C). However, unlike the Ballentine outfall, TSS and SS EMCs in stormwater discharging at the Conway1 and Conway2 outfalls correlated positively with each other, but not with turbidity (appendixes 3B, 3C). In stormwater discharging at the Conway1 and Conway2 outfalls, nitrogen EMCs correlated negatively with rainfall amounts, which indicates decreasing concentrations with greater rainfall (appendixes 3B, 3C). Total phosphorus EMCs in stormwater discharging at the Conway2 grass-lined ditch outfall also correlated negatively with rainfall (appendix 3C). One plausible explanation for the negatively correlated hydrologic characteristics and nutrient EMCs may be related to the nature of the sampling process, which required compositing multiple flow-weighted samples over the entire time period of the hydrograph. If the greatest nutrient amounts are transported during the "first flush" of a storm, then the amount of nutrients in subsequent runoff will decrease. However, for storms that have less rainfall and stormwater discharge, the "first-flush" transported nutrients undergo limited dilution from subsequent stormflow and produce overall greater EMCs in the composited sample.

Interestingly, EMCs of phosphorus and suspended sediment constituents (TSS, SS) were more commonly correlated with each other and with BOD_5 than with hydrologic characteristics at Conway outfalls (appendixes 3B, 3C). Correlations of greater TSS, TP (particulate plus dissolved), and orthophosphate to greater BOD_5 were identified at the Conway1 outfall (appendix 3B). Conway2 outfall had greater TSS, SS, and nutrient EMCs, which correlated to greater BOD_5 EMCs (appendix 3C). *Escherichia coli* concentrations were not correlated to any hydrologic characteristics or to EMCs of nutrients or BOD_5 at the Conway1 outfall; however, enterococcus concentrations correlated negatively to antecedent conditions (days since last rainfall) (appendix 3B). Phosphorus and suspended sediment EMCs in stormwater at the Conway2 grass-lined ditch outfall were not correlated to hydrologic characteristics (appendix 3C).

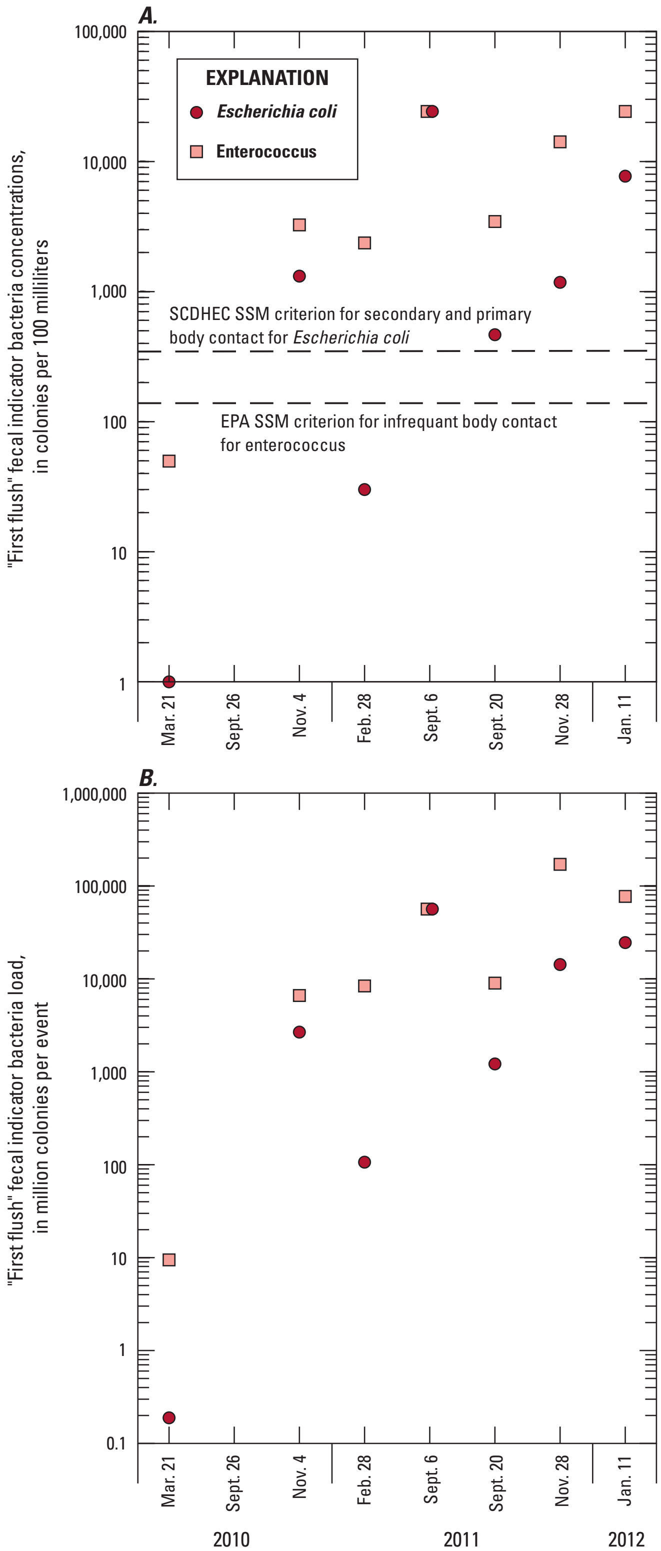


Figure 16. Temporal variation in *Escherichia coli* and enterococcus *A*, concentrations and *B*, loads in "first flush" grab samples collected in stormwater from the Conway2 outfall, Conway, South Carolina, 2010–2012. [SCDHEC, South Carolina Department of Health and Environmental Control; SSM, single sample maximum; EPA, U.S. Environmental Protection Agency]

North Charleston Maintenance Yard

Stormwater draining the North Charleston maintenance yard discharges into Turkey Creek through multiple outlets consisting of a combination of pipes, ditches, and overland flow (fig. 4). To capture all stormwater contributions from the maintenance yard, stormwater samples were collected from the main channel of Turkey Creek at the upstream (North Charleston1) and downstream (North Charleston2) limits of the SCDOT facility during each storm. Therefore, any changes in constituent EMCs, loads, and yields between the two locations on Turkey Creek were attributed to stormwater contributions from the maintenance yard.

Event-mean concentrations of the suspended sediment, nutrients, biochemical oxygen demand, and fecal indicator bacteria in stormwater at the paired locations on Turkey Creek (North Charleston1 and North Charleston2) are summarized for the North Charleston facility in tables 11 and 12. Differences in EMCs between the paired North Charleston1 and North Charleston2 sites are described on the basis of the Wilcoxon Signed-Rank Test results (table 13). Constituent loads and yields in stormwater discharging from the North Charleston maintenance yard to Turkey Creek were computed for each storm as the load and yield at North Charleston1 minus the load and yield at North Charleston2 to remove the upstream Turkey Creek contribution (table 14).

Suspended Sediment and Total Suspended Solids

Event-mean SS and TSS concentrations were used to quantify the levels of suspended organic and inorganic particles in Turkey Creek during the eight storms upstream and downstream from the North Charleston maintenance yard. Event-mean concentrations of SS in the stormwater runoff at the North Charleston1 location on Turkey Creek upstream from the maintenance yard, ranged from 26.0 to 112 mg/L with a median of 73.5 mg/L (fig. 17*A*; table 11). The SS EMCs in samples from Turkey Creek at North Charleston2 ranged from 20.0 to 160 mg/L with a median of 54.0 mg/L (fig. 17*B*; table 12). The EMCs of TSS ranged from <5.0 to 120 mg/L with a median of 56.0 mg/L at North Charleston1 (fig. 17*C*; table 11), whereas the TSS EMCS at North Charleston2 ranged from 23.0 to 130 mg/L with a median of 28.5 mg/L (fig. 17*D*; table 12). Although no statistical relation was identified between SS and TSS EMCs, maximum EMCs for these suspended sediment constituents occurred during the June 15, 2011, storm at North Charleston1 and North Charleston2 in Turkey Creek (fig. 17*A*, *B*, *C*, *D*; appendixes 1E, 1F). The June 15, 2011, storm had the maximum rainfall intensity of the eight storms (1.73 in/h), which produced an event-mean stormwater discharge of 3.73 ft^3/s at North Charleston1 and the maximum event-mean stormwater discharge of 11.9 ft^3/s at North Charleston2 (fig. 5; appendix 1A).

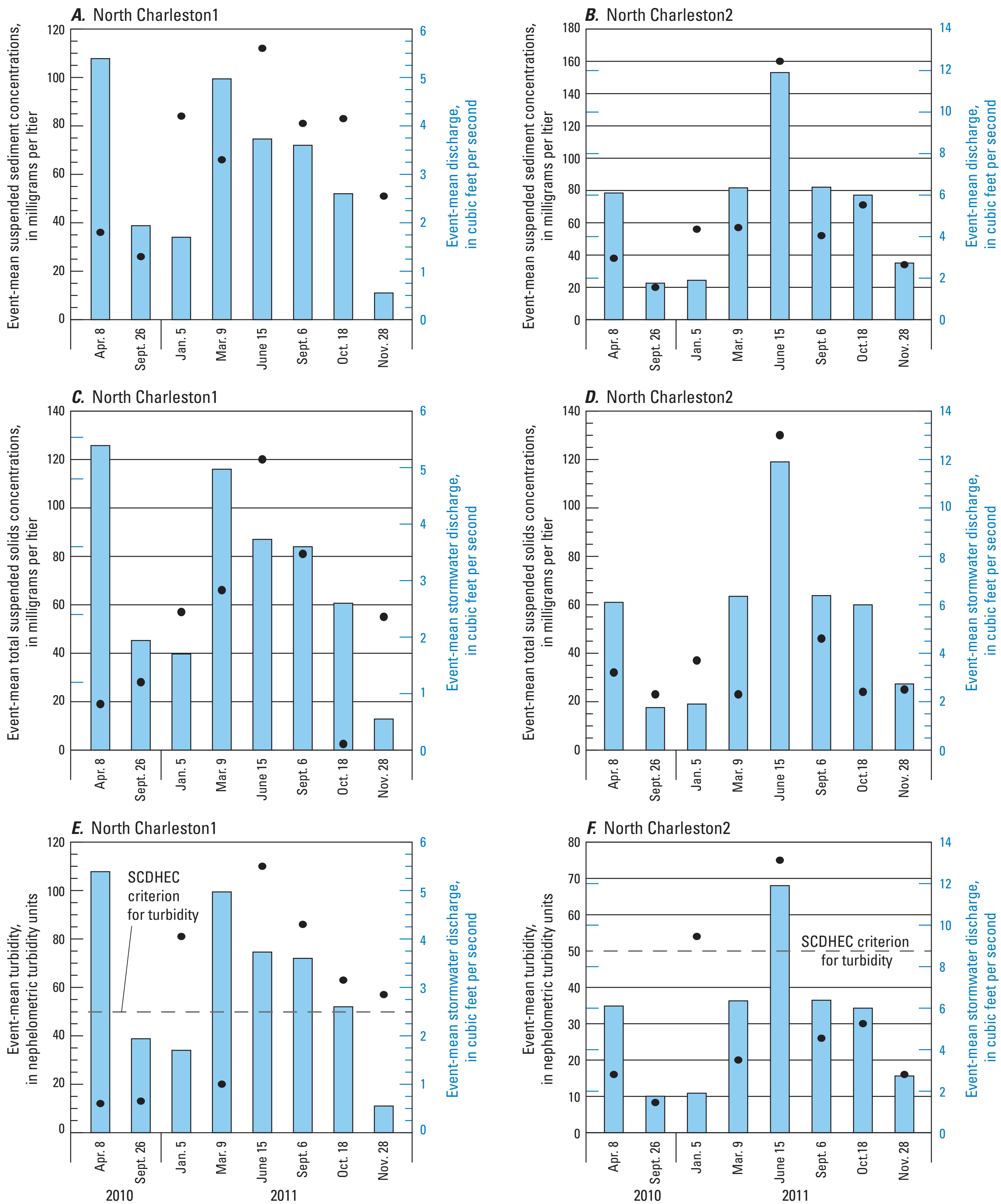


Figure 17. Event-mean concentrations of *A*, suspended sediment, *C*, total suspended solids, and *E*, turbidity in stormwater at North Charleston1 and *B*, suspended sediment, *D*, total suspended solids, and *F*, turbidity in stormwater in Turkey Creek at North Charleston2, North Charleston, South Carolina, 2010–2011. [SCDHEC, South Carolina Department of Health and Environmental Control]

Table 11. Summary statistics for selected constituent concentrations, loads, and yields in stormwater at the North Charleson1 outfall on Turkey Creek upstream from the South Carolina Department of Transportation maintenance yard in North Charleston, South Carolina, 2010 to 2012.

[Number, number of samples; StDev, standard deviation; 25th Q, twenty-fifth quartile; 75th Q, seventy-fifth quartile; Min, minimum; Max, maximum; °C, degrees Celsius; SU, standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; col/100 mL, colonies per 100 milliliters; <, less than the laboratory reporting level; mg/L, milligrams per liter; µg/L, micrograms per liter; Mcol/event, million colonies per event; (Mcol/event)/ha, million colonies per event per hectare; ND, not applicable; E, estimated value; Statistics highlighted in bold italics were computed using the Regression on Order Statistics for datasets with censored values]

Constituent	Number (censored)	Units	Mean	StDev	Median	25th Q	75th Q	Min	Max
North Charleston1 event-mean concentrations									
Water temperature	8 (0)	°C	20.9	5.6	21.6	19.7	25.1	9.3	26.3
pH	8 (0)	SU	7.1	0.1	7.1	7.0	7.1	7.0	7.3
Specific conductance	8 (0)	µS/cm	330	138	284	266	306	250	663
Dissolved oxygen	8 (0)	mg/L	5.6	2.4	5.8	5.3	6.3	0.8	9.3
Hardness	8 (0)	mg/L	94.2	24.3	88.3	75.5	118	65.3	125
Turbidity	8 (0)	NTU	55.3	37.0	60.0	18.3	82.3	12.0	110
Total Kjeldahl nitrogen	8 (0)	mg/L	1.40	0.33	1.30	1.18	1.65	1.00	1.90
Total nitrogen	8 (0)	mg/L	1.85	0.25	1.76	1.70	2.02	1.55	2.29
Nitrate plus nitrite	8 (0)	mg/L	0.45	0.13	0.43	0.38	0.53	0.26	0.66
5-day biochemical oxygen demand	***8 (2)***	***mg/L***	***32***	***80***	***4.4***	***2.7***	***6.3***	***<2.0***	***230***
Total phosphorus	8 (2)	mg/L	0.61	0.59	0.42	0.34	0.48	0.20	1.8
Orthophosphate	***8 (2)***	***mg/L***	***0.047***	***0.022***	***0.044***	***0.031***	***0.057***	***< 0.016***	***0.089***
Enterococcus	8 (0)	col/100 mL	3,949	6,738	691	456	4,806	41	19,863
Escherichia coli	8 (0)	col/100 mL	570	711	284	119	710	30	2,143
Suspended sediment	8 (0)	mg/L	67.4	28.4	73.5	47.3	83.3	26.0	112
Total suspended solids	8 (1)	mg/L	53.9	36.9	56.0	25.8	69.8	< 5	120
Suspended sediment finer than 63 micron	8 (0)	percent	95.4	3.2	96.5	92	98	91	99
Total cadmium	***8 (5)***	***µg/L***	***0.13***	***0.06***	***< 0.13***	***< 0.13***	***0.18***	***< 0.13***	***E 0.22***
Dissolved cadmium	***8 (8)***	***µg/L***	***ND***	***ND***	***< 0.095***	***ND***	***ND***	***< 0.095***	***< 0.095***
Total chromium	8 (0)	µg/L	7.2	4.6	5.9	3.9	9.3	E 2.7	16
Dissolved chromium	***8 (7)***	***µg/L***	***ND***	***ND***	***< 2.5***	***ND***	***ND***	***< 2.5***	***6.1***
Total copper	8 (0)	µg/L	4.9	2.7	3.6	3.5	6.4	1.6	9.8
Dissolved copper	***7 (1)***	***µg/L***	***1.8***	***0.72***	***1.7***	***1.2***	***2.2***	***< 1.1***	***3***
Total lead	8 (0)	µg/L	4.2	2.7	4.3	2.6	4.8	1.1	10
Dissolved lead	***8 (6)***	***µg/L***	***ND***	***ND***	***< 0.20***	***ND***	***ND***	***< 0.20***	***0.57***
Dissolved nickel	***8 (8)***	***µg/L***	***ND***	***ND***	***< 2.0***	***ND***	***ND***	***< 2.0***	***< 2.0***
Total zinc	7 (0)	µg/L	55.1	32.7	53	36.5	60	20	120
Dissolved zinc	***7 (2)***	***µg/L***	***11.4***	***3.5***	***11***	***8.5***	***14***	***< 8.3***	***17***
North Charleston1 event-mean loads									
Enterococcus	8 (0)	Mcol/event	5,018	6,800	2,229	444	6,314	39.7	18,679
Escherichia coli	8 (0)	Mcol/event	701	699	536	234	802	22.9	2,064
North Charleston1 event-mean yields									
Enterococcus	8 (0)	(Mcol/ event)/ha	12.8	17.4	5.70	1.14	16.2	0.102	47.8
Escherichia coli	8 (0)	(Mcol/ event)/ha	1.79	1.79	1.37	0.599	2.05	0.059	5.28

Table 12. Summary statistics for selected constituent concentrations, loads, and yields in stormwater at the North Charleston2 location on Turkey Creek downstream from the South Carolina Department of Transportation maintenance yard in North Charleston, South Carolina, 2010 to 2012.

[Number, number of samples; StDev, standard deviation; 25th Q, twenty-fifth quartile; 75th Q, seventy-fifth quartile; Min, minimum; Max, maximum; ºC, degrees Celsius; SU, standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; col/100 mL, colonies per 100 milliliters; <, less than the laboratory reporting level; mg/L, milligrams per liter; µg/L, micrograms per liter; Mcol/event, million colonies per event; (Mcol/event)/ha, million colonies per event per hectare; ND, not applicable; E, estimated value; Statistics highlighted in bold italics were computed using the Regression on Order Statistics for datasets with censored values]

Constituent	Number (censored)	Units	Mean	StDev	Median	25th Q	75th Q	Min	Max
North Charleston2 location event-mean concentrations									
Water temperature	8 (0)	ºC	21.0	5.6	22.0	19.7	24.6	9.3	26.7
pH	8 (0)	SU	7.1	0.1	7.1	7.0	7.1	6.9	7.2
Specific conductance	8 (0)	µS/cm	315	154	267	233	325	173	664
Dissolved oxygen	8 (0)	mg/L	6.54	1.27	6.37	5.84	6.67	5.01	9.25
Hardness	8 (1)	mg/L	75.7	20.5	71.1	64.6	85.5	47.4	109
Turbidity	8 (0)	mg/L	30.7	22.6	23.0	16.0	36.0	8.30	75.0
Total Kjeldahl nitrogen	8 (0)	mg/L	1.17	0.48	1.20	0.89	1.53	0.41	1.80
Total nitrogen	8 (0)	mg/L	1.61	0.4	1.67	1.42	1.84	0.99	2.19
Nitrate plus nitrite	8 (0)	mg/L	0.44	0.11	0.42	0.37	0.55	0.31	0.58
5-day biochemical oxygen demand	8 (1)	mg/L	9.2	12.7	4.2	2.9	8.1	2.2	40
Total phosphorus	6 (0)	mg/L	0.23	0.09	0.26	0.17	0.27	0.11	0.34
Orthophosphate	***8 (3)***	***mg/L***	***0.034***	***0.022***	***0.025***	***0.017***	***0.058***	***< 0.016***	***0.063***
Enterococcus	8 (0)	col/100 mL	5,685	2,776	6,329	4,609	7,378	1,153	9,208
Escherichia coli	8 (0)	col/100 mL	5,468	4,905	4,359	2,422	6,408	521	15,648
Suspended sediment	8 (0)	mg/L	61.0	43.0	54.0	37.0	61.0	20.0	160
Total suspended solids	8 (0)	mg/L	42.5	36.3	28.5	23.8	39.3	23.0	130
Suspended sediment finer than 63 micron	8 (0)	percent	90.4	4.3	90.5	89	92.3	82	97
Total cadmium	***8 (6)***	***µg/L***	***ND***	***ND***	***< 0.13***	***ND***	***ND***	***< 0.13***	***E 0.27***
Dissolved cadmium	***8 (8)***	***µg/L***	***ND***	***ND***	***< 0.095***	***ND***	***ND***	***< 0.095***	***< 0.095***
Total chromium	***8 (3)***	***µg/L***	***6.1***	***5.3***	***5.1***	***2.6***	***7.0***	***< 2.5***	***18***
Dissolved chromium	***8 (8)***	***µg/L***	***ND***	***ND***	***< 2.5***	***ND***	***ND***	***< 2.5***	***< 2.5***
Total copper	8 (0)	µg/L	5.3	4.5	3.9	3.3	5.4	1.9	16
Dissolved copper	8 (0)	µg/L	E 2.0	0.9	E 1.8	E 1.4	E 2.4	E 1.1	E 3.9
Total lead	8 (0)	µg/L	6.5	6.4	4.1	2.6	7.1	E 1.2	20
Dissolved lead	***8 (5)***	***µg/L***	***0.24***	***0.25***	***< 0.20***	***< 0.20***	***0.37***	***< 0.20***	***E 0.73***
Dissolved nickel	***8 (8)***	***µg/L***	***ND***	***ND***	***< 2.0***	***ND***	***ND***	***< 2.0***	***< 2.0***
Total zinc	7 (0)	µg/L	51.3	45.4	31.0	25.5	52.5	22.0	150
Dissolved zinc	***7 (2)***	***µg/L***	***9.9***	***0.39***	***9.1***	***6.7***	***11.0***	***< 8.3***	***18***
North Charleston2 location event-mean loads									
Enterococcus	8 (0)	Mcol/event	25,469	16,582	23,887	13,030	33,555	6,939	53,974
Escherichia coli	8 (0)	Mcol/event	24,234	24,633	15,927	8,089	30,127	3,879	77,632
North Charleston2 location event-mean yields									
Enterococcus	8 (0)	(Mcol/event)/ha	63.7	41.5	59.8	32.6	84.0	17.4	135
Escherichia coli	8 (0)	(Mcol/event)/ha	60.6	61.6	39.9	20.2	75.4	9.71	194

Table 13. Statistical summary of the Wilcoxon signed-rank test on selected water-quality constituents and hydrologic characteristics to determine if the event-mean concentrations in stormwater at Turkey Creek upstream (North Charleston1) from the South Carolina Department of Transportation maintenance yard facility in North Charleston, South Carolina, were similar, greater, or less than the event-mean concentrations in Turkey Creek downstream (North Charleston2) from maintenance yard during nine storm events, 2010 to 2012.

[V-statistic is the test statistic used to compute the p-value when no ties in the data existed; Z-score was used to compute the p-value when ties existed in the data; p-value, probability value; alpha level of 0.05 was used to determine statistical significance; Rows highlighted in bold italics represent statistically significant differences]

Constituent	Number	Wilcoxon signed rank test								
		North Charleson1 different than North Charleston2 (two-sided test)			North Charleson1 greater than North Charleston2			North Charleson1 less than North Charleston2		
		V-statistic	Z-score	p-value	V-statistic	Z-score	p-value	V-statistic	Z-score	p-value
Peak stormwater discharge	8	5	--	0.078	--	--	--	5	--	0.039
Event-mean stormwater discharge	***8***	***1***	***--***	***0.016***	***--***	***--***	***--***	***1***	***--***	***0.008***
Hardness	***8***	***36***	***--***	***0.008***	***36***	***--***	***0.004***	***--***	***--***	***--***
Turbidity	***8***	***--***	***2.106***	***0.035***	***2.106***	***--***	***0.018***	***--***	***--***	***--***
Total Kjeldahl nitrogen	8	--	1.47	0.141	--	--	--	--	--	--
Total nitrogen	8	30	--	0.109	--	--	--	--	--	--
Nitrate plus nitrite	8		0.281	0.779	--	--	--	--	--	--
5-day biochemical oxygen demand	8	15	--	0.742	--	--	--	--	--	--
Total phosphorus	***6***	***21***	***--***	***0.031***	***21***		***0.016***	***--***	***--***	***--***
Orthophosphate	8	--	1.701	0.089	--	--	--	--	1.701	0.044
Enterococci	8	8	--	0.195	--	--	--	--	--	--
Escherichia coli	***8***	***0***	***--***	***0.008***	***--***	***--***	***--***	***0***	***--***	***0.004***
Suspended sediment	8	27	--	0.250	--	--	--	--	--	--
Total suspended solids	8	26	--	0.313	--	--	--	--	--	--
Total cadmium	8	--	0.492	0.623	--	--	--	--	--	--
Dissolved cadmium	8	--	--	--	--	--	--	--	--	--
Total chromium	8	--	1.472	0.141	--	--	--	--	--	--
Dissolved chromium	8	--	--	--	--	--	--	--	--	--
Total copper	8	--	-0.21	0.833	--	--	--	--	--	--
Dissolved copper	***7***	***2***	***--***	***0.047***	***--***	***--***	***--***	***2***	***--***	***0.023***
Total lead	8	10	--	0.313	--	--	--	--	--	--
Dissolved lead	8	--	-1.64	0.101	--	--	--	--		
Total zinc	8	--	0.254	0.800	--	--	--	--	--	--
Dissolved zinc	8	--	0.339	0.734	--	--	--	--	--	--
Total polycyclic aromatic hydrocarbons	8	29	--	0.148	--	--	--	--	--	--

Unlike turbidity at the Conway and Ballentine facilities, at the North Charleston1 and North Charleston2, turbidity correlated to SS EMCs but not to TSS EMCs (appendixes 3D, 3E). Event-mean turbidity in Turkey Creek at North Charleston1 ranged from 12.0 to 110 NTUs with a median of 60.0 NTU for the eight sampled storms (fig. 17*E*; table 11). For Turkey Creek at North Charleston2, event-mean turbidity ranged from 8.30 to 75.0 NTUs with a median of 23.0 NTUs (fig. 17*E*; table 12). For screening purposes, the turbidity values of the stormwater were compared to the SCDHEC turbidity criterion of 50 NTUs that was established for ambient conditions in freshwater streams and rivers to assess the potential of the stormwater to impair the receiving water. Turkey Creek at North Charleston1, which received no stormwater contribution from the North Charleston maintenance yard, had event-mean turbidity greater than the 50-NTU criterion for 5 of the 8 sampled storms (fig. 17*E*; appendix 1E). Downstream from the maintenance yard at North Charleston2, Turkey Creek event-mean turbidity was greater than 50 NTUs for only 2 of the 8 storms (fig. 17*F*; appendix 1F). Maximum event-mean turbidity co-occurred with maximum SS and TSS EMCs during the June 15, 2011, storm at both locations (figs. 17*E*, *F*; appendixes 1E, 1F).

If a statistically significant increase in the EMCs of a constituent occurred in Turkey Creek between the North Charleston1 and North Charleston2 locations during the sampled storms, that change would be attributed to a significant stormwater contribution of that constituent from the maintenance yard. If constituent EMCs did not change significantly between the two locations, then no significant stormwater contribution of that constituent from the maintenance yard occurred. Significant increases in peak and event-mean stormwater discharge occurred in Turkey Creek between the two locations during the eight sampled storms (table 13). However, the North Charleston maintenance yard did not contribute significant SS or TSS to Turkey Creek because no changes were identified between the North Charleston1 and North Charleston2 for those constituents during storms (table 13). A change in event-mean turbidity was identified and indicated that the stormwater contribution from the North Charleston maintenance yard produced a significant decrease, rather than increase, in turbidity in Turkey Creek at the North Charleston2 location (table 13). These results indicate that, at worst, stormwater entering Turkey Creek from the maintenance yard did not transport enough suspended sediment to change the SS or TSS concentrations in Turkey Creek and, at best, the stormwater from the maintenance yard improved the turbidity and reduced the number of exceedances of the 50-NTU criterion (fig. 17*A*–*F*; table 13).

Because constituent event-mean loads transported to Turkey Creek from the North Charleston maintenance yard in stormwater were not measured directly from outfalls, event-mean loads in stormwater discharging from the maintenance yard were estimated by subtracting the event-mean loads in Turkey Creek at North Charleston1 location from the North Charleston2 location. The difference in loads between the two locations was attributed to stormwater contribution from the North Charleston maintenance yard (table 14). Event-mean loads in Turkey Creek at the North Charleston1 location were considered to be the baseline load contributed by the watershed upstream from North Charleston1 location and not associated with the maintenance yard (figs. 1, 4). For some storms, the differences in event-mean loads for most constituents were negative but within the analytical and sampling bias quantified by replicate quality assurance/quality control samples (appendix 1H) and the inherent error in discharge measurements made at the time of sampling. However, for TSS, negative values less than 30 percent seem to indicate a loss of mass (appendix 1H). For this report, the negative loads and yields for TSS and SS were replaced with a censoring value of less than 0.001 in the statistical summary and plotted as the censoring level in graphs.

Stormwater discharging from the North Charleston maintenance yard to Turkey Creek was estimated to contribute event-mean TSS loads that ranged from <0.001 to 74.7 kg/event with a median of 3.95 kg/event and event-mean SS loads that ranged from <0.001 to 101 kg/event with a median of 10.2 kg/event (fig. 18*A*; table 14). Estimated event-mean loads of TSS and SS at the North Charleston maintenance yard were compared to the baseline loads at Turkey Creek at North Charleston1 (upstream from the yard) to determine whether loads at the North Charleston yard were similar to or greater than the baseline loads at Turkey Creek (table 15). Specifically, North Charleston yard loads that were more than 20 percent greater than Turkey Creek baseline loads were considered to represent greater loads on the basis of inherent laboratory analytical, sampling, and discharge measurement error (appendix 1H). Event-mean TSS and SS loads at North Charleston maintenance yard were greater than the loads in Turkey Creek at North Charleston1 for 4 of the 8 storms by a relatively large percentage (April 8, 2010; June 15, 2011; October 18, 2011; and November 28, 2011) (table 15). Maximum event-mean loads of SS and TSS at the North Charleston yard occurred during the June 15, 2011, storm, which had the maximum mean stormwater discharge and rainfall intensity of the eight sampled storms (fig. 18*A*, *B*; appendix 1A). Minimum values were negative event-mean loads of SS and TSS that occurred during the September 26, 2010, and January 5, 2011, storms that produced minimal (–10 and 12 percent, respectively) changes in discharge in Turkey Creek between North Charleston1 (1.94 and 1.74 ft^3/s, respectively) and North Charleston2 (1.76 and 1.90 ft^3/s, respectively) (appendix 1A).

Nutrients and Biochemical Oxygen Demand

During the sampled storms, stormwater in Turkey Creek at North Charleston1, upstream from the maintenance yard, had TN EMCs that ranged from 1.55 to 2.29 mg/L with a median of 1.76 mg/L (fig. 19*A*; table 11). Total Kjeldahl nitrogen, the major form of nitrogen in Turkey Creek, had a median EMC of 1.30 mg/L, and concentrations ranged from 1.00 to

Table 14. Summary statistics for selected constituent event-mean loads in stormwater at the South Carolina Department of Transportation maintenance yard in North Charleston, South Carolina, 2010–2012, computed from event-mean loads at the North Charleston2 location on Turkey Creek minus the event-mean loads at the North Charleston1 location and event-mean yields computed as loads divided by intervening drainage area between the two locations on Turkey Creek.

[Number, number of samples; StDev, standard deviation; 25th Q, twenty-fifth quartile; 75th Q, seventy-fifth quartile; Min, minimum; Max, maximum; <, difference between locations is less than quantification level; kg/event, kilograms per event; g/event, grams per event; (kg/event)/ha, kilograms per event per hectare; (g/event)/ha, grams per event per hectare; (mg/event)/ha, milligrams per event per hectare; Mcol/event, million colonies per event; (Mcol/event)/ha, million colonies per event per hectare; ND, not applicable; E, estimated value; Statistics in bold italics were computed using the Regression on Order Statistics for datasets with censored values]

Constituent	Number (censored)	Units	Mean	StDev	Median	25th Q	75th Q	Min	Max
North Charleston maintenance yard loads									
5-day biochemical oxygen demand	***8 (3)***	***kg/event***	***11.5***	***27.5***	***0.695***	***0.037***	***5.63***	***< 0.001***	***79.2***
Hardness	***8 (3)***	***kg/event***	***19.4***	***13.0***	***17.3***	***10.3***	***23.3***	***< 0.001***	***47.3***
Total Kjeldahl nitrogen	***8 (3)***	***kg/event***	***0.294***	***0.417***	***0.0707***	***0.0171***	***0.513***	***< 0.0001***	***1.15***
Total nitrogen	***8 (1)***	***kg/event***	***0.443***	***0.502***	***0.289***	***0.0694***	***0.731***	***< 0.0001***	***1.34***
Nitrate plus nitrite	***8 (1)***	***kg/event***	***0.169***	***0.138***	***0.166***	***0.0530***	***0.220***	***< 0.0001***	***0.448***
Total phosphorus	***6 (4)***	***kg/event***	***ND***	***ND***	***< 0.0001***	***ND***	***ND***	***< 0.0001***	***0.189***
Enterococcus	8 (0)	Mcol/event	20,451	18,129	12,313	8,105	30,498	2,659	53,405
Escherichia coli	8 (0)	Mcol/event	23,533	24,439	15,502	7,659	28,219	3,719	77,124
Suspended sediment	***8 (2)***	***kg/event***	***24.5***	***34.9***	***10.2***	***4.58***	***32.3***	***< 0.001***	***101***
Total suspended solids	***8 (3)***	***kg/event***	***18.4***	***26.7***	***3.95***	***0.23***	***31.9***	***< 0.001***	***74.7***
Total cadmium	***8 (6)***	***g/event***	***ND***	***ND***	***< 0.0468***	***ND***	***ND***	***< 0.0001***	***E 0.165***
Dissolved cadmium	***8 (8)***	***g/event***	***ND***	***ND***	***< 0.0352***	***ND***	***ND***	***< 0.0001***	***< 0.0796***
Total chromium	***8 (4)***	***g/event***	***1.70***	***4.07***	***0.289***	***0.0729***	***0.552***	***< 0.0001***	***11.8***
Dissolved chromium	***8 (8)***	***g/event***	***ND***	***ND***	***< 0.697***	***ND***	***ND***	***< 0.0001***	***< 1.39***
Total copper	8 (0)	g/event	2.73	3.51	1.10	0.644	3.93	0.0306	10.5
Dissolved copper	***7 (1)***	***g/event***	***1.20***	***0.783***	***1.28***	***0.239***	***1.77***	***< 0.042***	***2.39***
Total lead	8 (1)	g/event	4.83	5.96	2.23	0.468	9.33	< 0.0001	14.6
Dissolved lead	***8 (6)***	***g/event***	***ND***	***ND***	***< 0.0742***	***ND***	***ND***	***< 0.0001***	***E 0.446***
Dissolved nickel	***8 (8)***	***g/event***	***ND***	***ND***	***< 0.742***	***ND***	***ND***	***< 0.0001***	***< 1.68***
Total zinc	***7 (2)***	***g/event***	***23.2***	***32.2***	***7.75***	***2.77***	***36.8***	***< 0.0001***	***90.9***
Dissolved zinc	***7 (4)***	***g/event***	***2.79***	***1.26***	***2.52***	***1.98***	***3.32***	***< 0.0001***	***5.35***

Table 14. Summary statistics for selected constituent event-mean loads in stormwater at the South Carolina Department of Transportation maintenance yard in North Charleston, South Carolina, 2010–2012, computed from event-mean loads at the North Charleston2 location on Turkey Creek minus the event-mean loads at the North Charleston1 location and event-mean yields computed as loads divided by intervening drainage area between the two locations on Turkey Creek.—Continued

[Number, number of samples; StDev, standard deviation; 25th Q, twenty-fifth quartile; 75th Q, seventy-fifth quartile; Min, minimum; Max, maximum; <, difference between locations is less than quantification level; kg/event, kilograms per event; g/event, grams per event; (kg/event)/ha, kilograms per event per hectare; (g/event)/ha, grams per event per hectare; (mg/event)/ha, milligrams per event per hectare; Mcol/event, million colonies per event; (Mcol/event)/ha, million colonies per event per hectare; ND, not applicable; E, estimated value; Statistics in bold italics were computed using the Regression on Order Statistics for datasets with censored values]

Constituent	Number (censored)	Units	Mean	StDev	Median	25th Q	75th Q	Min	Max
North Charleston maintenance yard yields									
5-day biochemical oxygen demand	***8 (3)***	***(kg/event)/ha***	***0.134***	***0.32***	***0.008***	***0.000***	***0.066***	***< 0.0001***	***0.921***
Hardness	***8 (3)***	***(kg/event)/ha***	***0.225***	***0.152***	***0.202***	***0.119***	***0.270***	***< 0.0001***	***0.550***
Total Kjeldahl nitrogen	***8 (3)***	***(g/event)/ha***	***0.00342***	***0.00485***	***0.00082***	***0.00020***	***0.00596***	***< 0.00001***	***0.0134***
Total nitrogen	***8 (1)***	***(g/event)/ha***	***0.00515***	***0.00584***	***0.00335***	***0.000807***	***0.00850***	***< 0.0001***	***0.0156***
Nitrate plus nitrite	***8 (1)***	***(g/event)/ha***	***0.00196***	***0.00161***	***0.0019***	***0.000616***	***0.00256***	***< 0.00001***	***0.00521***
Total phosphorus	***6 (4)***	***(g/event)/ha***	***ND***	***ND***	***< 0.00001***	***ND***	***ND***	***< 0.00001***	***0.0022***
Enterococcus	8 (0)	(Mcol/event)/ha	238	211	143	94.2	355	30.9	621
Escherichia coli	8 (0)	(Mcol/event)/ha	274	284	180	89.1	328	43.2	897
Suspended sediment	***8 (2)***	***(kg/event)/ha***	***0.285***	***0.405***	***0.119***	***0.0533***	***0.376***	***< 0.0001***	***1.17***
Total suspended solids	***8 (3)***	***(kg/event)/ha***	***0.214***	***0.310***	***0.0459***	***0.00267***	***0.371***	***< 0.0001***	***0.869***
Total cadmium	***8 (6)***	***(mg/event)/ha***	***ND***	***ND***	***< 0.00054***	***ND***	***ND***	***< 0.00001***	***E 0.00192***
Dissolved cadmium	***8 (8)***	***(mg/event)/ha***	***ND***	***ND***	***< 0.00041***	***ND***	***ND***	***< 0.00001***	***< 0.00093***
Total chromium	***8 (4)***	***(mg/event)/ha***	***0.0198***	***0.0474***	***0.00336***	***0.000848***	***0.00642***	***< 0.00001***	***0.137***
Dissolved chromium	***8 (8)***	***(mg/event)/ha***	***ND***	***ND***	***< 0.00810***	***ND***	***ND***	***< 0.00001***	***< 0.0161***
Total copper	8 (0)	(mg/event)/ha	0.0317	0.0408	0.0128	0.00749	0.0458	0.000356	0.122
Dissolved copper	***7 (1)***	***(mg/event)/ha***	***0.0140***	***0.00911***	***0.0149***	***0.00278***	***0.0206***	***< 0.0005***	***0.0278***
Total lead	***8 (1)***	***(mg/event)/ha***	***0.0573***	***0.0683***	***0.0259***	***0.00878***	***0.108***	***< 0.00001***	***0.170***
Dissolved lead	***8 (6)***	***(mg/event)/ha***	***ND***	***ND***	***< 0.00086***	***ND***	***ND***	***< 0.00001***	***E 0.0052***
Dissolved nickel	***8 (8)***	***(mg/event)/ha***	***ND***	***ND***	***< 0.00863***	***ND***	***ND***	***< 0.00001***	***< 0.0129***
Total zinc	***7 (2)***	***(mg/event)/ha***	***0.239***	***0.358***	***0.0849***	***0.0280***	***0.310***	***< 0.00001***	***1.06***
Dissolved zinc	***7 (4)***	***(mg/event)/ha***	***0.0330***	***0.0136***	***0.0300***	***0.0256***	***0.0369***	***< 0.00001***	***0.0622***

Table 15. Difference in event-mean loads of selected water-quality constituents between stormwater in Turkey Creek upstream from the North Charleston maintenance yard (North Charleston1 location) and stormwater discharging from the North Charleston maintenance yard during storm events sampled from 2010 to 2011.

[ft³/s, cubic feet per second; <, less than the quantitative level; E, estimated value; --, no data; Percent differences greater than 20 percent, highlighted in bold text, were considered to represent greater loads based on laboratory analytical sampling, and discharge measurement error]

Site location	Date of storm event	Event-mean stormwater discharge (ft³/s)	Event-mean loads, in kilograms per event							"First-flush" stormwater discharge (ft³/s)	"First-flush" event loads, in million colonies per event	
			5-Day biochemical oxygen demand	Total suspended solids	Suspended sediment	Total Kjeldahl nitrogen	Orthophosphate	Total phosphorus	Total nitrogen		Enterococcus	*Escherichia coli*
North Charleston yard	04/08/10	0.709	79.2	31.5	12.8	<0.000	<0.004	<0.000	0.069	0.310	11,931	77,124
	09/26/10	0	0.102	< 0.001	<0.001	<0.000	<0.000	<0.000	<0.000	1.03	12,695	8,586
	01/05/11	0.2	0.001	< 0.001	<0.001	<0.000	<0.000	<0.000	0.069	0	27,239	37,985
	03/09/11	1.38	0.001	<0.001	7.78	0.361	<0.005	<0.000	0.345	2.42	8,506	3,719
	06/15/11	8.17	6.49	74.7	101	1.15	0.038	--	1.34	3.02	2,659	13,922
	09/06/11	2.78	0.001	0.303	6.48	0.030	0.019	0.018	0.232	3.35	40,275	17,083
	10/18/11	3.4	4.78	32.3	51.8	0.665	0.035	0.189	1.11	1.09	6,900	4,878
	11/28/11	2.18	1.29	7.42	12.7	0.111	0.010	--	0.350	2.51	53,405	24,964
Turkey Creek at North Charleston1 location	04/08/10	5.39	3.66	34.8	65.9	2.56	<0.029	0.586	3.21	1.15	4,780	130
	09/26/10	1.94	1.56	6.92	6.43	0.470	E0.009	0.445	0.566	0.718	4,884	617
	01/05/11	1.70	2.67	46.1	67.9	1.46	E0.029	0.162	1.67	1.1	743	275
	03/09/11	4.97	6.16	75.2	75.2	1.82	<0.018	0.467	2.29	0.829	41	84
	06/15/11	3.73	1.60	30.4	28.4	0.304	0.013	--	0.433	0.878	19,863	988
	09/06/11	3.60	134	47.1	47.1	0.639	0.035	0.250	0.901	0.55	638	292
	10/18/11	2.60	1.28	3.20	53.2	0.769	0.057	0.314	1.13	0.31	52	30
	11/28/11	0.55	0.312	5.91	5.48	0.107	0.005	--	0.178	0.493	591	2,143
Difference between North Charleston yard and Turkey Creek at North Charleston1 (percent)	04/08/10	13.2	2,163	90.6	19.4	<0.0	<13.2	<0.0	2.2	**27**	250	**59,326**
	09/26/10	0.0	6.6	< 0.0	<0.0	<0.0	<1.2	<0.0	<0.0	**144**	260	**1,392**
	01/05/11	11.8	0.0	< 0.0	<0.0	<0.0	<0.3	<0.1	4.2	0	3,666	**13,813**
	03/09/11	**27.8**	0.0	<0.0	10.3	19.8	<27.8	<0.0	15.1	**292**	20,747	**4,428**
	06/15/11	**219**	406	246	**356**	**379**	279	--	**309**	**344**	13	**1,409**
	09/06/11	**77.2**	0.0	0.6	13.8	4.7	54.0	7.2	**25.8**	**609**	6,313	**5,850**
	10/18/11	**131**	373	1,008	**97.4**	**86.5**	60.8	60.1	**98.2**	**352**	13,269	**16,260**
	11/28/11	**396**	413	126	**231**	**104**	182	--	**196**	**509**	9,036	**1,165**
Median of percent difference		**52.5**	190	45.6	**16.6**	**12.3**	40.9	0.0	**20.4**	**318**	**4,989**	**5,139**

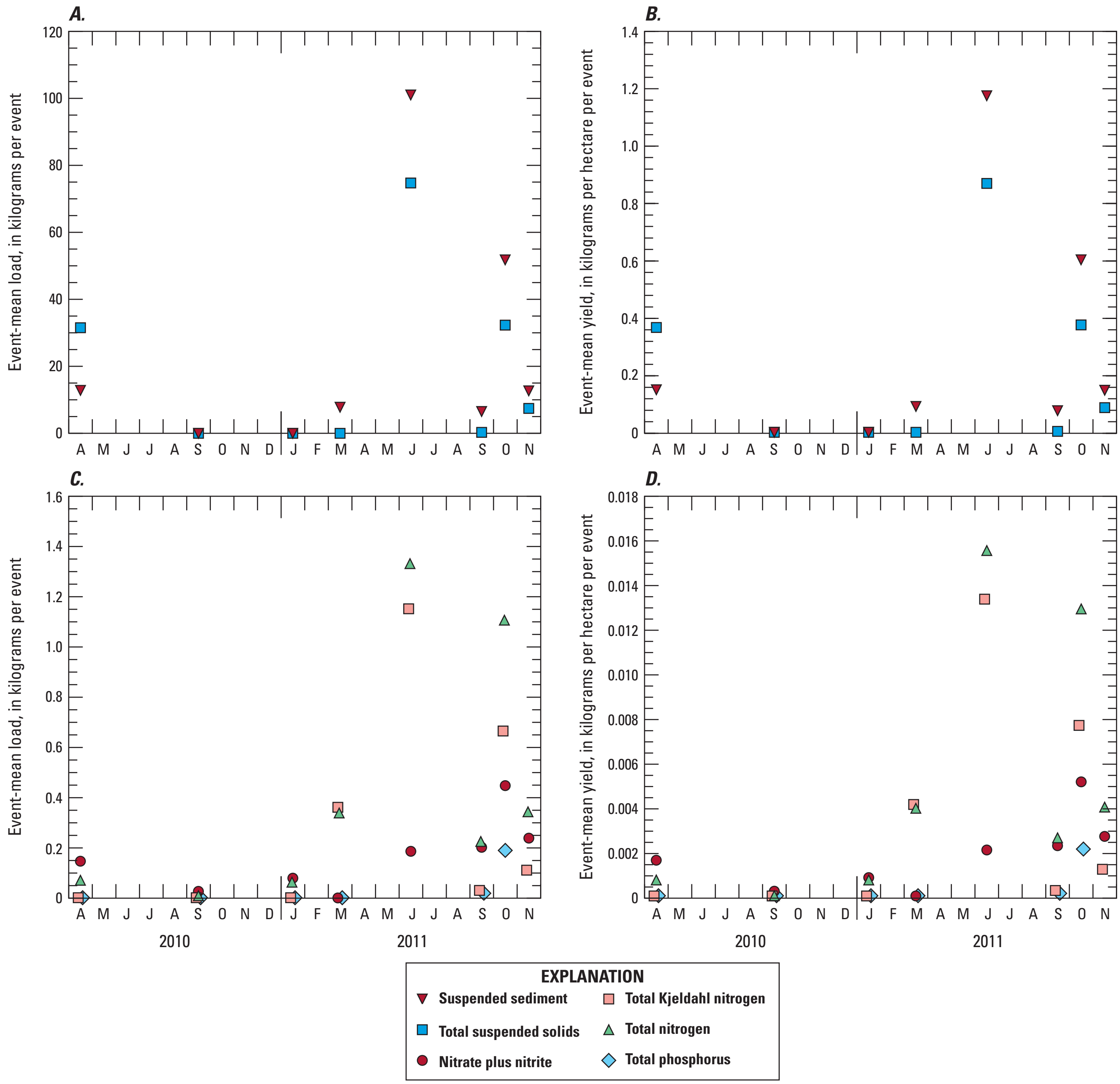


Figure 18. Temporal variation in total suspended solids and suspended sediment *A*, event-mean loads and *B*, event-mean yields and in nutrient *C*, event-mean loads and *D*, event-mean yields in stormwater entering Turkey Creek from the South Carolina Department of Transportation maintenance yard at North Charleston, South Carolina, 2010–2011.

1.90 mg/L (fig. 19*A*; table 11). Event-mean concentrations of nitrate plus nitrite, the more bioavailable inorganic form of nitrogen, at North Charleston1 ranged from only 0.26 to 0.66 mg/L, (fig. 19*A*; table 11). At North Charleston2, downstream from the maintenance yard, EMCs for TKN ranged from 0.41 to 1.80 mg/L with a median value of 1.20 mg/L, and EMCs for TN ranged from 0.99 to 2.19 mg/L with a median of 1.67 mg/L (fig. 20*A*; table 12). The median nitrate-plus-nitrite EMC of 0.42 mg/L at North Charleston2 is almost identical to the median of 0.43 mg/L at North Charleston1 (tables 11, 12). The EPA recommended TN criterion of 0.90 mg/L would be applicable to the sampled locations in Turkey Creek because the nutrient EMCs at North Charleston1 and North Charleston2 represent concentrations in a stream, not an outfall pipe. The TN EMCs for all eight sampled storms at North Charleston1 and North Charleston2 exceeded the EPA TN criterion.

During the sampled storms, no statistically significant change in nitrogen EMCs occurred between the North Charleston1 and North Charleston2 locations (table 13). These results indicate that the stormwater discharging from the North Charleston maintenance yard tended to contribute negligible amounts of nitrogen species to Turkey Creek during storms.

Stormwater in Turkey Creek upstream from the maintenance yard at North Charleston1 had TP EMCs with a median of 0.42 mg/L and a range from 0.20 to 1.8 mg/L (fig. 19*B*; table 11). Downstream at North Charleston2, the median TP EMC of 0.26 mg/L and range of TP EMCs from 0.11 to 0.34 mg/L were less than those at North Charleston1 (fig. 20*B*; table 12). Although orthophosphate EMCs were an order of magnitude lower than TP EMCs for most storms, the median orthophosphate EMC decreased from North Charleston1 (0.044 mg/L) to North Charleston2 (0.025 mg/L) (tables 11, 12). The EPA recommended TP criterion of 0.04 mg/L is applicable to the sampled locations in Turkey Creek because the nutrient EMCs at North Charleston1 and North Charleston2 represent concentrations in a stream, not an outfall pipe. The TP EMCs for all of the eight sampled storms at North Charleston1 and North Charleston2 exceeded the EPA TP criterion.

For all sampled storms, the decrease in TP and orthophosphate EMCs from North Charleston1 to North Charleston2 was statistically significant (table 13; appendixes 1E, 1F). These results indicate that the stormwater discharging from the North Charleston maintenance yard contributed negligible amounts of phosphorus and, at best, tended to produce an overall “dilution” effect on phosphorus concentrations in Turkey Creek during storms. Even the maximum TP EMC at North Charleston2 (0.34 mg/L) that occurred during the October 18, 2011, storm was lower than that at North Charleston1

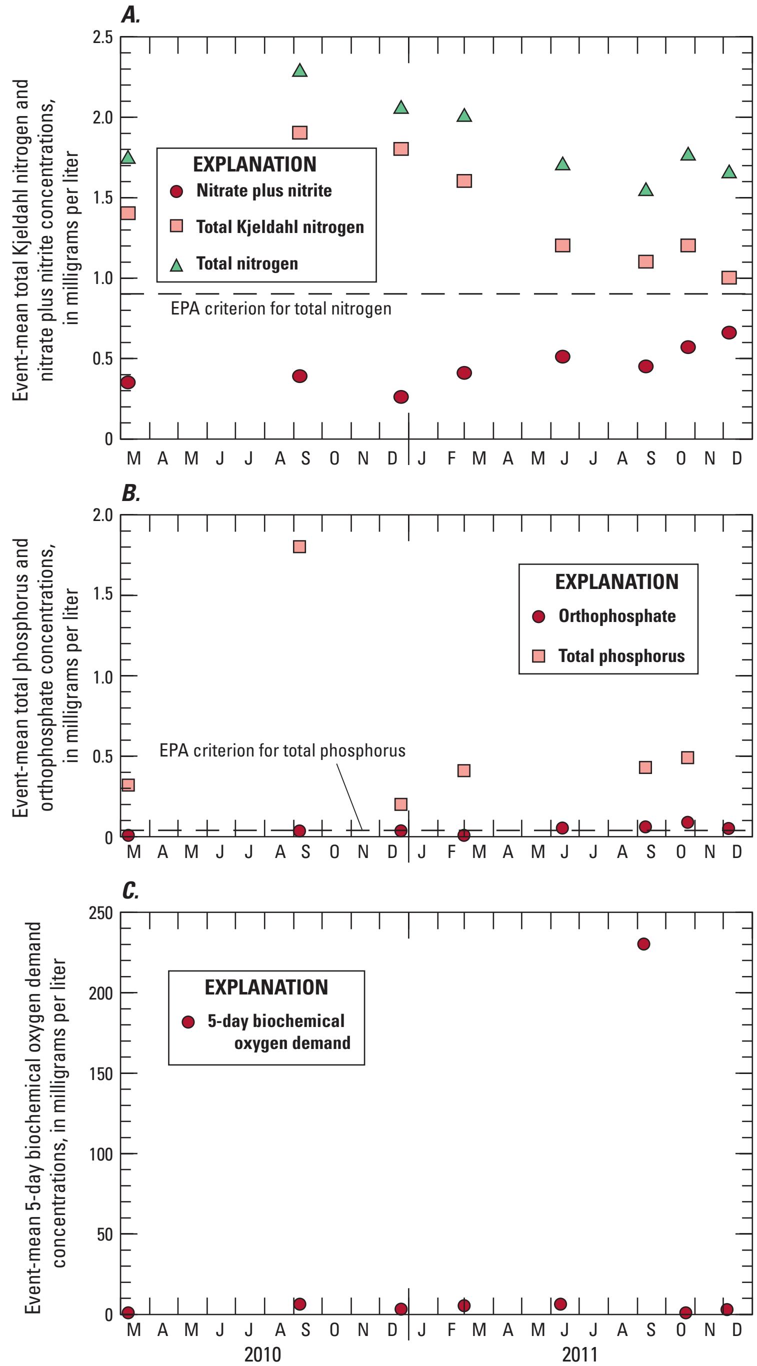


Figure 19. Event-mean concentrations of *A*, nitrogen species, *B*, phosphorus species, and *C*, 5-day biochemical oxygen demand in stormwater in Turkey Creek at North Charleston1, North Charleston, South Carolina, 2010–2012.

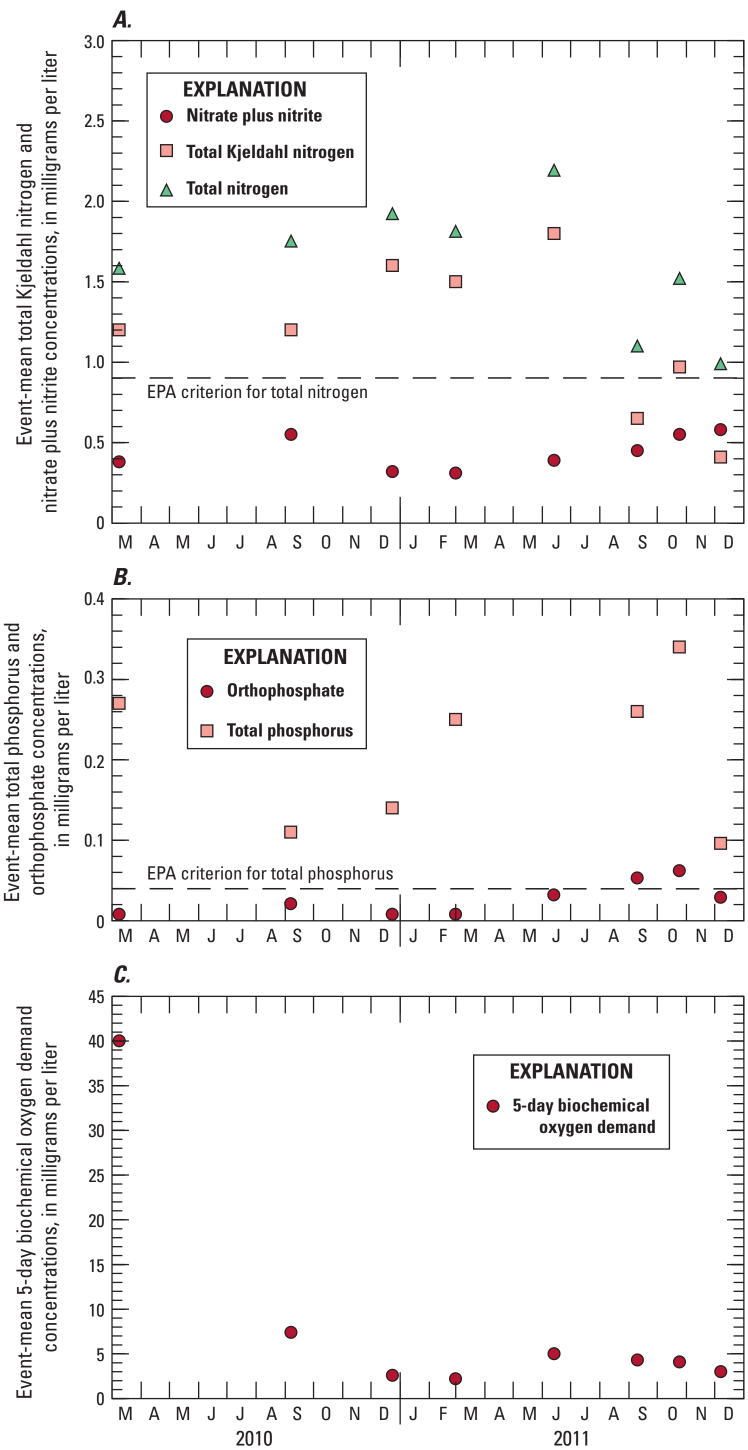


Figure 20. Event-mean concentrations of *A*, nitrogen species, *B*, phosphorus species, and *C*, 5-day biochemical oxygen demand in stormwater in Turkey Creek at North Charleston2, North Charleston, South Carolina, 2010–2012.

(0.49 mg/L), whose maximum TP EMC (1.8 mg/L) occurred during the September 2010 storm (figs. 19*B*, 20*B*; appendixes 1E, 1F). The October 18, 2011, storm was characterized as having an intermediate rainfall intensity of 0.23 in/h and event-mean stormwater discharge of 6.0 ft^3/s at the North Charleston2 location (appendix 1A). The maximum TP EMC of 1.8 mg/L at North Charleston1 occurred during the September 26, 2010, storm that had relatively low mean stormwater discharge (1.94 ft^3/s) and rainfall intenstiy (0.24 in/h) (fig. 19*B*; appendix 1E). No TP data were available for the June 15, 2011, storm at either outfall because of laboratory analytical error (appendixes 1E, 1F).

For the sampled storms, BOD_5 EMCs at North Charleston1 ranged from <2.0 to 230 mg/L with a median of 4.4 mg/L (fig. 19*C*; table 11). North Charleston2 had BOD_5 EMCs ranging from 2.2 to 40 mg/L with a median of 4.2 (fig. 20*C*; table 12). Statistically, the BOD_5 EMCs in Turkey Creek did not change from North Charleston1, upstream from the maintenance yard, to North Charleston2, downstream from the maintenance yard, for the sampled storms (table 13). The maximum BOD_5 EMCs, which were extreme outliers, occurred during the September 6, 2011, storm at North Charleston1 and the April 8, 2010, storm at North Charleston2 in Turkey Creek (figs. 19*C*, 20*C*).

For this report at the North Charleston yard facility, the negative nutrient loads and yields were replaced with a censoring value of less than 0.0001 in the statistical summary and plotted as the censoring level in graphs. Stormwater discharging from the North Charleston maintenance yard to Turkey Creek contributed estimated event-mean loads of TN that ranged from <0.0001 to 1.34 kg/event with a median of 0.289 kg/event (fig. 18*C*; table 14). Estimated event-mean TKN loads ranged from <0.0001 to 1.15 kg/event with a median of 0.0707 kg/event (fig. 18*C*; table 14). Stormwater discharge from the North Charleston maintenance yard had event-mean loads of TN that were greater than the loads at North Charleston1 for 4 of the 8 storms (June 15, 2011; September 6, 2011; October 18, 2011; and November 28, 2011) and event-mean loads of TKN for 3 of 8 storms (June 15, 2011; October 18, 2011; and November 28, 2011) (table 15). More than one-half of the estimated event-mean loads of TP in the stormwater discharging from the maintenance yard were <0.0001 kg/event, the maximum event-mean TP load was 0.189 kg/event (fig. 18*C*). Only 1 of the 6 storms had computed event-mean TP loads at North Charleston2 that were greater than those at North Charleston1 (table 15). Event-mean BOD_5 loads in stormwater discharging from the North Charleston maintenance yard ranged from <0.001 to 79.2 kg/event with a median of 0.695 kg/event (table 14). When compared to event-mean BOD_5 loads at North Charleston1, the BOD_5 loads at the North Charleston2 were greater in the same four (out of 8) storms as event-mean TSS loads (table 15).

Event-mean yields of TN contributed by the North Charleston maintenance yard to Turkey Creek ranged from <0.0001 to 0.0156 (g/event)/ha with a median of 0.00335 (g/event)/ha (table 14; fig. 18*D*). Median TN yields at the other facilities (range of 113 (g/event)/ha at Ballentine to 209 (g/event)/ha at Conway1) were 5 orders of magnitude greater than the median TN yield at the North Charleston yard (tables 9–11, 14). More than one-half the sampled storms had negligible event-mean yields of TP contributed by North Charleston maintenance yard (median <0.001 (g/event)/ha) with a maximum yield of only 0.0022 (g/event)/ha (fig. 18*D*; table 14). As was observed for median TN yields, median TP yields at the other facilities (range of 10.1 (g/event)/ha at Ballentine to 16.7 (g/event)/ha at Conway1) were 5 orders of magnitude greater than at the North Charleston locations (tables 9–11, 14). Less extreme differences in median event-mean yields of BOD_5 were observed at North Charleston yard (0.00809 (kg/event)/ha) than at the other facilities (range of 0.43 at Ballentine to 1.00 (kg/event)/ha at Conway2), but median BOD_5 yield at the North Charleston yard was still less than that at the other facilities, by 3 orders of magnitude or more (tables 9–11, 14).

Fecal Indicator Bacteria

Escherichia coli concentrations in "first-flush" samples collected from stormwater in Turkey Creek at the North Charleston1 were highly variable, ranging from 30 to 2,143 col/100 mL with a median of 284 col/100 mL (fig. 21*A*; table 11). In contrast to the downward trend identified for nutrient and sediment EMCs downstream in Turkey Creek, a statistically significant increase in *E. coli* concentrations was identified for Turkey Creek from North Charleston1 to North Charleston2 (table 13). North Charleston2 had *E. coli* concentrations, ranging from 521 to 15,648 col/100 mL with a median of 4,359 col/100 mL, an order-of-magnitude greater than those at North Charleston1 (fig. 22*A*; table 12). Maximum *E. coli* concentrations occurred during the November 28, 2011, storm at North Charleston1 and the April 8, 2010, storm at North Charleston2 (figs. 21*A*, 22*A*; appendixes 1E and 1F). The November 28, 2011, and April 8, 2010, storms were characterized by low rainfall intensities (0.22 and 0.16 in/h, respectively; appendix 1A).

Because *E. coli* concentrations were measured in Turkey Creek, not in stormwater discharging from the maintenance yard, the SCDHEC proposed SSM criterion for primary and secondary body contact of 349 col/100 mL is applicable to Turkey Creek at both locations. For the 8 storms sampled, 2 (25 percent) "first flush" *E. coli* concentrations at North Charleston1, upstream from the maintenance yard, exceeded the SSM criterion, but all 8 (100 percent) of the *E. coli* concentrations exceeded the SSM criterion at North Charleston2, downstream from the maintenance yard (figs. 21*A*, 22*A*).

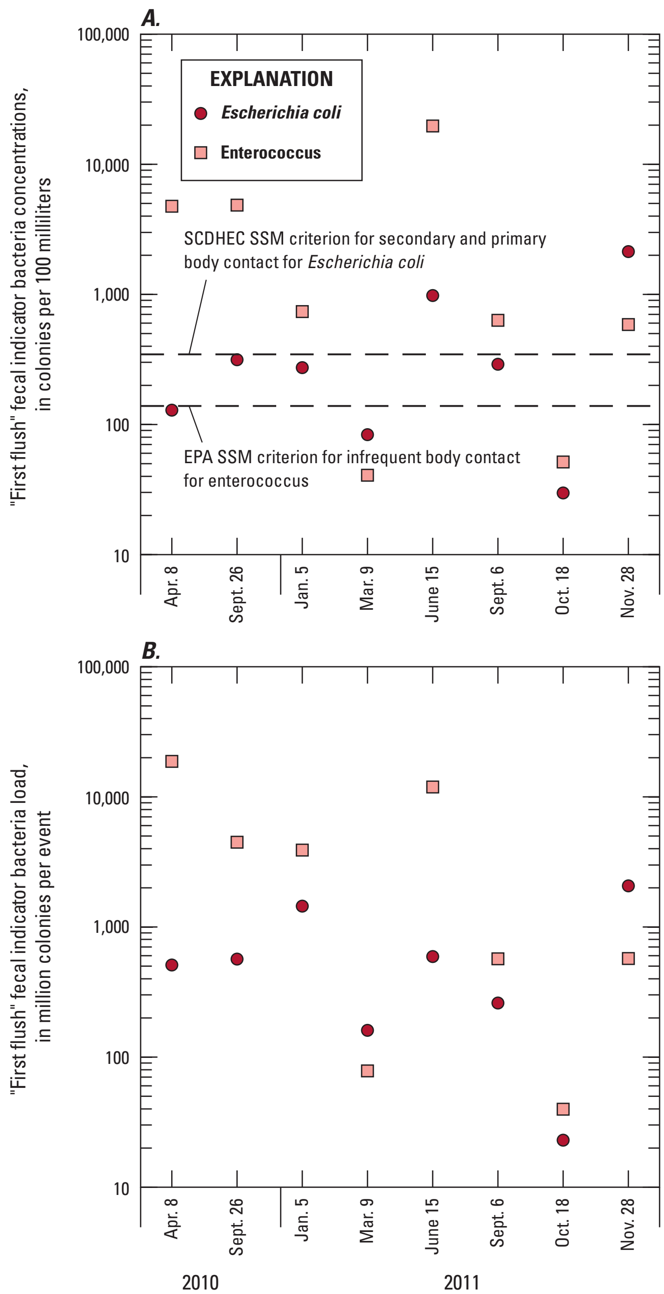


Figure 21. Temporal variation in *Escherichia coli* and enterococcus *A*, concentrations and *B*, loads in "first flush" grab samples collected in stormwater in Turkey Creek at North Charleston1, North Charleston, South Carolina, 2010–2012. [SCDHEC, South Carolina Department of Health and Environmental Control; SSM, single sample maximum; EPA, U.S. Environmental Protection Agency]

These findings indicate that the maintenance yard could be contributing significant fecal indicator bacteria that affect the water-quality conditions in Turkey Creek during storms; however, determining how these "first flush" concentrations compare to event-mean concentrations was not possible. "First flush" enterococcus concentrations at North Charleston1

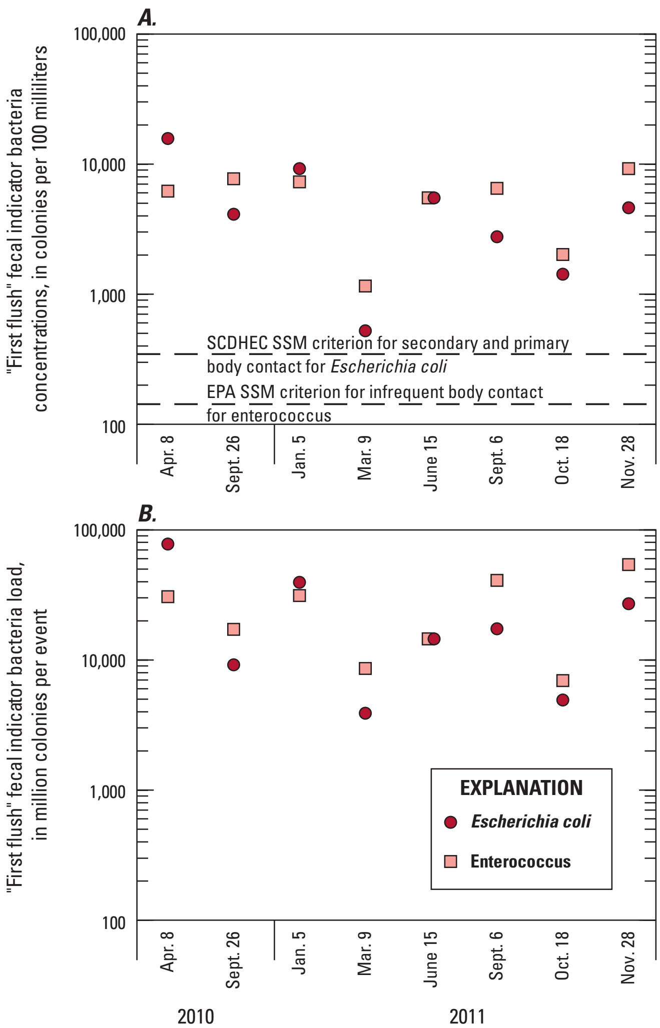


Figure 22. Temporal variation in *Escherichia coli* and enterococcus *A*, concentrations and *B*, loads in "first flush" grab samples collected in stormwater in Turkey Creek at North Charleston2, North Charleston, South Carolina, 2010–2012. [SCDHEC, South Carolina Department of Health and Environmental Control; SSM, single sample maximum; EPA, U.S. Environmental Protection Agency]

ranged from 41.0 to 19,863 col/100 mL with a median of 691 col/100mL (fig. 21*A*; table 11). In contrast to the upward trend in *E. coli* concentrations in Turkey Creek, no statistically significant change in enterococcus concentrations was identified between the North Charleston1 and North Charleston2 locations on Turkey Creek (table 13). Turkey Creek at North Charleston2 had enterococcus concentrations that ranged from 1,153 to 9,208 col/100mL with a median of 6,329 col/100 mL (fig. 22*A*; table 12). Maximum enterococcus concentrations occurred during June 15, 2011, storm at North Charleston1 and during the November 28, 2011, storm at North Charleston2 (figs. 21*A*, 22*A*). The two storms had extremely different characteristics; minimum mean stormwater discharge and relatively low rainfall intensity during the November 28, 2011, storm were 0.55 ft^3/s and 0.22 in/h, respectively, and maximum mean stormwater discharge and rainfall intensity during the June 15, 2011, storm were 11.9 ft^3/s and 1.73 in/h, respectively (appendix 1A).

Samples from 6 of the 8 storms at North Charleston1 had enterococcus concentrations that exceeded the SCDHEC SSM criterion of 104 col/100 mL (fig. 21*A*). Although no statistical difference in enterococcus concentration was identified, North Charleston2 had "first flush" enterococcus concentrations that exceeded the SCDHEC SSM criterion for primary and secondary body contact of 104 col/100 mL during all eight storms (fig. 22*A*).

At North Charleston1, *E. coli* loads ranged from 22.9 to 2,064 Mcol/event with a median of 536 Mcol/event for the eight storms (fig. 21*B*; table 11). *E. coli* loads at North Charleston2 ranged from 3,879 to 77,632 Mcol/event with a median of 15,927 Mcol/event (fig. 22*B*; table 12). Enterococcus loads ranged from 39.7 to 18,679 Mcol/event with a median of 2,229 Mcol/event at North Charleston1 (fig. 21*B*; table 11). At North Charleston2, enterococcus loads ranged from 6,939 to 53,974 Mcol/event with a median of 23,887 Mcol/event (fig. 22*B*; table 12).

"First-flush" *E. coli* and enterococcus loads in stormwater from the North Charleston maintenance yard were estimated as the difference between the computed bacterial loads at North Charleston1 and North Charleston2. Estimated *E. coli* loads in stormwater discharging from the North Charleston yard ranged from 3,719 to 77,124 Mcol/event with a median of 15,502 Mcol/event (fig. 23; table 14). Enterococcus loads ranged from 2,659 to 53,405 Mcol/event with a median of 12,313 Mcol/event (fig. 23; table 14). The greatest estimated *E. coli* loads in stormwater discharging from the North Charleston yard occurred during the April 8, 2010, and the January 5, 2011, storms that had the lowest rainfall intensities and longest durations but the lowest "first-flush" discharges from the maintenance yard (fig. 23; table 15; appendix 1A). The greatest estimated enterococcus loads in stormwater from the North Charleston yard occurred during the September 6, 2011, and November 28, 2011, storms that had intermediate rainfall intensities and durations, but relatively high "first-flush" discharges from the maintenance yard (fig. 23; table 15; appendix 1A).

Relations Among Water-Quality Constituents and Hydrologic Characteristics

Some similar relations among water-quality constituents and hydrologic characteristics were identified at the two locations upstream and downstream from the North Charleston maintenance yard compared to the relations observed for the Ballentine and Conway outfalls. Commonly associated sediment constituents of SS and turbidity had EMCs at North Charleston1 and North Charleston2 that were correlated to each other but not to hydrologic characteristics (appendixes 3D-E). At North Charleston2, SS EMCs were

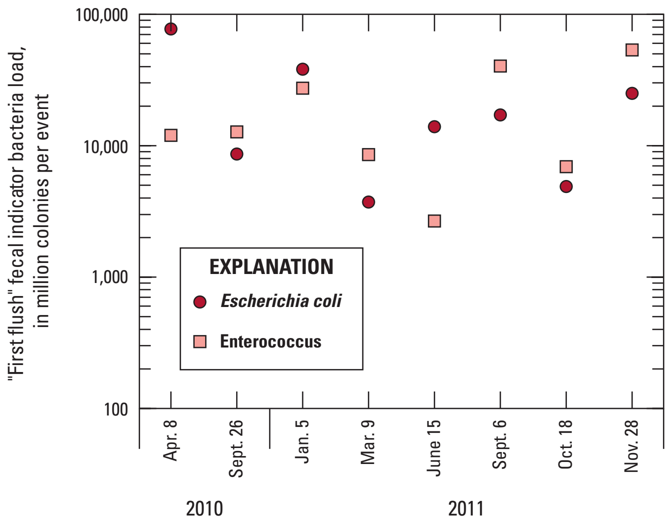


Figure 23. Temporal variation in estimated *Escherichia coli* and enterococcus loads in "first flush" stormwater discharging to Turkey Creek from the South Carolina Department of Transportation maintenance yard in North Charleston, South Carolina, 2010–2012.

correlated positively to days since last rainfall, which indicated greater SS EMCs tended to co-occur with greater time between storms (appendix 3E). At North Charleston1 and North Charleston2, nitrogen EMCs were not correlated to hydrologic characteristics of rainfall amounts, rainfall intensity, and mean stormwater discharge or to any other nutrient or suspended sediment constituent, with the exception of a negative correlation between TP and rainfall duration at North Charleston1 (appendixes 3D, 3E). At North Charleston1, "first-flush" *E. coli* and enterococcus concentrations were not correlated to any nutrient, suspended sediment, or hydrologic variable (appendix 3D). However, at the North Charleston2 location on Turkey Creek, enterococcus concentrations were correlated negatively to total organic nitrogen EMCs (appendix 3E). Although no significant correlation was identified between nutrients and hydrologic characteristics at North Charleston1, peak stormwater discharge was correlated positively to total nitrogen EMCs in Turkey Creek at North Charleston2 (appendixes 3D, 3E). At both locations on Turkey Creek, BOD_5 EMCs were not correlated to hydrologic conditions (appendix 3D). However, as was observed at the Conway and Ballentine facilities, the SS EMCs were not correlated significantly to the TSS EMCs at the North Charleston1 and North Charleson2 outfalls (appendixes 3D, 3E).

Trace-Metal Concentrations, Loads, and Yields

Elevated metal concentrations have been associated with stormwater draining urban, industrial, and commercial land uses in areas that are similar to, but tend to be on a larger scale than, the maintenance yard and section shed facilities in this study (Pitt and Maestre, 2005). As mentioned previously, total metals represent the dissolved and the particulate forms of the metals. Natural sediment particles that contain minerals with metallic composition can compose a fraction of the particulate metal concentrations and not be associated with human-induced activities. Additionally, dissolved metals in stormwater are the most bioavailable form to aquatic biota when transported to a receiving water body; therefore, dissolved metals were used to establish aquatic life criteria. The criteria for dissolved metals are hardness-dependent, and dissolved metals were calculated by using values established by the EPA and adopted by the SCDHEC for receiving waters (appendixes 2A, 2B; U.S. Environmental Protection Agency, 2006; South Carolina Department of Health and Environmental Control, 2012). Conversion factors, established by the EPA, can be used to convert total metal concentrations to estimated dissolved metal concentrations prior to comparison to aquatic life criteria; however, the estimated concentration often tends to overestimate the actual dissolved fraction and represents a more conservative comparison to aquatic life criteria (appendixes 2A, 2B).

The EMCs for total and dissolved cadmium, chromium, copper, lead, and zinc, and dissolved nickel were compared among storms at each site. Although a detailed summary of the aquatic life criteria is provided in appendix 2A, both estimated dissolved (estimated from a conversion factor applied to total) and dissolved trace-metal EMCs at each facility are compared to the corresponding ambient freshwater CMCs and CCCs in this section as a screening process to determine whether the concentrations could have some potential to affect the receiving water chemistry. The CMC was selected for comparison because it is considered an acute criterion related to one-time maximum contribution to a water body, which is the type of effect stormwater has on a receiving water body. Event-mean loads and yields of a subset of the trace metals that exceeded criteria levels also are compared among storms at each facility.

Ballentine Section Shed

Stormwater discharging from the retention pond outfall at the Ballentine section shed had trace- metal EMCs of differing concentration ranges (fig. 24). For the Ballentine facility, total trace metals with median EMCs, listed in order of decreasing concentrations, are zinc, 85.0 µg/L; copper, 10.0 µg/L; chromium, 8.0 µg/L; lead, 5.1 µg/L; and cadmium, <0.13 µg/L (table 8). Dissolved trace metals with median EMCs (which consistently were less than the medians EMCs of total trace metals), listed in order of decreasing concentrations, are zinc, 27 µg/L; copper, 6.4 µg/L; nickel, 2.3 µg/L; lead, 0.21 µg/L; chromium, <2.5 µg/L; and cadmium, <0.095 µg/L (table 8). Total cadmium EMCs had detectable levels for only 4 of the 9 storms, with the maximum EMC of 0.54 µg/L occurring during the March 10, 2010, storm (table 8; fig. 24*A*;

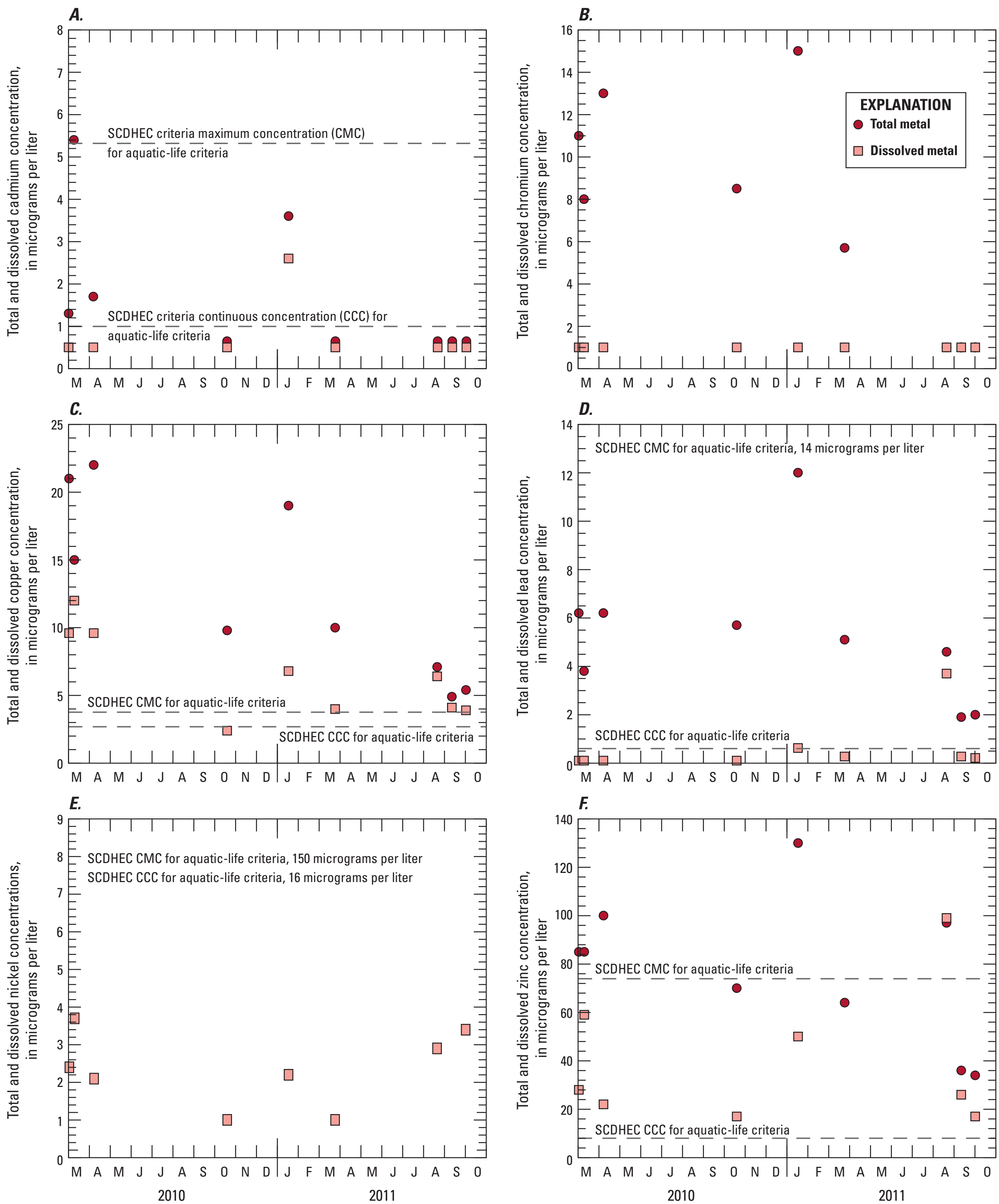


Figure 24. Temporal variation in event-mean concentrations of total and dissolved *A*, cadmium, *B*, chromium, *C*, copper, *D*, lead, *E*, nickel, and *F*, zinc in stormwater discharging at the Ballentine outfall, Ballentine, South Carolina, 2010–2012. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration; Criteria are based on a hardness of 25 milligrams per liter]

appendix 1B). Dissolved cadmium was detected only once (EMC of E0.26 µg/L) during the January 25, 2011, storm; during that storm, dissolved cadmium represented about 72 percent of the total cadmium EMC (table 8; fig. 24*A*; appendix 1B). Although dissolved chromium was not detected in stormwater during any storm at the Ballentine facility, total chromium was detected in 67 percent of the storm samples, and EMCs ranged from <2.50 to 15.0 µg/L (table 8; appendix 1B; fig. 24*B*). The maximum EMC for total chromium occurred during the January 25, 2011, storm (fig. 24*B*; appendix 1B). For the nine storms, total copper EMCs ranged from 4.9 to 22 µg/L, and dissolved copper EMCs ranged from E2.4 to 12 µg/L (table 8; fig. 24*C*). Additionally, the maximum total copper EMC that occurred during the April 8, 2010, storm was not concurrent with the maximum EMC for dissolved copper that occurred during the March 10, 2010, storm (fig. 24*C*; appendix 1B). Total lead EMCs ranged from 1.9 to 12 µg/L, whereas dissolved lead EMCs ranged from <0.20 to 3.7 µg/L at the Ballentine retention pond outfall (table 8; fig. 24*D*). As was observed with copper, the maximum total lead EMC that occurred during the January 25, 2011, storm was not concurrent with the maximum EMC for dissolved lead that occurred during the September 5, 2011, storm (fig. 24*D*; appendix 1B). Dissolved nickel EMCs were at detectable levels in all but two of the sampled storms and ranged from <0.2 to E3.7 µg/L (table 8; fig. 24*E*). The greatest range in trace-metal EMCs was observed for total zinc, from 34 to 130 µg/L, and dissolved zinc, from 17 to 99 µg/L (table 8; fig. 24*F*). Additionally, the maximum total zinc EMC, which occurred during the January 25, 2011, storm, was not concurrent with the maximum dissolved zinc EMC, which occurred during the September 5, 2011, storm (fig. 24*F*; appendix 1B). During the September 5, 2011, storm, the EMCs of dissolved copper, zinc, and lead represented the greatest fraction of the EMCs for the corresponding total metal (fig. 24; appendix 1B).

EMCs of total and dissolved trace metals in stormwater discharging at the Ballentine facility are compared to generalized SCDHEC-established CMCs for a water hardness of 25 mg/L (median for the Ballentine facility was 17 mg/L; table 8) to determine the “worst case scenario” of stormwater effects on receiving water (no dilution) (table 3; fig. 24). Even with this conservative approach, the levels of dissolved and total chromium, cadmium, and lead, and dissolved nickel in the stormwater runoff were not considered to be a potential problem to receiving waters because the maximum EMCs were well below the CMCs and even the CCCs for freshwater aquatic life (table 8; fig. 24*A*, *B*, *D*, *E*; table 3). However, all total copper EMCs and all but one of the dissolved copper EMCs for stormwater discharging at the retention pond outfall were greater than the freshwater CMC of 3.8 µg/L, indicating that stormwater from this facility had some potential to affect receiving water chemistry during storms (table 3; fig. 24*C*). Total zinc EMCs also indicated some potential to affect receiving water chemistry because 5 of the 9 storm events had stormwater with total zinc EMCs greater than the SCDHEC-established CMC for freshwater aquatic life of 75 µg/L. However, the applicable dissolved zinc EMCs were greater than the CMC in only 1 of the 9 storms (table 3; fig. 24*F*).

For the generalized CMC, a hardness near 25 mg/L is assumed; however, hardness in stormwater ranged from E6.3 to 194 mg/L at the Ballentine retention pond outfall (table 8). Therefore, sample-specific exceedances of the hardness-dependent CMC also were evaluated on the basis of the hardness that corresponded to the trace-metal EMCs for a storm (appendix 2A; fig. 25). For stormwater discharging from the retention pond outfall at the Ballentine facility, the measured dissolved copper EMCs exceeded the CMC criterion in 5 and the measured dissolved zinc EMCs exceeded the CMC criterion in 3 of the nine sampled storms (fig. 25*A*). Because the dissolved copper and zinc EMCs estimated from their total EMCs (total concentration multiplied by the EPA-established conversion factor) were much greater than the actual measured dissolved fraction of that metal, the exceedances in sampled storms increased to 7 for copper and 6 for zinc (fig. 25*B*). In addition, estimated dissolved lead EMCs computed from the conversion of total EMCs were greater than measured dissolved lead EMCs, such that the estimated dissolved lead EMC exceeded the CMC in one storm. This comparison of measured dissolved concentrations to estimated dissolved concentrations indicates that the analysis for dissolved metals is preferred over total metals to more accurately depict exceedances.

Event-mean trace-metal loads in stormwater discharging at the retention pond outfall at the Ballentine facility also varied by trace metal (table 8). Dissolved cadmium and chromium loads are mainly censored values (table 8). Total cadmium event-mean loads had the smallest range (<0.0002 to 0.022 grams per event (g/event)) with a median of 0.0012 g/event. Total chromium loads ranged from <0.077 to 1.87 g/event with a median of 0.11 g/event. Event-mean loads of total lead had a smaller range (0.00025 to 0.28 g/event) than, but a median (0.11 g/event) similar to, that of total chromium (table 8). Stormwater discharging at the Ballentine outfall had median event-mean loads of total and dissolved copper of 0.48 and 0.21 g/event, respectively. Median total and dissolved zinc loads were 2.2 and 0.96 g/event (table 8).

Conway Maintenance Yard

Stormwater discharging from the Conway1 pipe outfall and the Conway2 grass-lined ditch outfall at the Conway maintenance yard had statistically similar total trace-metal EMCs (appendix 3F). For the Conway1 outfall, the total trace metals and median EMCs, listed in order of decreasing concentrations, are zinc, 110 µg/L; chromium, 7.8 µg/L; copper, 5.7 µg/L; lead, 4.7 µg/L; and cadmium, <0.13 µg/L (table 9). The median EMCs of dissolved trace metals consistently were less than the median EMCs of total metals in stormwater at Conway1; listed in order of decreasing concentration, they

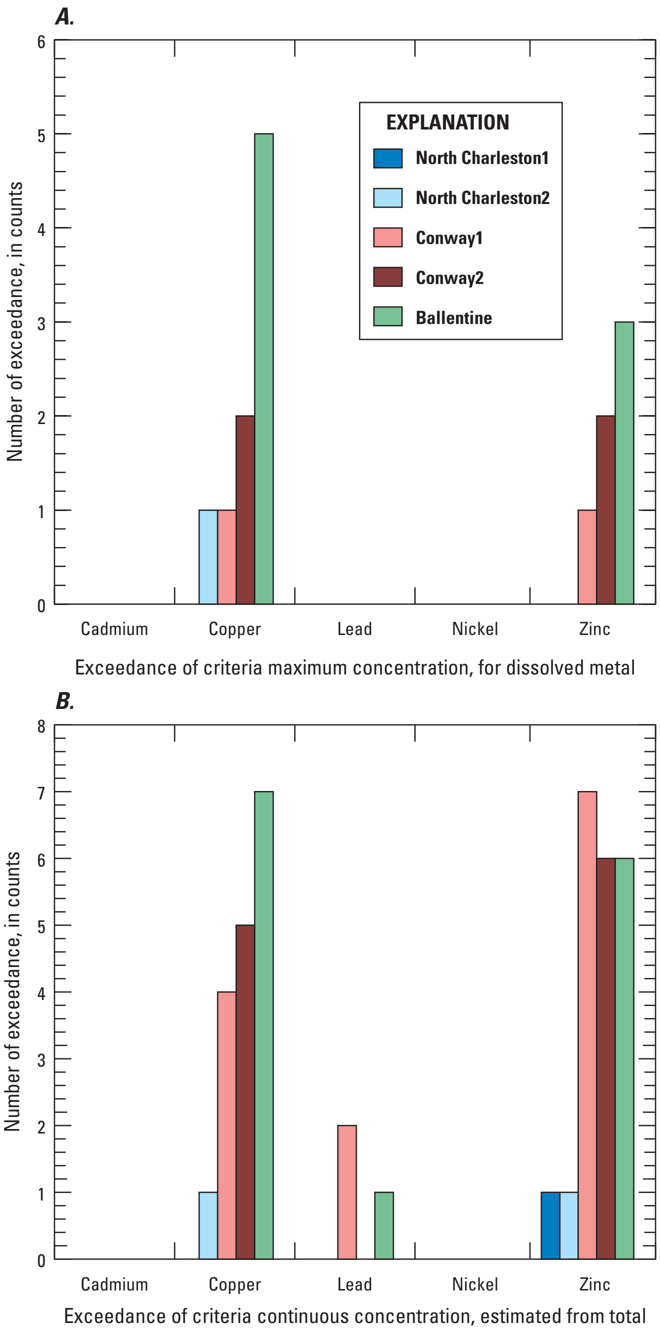


Figure 25. Number of samples exceeding the South Carolina Department of Health and Environmental Control continuous maximum criteria (CMC) for aquatic life by *A*, event-mean concentrations of measured dissolved trace-metals and *B*, event-mean concentrations of estimated dissolved trace metals in stormwater discharging at Ballentine, Conway1, Conway2, North Charleston1, and North Charleston2, South Carolina, 2010–2012.

are zinc, 17.5 µg/L; nickel, 2.3 µg/L ; copper, 2.1 µg/L; chromium, <2.5 µg/L; lead, <0.20 µg/L; and cadmium, <0.095 µg/L (table 9). Total cadmium was detectable in only 1 of the 9 storms with an estimated EMC of 0.19 µg/L occurring during the February 28, 2011, storm (fig. 26*A*; appendix 1C). Event-mean concentrations for dissolved cadmium were consistently below the laboratory reporting level of 0.095 µg/L (table 9; fig. 26*A*). Dissolved chromium was detected in stormwater sampled during 2 of the 9 storms at the Conway1 outfall with the maximum EMC of 21 µg/L occurring during the October 10, 2011, storm (fig. 26*B*; appendix 1C). Event-mean concentrations for total chromium at Conway1 ranged from <2.5 to 68 µg/L with the maximum EMC of total chromium occurring during the November 4, 2010, storm (table 9; fig. 26*B*; appendix 1C). For the nine storms, total copper EMCs ranged from E1.4 to 17 µg/L, and EMCs for dissolved copper ranged from <1.1 to 11 µg/L (table 9; fig. 26*C*). Additionally, the maximum EMC for total copper occurred during the March 21, 2010, storm concurrently with the maximum EMC for dissolved copper (table 9; fig. 26*C*; appendix 1C). Total lead EMCs ranged from 1.6 to 14 µg/L, whereas dissolved lead EMCs ranged from <0.2 to 1.7 µg/L at the Conway1 pipe outfall (table 9; fig. 26*D*). As was observed for copper, the maximum dissolved lead EMC occurred during the March 21, 2010, storm, but not concurrently with the maximum total lead EMC, which occurred during the February 28, 2011, storm (table 9; fig. 26*D*; appendix 1C). Dissolved nickel EMCs were at detectable levels in only three of the sampled storms and ranged from <2.0 to 6.8 µg/L (table 9; fig. 26*E*). The greatest range in EMCs was observed for total zinc, from 56 to 210 µg/L, and dissolved zinc, from <8.3 to 75 µg/L (table 9; fig. 26*F*). Additionally, the maximum total zinc EMC occurred during the November 4, 2010, storm concurrently with the minimum dissolved zinc EMC (fig. 26*F*; appendix 1C).

Total and dissolved trace-metal EMCs in stormwater discharging from Conway1 pipe outfall were compared to the generalized SCDHEC-established CMCs and CCCs for a water hardness of 25 mg/L (median for Conway1 was 37 mg/L) to determine the “worst case scenario” of stormwater effects on receiving water (no dilution) (table 3; fig. 26). Even with this conservative approach, the levels of dissolved and total chromium, cadmium, and lead, and dissolved nickel in the stormwater runoff were not considered to be a potential problem to receiving waters because the maximum EMCs were well below the CMCs for freshwater aquatic life (table 3; fig. 26*A*, *B*, *D*, *E*; table 9). However, 7 of the total copper EMCs and 2 of the dissolved copper EMCs were greater than the freshwater CMC of 3.8 µg/L, indicating that stormwater from this facility had some potential to affect receiving water chemistry during storms (table 3; fig. 26*C*). Total zinc EMCs also indicated some potential to affect receiving water chemistry because 6 of the 9 storms had stormwater with total zinc EMCs greater than the SCDHEC-established CMC for freshwater aquatic life of 75 µg/L. However, the dissolved zinc EMC for only 1 of the 9 storms was equal to the CMC (table 3; fig. 26*F*).

Stormwater discharging from the Conway2 grass-lined ditch outfall contained the total trace metals, listed with EMC medians in order of decreasing concentrations, zinc,

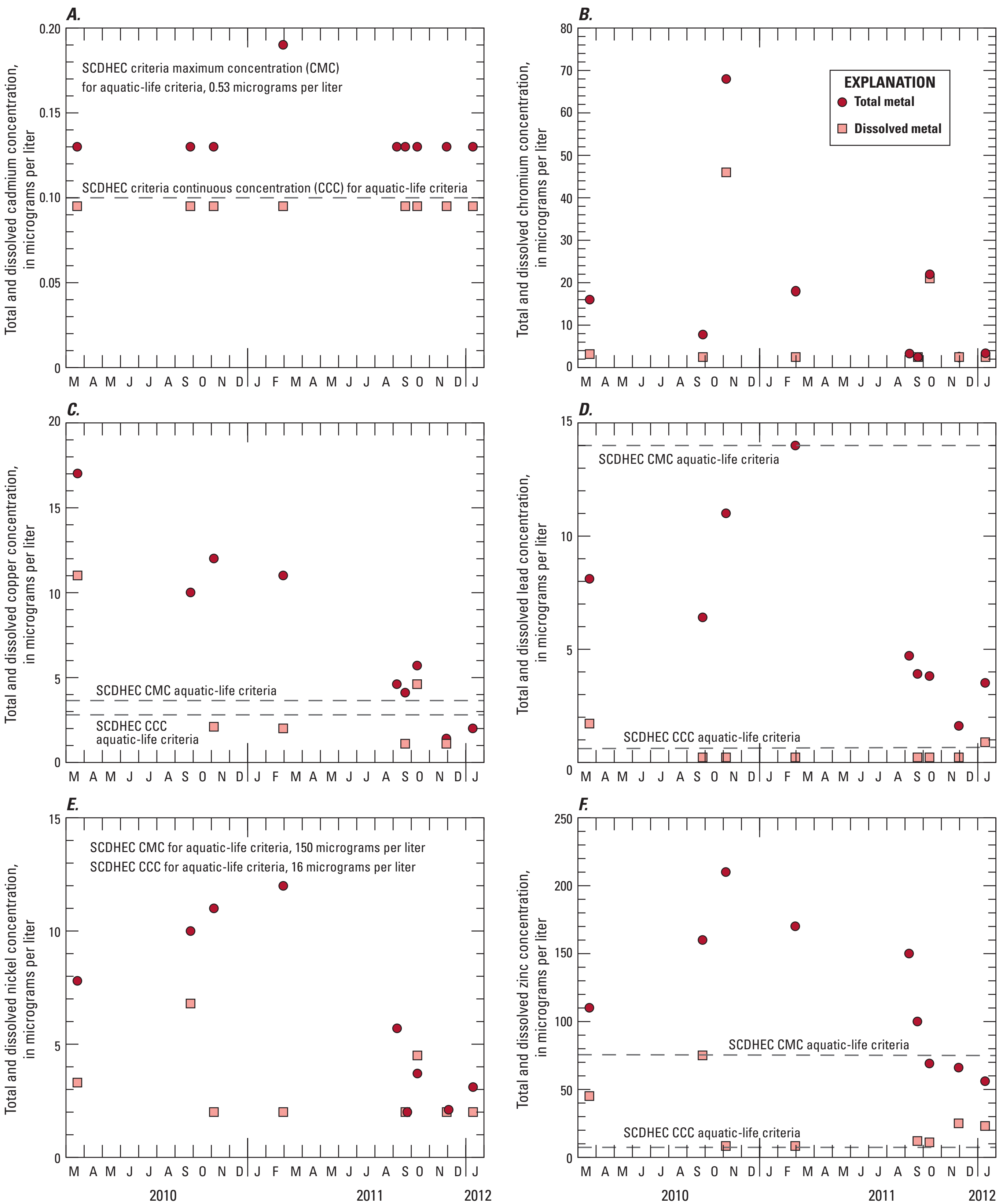


Figure 26. Temporal variation in event-mean concentrations of total and dissolved *A*, cadmium, *B*, chromium, *C*, copper, *D*, lead, *E*, nickel, and *F*, zinc in stormwater discharging at the Conway1 outfall, Conway, South Carolina, 2010–2012. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration; Criteria are based on a hardness of 25 milligrams per liter]

103 µg/L; copper, 6 µg/L; chromium, 5.5 µg/L; lead, 4.1 µg/L; and cadmium, <0.13 µg/L (table 10). Median EMCs of the dissolved trace metals consistently were less than the median total trace-metal EMCs in stormwater at Conway1; listed in order of decreasing concentrations, they are zinc, 21.5 µg/L; chromium, 2.3 µg/L; copper, 2.0 µg/L; nickel, <2.0 µg/L ; lead, <0.2 µg/L; and cadmium, <0.095 µg/L (table 10). Total cadmium was present at detectable EMC levels in 3 of the 9 storms, with a maximum estimated EMC of 0.25 µg/L occurring during the September 26, 2010, storm (table 10; fig. 27*A*; appendix 1D). Dissolved cadmium was detected only during the September 26, 2010, storm at an estimated EMC of 0.15 µg/L (table 10; fig. 27*A*; appendix 1D). Dissolved chromium ranged from <2.5 to 46 µg/L in stormwater discharging at the Conway2 outfall, with the maximum EMC occurring during the September 26, 2010, storm (table 10; fig. 27*B*; appendix 1D). At the same outfall, total chromium EMCs ranged from <2.5 to 14 µg/L, with the maximum total chromium EMC occurring during the February 28, 2011, storm (table 10; fig. 27*B*; appendix 1D). For the nine storms, total copper EMCs ranged from <1.1 to 14 µg/L, and dissolved copper EMCs ranged from 1.3 to 10 µg/L (table 10; fig. 27*C*). As was observed for copper EMCs for Conway1, the maximum total copper EMC occurred in stormwater during the March 21, 2010, storm at the Conway2 outfall concurrently with the maximum dissolved copper EMC (table 10; fig. 27*C*; appendix 1D). Total lead EMCs ranged from <0.5 to 11 µg/L, whereas dissolved lead EMCs ranged from <0.2 to E0.39 µg/L at Conway2 (table 10; fig. 27*D*). As was observed for dissolved cadmium, the maximum dissolved lead EMC occurred during the September 26, 2010, storm at the Conway2 outall, but not concurrently with the maximum total lead EMC, which occurred during the February 28, 2011, storm (table 10; fig. 27*D*; appendix 1D). Dissolved nickel EMCs were present at detectable levels in only two of the sampled storms and ranged from <2.0 to 8.2 µg/L, with the maximum occurring during the September 26, 2010, storm (table 10; fig. 27*E*; appendix 1D). The greatest range in EMCs was observed for total zinc, from E14 to 330 µg/L, and dissolved zinc, from E9.5 to 280 µg/L (table 10; fig. 27*F*). Additionally, the maximum total zinc EMC occurred during the September 26, 2010, storm concurrently with the maximum dissolved zinc EMC (fig. 27*F*; appendix 1D).

Total and dissolved trace-metal EMCs in stormwater discharging from Conway2 were compared to the generalized SCDHEC-established CMCs and CCCs for a water hardness of 25 mg/L (median hardness for Conway2 was 24 mg/L) to determine the “worst case scenario” of stormwater effects on receiving water (no dilution) (table 3; fig. 27). Even with this conservative approach, the levels of dissolved and total cadmium and lead, and dissolved nickel in the stormwater runoff were not considered to be a potential problem to receiving waters because even the maximum EMCs were well below the CMCs for freshwater aquatic life (table 3; fig. 27*A*, *D*, *E*; table 10). However, 5 of the total copper EMCs and 1 of the dissolved copper EMCs in stormwater discharging at the Conway2 outfall were greater than the freshwater CMC of 3.8 µg/L, indicating that stormwater from this facility had some potential to affect receiving water during storms (table 3; fig. 27*C*). Total zinc EMCs also indicated some potential to affect receiving water because 5 of the 9 storms had stormwater with total zinc EMCs greater than the SCDHEC-established CMC of 75 µg/L for freshwater aquatic life. However, the dissolved zinc EMCs in only 1 of 7 storms (dissolved zinc data were not available for 2 of the storms) was at the CMC (table 3; fig. 27*F*; appendix 1D).

The generalized CMC assumes a hardness near 25 mg/L; however, hardness in stormwater ranged from 13 to 105 mg/L at the Conway1 pipe outfall (table 9) and from 4.5 to 53 mg/L at the Conway2 grass-lined ditch outfall (table 10). Therefore, sample-specific exceedances of the hardness-dependent CMC were evaluated on the basis of the hardness that corresponded to the trace-metal EMCs for a storm (appendix 2C, 2D; fig. 25). For stormwater discharging from the Conway1 outfall, the measured dissolved copper and zinc EMCs exceeded the CMC criteria in 1 of the nine sampled storms (fig. 25*A*). Because the dissolved copper EMCs were estimated from total EMCs (total concentration multiplied by the EPA-established conversion factor) and were much greater than the measured dissolved fraction of that metal, the number of exceedances increased to 4 storms for copper and 7 storms for zinc (fig. 25*B*). For stormwater discharging from the Conway2 outfall, the measured dissolved copper and zinc EMCs exceeded the CMC criteria in 2 of the 8 sampled storms (fig. 25*A*). Because the dissolved copper and zinc EMCs estimated from their total EMCs (total concentration multiplied by the EPA-established conversion factor) were much greater than the measured dissolved fractions of those metals, the number of exceedances increased to 5 storms for copper and 6 storms for zinc (fig. 25*B*).

Event-mean loads of metals in stormwater discharging at Conway1 varied by metal (table 9). Total and dissolved cadmium event-mean loads were generally less than 0.002 g/event, with the exception of the maximum total cadmium load of E0.006 g/event (table 9). Event-mean loads of total chromium ranged from <0.054 to 8.7 g/event with a median of 0.071 g/event. The range for dissolved chromium event-mean loads at Conway1 was similar to that of total chromium (<0.040 to 5.9 g/event) but with a much lower median (0.0043 g/event) (table 9). Event-mean loads of total lead and total copper had very similar ranges (0.013 to 1.4 g/event and 0.026 to 1.5 g/event, respectively) and medians (0.085 and 0.089 g/event, respectively) at Conway1 (table 9). However, the dissolved fraction of lead had much lower event-mean loads (median of <0.005 g/event) than the dissolved fraction of copper (median of 0.026 g/event) (table 9). Total zinc had the greatest range in event-mean loads (0.17 to 27 g/event) and the greatest median (2.2 g/event) of the trace metals in stormwater at Conway1 (table 9).

Event-mean trace-metal loads in stormwater discharging at Conway2 also varied by metal in a manner similar to that at Conway1 (table 10). At Conway2, dissolved cadmium

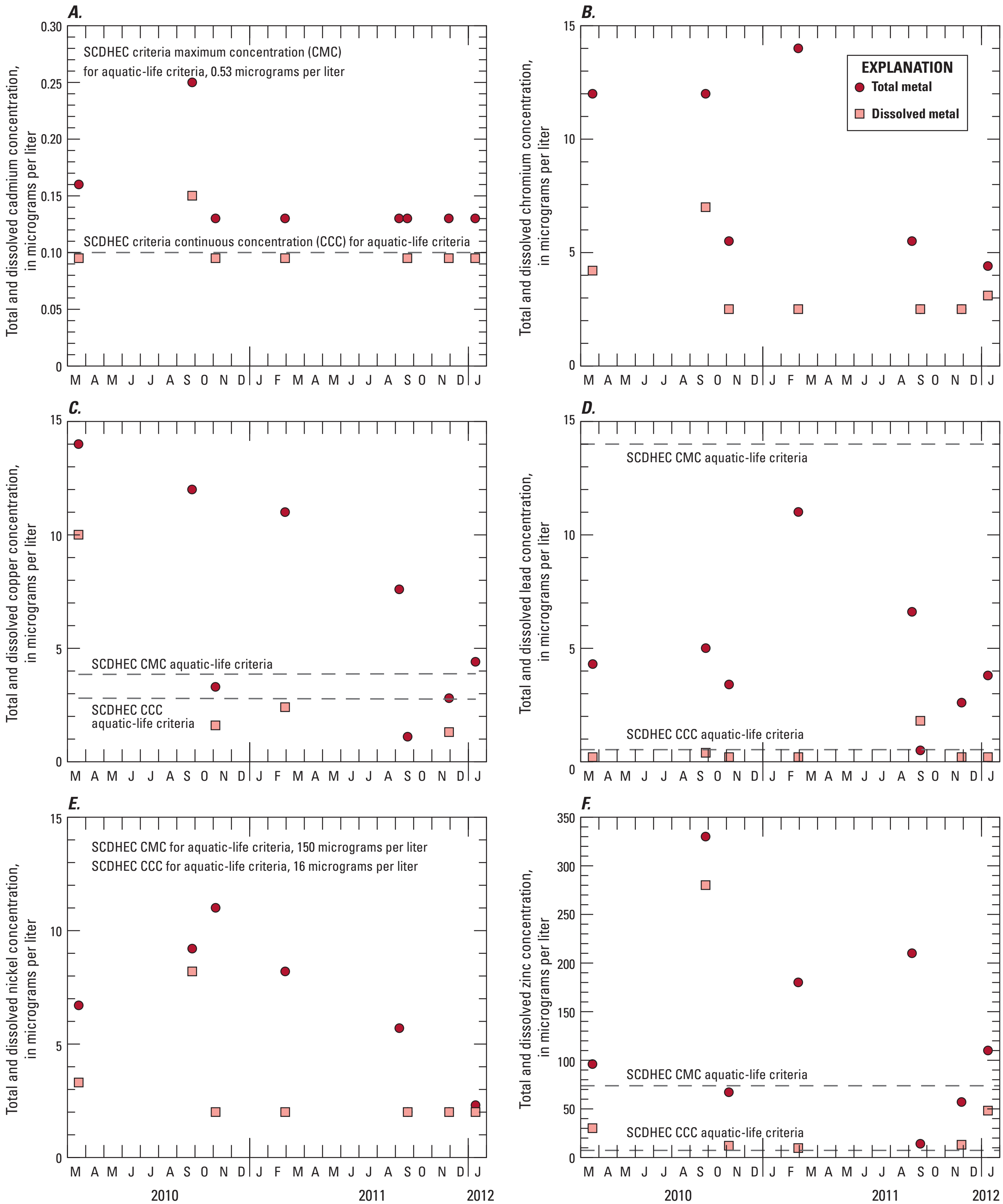


Figure 27. Temporal variation in event-mean concentrations of total and dissolved *A*, cadmium, *B*, chromium, *C*, copper, *D*, lead, *E*, nickel, and *F*, zinc in stormwater discharging at the Conway2 outfall, Conway, South Carolina, 2010–2012. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration; Criteria are based on a hardness of 25 milligrams per liter]

event-mean loads were generally <0.012 g/event, with the exception of the maximum dissolved cadmium load of E0.005 g/event (table 10). Total cadmium event-mean loads ranged from <0.014 to 0.012 g/event with a median of 0.0055 g/event (table 10). Event-mean loads of total chromium ranged from <0.27 to 2.75 g/event with a median of 0.45 g/event. The range for dissolved chromium event-mean loads at Conway1 was lower than the range for total chromium (<0.27 to 0.38 g/event) with a lower median (0.13 g/event) (table 10). Event-mean loads of total lead and total copper had very similar ranges (<0.053 to 2.2 g/event and <0.012 to 2.2 g/event, respectively) and medians (0.53 and 0.62 g/event, respectively) at Conway2 (table 10). As was observed in stormwater at Conway1, the dissolved fraction of lead had much lower event-mean loads (median of <0.039 g/event) than the dissolved fraction of copper (median of 0.041 g/event) in stormwater at Conway2 (table 10). Total zinc had the greatest range in event-mean loads (1.01 to 35.4 g/event) and the greatest median of 14.2 g/event of the trace metals in stormwater at Conway2 (table 10). Dissolved zinc event-mean loads had a lower range (0.32 to 9.2 g/event) and median (4.3 g/event) than those for total zinc (table 10).

North Charleston Maintenance Yard

In general, stormwater in Turkey Creek upstream from the North Charleston maintenance yard at North Charleston1 and downstream from the maintenance yard at North Charleston2 had statistically similar total trace-metal EMCs during the eight sampled storms (table 13). The exception was dissolved copper EMCs at North Charleston2 on Turkey Creek, which were statistically greater than those at North Charleston1, indicating some stormwater contribution from the maintenance yard (table 13).

At North Charleston1, median EMCs of total trace metals, listed in order of decreasing concentrations, are zinc, 53 µg/L; chromium, 5.9 µg/L; lead, 4.3 µg/L; copper, 3.6 µg/L; and cadmium, <0.13 µg/L (table 11). The median EMCs of dissolved trace metals consistently were less than the median EMCs of total trace metals at North Charleston1; median EMCs of dissolved trace metals, listed in order of decreasing concentrations, are zinc, 11.0 µg/L; copper, 1.7 µg/L; chromium, <2.5 µg/L; nickel, <2.0 µg/L; lead, <0.20 µg/L; and cadmium, <0.095 µg/L (table 11). Total cadmium EMCs ranged from <0.13 to E0.22 µg/L with the maximum EMC occurring during the October 18, 2011, storm (table 11; fig. 28*A*; appendix 1E). Dissolved cadmium EMCs were consistently below the laboratory reporting level of 0.095 µg/L (table 11; fig. 28*A*; appendix 1E). Dissolved chromium was detected during only 1 of the 8 storms at North Charleston1, with the maximum EMC of 6.1 µg/L occurring during the October 18, 2011, storm (table 11; fig. 28*B*; appendix 1E). Total chromium EMCs ranged from E2.7 to 16 µg/L, with the maximum total chromium EMC also occurring during the October 18, 2011, storm (table 11; fig. 28*B*; appendix 1E). For the 8 storms, total copper EMCs ranged from 1.6 to 9.8 µg/L, and dissolved copper EMCs ranged from <1.1 to 3 µg/L (table 11; fig. 28*C*). Additionally, the maximum total copper EMC that occurred during the June 15, 2011, storm occurred concurrently with the maximum dissolved copper EMC (fig. 28*C*; appendix 1E). Total lead EMCs ranged from 1.1 to 10 µg/L, whereas dissolved lead EMCs ranged from <0.20 to 0.57 µg/L at North Charlestonl (table 10; fig. 28*D*). As was observed for copper, the maximum total lead EMC that occurred during the June 15, 2011, storm occurred concurrently with the maximum dissolved lead EMC (table 10; fig. 28*D*; appendix 1E). Dissolved nickel EMCs were consistently less than the laboratory reporting level of 2.0 µg/L (table 11; fig. 28*F*). The greatest range in EMCs was observed for total zinc, from 20 to 120 µg/L, and dissolved zinc, from <8.3 to 17 µg/L (table 10; fig. 28*F*). Additionally, the maximum total zinc EMC that occurred in stormwater during the June 15, 2011, storm did not occur concurrently with the maximum dissolved zinc EMC, which occurred during the January 5, 2011, storm (fig. 28*F*; appendix 1E).

Total and dissolved trace-metal EMCs at North Charleston1 upstream from the North Charleston maintenance yard facility were compared to the generalized SCDHEC-established CMCs for a water hardness of 25 mg/L (median hardness for North Charleston1 was 88.3 mg/L, table 11) to determine the "worst case scenario" of stormwater effects on receiving water (no dilution) (table 3; fig. 28). Even with this conservative approach, the levels of dissolved and total cadmium and lead, and dissolved nickel in the stormwater runoff were not considered to be a potential problem to receiving waters because even the maximum EMCs (exception for total lead) were well below the CMCs for freshwater aquatic life (table 3; figs. 28*A*, *D*, *E*; table 11). However, three of the total copper EMCs at North Charleston1 were greater than the freshwater CMC of 3.8 µg/L, indicating that stormwater from this facility had some potential to affect receiving waters during storms (table 3; fig. 28*C*; appendix 1E). Total zinc EMCs also indicated some potential to affect receiving waters because EMCs greater than the SCDHEC-established CMC for freshwater aquatic life of 75 µg/L for zinc (fig. 28*F*) occurred in 1 of the 8 storms. However, the applicable dissolved lead, copper, and zinc EMCs did not exceed the CMC (table 3; figs. 28*C*, *D*, *F*).

In Turkey Creek at North Charleston2, the median total trace-metal EMCs varied by metal; listed in order of decreasing concentrations, they are zinc, 31.0 µg/L; chromium, 5.1 µg/L; lead, 4.1 µg/L; copper, 3.9 µg/L; and cadmium, <0.13 µg/L (table 12). At North Charleston1, the median EMCs of the dissolved trace metals consistently were less than the median EMCs of total metals; the trace metals, listed in order of decreasing concentrations, are zinc, 9.1 µg/L; copper, E1.8 µg/L; chromium, <2.5 µg/L; nickel, <2.0 µg/L; lead, <0.20 µg/L; and cadmium, <0.095 µg/L (table 12). Total cadmium EMCs were at detectable levels for only 2 of the 8 sampled storms, with an estimated maximum EMC of 0.27 µg/L occurring during the June 15, 2011, storm (table 12; fig. 29*A*; appendix 1F). Dissolved cadmium and chromium EMCs were consistently less than their laboratory reporting levels of 0.095 µg/L and 2.5, respectively (table 12; fig. 29*A*).

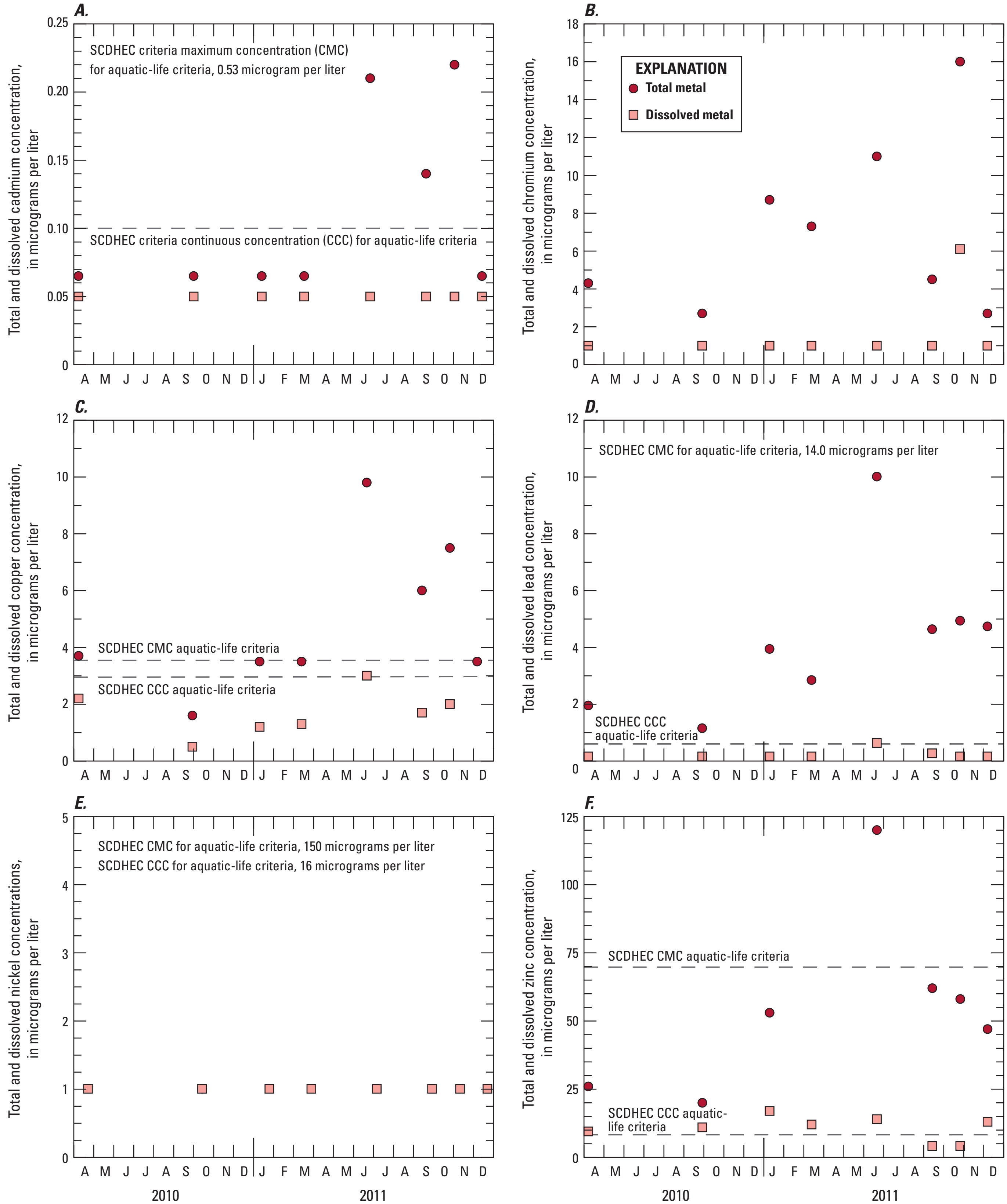


Figure 28. Temporal variation in event-mean concentrations of total and dissolved *A*, cadmium, *B*, chromium, *C*, copper, *D*, lead, *E*, nickel, and *F*, zinc in stormwater discharging at North Charleston1, North Charleston, South Carolina, 2010–2012. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration; Criteria are based on a hardness of 25 milligrams per liter]

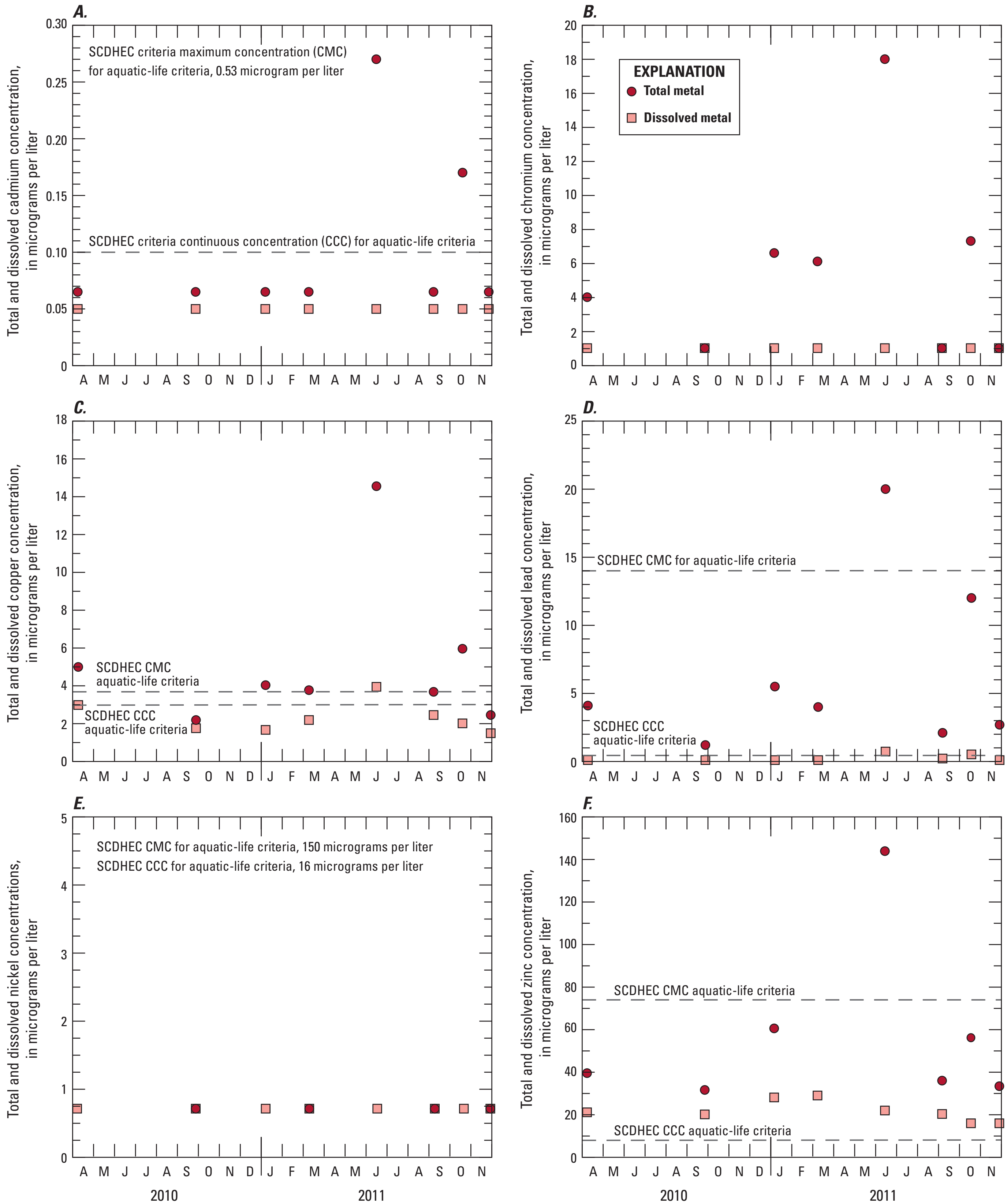


Figure 29. Temporal variation in event-mean concentrations of total and dissolved *A*, cadmium, *B*, chromium, *C*, copper, *D*, lead, *E*, nickel, and *F*, zinc in stormwater discharging at North Charleston2, North Charleston, South Carolina, 2010–2012. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration; Criteria are based on a hardness of 25 milligrams per liter]

Total chromium EMCs ranged from <2.5 to 18 µg/L, with the maximum total chromium EMC occurring during the June 15, 2011, storm (table 12; fig. 29*B*; appendix 1F). For the eight storms, total copper EMCs ranged from E1.9 to 16 µg/L, and dissolved copper EMCs ranged from E1.1 to E3.9 µg/L (table 12; fig. 29*C*). Additionally, the maximum EMC for total copper that occurred during the June 15, 2011, storm occurred concurrently with the maximum dissolved copper EMC (fig. 29*C*; appendix 1F).

At North Charleston2, total lead EMCs ranged from E1.2 to 20 µg/L, whereas dissolved lead EMCs ranged from <0.20 to E0.73 µg/L at North Charleston2 (table 12; fig. 29*D*). As was observed for copper, the maximum EMC of total lead occurred during the June 15, 2011, storm concurrently with the maximum EMC of dissolved lead (table 12; fig. 29*D*; appendix 1F). Dissolved nickel EMCs were consistently below the laboratory reporting level of 2.0 µg/L (table 12; fig. 29*E*). The greatest range in EMCs was observed for total zinc, from 22 to 150 µg/L, and dissolved zinc, from <8.3 to E18 µg/L (table 12; fig. 29*F*). Additionally, the maximum total zinc EMC that occurred in stormwater during the June 15, 2011, storm did not occur concurrently with the maximum dissolved zinc EMC, which occurred during the March 9, 2011, storm (fig. 29*F*; appendix 1F).

Event-mean concentrations of total and dissolved trace metals at North Charleston2 were compared to the generalized SCDHEC-established CMCs for a water hardness of 25 mg/L (median hardness for North Charleston2 was 71.1 mg/L; table 12) to determine the “worst case scenario” of stormwater effects on receiving water (no dilution) (table 3; fig. 29). Even with this conservative approach, the levels of dissolved and total cadmium and lead, and dissolved nickel in the stormwater runoff were not considered to be a potential problem to receiving waters because even the maximum EMCs (exception for total lead) were well below the CMCs for freshwater aquatic life (table 3; fig. 29*A*, *D*, *E*; table 12). However, 4 of the total copper EMCs and 1 of the dissolved copper EMCs at North Charleston2 were greater than the freshwater CMC of 3.8 µg/L, indicating that stormwater from this facility had some potential to affect receiving waters during storms (table 3; fig. 29*C*). Total zinc and total lead EMCs also indicate some potential to affect receiving waters because total zinc and total lead EMCs greater than the SCDHEC-established CMC for freshwater aquatic life of 75 µg/L and 14 µg/L, respectively, occurred during 1 of 8 storms (fig. 29*D*, *F*; table 3). However, the applicable dissolved lead and zinc EMCs had no exceedances of the CMC (fig. 29*D*, *F*).

The generalized CMC assumes a hardness near 25 mg/L; however, hardness in stormwater ranged from 65.3 to 125 mg/L in Turkey Creek at North Charleston1 (table 11) and from 47.4 to 109 mg/L at North Charleston2 (table 12). Therefore, sample-specific exceedances of the hardness-dependent CMC also were evaluated on the basis of the hardness that corresponded to the trace-metal EMCs for a storm (appendix 2E, 2F; fig. 25). For stormwater at North Charleston1, measured EMCs for dissolved trace metals did not exceed any of the CMCs (fig. 25*A*). Because the dissolved zinc EMCs estimated from total zinc EMCs (total concentration multiplied by the EPA-established conversion factor) were much greater than the actual measured dissolved fraction of that metal, the number of exceedances increased from 0 to 1 (fig. 25*B*). For stormwater at North Charleston2 downstream from the North Charleston maintenance yard, the measured dissolved copper and estimated dissolved copper EMCs exceeded the CMC criteria in 1 of the storms (fig. 25*A*). Because the dissolved zinc EMCs estimated from total zinc EMCs (total concentration multiplied by the EPA-established conversion factor) were much greater than the measured dissolved fraction of that metal, the number of exceedances increased from 0 to 1 North Charleston2 (fig. 25*B*).

Event-mean loads of metals in stormwater discharging from the North Charleston maintenance yard varied (table 14). Total cadmium and total chromium event-mean loads had the smallest ranges with medians of 0.17 and 3.02 g/event, respectively. Event-mean loads of total copper and total lead had relatively similar ranges with medians of 12.5 and 19.9 g/event, respectively. Total zinc had the greatest range in event-mean loads with a median of 108 g/event (table 14).

Occurrence of Synthetic and Semivolatile Organic Compounds

Flow-weighted stormwater samples were analyzed for 44 volatile organic compounds (VOCs), 10 herbicides, 7 Aroclor congeners (polychlorinated biphenyls (PCBs)), 18 organochlorine pesticides, and 16 PAHs (appendixes 1B–F). At all facilities, 1 to 3 VOCs were detected in stormwater during most sampled storms. The most frequently occurring VOCs in stormwater were cis-1,2-dichloroethene, bromodichloromethane, acetone, butyl methyl ketone, and o-xylene, usually at semiquantitative estimated concentrations less than the LRL (appendixes 1B–F). For regulated priority and non-priority pollutant compounds (cis-1,2-dichloroethene, bromodichloromethane, xylene), concentrations of VOCs were less than established SCDHEC drinking-water maximum contaminant level and human health criteria for the consumption of water and fish (South Carolina Department of Health and Environmental Control, 2012). No herbicides or PCBs were detected in stormwater discharging at the sampled outfalls or stream locations at the three facilities. The only organochlorine pesticide that was detected, dieldrin, was detected in one sample from the Turkey Creek downstream site (North Charleston2) at a concentration of 0.13 µg/L (March 9, 2011; appendix 1F). The dieldrin concentration of 0.13 µg/L was less than the CMC (chronic criterion) of 0.24 µg/L established for the protection of aquatic life (South Carolina Department of Health and Environmental Control, 2012). Because of the low-level detection of dieldrin at this site and its occurrence during only 1 of 8 storms, a potential risk to aquatic life was not indicated at North Charleston2.

Table 16. Median concentrations and detection frequency of polycyclic aromatic hydrocarbon (PAH) in stormwater discharging at the retention pond outfall at the section shed at Ballentine, at the pipe (Conway1) and grass-lined ditch (Conway2) outfall at the maintenance yard at Conway, and in Turkey Creek upstream (North Charleston1) and downstream (North Charleston2) from the South Carolina Department of Transportation maintenance yard in North Charleston, South Carolina, 2010 to 2012 and compiled median PAH concentrations from previous studies.

[<, less than the laboratory reporting level; E, semiquantitative, estimated value that is above the method detection limit, but below the laboratory reporting level; Statistics were computed using the Regression on Order Statistics for datasets with censored values. Censored values below the laboratory reporting level (<) were replaced with zero prior to computing total PAH concentrations]

Polycyclic aromatic hydrocarbon (PAH)	Relative molecular weight	Median concentrations (micrograms per liter)					Frequency of detection (percent)				
		Ballentine retention pond outfall	Conway1 pipe outfall	Conway2 grass-lined ditch outfall	North Charleston1 location on Turkey Creek	North Charleston2 location on Turkey Creek	Ballentine retention pond outfall	Conway1 pipe outfall	Conway2 grass-lined ditch outfall	North Charleston1 location on Turkey Creek	North Charleston2 location on Turkey Creek
9H-Fluorene	Low	< 0.022	< 0.021	< 0.022	< 0.022	< 0.022	11.1	0	0	25	12.5
Acenaphthene	Low	< 0.13	< 0.13	< 0.13	< 0.13	< 0.13	0	0	12.5	0	0
Acenaphthylene	Low	2.9	E 0.09	0.79	< 0.21	< 0.20	77.8	33.3	62.5	12.5	0
Anthracene	Low	0.064	< 0.007	E 0.022	E 0.005	< 0.007	55.6	33.3	62.5	50	12.5
Naphthalene	Low	< 0.14	< 0.14	< 0.15	< 0.15	< 0.14	0	0	0	0	0
Phenanthrene	Low	0.94	0.18	0.62	0.084	0.046	87.5	100	100	87.5	87.5
Benzo[a] anthracene	High	0.57	0.055	0.41	0.052	< 0.042	87.5	55.6	100	62.5	25
Benzo[a]pyrene	High	1.1	0.098	0.69	0.093	0.058	87.5	88.9	100	87.5	75
Benzo[b] fluoranthene	High	2.1	0.27	1.3	0.16	0.14	88.9	100	100	100	87.5
Benzo[ghi] perylene	High	1.3	0.13	1.1	0.10	0.088	87.5	100	100	75	75
Benzo[k] fluoranthene	High	0.96	< 0.013	0.58	0.071	0.042	88.9	44.4	100	87.5	62.5
Chrysene	High	1.6	0.19	1.2	0.14	0.098	87.5	100	100	75	75
Dibenzo[a,h] anthracene	High	0.20	0.12	0.60	0.025	< 0.011	77.8	77.8	87.5	62.5	25
Fluoranthene	High	3.1	0.44	2.6	0.22	0.17	87.5	100	100	62.5	75
Indeno[1,2,3-cd] pyrene	High	1.2	0.14	0.87	0.071	0.054	75	100	100	75	75
Pyrene	High	2.6	0.20	1.5	0.16	0.13	87.5	100	100	87.5	75
Total (ΣPAH_{16})		27.8	2.56	14.2	1.37	0.82	87.5	100	100	100	87.5

Polycyclic aromatic hydrocarbons were the most frequently detected organic compounds in stormwater at the three facilities. Stormwater draining from the parking lots, sheds, and work yards of the SCDOT facilities can transport PAHs derived from leaking motor oil, tire particles, vehicle exhaust, atmospheric deposition, and the asphalt parking lot, especially if sealed with coal-tar-based sealant (Mahler and others, 2005; Selbig, 2009; Watts and others, 2010; Mahler and others, 2012). The total PAH concentrations (ΣPAH_{16}) in stormwater at the three facilities were highly variable in this study. By assigning zeros to censored concentrations (reported as less-than values), the total PAH concentrations ranged from 0 (no detections) to 95.7 µg/L (appendix 2B). At the section shed in Ballentine, stormwater discharging from the retention pond outfall had statistically greater ΣPAH_{16} than stormwater at Conway1 outfall and Turkey Creek at North Charleston1 and North Charleston2 (appendix 3G). At the Ballentine pond outfall, the ΣPAH_{16} ranged from 0 (no detections) to 95.7 µg/L with a median of 27.8 µg/L (appendix 2B; table 16). At the Conway1 pipe outfall, stormwater had ΣPAH_{16} that ranged from 1.25 to 20 µg/L with a median of 2.56 µg/L. For the sampled storms, stormwater discharging at the Conway2 outfall had a greater range in ΣPAH_{16} (9.14 to 39.0 µg/L) and a greater median of 14.2 µg/L than stormwater discharging at the Conway1 outfall (appendix 3F). At North Charleston1, ΣPAH_{16} for the 8 storms ranged from 0.020 to 30.0 µg/L with a median of 1.37 µg/L (appendix 2B; table 16). Downstream from the maintenance yard, North Charleston2 ΣPAH_{16} was significantly less, ranging from 0 (no detections) to 2.85 µg/L with a median of 0.82 µg/L (table 16). The lower range and median of ΣPAH_{16} at North Charleston2 relative to concurrent samples from North Charleston1 indicate that the contribution of PAHs to Turkey Creek from the maintenance yard was negligible relative to the upstream contribution and that ΣPAH_{16} concentrations were decreased by dilution or other attenuation processes during storms.

One sample collected at the Ballentine outfall during the 9 storms had incomplete PAH results (March 10, 2010; appendix 2B); therefore, those results were not included in the analysis of the PAH data. In samples from the other eight storms at the Ballentine facility, HMW PAH compounds were detected more frequently in stormwater than most LMW PAH compounds, with the exception of acenaphthlyene and phenanthrene (table 16). The LMW PAH fluorene was detected in samples from only one storm, whereas acenaphthene and naphthalene were not detected in samples from any storm at the Ballantine facility (table 16; appendix 2B). Concurrently, HMW PAHs, except indeno[1,2,3-cd]pyrene, were detected in samples from all but one of the sampled storms at this facility; indeno[1,2,3-cd]pyrene was detected in samples from 6 of 8 storms (table 16).

With the exception of the median concentrations of acenaphthylene (2.9 µg/L) and phenanthrene (0.94 µg/L) concentrations, median concentrations of individual LMW PAHs were 1 to 2 orders of magnitude less than the median concentrations of HMW PAHs in stormwater at the Ballentine outfall (table 16; fig. 30). The median phenanthene concentration in stormwater at this outfall compared well to the range of reported concentrations of this compound in stormwater draining from similar land uses (fig. 30; Ngabe and others, 2000; Menzie and others, 2002; Selbig, 2009). However, the median acenaphythylene concentration was about 2 orders of magnitude greater than the reported range for stormwater draining parking lots, commercial roofs, and urban land-use areas (fig. 30; Ngabe and others, 2000; Menzie and others, 2002; Selbig, 2009). The reason for the elevated median acenaphthylene concentration is that the concentrations of this compound in stormwater were greater than 10 µg/L during 4 of the 5 storms sampled for PAHs in 2011 at Ballantine, and acenaphthylene represented more than 70 percent of the ΣPAH_{16} during the last 3 storms in 2011 (appendix 2B). In general, the larger proportion of HMW PAHs relative to LMW PAHs is indicative of PAHs that have a combustion source (pyrogenic, including vehicle exhaust) for storms in 2010, but not in 2011 (fig. 30; appendix 2B; Hwang and Foster, 2006). Oily sheen indicative of a petrigenic (fuel) source was observed periodically in the stormwater discharging at the Ballantine outfall (fig. 31). The median concentrations of the HMW PAHs fell within the reported ranges of these compounds in stormwater draining areas covered by parking lots, commercial roofs, and urban and commercial land (fig. 30). In fact, median HMW PAH concentrations at the Ballentine facility tend to fall within the range for sealed and unsealed parking lots, with the exception of dibenzo[a,h]anthracene (fig. 30; Ngabe and others, 2000; Menzie and others, 2002; Selbig, 2009).

For the nine sampled storms at the Conway1 pipe outfall at the maintenance yard facility, HMW PAH compounds were detected more frequently in stormwater than most LMW PAH compounds, with the exception of phenanthrene (100 percent detection frequency) (table 16). The LMW PAHs naphthalene, acenaphthene, and fluorene were not detected in stormwater from the Conway1 outfall during any storm (table 16; appendix 2B). Benzo[a]anthracene and benzo[k]fluoranthene were detected least frequently of the HMW PAH compounds (5 and 4, respectively, of the 9 sampled storms) at Conway1 (table 16). Except for the HMW PAHs above, dibenzo[a,h]anthracene (77.8 percent) and benzo[a]pyrene (88.9 percent), HMW PAHs were detected in stormwater during all storms at the Conway1 outfall (table 16).

The median phenanthrene concentration (0.18 µg/L) represented the greatest median LMW PAH concentration and compared well to the median HMW PAH concentrations in stormwater at the Conway1 pipe outfall (table 16; fig. 32*A*). The median phenanthrene concentration in stormwater at this outfall was less than the range of reported median and mean concentrations of this compound in stormwater draining similar land-use areas (fig. 32*A*; Ngabe and others, 2000; Menzie and others, 2002; Selbig, 2009). However, as was observed for stormwater at the Ballentine outfall, the median acenaphythylene concentration at Conway1was greater than the reported range for stormwater draining parking lots, commercial roofs, and urban land-use areas (fig. 32*A*; Ngabe and others, 2000;

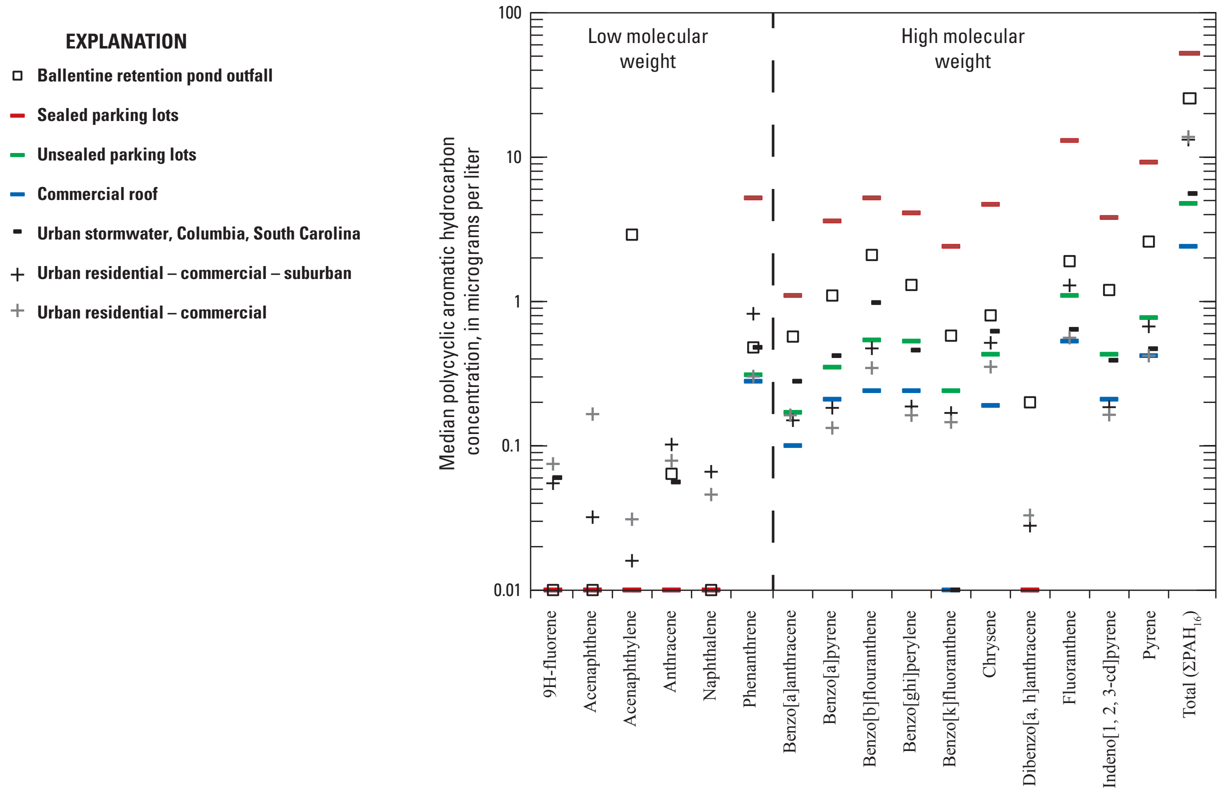


Figure 30. Median polycyclic aromatic hydrocarbon concentrations in stormwater at the Ballentine outfall, Ballentine, South Carolina, and median or mean polycyclic aromatic hydrocarbon concentrations in stormwater draining sealed and unsealed parking lots (Selbig, 2009), commercial roofs (Selbig, 2009), and urban and commercial land use (Ngabe and others, 2000; Menzie and others, 2002).

Menzie and others, 2002; Selbig, 2009). The acenaphthylene concentration was elevated in stormwater during the November 28, 2011, storm (19.0 µg/L) and represented more than 90 percent of the ΣPAH_{16} (20.0 µg/L) during that storm (appendix 2B). For all other storms, the larger proportion of HMW PAHs relative to LMW PAHs generally was indicative of PAHs that have a combustion source (pyrogenic, including vehicle exhaust) (fig. 32*A*; appendix 2B; Hwang and Foster, 2006). With the exception of dibenzo[a,h]anthracene, median concentrations of the individual HMW PAH compounds in stormwater at the Conway1 outfall were lower than the reported ranges of these compounds in stormwater draining areas covered by parking lots and urban-commercial land (fig. 32*A*). Additionally, median concentrations for 6 of the 11 HMW PAH compounds were lower than reported ranges in stormwater draining commercial roofs (fig. 32*A*). In fact, median ΣPAH_{16} concentrations at the Conway1 facility tended to fall below the range for sealed and unsealed parking lots and urban-commercial land use but within the range of commercial roofs (fig. 32*A*; Ngabe and others, 2000; Menzie and others, 2002; Selbig, 2009).

Figure 31. Oily sheen in stormwater discharging from the retention pond at the section shed at Ballentine, South Carolina, during the falling limb of the storm hydrograph, February 22, 2010. (Photograph by William F. Falls, Hydrologist, U.S. Geological Survey South Carolina Water Science Center)

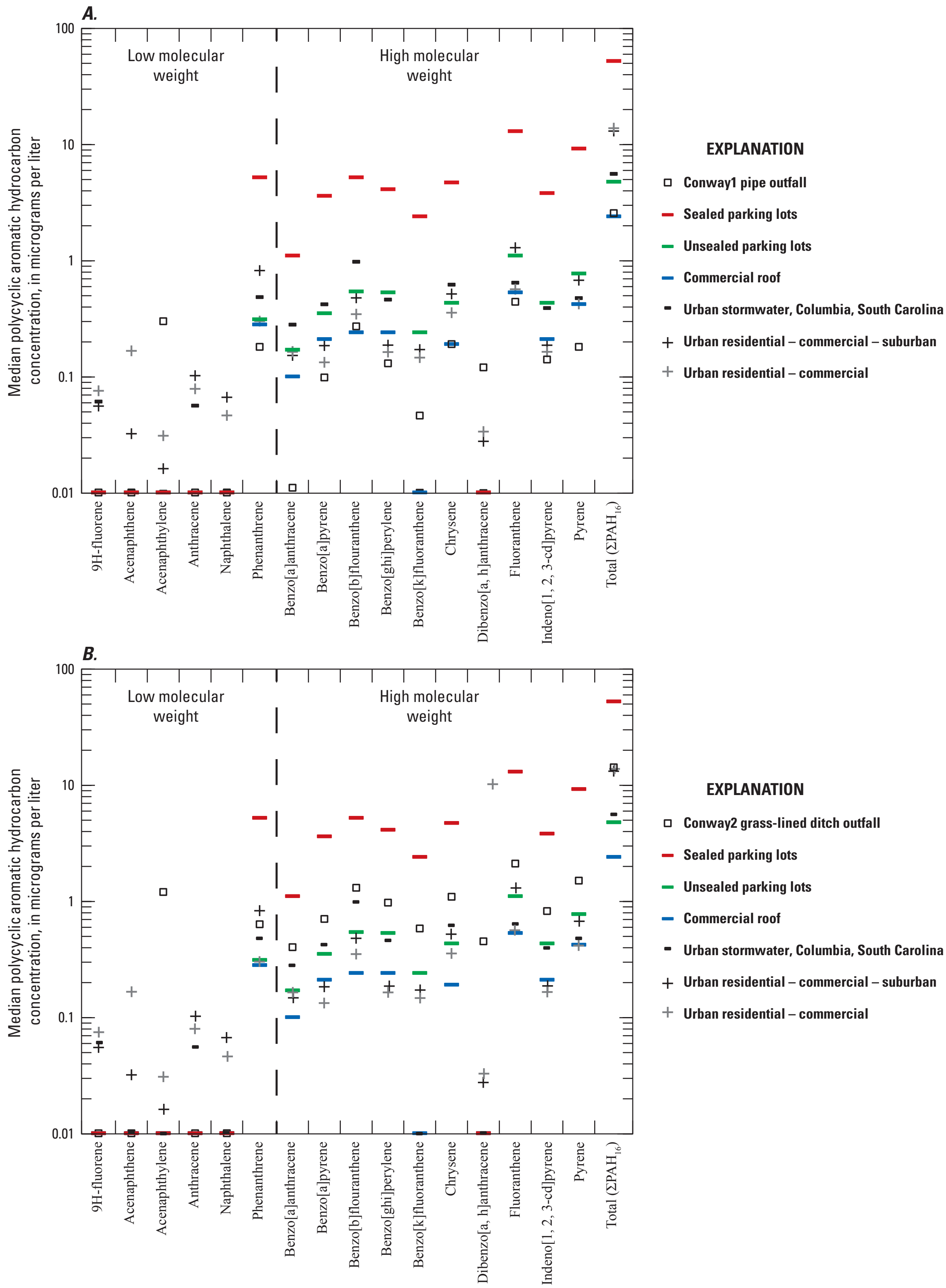


Figure 32. Median polycyclic aromatic hydrocarbon concentrations in stormwater discharging at the *A*, Conway1 outfall and *B*, Conway2 outfall, Conway, South Carolina, and median or mean polycyclic aromatic hydrocarbon concentrations in stormwater draining sealed and unsealed parking lots (Selbig, 2009), commercial roofs (Selbig, 2009), and urban and commercial land use (Ngabe and others, 2000; Menzie and others, 2002).

Overall, detection frequency and concentrations of PAHs in stormwater during the eight sampled storms at Conway2 tended to be greater than in stormwater at Conway1 (table 16; fig. 32*A*, *B*). Stormwater from Conway2 drained a larger portion of the maintenance yard facility than Conway1, including greater parking lot and commercial roof area (fig. 3). The HMW PAH compounds were detected more frequently in stormwater than most LMW PAH compounds, with the exception of phenanthrene (100 percent detection frequency) (table 16). The LMW PAH naphthalene and fluorene were not detected, and acenaphthene was detected only once in stormwater at the Conway2 outfall. Dibenzo[a,h]anthrracene was detected in 7 of the 8 (87.5 percent) sampled storms at Conway2, but the remaining HMW PAH compounds were detected in all sampled storms at this facility (table 16).

Median acenaphthylene (0.79 µg/L) and phenanthrene (0.62 µg/L) concentrations represented the greatest LMW PAH concentrations at the Conway2 outfall and compared well with the median HMW PAH concentrations in stormwater at the Conway2 outfall (table 16; fig. 32*B*). The median phenanthene concentration in stormwater at this outfall compared well to the range of reported concentrations of this compound in stormwater draining a similar land use (fig. 34*B*; Ngabe and others, 2000; Menzie and others, 2002; Selbig, 2009). However, as was observed in stormwater at the Ballentine and Conway1 outfalls, the median acenaphythylene concentration was an order of magnitude greater than the reported range for stormwater draining parking lots, commercial roofs, and urban land-use areas (fig. 34*B*; Ngabe and others, 2000; Menzie and others, 2002; Selbig, 2009). The acenaphthylene concentration was elevated in stormwater during the September 20, 2011, (14.0 µg/L) and November 28, 2011, storms (29.0 µg/L) and represented more than 75 percent of the ΣPAH_{16} (18.1 and 39.0 µg/L, respectively) (appendix 2B). For all other storms, the larger proportion of HMW PAHs relative to LMW PAHs generally was indicative of PAHs that have a combustion source (pyrogenic, including vehicle exhaust) (fig. 32*B*; appendix 2B; Hwang and Foster, 2006). In general, median concentrations of the individual HMW PAHs in stormwater at the Conway2 outfall were similar to the reported ranges of these compounds in stormwater draining areas covered by parking lots, commercial roofs, and urban and commercial land, with the exception of dibenzo[a,h]anthracene and chrysene (fig. 32*B*). In fact, median ΣPAH_{16} concentrations at the Conway2 facility tended to fall within the range for sealed and unsealed parking lots and urban land use (fig. 32*B*; Ngabe and others, 2000; Menzie and others, 2002; Selbig, 2009).

In contrast to stormwater that drained predominantly paved areas and roofs and discharged to the outfalls at the Ballentine and Conway facilities, stormwater from the North Charleston facility mixed with the streamwater in Turkey Creek and resulted in lower PAH concentrations and some differences in PAH composition (figs. 32, 33, 34). In Turkey Creek, HMW PAH compounds were detected more frequently in stormwater than most LMW PAH compounds, with the exception of phenanthrene (87.5 percent detection frequency), for the eight sampled storms at North Charleston1 (upstream from the maintenance yard; table 16). The LMW PAH compounds naphthalene and acenaphthene were not detected in stormwater at North Charleston1 during any storm at this facility (table 16; appendix 2B). Median concentrations of the individual HMW PAH compounds in Turkey Creek at North Charleston1 were comparable to the median concentration of the LMW PAH compound phenathrene (table 16; fig. 35*A*). In contrast to stormwater from Ballentine and Conway facilities, median acenaphythylene and phenanthene concentrations in stormwater at North Charleston1 were within the range of the other LMW PAHs and less than or equal to the reported range for stormwater draining parking lots, commercial roofs, and urban land-use areas (fig. 33*A*; Ngabe and others, 2000; Menzie and others, 2002; Selbig, 2009). In fact, all median LMW and HMW PAH concentrations in stormwater at North Charleston1 tended to be less than or equal to the range of reported median and mean PAH concentrations in stormwater draining similar land-use areas (fig. 33*A*; Ngabe and others, 2000; Menzie and others, 2002; Selbig, 2009). The larger proportion of HMW PAHs relative to LMW PAHs generally is indicative of PAHs that have a combustion source (pyrogenic, including vehicle exhaust) (fig. 33*A*; appendix 2B; Hwang and Foster, 2006). As noted earlier, the fact that stormwater from the North Charleston maintenance yard was not sampled directly at outfalls but was collected from the main channel of Turkey Creek during each storm may have contributed to these lower median concentrations.

Stormwater in Turkey Creek at North Charleston2 (downstream from the maintenance yard) had a similar pattern of median PAH concentrations as the upstream North Charleston1, but stormwater at North Charleston2 had less frequent detections and lower median concentrations of PAHs than at North Charleston1 (table 16; fig. 33*B*). For the eight sampled storms, HMW PAH compounds were detected more frequently in stormwater than most LMW PAH compounds, with the exception of phenanthrene (87.5 percent detection frequency) (table 16). The LMW PAHs acenaphthene, acenaphthylene, and naphthalene were not detected, and fluorene and anthracene were detected only once at North Charleston2 during the eight storms (table 16; appendix 2B). The median ΣPAH_{16} concentration of 0.82 µg/L for North Charleston2 was more than half of the median ΣPAH_{16} concentration at the upstream North Charleston1 (1.37 µg/L) (table 16; fig. 33*A*, *B*). Lower detection frequencies and median concentrations at North Charleston2 compared to North Charleston1 may be attributed to stormwater draining the North Charleston maintenance yard that did not contain elevated concentrations of PAHs.

With the exception of the median phenanthrene concentration (0.046 µg/L), individual median LMW PAH concentrations were less than the median HMW PAH concentrations in stormwater at North Charleston2 (table 16; fig. 33*A*, *B*). The larger proportion of HMW PAHs relative to LMW PAHs generally is indicative of combustion-derived PAHs (pyrogenic, including vehicle exhaust) (fig. 33*B*; appendix 2B; Hwang and Foster, 2006). Similar to PAHs in

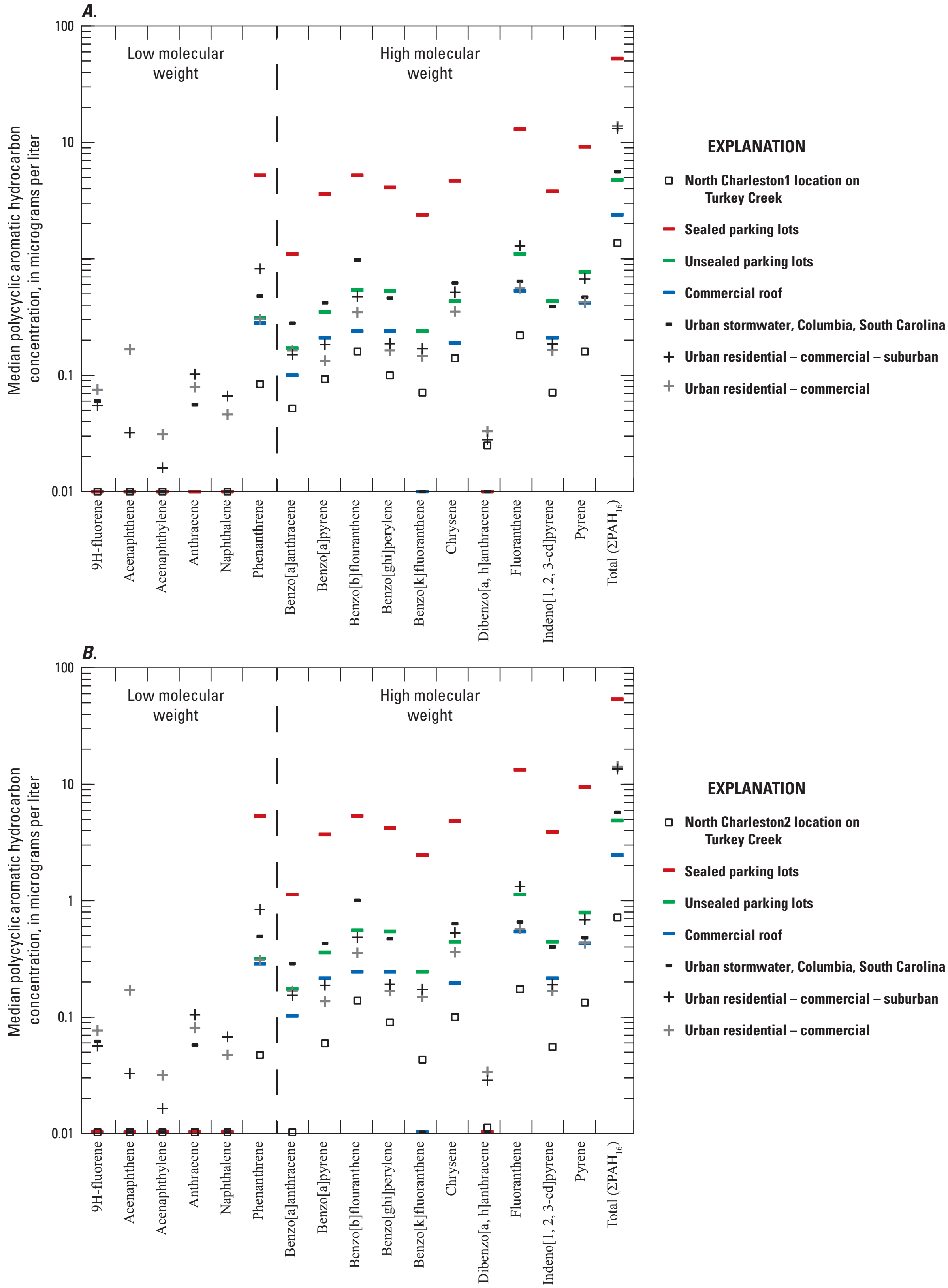


Figure 33. Median polycyclic aromatic hydrocarbon concentrations in stormwater discharging at *A*, North Charleston1 and *B*, North Charleston2 North Charleston, South Carolina, and median or mean polycyclic aromatic hydrocarbon concentrations in stormwater draining sealed and unsealed parking lots (Selbig, 2009), commercial roofs (Selbig, 2009), and urban and commercial land use (Ngabe and others, 2000; Menzie and others, 2002).

stormwater in Turkey Creek at North Charleston1, median LMW and HMW PAH concentrations in stormwater at North Charleston2 were less than or equal to the range of reported median and mean concentrations in stormwater draining similar land use (fig. 33*B*; Ngabe and others, 2000; Menzie and others, 2002; Selbig, 2009). Additionally, median ΣPAH_{16} concentrations at North Charleston2 tended to fall below the range for sealed and unsealed parking lots, commercial roofs, and urban-commercial land use but within the range for commercial roofs (fig. 33*B*; Ngabe and others, 2000; Menzie and others, 2002; Selbig, 2009). However, median PAH concentrations in Turkey Creek may not be directly comparable to the reported concentrations in stormwater from specific sources because the sampled stormwater at the North Charleston facility was not collected at the maintenance yard outfalls.

Because North Charleston1 and North Charleston2 locations were in Turkey Creek, SCDHEC criteria for PAH concentrations can be used to determine impairment. Concentrations of the PAH compounds anthracene, fluorene, acenapthlene, fluoranthene, and pyrene in stormwater at all sampled outfalls were well below the established SCDHEC criteria that ranged from 140 to 40,000 µg/L for these PAHs (table 4; appendix 2B). However, the HMW PAH compounds of benzo[a]anthracene, benzo[a]pyrene, benzo[k]fluoranthene, chrysene, dibenzo[a,h]anthracene, and indeno[1,2,3-cd] pyrene have a much lower SCDHEC human health criterion of 0.018 µg/L for the consumption of fish, such that any detection exceeds the criteria (table 4; table 16). Concentrations of benzo[a]anthracene, benzo[a]pyrene, benzo[k]fluoranthene, chrysene, dibenzo[a,h]anthracene, and indeno[1,2,3-cd]pyrene in Turkey Creek samples represent a potential human health risk in relation to fish consumption on the basis of the detected concentrations of these compounds during storms at the North Charleston1 and North Charleston2 (appendix 2B). Concentrations of PAHs that exceeded the SCDHEC human health criterion of 0.018 µg/L occurred in 62.5 to 87.5 percent of the sampled storms in Turkey Creek at North Charleston1, which represents the stormwater-quality conditions prior to the maintenance yard contributions. However, Turkey Creek downstream from the maintenance yard at North Charleston2 had PAH concentrations that exceeded the SCDHEC human health criterion less frequently than those at the upstream North Charleston1, ranging from only 25 to 75 percent of storms (table 16). The lower concentrations and detection frequencies of these PAH compounds at the North Charleston2 than at North Charleston1 indicate minimal to negligible contributions of PAH compounds from the maintenance yard during storms.

Although these SCDHEC human health criteria were developed for application to concentrations in receiving waters, not stormwater, the results can serve as a screening tool for potential surface-water impairment. Concentrations of these HMW PAH compounds in stormwater exceeded the SCDHEC criterion in 75 to 88.9 percent of the sampled storms at the Ballentine retention pond outfall, 55.6 to 100 percent of the sampled storms at the Conway1 pipe outfall, and 87.5 to 100 percent of the sampled events at the Conway2

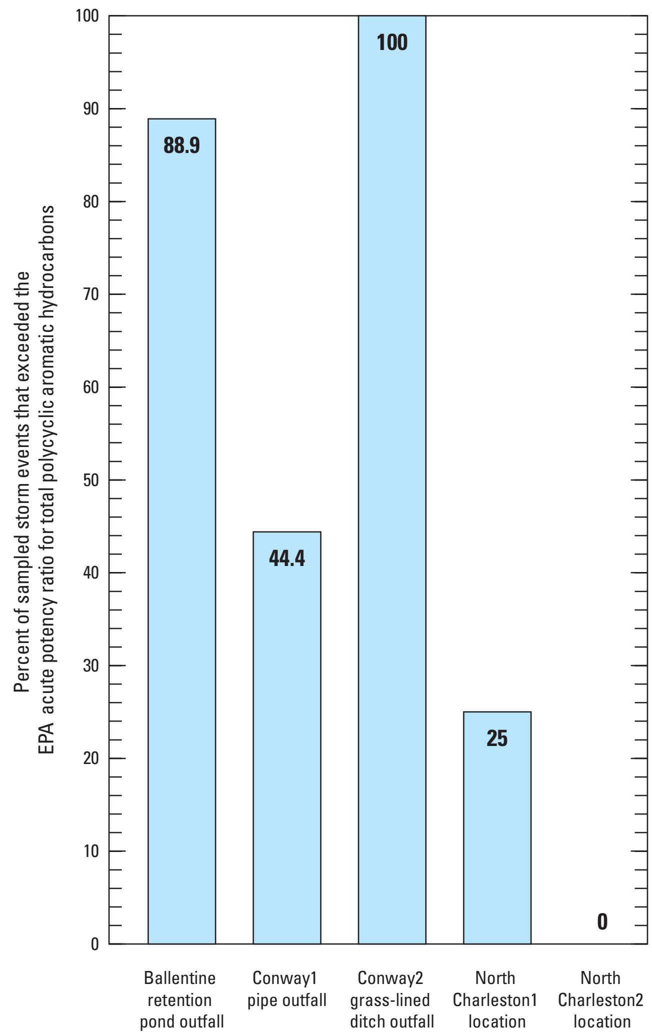


Figure 34. Percent of sampled storm events that had total polycyclic aromatic hydrocarbon concentrations that exceeded the U.S. Environmental Protection Agency (EPA) acute potency ratio in stormwater at the retention pond outfall at the section shed in Ballentine, the Conway1 pipe and Conway2 grass-lined ditch outfall at the maintenance yard in Conway, and in Turkey Creek at the North Charleston1 upstream and North Charleston2 downstream locations of the maintenance yard in North Charleston, South Carolina, 2010–2012.

grass-lined ditch outfall (table 16). Accordingly, some potential for human-health effects resulting from the consumption of tainted fish would be expected for the PAH concentrations in stormwater from the Ballentine and Conway facilities, assuming no dilution or removal prior to discharge to receiving water.

In general, potency-adjusted PAH concentrations observed at the sampled outfalls and stream locations indicate a potential for acute aquatic life effects during many of the sampled storms (appendix 2B; fig. 34). However, these acute aquatic life benchmarks were developed for application to ambient concentrations in receiving waters, not stormwater that was sampled at the outfalls of the Ballentine and Conway facilities; therefore, these comparative results serve only as a screening tool to assess potential impairment of the receiving water body. Stormwater discharge at the Ballentine outfall exceeded the acute potency ratio in 8 of the 9 sampled storms (88.9 percent) (fig. 34). Stormwater discharging at the Conway2 grass-lined ditch outfall had PAH concentrations that exceeded the EPA acute potency ratio in every sampled storm; but stormwater at the Conway1 pipe outfall had PAH concentrations that exceeded the ratio in only 44 percent of the sampled storms (appendix 2B; fig. 34). On the basis of the screening effort, PAH concentrations in stormwater from the Ballentine and Conway facilities had some potential to affect the aquatic life in receiving water during storms, assuming no dilution or removal.

PAH concentrations at Turkey Creek upstream from the North Charleston1 had EPA acute potency ratios that exceeded the benchmark in only 25 percent of the sampled storms (fig. 34). But assessment of the PAH concentrations in Turkey Creek after the contribution of stormwater from the North Charleston maintenance yard indicated a decrease in PAH concentrations, such that no exceedances of the EPA benchmark for aquatic life were observed at North Charleston2 (fig. 34). This finding, again, is indicative of minimal to negligible contributions of PAH compounds to Turkey Creek from the North Charleston maintenance yard.

Comparison of Constituents Among Facilities

Event-mean yields of selected nutrients, suspended sediment, and trace metals and “first-flush” yields of *E. coli* and enterococcus were compared among the four outfalls: Ballentine retention pond outfall (Ballentine), Conway1 pipe outfall, Conway2 grass-lined ditch outfall, and the North Charleston maintenance yard (estimated as the difference in load between North Charleston1 and North Charleston2 locations on Turkey Creek divided by the intervening drainage area). A comparison of yields among facilities was used to evaluate the greatest contribution of the selected water-quality constituent per hectare. Although statistically significant differences in median event-mean BOD_5, TP, TSS, and SS yields were identified by the Kruskal-Wallis analysis, the less robust Tukey test was unable to specify which of the above sites differed from the others probably because of the high variability and low sample size (appendix 3G). North Charleston yard had stormwater with event-mean yields of TN, TP, and BOD_5 that were more than 2 orders of magnitude lower than those for the other outfalls (table 17). Event-mean yields of TN and TKN in stormwater discharging at the Conway1 outfall were greater statistically than yields in stormwater at the Ballentine site and North Charleston yard (appendix 3G). Median event-mean yields of SS and TSS in stormwater discharging at the Conway1 outfall (13.0 and 15.4 (kg/event)/ha, respectively) were greater than the event-mean yields at the Conway2 outfall (10.6 and 9.16 (kg/event)/ha, respectively), Ballentine (6.48 and 5.18 (kg/event)/ha, respectively), and North Charleston yard (0.0119 and 0.0459 (kg/event)/ha, respectively) (table 17).

Median enterococcus event-mean yields in stormwater ranged from 143 (Mcol/event)/ha at the North Charleston yard to 9,273 (Mcol/event)/ha at Conway2 (table 17). Stormwater discharging at the Conway2 grass-lined ditch outfall had statistically greater “first-flush” enterococcus yields than the Ballentine retention pond outfall, North Charleston yard, or Conway1 pipe outfall (appendix 3G). “First-flush” event-mean yields of *E. coli* in stormwater ranged from 106 (Mcol/event)/ha at the Ballentine outfall to 2,748 (Mcol/event)/ha at the Conway2 outfall (table 17). Although an order of magnitude difference in median yields was observed among the sampled facilities, no statistical difference among the *E. coli* yields was identified for the sampled storms (appendix 3G).

Event-mean yields of the trace metals total lead, total copper, total chromium, and total zinc also were compared among the 4 outfalls at the 3 facilities for the sampled storms (appendix 3G). No statistical difference was identified in event-mean yields of total chromium, total cadmium, dissolved lead, and dissolved nickel in stormwater discharging from the four outfalls (appendix 3G). Although a statistical differences in event-mean yields for total copper, total zinc, total lead, dissolved chromium, dissolved copper, and dissolved zinc were identified in the Kruskal-Wallis analysis, the less robust Tukey test was unable to determine the sites that were different, probably because of high variability and small sample sizes (appendix 3G). However, event-mean total copper, lead, and zinc yields in stormwater discharging from the Conway1 and Conway2 outfalls had greater ranges and medians than those at the Ballentine and North Charleston yard facilities (table 17).

At the SCDOT section shed and maintenance yards, runoff during storms flowed over impervious surfaces (for example, paved driveways, parking lots, and building rooftops) without infiltrating into the ground and discharged to the sampled outfall. Past research has indicated that stormwater running off impervious surfaces tends to accumulate debris, chemicals, sediment, or other contaminants that could adversely affect water quality (Brabec and others, 2002). To assess whether impervious surface alone was the major environmental factor affecting the stormwater quality at each facility that drains to sampled outfalls, area and percent of impervious surface were computed and compared to median event-mean (or “first-flush” for bacteria) yields at each of the four outfalls (tables 1, 17; fig. 35). Sample size was extremely limited (n = 4); therefore, Kendall tau correlation coefficients were not computed and result were used only as exploratory analysis. Area percentages of impervious surface at the sampled facilities were comparable to that of other industrial or commercial land (Brabec and others, 2002), ranging from 62 percent at the North Charleston maintenance yard to 100 percent at Conway1 and Conway2 (tables 1, 17).

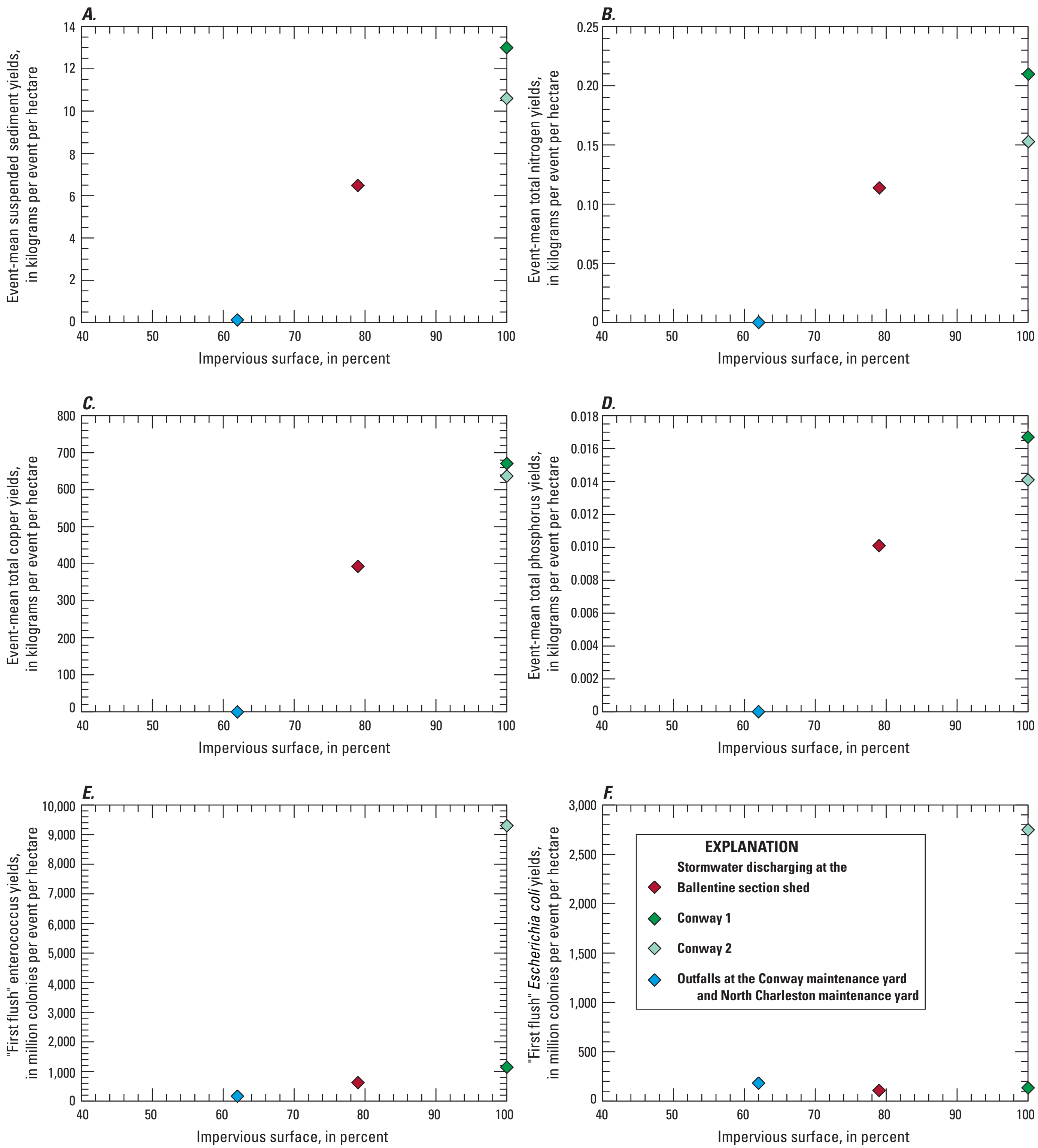


Figure 35. Scatter plots of impervious surface and median event-mean yields of *A*, suspended sediment, *B*, total nitrogen, *C*, total copper, and *D*, total phosphorus and "first-flush" yields of *E*, enterococcus and *F*, *Escherichia coli* in stormwater discharging at the Ballentine section shed, Conway1, Conway2 outfalls at the Conway maintenance yard, and North Charleston maintenance yard, South Carolina, 2010–2012.

Table 17. Impervious surface and median event-mean and “first-flush” (enterococcus and *Escherichia coli* (*E. coli*) only) yields in stormwater discharging to the retention pond outfall at the South Carolina Department of Transportation (SCDOT) section shed at Ballentine, South Carolina (Ballentine); pipe (Conway1) and grass-lined ditch (Conway2) outfalls at the SCDOT maintenance yard at Conway, South Carolina; and Turkey Creek at the SCDOT maintenance yard at North Charleston, South Carolina (North Charleston Yard) during sampled storm events from 2010 to 2012.

Site	Outfall type	Impervious surface		Median event-mean and “Firsh Flush” (bacteria only) yields									
				Suspended sediment	Total suspended solids	Total nitrogen	Total phosphrous	Biochemical oxygen demand	Total copper	Total lead	Total zinc	Enterococcus	*E. coli*
		Percent	Square meters	Kilograms per event per hectare					Milligrams per event per hectare			Million colonies per event per hectare	
Ballentine	Retention pond	79	9,586	6.48	5.18	0.113	0.010	0.43	393.1	110.8	1,787	594	106
Conway1	Pipe	100	1,200	13.0	15.4	0.209	0.017	0.75	671	638	16,683	1,116	132
Conway2	Grass-lined ditch	100	9,912	10.6	9.16	0.152	0.014	1.00	637	552	14,656	9,273	2,748
North Charleston yard	Turkey Creek	62	53,319	0.119	0.046	0.000	< 0.00001	0.008	0.013	0.026	0.085	143	180

Increased transport of particulate matter, including sediment (Brabec and others, 2002), has been attributed to greater areas of impervious surface in a drainage basin, and impervious surface appears to be a contributing factor in the transport of particulate matter at the sampled facilities. At the four outfalls, median event-mean yields of SS, total copper, TN, and TP demonstrated strong linear relations to impervious surface compared to median yields of fecal indicator bacteria (fig. 35*A–D*). Impervious surface area also was compared to the total (particulate plus dissolved) forms of nitrogen and phosphorus.

Median "first-flush" yields of *E. coli* and enterococci were compared to impervious surface areas among the four outfalls (figs. 35*E*, *F*). No linear pattern was identified that would indicate that impervious surface was the major environmental factor affecting the fecal indicator bacterial yields at SCDOT section sheds or maintenance yards. The statistically greater "first-flush" enterococcus yield and *E. coli* yield at the Conway2 outfall was an outlier in the scatter plot (fig. 35*E*, *F*). As described earlier in this report, *E. coli* and enterococci can survive in aquatic sediment, and viable sediment-bound bacteria can re-suspend primarily during the "first flush" or rising limb of the storm hydrograph (LaLiberte, and Grimes, 1982; Byappanahalli and others, 2003; Francy and others, 2003; Ferguson and others, 2004, Cinotto, 2005; Jamieson and others, 2005). If sediment re-suspension was a major mechanism that contributed *E. coli* and enterococci to stormwater runoff during storms at the sampled outfalls, then many other environmental factors that varied among the three facilities probably affected the survivability of these bacteria and, subsequently, bacterial counts. Some potential contributing environmental factors that could have affected the survivability of *E. coli* and enterococci include temperature, exposure to solar radiation, available nutrients, soil type, and organic matter content (Anderson and others, 2005; Haller and others, 2008).

Summary and Conclusions

The South Carolina Department of Transportation operates section shed and maintenance yard facilities throughout the State. The U.S. Geological Survey conducted a cooperative investigation with the South Carolina Department of Transportation to characterize water-quality constituents that are transported in stormwater from representative maintenance yard and section shed facilities in three different areas of South Carolina. Two maintenance yards, in North Charleston and Conway, S.C., represented facilities where equipment and road maintenance materials are stored and complete equipment repair operations are conducted. One section shed, in Ballentine, S.C., stores equipment and road maintenance material. Stormwater from the 12,133-square-meter section shed facility in Ballentine discharges to a retention pond, then to the sampled outfall (Ballentine). At the Conway maintenance yard, stormwater discharges to two outfalls. Stormwater in the southernmost section of the Conway maintenance yard drains to a predominantly impervious surface area of 1,200 square meters and discharges to a pipe outfall (Conway1). Another 9,912-square-meter area drains and discharges stormwater to a grass-lined ditch in the northern section of the yard (Conway2). At the North Charleston maintenance yard, stormwater discharges from the yard to Turkey Creek through a combination of pipes, ditches, and overland flow. To completely capture all stormwater from this yard, samples were collected from the main channel of Turkey Creek at the upstream (North Charleston1) and downstream (North Charleston2) limits of the North Charleston maintenance yard facility.

Stormwater samples from the facilities were analyzed for multiple constituents and characteristics. Concentrations of sediment and concentrations of nutrients and fecal indicator bacteria, which are commonly transported with the sediment in stormwater, were measured. Total and dissolved concentrations of six trace metals were determined in the samples. Stormwater samples also were analyzed for organic compounds, including 10 herbicides, 18 organochlorine pesticides, 7 Aroclor congeners, 44 volatile organic compounds, and 16 polycyclic aromatic hydrocarbons.

The storms investigated during this study had a wide range of rainfall amounts, durations, and intensities among the facilities and, therefore, were considered to be reasonably representative of the potential for contaminant transport. Hydrologic characteristics measured during storms, including rainfall intensity, rainfall amounts, and stormwater discharge, varied among the three facilities, but at all facilities, stormwater discharge was significantly correlated to rainfall amount and intensity. Event-mean unit-area stormwater discharge (normalized for differences in drainage areas) increased with increasing impervious surface at the Conway and North Charleston maintenance yards. However, the Ballentine facility with 79 percent impervious surface had a mean unit-area discharge (70.2 cubic feet per second per square mile) similar to that of the North Charleston maintenance yard (71.2 cubic feet per second per square mile) with 62 percent impervious surface. That similarity may be attributed, in part, to the effects of the retention pond on the stormwater runoff at the Ballentine facility and to the greater rainfall intensities and amounts at the North Charleston facility.

Stormwater often transports large quantities of sediment and sediment-bound contaminants, including nutrients and fecal indicator bacteria. At the retention pond outfall at the Ballentine section shed, event-mean concentrations in stormwater of suspended sediment ranged from 37.0 to 252 milligrams per liter (mg/L) and of total suspended solids ranged from 30.0 to 290 mg/L. In general, event-mean concentrations of total nitrogen consisted mainly of total Kjeldahl nitrogen (organic nitrogen plus ammonia) rather than nitrate plus nitrite and tended to fall close to its median concentration of 2.00 mg/L. Total phosphorus event-mean concentrations in stormwater leaving the retention pond outfall tended to be an order of magnitude less than the maximum and to fall close to the median concentration of 0.15 mg/L.

Escherichia coli (*E. coli*) and enterococcus concentrations varied by 3 orders of magnitude in grab samples collected during the “first flush” of stormwater from the retention pond outfall at the Ballentine section shed. Additionally, enterococcus concentrations consistently were greater than the *E. coli* concentrations. Specifically, *E. coli* concentrations ranged from 10 to 2,070 colonies per 100 milliliters (col/100 mL). Only 4 of the 9 storms had *E. coli* concentrations greater than the South Carolina Department of Health and Environmental Control-proposed single sample maximum criterion for secondary and primary body contact of 349 col/100 mL. “First-flush” loads of *E. coli* ranged from 0.15 to 1,671 million colonies per event (Mcol/event; median of 130 Mcol/event) at the Ballentine retention pond outfall.

Although stormwater discharges (mean and peak) at the Conway1 and Conway2 outfalls at the Conway maintenance yard were statistically different, event-mean concentrations of suspended sediment and nutrients in that stormwater discharge were statistically similar. Event-mean concentrations of suspended sediment in the stormwater discharging at the Conway1 pipe outfall ranged from 33 to 263 mg/L and at the Conway2 grass-lined ditch outfall ranged from 40 to 260 mg/L. Event-mean concentrations of total suspended solids ranged from 29.0 to 310 mg/L at Conway1 and from 30 to 210 mg/L at Conway2. Although total Kjeldahl nitrogen and nitrate plus nitrate forms of nitrogen were present in the stormwater runoff, total nitrogen comprised mainly total Kjeldahl nitrogen at both outfalls and ranged from 0.50 to 4.96 mg/L at Conway1 and from 0.31 to 3.54 at Conway2. At the Conway maintenance yard facility, stormwater discharging at the sampled outfalls had median total phosphorus event-mean concentrations of 0.15 mg/L for Conway1 and 0.16 mg/L for Conway2.

Stormwater discharging at the Conway1 outfall had *E. coli* and enterococcus “first-flush” concentrations that were statistically similar to concentrations in the stormwater discharging at the Conway2 outfall. For each storm, enterococcus concentrations consistently were greater than the *E. coli* concentrations in stormwater discharging at Conway1 and Conway2 outfalls. *Escherichia coli* concentrations in samples collected from stormwater at the Conway1 outfall varied by 3 orders of magnitude with a range of less than (<)10 to 4,725 col/100 mL, and only the maximum concentration exceeded the proposed single sample maximum criterion. At Conway2 grass-lined ditch outfall, the *Escherichia coli* concentrations ranged from 1 to greater than 24,196 col/100 mL and exceeded the proposed single sample maximum criterion for 5 of the 7 sampled storms. During the nine storms at the Conway1 outfall, *E. coli* loads ranged from <2 to 317 Mcol/event with a median of 18 Mcol/event. During the same storms at the Conway2 outfall, *E. coli* loads ranged from <1 to greater than 56,032 Mcol/event with a median of 2,654 Mcol/event.

Interestingly, storms that had the greatest rainfall intensities and stormwater discharge did not produce the maximum nitrogen, phosphorus, suspended sediment, and suspended solid event-mean concentrations in stormwater at the Ballentine section shed and Conway maintenance yard facilities. One plausible explanation for the negatively correlated nature of hydrologic characteristics and water-quality constituents may be related to the nature of the sampling process that required compositing of multiple flow-weighted samples over the entire hydrograph. If the greatest nutrient amounts are transported during the “first flush” of a storm, then the amount of nutrients in subsequent runoff will decrease with continued stormwater runoff. However, for storms that have less rainfall and stormwater discharge, the “first-flush” transported nutrients undergo limited dilution from subsequent stormflow and produce overall greater event-mean concentrations in the composited sample.

Changes in event-mean concentrations of water-quality constituents between the North Charleston1 location in Turkey Creek (upstream from the maintenance yard) and the North Charleston2 location in Turkey Creek (downstream from maintenance yard) were attributed to stormwater contributions from the maintenance yard. Event-mean concentrations of suspended sediment ranged from 26.0 to 112 mg/L in the Turkey Creek at North Charleston1 and from 20.0 to 160 mg/L at North Charleston2. Event-mean concentrations of total suspended solids ranged from <5 to 120 mg/L at North Charleston1 and from 23.0 to 130 mg/L at North Charleston2. Although significant increases in stormwater discharge (peak and mean) occurred in Turkey Creek between the two sampling locations during the eight sampled storms, statistical analysis determined that stormwater entering Turkey Creek from the maintenance yard did not transport enough suspended sediment to change the suspended sediment or total suspended solids concentrations in Turkey Creek. At best, the stormwater from the maintenance yard improved the turbidity and reduced the frequency of exceedance of the South Carolina Department of Health and Environmental Control turbidity criterion of 50 nephelometric turbidity units from 62.5 percent to 25 percent of the sampled storms. During the eight sampled storms, stormwater in Turkey Creek had event-mean concentrations of total nitrogen that ranged from 1.55 to 2.29 mg/L at North Charleston1, upstream from the maintenance yard, and from 0.99 to 2.19 mg/L at North Charleston2, downstream from the maintenance yard. Stormwater in Turkey Creek had total phosphorus event-mean concentrations that ranged from 0.20 to 1.8 mg/L at North Charleston1 and from 0.11 to 0.34 mg/L at North Charleston2. Statistical tests indicate that stormwater discharging from the North Charleston maintenance yard tended to produce an overall dilution effect on nitrogen and phosphorus concentrations in Turkey Creek during storms.

Escherichia coli concentrations in “first-flush” samples collected from stormwater in Turkey Creek at North Charleston1 were highly variable, ranging from 30 to 2,143 col/100 mL. In contrast to the downstream downward trend identified for nutrient and sediment concentrations in Turkey Creek, a statistically significant increase in *E. coli* concentrations was identified in Turkey Creek from North Charleston1 to North Charleston2. North Charleston2 had order-of-magnitude greater *E. coli* concentrations that ranged from 521 to 15,648 col/100 mL. For 2 of the 8 storms sampled (25 percent), “first flush” *E. coli* concentrations exceeded the single sample maximum criterion at North Charleston1, but all eight (100 percent) of the *E. coli* concentrations exceeded the criterion at North Charleston2 . These findings indicate that the maintenance yard could be contributing significant fecal indicator bacteria that affect the water-quality conditions in Turkey Creek during storms. In Turkey Creek at North Charleston1, *E. coli* loads ranged from 22.9 to 2,064 Mcol/event with a median of 536 Mcol/event for the eight storms. The corresponding *E. coli* loads in Turkey Creek at North Charleston2 ranged from 3,879 to 77,632 Mcol/event with a median of 15,927 Mcol/event. Estimated *E. coli* loads in stormwater discharging from the maintenance yard to Turkey Creek ranged from 3,719 to 77,124 Mcol/event with a median of 15,502 Mcol/event.

Sample-specific exceedance of the hardness-dependent South Carolina Department of Health and Environmental Control aquatic life Criterion Maximum Concentration (CMC) for trace metals in freshwater were evaluated on the basis of hardness that corresponded to the trace-metal event-mean concentration for a storm. Of the six trace metals (cadmium, copper, chromium, lead, nickel, zinc) measured in stormwater, only copper and zinc had event-mean concentrations that were greater than the associated CMC. In stormwater discharging from the retention pond outfall at the Ballentine facility, measured dissolved copper and zinc concentrations were greater than the criteria in 5 and 3, respectively, of the nine sampled storms. In stormwater discharging at Conway1, measured dissolved copper and zinc concentrations were greater than the criteria in 1 of the nine sampled storms. For stormwater discharging from Conway2, measured dissolved copper and zinc concentrations were greater than the criteria in 2 and 3, respectively, of the eight sampled storms. For stormwater in Turkey Creek at North Charleston1, the measured dissolved trace-metal concentrations were all less than the CMCs. For stormwater in Turkey Creek at North Charleston2 downstream from the North Charleston maintenance yard, the measured dissolved copper concentrations exceeded the CMC in 1 of the 9 sampled storms.

Stormwater samples were analyzed for 10 herbicides, 18 organochlorine pesticides, 7 Aroclor congeners, 44 volatile organic compounds, and 16 polycyclic aromatic hydrocarbons. Of the volatile organic compounds, cis-1,2-dichloroethene, bromdichloromethane, acetone, butyl methyl ketone, and o-xylene were the most frequently occurring compounds, usually at estimated concentrations, at all three facilities.

In general, cumulative polycyclic aromatic hydrocarbon (PAH) concentrations at the three facilities in this study were consistent with levels reported for urban stormwater and for runoff from asphalt pavements. Samples from Turkey Creek at North Charleston1 upstream from the maintenance yard had total PAH concentrations in the nine storms that ranged from 0.020 to 30.0 micrograms per liter (µg/L). Downstream from the maintenance yard, Turkey Creek at North Charleston2 had much lower cumulative polycyclic aromatic hydrocarbon concentrations that ranged from zero detections to 2.85 µg/L. This lower range of cumulative PAH concentrations at the downstream site on Turkey Creek when compared with concurrent samples from the upstream site indicates a reduction in total PAH concentrations by dilution or other attenuation processes during storms rather than additional contribution to Turkey Creek from stormwater from the maintenance yard. At the Conway1 pipe outfall, stormwater contained total PAH concentrations that ranged from 1.25 to 20.0 µg/L. Stormwater discharging at the Conway2 had a greater range in cumulative PAH concentrations of 9.14 to 39.0 µg/L. The retention pond outfall at the Ballentine section shed facility had the greatest range and mean of cumulative PAH concentrations than the other facilities in this study. At the Ballentine outfall, the cumulative polycyclic aromatic hydrocarbon concentrations ranged from zero detections to 95.6 µg/L.

Event-mean yields of selected nutrients, suspended sediment, and trace metals and “first-flush” yields of *E. coli* and enterococcus were compared among the outfalls at the three facilities. Stormwater discharging at the Conway1 outfall had the greatest range in event-mean yields for the total phosphorus, total nitrogen, total suspended solids, and suspended sediment, and both Conway outfalls tended to have median event-mean yields greater than the Ballentine and North Charleston facilities. A statistical difference was identified by statistical analysis for total nitrogen and total Kjeldahl nitrogen. “First-flush” yields of *E. coli* in stormwater were not statistically different among the three facilities. Greater impervious-surface coverage in a drainage area has been identified with increased transport of particulate matter, including sediment, and appeared to be a contributing factor at the sampled facilities. At the four outfalls (Ballentine, Conway1, Conway2, and North Charleston maintenance yard), median event-mean yields of suspended sediment, total nitrogen, total phosphorus, and total copper demonstrated a strong linear relation to impervious surface compared to other selected water-quality constituents. Median ”first-flush” yields of enterococcus and *E. coli* did not demonstrate a strong linear relation to impervious surface.

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