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Characterization of Nutrients and Fecal Indicator Bacteria at a Concentrated Swine Feeding Operation in Wake County, North Carolina, 2009–2011

Open-File Report 2012–1047

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

Cover: Primary wastewater storage lagoon (site SL1) at the Lake Wheeler Road Field Laboratory study area.

Cover inset: Looking downstream at in-field runoff site SR1.

Back cover inset left: Wastewater application at site SF1.

Back cover inset right: Looking upstream at in-field runoff site SR1.

(photographs taken by Stephen L. Harden, U.S. Geological Survey)

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
	Mass	
pound avoirdupois (lb)	0.4536	kilogram (kg)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
	Volume	
liter (L)	0.2642	gallon (gal)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

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

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 Nutrients and Fecal Indicator Bacteria at a Concentrated Swine Feeding Operation in Wake County, North Carolina, 2009–2011

By Stephen L. Harden[1], Shane W. Rogers[2], Michael A. Jahne[2], Carrie E. Shaffer[2], and Douglas G. Smith[1]

Abstract

Hydrologic and water-quality data were collected during October 2009–January 2011 to characterize nutrient and bacteria concentrations in stormwater runoff from agricultural fields that receive wastewater originating at a swine facility at North Carolina State University's Lake Wheeler Road Field Laboratory (LWRFL) in Wake County, North Carolina. The swine facility consists of six swine houses, two wastewater storage lagoons, and wastewater spray fields. The data-collection network consisted of 11 sampling sites, including 4 wastewater sites, 3 in-field runoff sites, and 4 stream sites. Continuous precipitation data were recorded with a raingage to document rainfall conditions during the study.

Study sites were sampled for laboratory analysis of nutrients, total suspended solids (TSS), and (or) fecal indicator bacteria (FIB). Nutrient analyses included measurement of dissolved ammonia, total and dissolved ammonia + organic nitrogen, dissolved nitrate + nitrite, dissolved orthophosphate, and total phosphorus. The FIB analyses included measurement of *Escherichia coli* and enterococci. Samples of wastewater at the swine facility were collected from a pipe outfall from the swine housing units, two storage lagoons, and the spray fields for analysis of nutrients, TSS, and FIB. Soil samples collected from a spray field were analyzed for FIB. Monitoring locations were established for collecting discharge and water-quality data during storm events at three in-field runoff sites and two sites on the headwater stream (one upstream and one downstream) next to the swine facility. Stormflow samples at the five monitoring locations were collected for four storm events during 2009 to 2010 and analyzed for nutrients, TSS, and FIB. Monthly water samples also were collected during base-flow conditions at all four stream sites for laboratory analysis of nutrients, TSS, and (or) FIB.

[1]U.S. Geological Survey.

[2]Clarkson University, Institute for a Sustainable Environment, Potsdam, New York.

Introduction

North Carolina is the second highest swine producing State in the Nation (United States Department of Agriculture, 2009). As such, there is significant interest in understanding the extent to which concentrated animal feeding operations (CAFOs) involving swine may influence water quality, especially in eastern North Carolina where a majority of the more than 2,100 swine operations permitted in the State are located. The potential for CAFOs to contaminate both surface water and groundwater has been well established (Burkholder and others, 2007). Nutrients, bacteria, and many organic wastewater compounds (OWCs) are potential contaminants that may be derived from swine CAFOs. Several studies in eastern North Carolina have indicated that nutrients derived from swine CAFOs have influenced water-quality conditions in surface water and groundwater (Stone and others, 1995; Gilliam and others, 1996; Karr and others, 2001; Harden and Spruill, 2004; Tesoriero and others, 2005; Harden and Spruill, 2008). Excessive nutrient loadings in eastern North Carolina have contributed to the degradation of surface-water quality in the Neuse and Tar-Pamlico River Basins (Gilliam and others, 1997; Spruill and others, 1998; Luettich and others, 2000; Burkholder and others, 2006).

The U.S. Environmental Protection Agency's (USEPA) 2010 National Water Quality Inventory lists fecal pathogens as the leading cause of impairment of rivers and streams in the United States (57 percent of the 20,464 miles threatened or impaired). Agricultural activities contributed to 43 percent of river and stream impairments (U.S. Environmental Protection Agency, 2010). Pathogens from animal manure, when introduced into the environment, can move into locations where people can be exposed to them and become ill. The longer a microorganism survives, the greater risk it poses to potential receptors through recreational waters or drinking water supplies, as well as other routes of infection. Understanding the persistence and transport pathways of pathogenic microorganisms is especially important to public-health officials and water-resource managers for managing and understanding the risks of microorganisms from land-applied manure.

In late 2009, the USEPA and the U.S. Geological Survey (USGS) initiated a cooperative study at the Lake Wheeler Road Field Laboratory (LWRFL; fig. 1) to better understand the occurrence and movement of nutrients and fecal indicator bacteria (FIB) in land-applied wastewater from a swine CAFO. This work is part of a larger research program between the USEPA and the U.S. Department of Agriculture (USDA) designed to (1) obtain detailed data concerning the survival of fecal bacteria from manure applied to soil under different waste management practices, (2) evaluate the movement of these organisms in runoff to receiving waters during storm events, and (3) evaluate the variability of host-specific molecular biomarkers from fecal bacteria in wastes under different management practices. The primary focus of the study conducted at the LWRFL was to determine nutrient and (or) bacteria concentrations in soil and stormwater runoff from fields sprayed with wastewater from the swine facility, a field not receiving wastewater applications, and a small stream within the swine facility.

Purpose and Scope

Data compiled in this report are intended to assist the USEPA in better understanding (1) the survival of bacterial indicator organisms in soils receiving applications of swine lagoon wastewater and (2) the transport of nutrients and fecal bacteria through runoff from waste-application fields to adjacent streams. The purpose of this report is to describe the LWRFL study area and the sampling and analytical methods used in the study, and to summarize the hydrologic and analytical data collected during October 2009 to January 2011 at the study sites (fig. 1). During the study, continuous precipitation data were recorded to document rainfall conditions at the monitoring sites. Samples of wastewater were collected from the swine housing units, two storage lagoons, and the spray application fields for analysis of nutrients and FIB (*Escherichia coli* (*E. coli*) and enterococci). Analyses of FIB also were conducted on soil samples collected from the spray application fields. Surface-water samples were collected from three in-field runoff sites and four sites on a stream adjacent to the LWRFL swine facility and analyzed for nutrients and (or) FIB. Continuous water-stage data were collected at each in-field runoff site and two sites on the stream. Values of discharge for collected samples were based on direct measurements or the stage-discharge relation determined for each site.

Description of the Study Area

The LWRFL is part of the North Carolina State University's farm campus system and is located south of Raleigh in Wake County, North Carolina in the Piedmont Physiographic Province (fig. 1). The LWRFL is an agricultural site used for both research and teaching purposes. The most common soil types in the agricultural fields sampled during storm runoff for this study are classified as Appling sandy loam or Cecil sandy loam (U.S. Department of Agriculture, 2011), consisting of well-drained sandy to sandy-clay loam and clay with slopes ranging from 2 to 15 percent. The hydrogeologic setting of the LWRFL was described previously by Chapman and others (2005). Storm runoff from the LWRFL study site drains to two, perennial, headwater streams in the Swift Creek watershed that is part of the Neuse River Basin. The west-east oriented stream adjacent to the LWRFL swine facility and spray fields flows to a larger north-south oriented stream along the eastern edge of the study area (fig. 1).

The swine facility at the LWRFL consists of six swine houses, two animal-wastewater storage lagoons, and wastewater application fields (fig. 1). During 2010, about 1,000 swine, weighing an average of 163 pounds (lbs) each, occupied the six swine houses at the swine facility (Curtis Powell, North Carolina State University, Lake Wheeler Road Field Laboratory, written commun., June 2011). The treatment of wastewater from the swine facility occurs in several stages (Curtis Powell, North Carolina State University, Lake Wheeler Road Field Laboratory, oral commun., November 2011). In the swine houses, untreated water from a groundwater well is used to wash animal waste materials from the floors in the swine holding pens to a trough collection system. Waste materials in the trough collection system are flushed from the swine houses eight times every 24 hours using a network of 13 flush tanks (800 gallons (gal) each).

The wastewater flushed from the swine houses flows through a pipe to a settling basin before discharging into the primary retention lagoon, which has a maximum capacity of about 2.788 million gallons (Mgal). From the primary lagoon, wastewater is either reclaimed for filling the tanks to flush the waste-collection troughs or gravity-fed into a smaller secondary holding lagoon. The secondary lagoon has a maximum capacity of about 2.139 Mgal but is maintained at an operating capacity of 1.650 Mgal to allow sufficient freeboard volume to handle potential rainfall associated with a 25-year storm during a 24-hour period. Depending on the season, wastewater from the secondary lagoon is spray-applied to a field with one of two grass-cover crops (fescue or Bermuda) through an in-ground sprinkler system.

Description of Sampling Sites

The data-collection network consisted of 11 sampling sites, including 4 wastewater sites, 3 in-field runoff sites, and 4 stream sites (table 1). Four wastewater sample sites were established along the waste-stream flowpath at the swine facility (fig. 1) to characterize potential changes in nutrient and FIB levels in the swine-waste material that occurs during transport, storage, and spraying of the wastewater to the application fields. The wastewater sites include, in order of

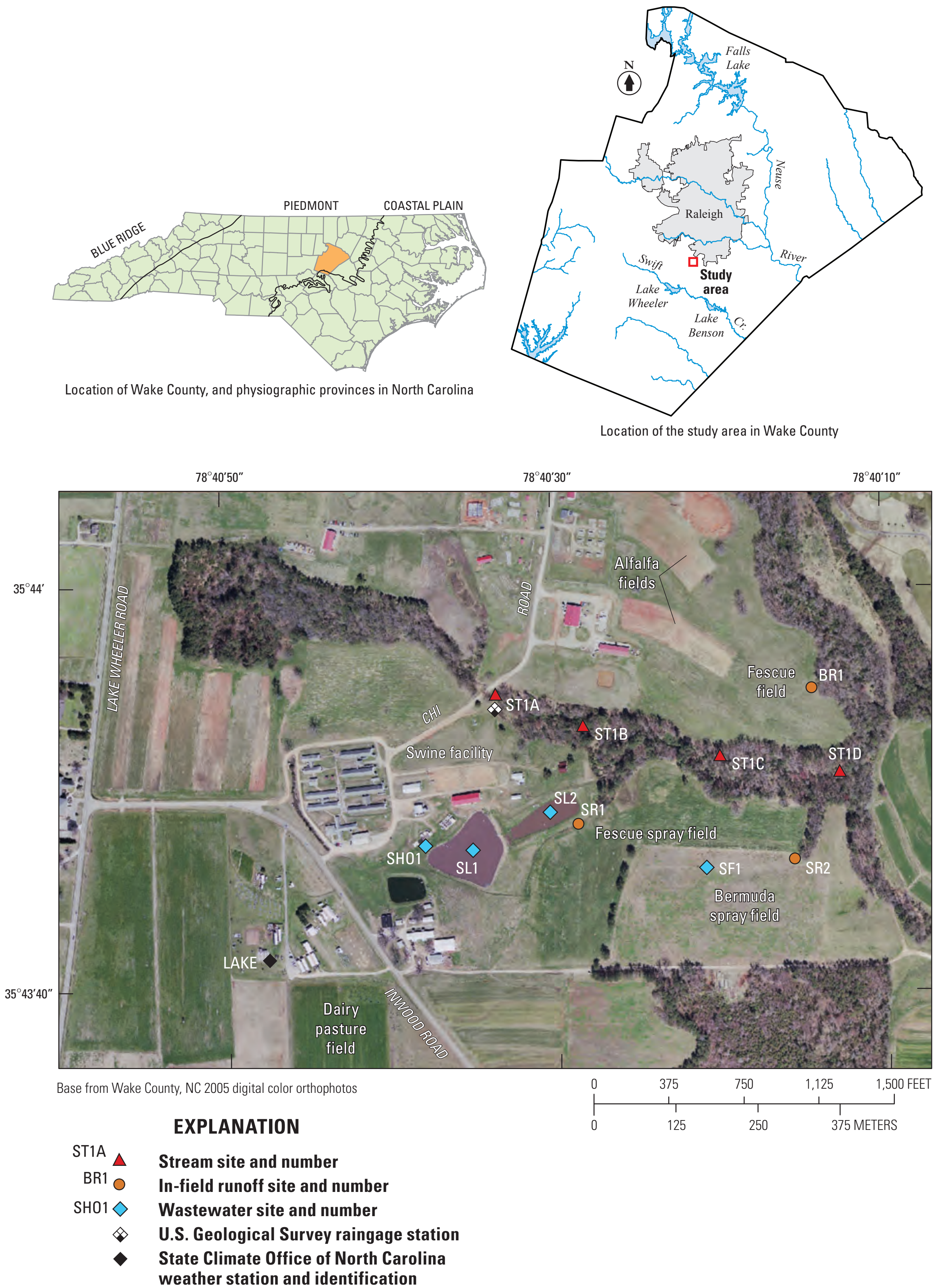

Figure 1. Location of the Lake Wheeler Road Field Laboratory (LWRFL) study area and sample sites, Wake County, North Carolina.

flow from the swine facility, the pipe outfall from the swine houses to the settling basin (site SHO1), the primary retention lagoon (site SL1), the secondary holding lagoon (SL2), and the spray fields (site SF1). The spray fields are located south of the receiving stream and consist of a fescue field (12.51 acres) that is used for wastewater applications during the cool seasons and a Bermuda field (12.78 acres) that is used for wastewater applications during the warm seasons. The fescue and Bermuda spray fields collectively are referred to as site SF1 (fig. 1; table 1). The agricultural fields located north of the receiving stream consist of 8.4 acres of fescue and 5.7 acres of alfalfa that are not used for disposal of wastewater from the swine facility. These fields are considered to represent background conditions for storm runoff in an area that does not receive spray applications of swine wastewater.

Three in-field runoff sites (BR1, SR1, and SR2) and four sites on the stream adjacent to the swine facility (ST1A, ST1B, ST1C, and ST1D) were used to collect discharge data and (or) water-quality samples during stormflow and base-flow conditions (table 1; fig. 1). The three in-field runoff sites (including one background site and two spray-field sites) were established in grassed waterways that transmit stormflow through the fields during periods of storm-derived runoff. The four stream sites (including upstream site ST1A, intermediate stream sites ST1B and ST1C, and downstream site ST1D) were established on the west-east oriented stream adjacent to the swine facility (fig. 1).

In-field runoff site BR1 is located along the down-gradient edge of the fescue and alfalfa fields north of the swine facility that do not receive wastewater applications (fig. 1). This background runoff site has a drainage area of 0.021 square miles (mi^2), or 13.8 acres, and receives much of the storm runoff from the fescue and alfalfa fields that flows eastward to the north-south oriented stream along the eastern edge of the study area. Some runoff from part of the fescue field in this background area also drains south-ward to the receiving stream next to the swine facility.

In-field runoff sites SR1 and SR2 are located along the downgradient edge of the spray fields at the swine facility (fig. 1). Much of the storm runoff in the drainage area of site SR1 (0.059 mi^2, or 37.8 acres) is derived from the western part of the fescue spray field; however, the headwater drainage of this site is located just southwest of Inwood Road, and SR1 receives some runoff from a dairy pasture field to which lagoon wastewater from a dairy facility at the LWRFL is occasionally applied. Storm runoff through site SR1 flows northward and empties into the channel between stream sites ST1B and ST1C. All storm runoff in the drainage area of site SR2 (0.0078 mi^2, or 5.0 acres) originates from the spray fields, primarily the Bermuda field (fig. 1). Stormflow through runoff site SR2 enters a small channel and flows eastward to the larger north-south oriented stream along the eastern boundary of the LWRFL, hence, bypassing downstream site ST1D on the stream adjacent to the swine facility (fig. 1).

Discharge and water-quality data were collected at stream sites ST1A, ST1B, ST1C, and ST1D at the swine facility (table 1; fig 1). Daily precipitation also was recorded with a raingage at upstream site ST1A. Upstream site ST1A has a drainage area of 0.21 mi^2 and is located at Chi Road, upstream from the swine-facility wastewater lagoons and spray fields. Intermediate site ST1B is located about 550 feet (ft) downstream from ST1A and upstream from the confluence with the drainage channel from in-field runoff site SR1. Intermediate site ST1C is located about 700 ft downstream from site ST1B and is downstream from the confluence with drainage from SR1. The farthest downstream site is ST1D (drainage area of 0.33 mi^2), which is located about 100 ft above the confluence with the larger north-south oriented stream. Stream sites ST1C and ST1D both receive some stormflow inputs from the swine facility spray fields (primarily the fescue field), either as direct runoff through the site SR1 drainage or as sheet flow that drains northward into the adjacent riparian buffer between runoff sites SR1 and SR2. As previously described, storm runoff through in-field runoff site SR2 at the edge of the Bermuda spray field enters a channel that empties into the larger stream downstream from site ST1D.

Methods

The collection of hydrologic and analytical data at the LWRFL study site began in October 2009 and was completed in January 2011. The methods used to measure precipitation, water stage, and discharge, and to collect and analyze samples are described in the following sections.

Precipitation

The USGS monitored rainfall at site ST1A (table 1; fig. 1) by using a tipping-bucket raingage that recorded precipitation at 15-minute intervals. In accordance with USGS guidelines for collecting and processing precipitation data, calibration checks were conducted semi-annually on the raingage to ensure the accuracy of recorded data. Precipitation data collected by the USGS at site ST1A are provided in Appendix 1; periods of frozen precipitation or times of equipment malfunction are not reported. Additional precipitation data for the LWRFL study area are available from a weather station operated by the State Climate Office of North Carolina (Station identification: LAKE, Station name: Lake Wheeler Rd Field Lab). Data for the LAKE weather station at the LWRFL (fig. 1) are available through the North Carolina Climate Retrieval and Observations Network of the Southeast (CRONOS) database (State Climate Office of North Carolina, 2011).

Water Stage and Discharge

Commercially manufactured fiberglass H-flumes were used from January 2010 to January 2011 to measure stormflow through the grassed waterways at in-field runoff sites BR1, SR1, and SR2. A 1.5-ft H-flume was installed at site SR2, and a 2.0-ft H-flume was installed at sites BR1 and SR1. The flumes were outfitted with pressure sensors and data loggers to monitor and record water stage at 5-minute intervals to document rapid water-level changes during storm events. The continuous water-stage data were used in combination with the flume stage-discharge ratings provided by the manufacturer to compute discharge data for each recorded 5-minute stage value.

Pressure sensors and data loggers were used at upstream site ST1A and downstream site ST1D to monitor and record water stage at 15-minute intervals. Discharge measurements at all stream sites were made by using a velocity meter or by volumetric methods (Rantz and others, 1982; Turnipseed and Sauer, 2010). Discrete discharge measurements were used to develop a stage-discharge relation at stream monitoring sites ST1A and ST1D and for subsequent computation of discharge data for each recorded 15-minute stage value.

Wastewater, Soil, and Water Sampling

Wastewater samples from the swine facility were collected at sites SHO1, SL1, SL2 and SF1 (fig. 1). At site SHO1, grab samples were collected directly from the pipe outlet as wastewater entered into a settling basin. For each lagoon site (SL1 and SL2), subsamples were collected about 0.5 ft beneath the surface on each side of the lagoon and composited into two sample bottles, one for nutrients and total suspended solids (TSS), and one for FIB analyses. In the fescue and Bermuda spray fields (site SF1, fig. 1), wastewater samples were collected during five spray applications as wastewater from lagoon SL2 was actively applied to the fields. A network of 29 grid blocks (200 ft x 200 ft) was established for site SF1 (fig. 2) to aid in

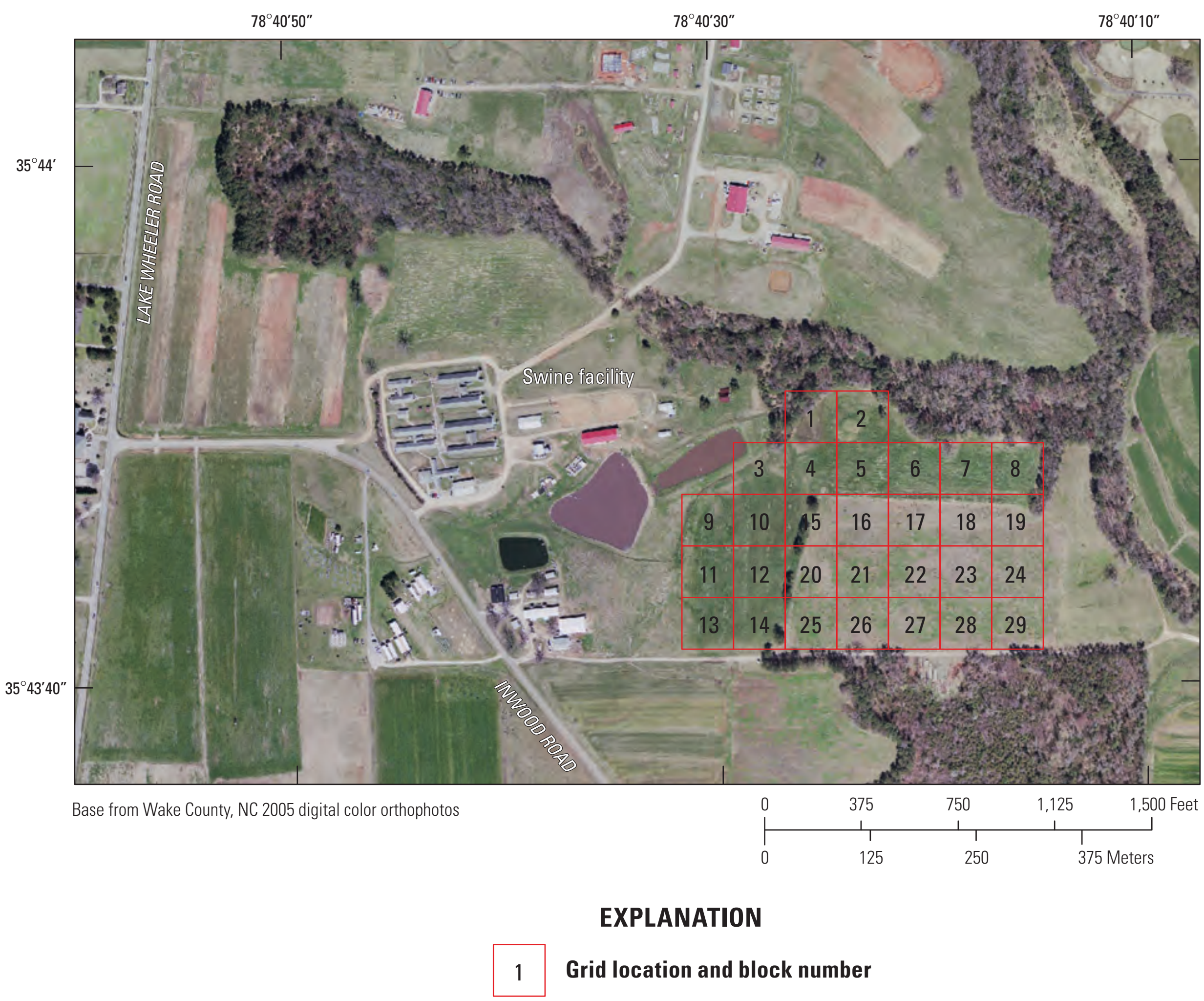

Figure 2. Sampling block grid at the swine wastewater spray fields at the LWRFL study area in North Carolina.

the random selection of wastewater sampling locations. Grid blocks 1–14 were located in the fescue spray field, and grid blocks 15–29 were located in the Bermuda spray field (figs. 1 and 2).

For collecting wastewater samples during an individual spray application to either the fescue or Bermuda field, three sterile plastic containers were placed on the ground surface in each of three randomly selected grid blocks (fig. 2) to capture wastewater as it was applied to the field through the in-ground sprinkler system. For each block, the collected wastewater in all three containers was combined to produce a composite sample. A subsample of each block composite sample was further combined into a single sample that was submitted for laboratory analysis of nutrients and TSS. The remaining individual composite samples for each block were submitted for laboratory analysis of FIB. Measurement of field properties (barometric pressure, air and water temperature, specific conductance, pH, and dissolved oxygen (DO)) were determined in the field at the time of sampling (U.S. Geological Survey, variously dated). Information on the timing and volume of wastewater applications (gallons per acre) and plant available nitrogen (pounds per acre) applied during all spray events to the fescue and Bermuda spray fields during the study period (Curtis Powell, North Carolina State University, Lake Wheeler Road Field Laboratory, written commun., June 2011) is summarized in table 2. Information on the grid blocks and corresponding spray field used for collecting wastewater samples during five of the spray applications also is presented in table 2.

In addition to collecting wastewater samples in the spray fields, samples of soil also were collected in the Bermuda spray field as part of an experiment to document the decay of FIB in soil after the field was sprayed with wastewater from the secondary lagoon. Soil sampling was conducted in the eastern half of the Bermuda field (grid blocks 18, 19, 23, 24, 28, and 29; fig. 2) in association with the wastewater application on April 12, 2010 (table 2). On the initial day of wastewater application to the field, or day zero, one set of soil samples was collected immediately before spraying, and one set of soil samples was collected after spraying. Soil samples also were collected at 1, 3, 7, 14, and 28 days following the spray event. For each sampling round, three soil cores (1 ft deep) were removed from each of three randomly selected grid blocks. For each block, each of the three soil cores were split into upper (0–0.5 ft) and lower (0.5–1.0 ft) halves and composited into upper and lower samples. Hence, a total of six soil samples were collected for each sampling round, consisting of three upper and three lower composite samples for all sampled grid blocks.

For water-quality sampling, three in-field runoff sites (BR1, SR1, and SR2) and four sites on the receiving stream at the swine facility (ST1A, ST1B, ST1C, and ST1D) were used to collect samples during base-flow and stormflow conditions (fig. 1; table 1). Water-quality samples were collected at all four stream sites on an approximately monthly basis, primarily to document background concentrations of FIB in stream water during base flow.

Stormflow samples were collected at sites BR1, SR1, SR2, ST1A, and ST1D to document nutrient and bacteria concentrations associated with storm runoff from fields with and without spray applications of swine wastewater. These sites were sampled during four storm events from December 2009 to September 2010. Prior to installing the flumes and water-stage recorders at in-field runoff sites BR1, SR1, and SR2 in January 2010, manual grab samples were collected for FIB analyses, and instantaneous discharge was measured at all five sites following a rainfall event on December 9, 2009. Beginning in March 2010, automated water-quality samplers were used at the three in-field runoff sites (BR1, SR1, and SR2) and two stream sites (upstream site ST1A and downstream site ST1D) to collect samples during selected storm events.

The automated sampler at each site was programmed to collect up to eight individual water samples during a storm sampling event. For an individual sample, three clean and sterile collection bottles each were filled with approximately 800 milliliters (mL) of water drawn through a sample intake line. The intake line was automatically flushed with native water before each three-bottle sample set was collected. Individual samples collected with the automated sampler were subdivided such that one bottle was used for nutrient and TSS analyses, and two bottles were used for bacteria analyses. Subsequent to collection, samples were stored in the automated sampler until retrieved for processing. Specific conductance was the only field property measured during processing of storm-event samples because values for other field properties would likely change during the interval between sample collection and retrieval from the automated sampler. In some cases, manual grab samples were obtained to supplement the samples collected by the automated samplers during storm events. When manual grab samples were collected at the runoff or stream sites, during either stormflow or base-flow conditions, all field properties (barometric pressure, air and water temperature, specific conductance, pH, and DO) were measured at the time of sampling.

Laboratory Analysis

Established, documented protocols for processing samples for chemical analyses were followed (U.S. Geological Survey, variously dated; U.S. Geological Survey, 2010). Samples were processed in the field or in the nearby USGS North Carolina Water Science Center laboratory in Raleigh and shipped on ice by overnight delivery to the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado, for analysis of nutrients and TSS or to the Institute for a Sustainable Environment at Clarkson University in Potsdam, New York, for laboratory analysis of FIB.

Nutrients (including dissolved ammonia, total and dissolved ammonia + organic nitrogen (N), dissolved nitrate

+ nitrite, dissolved orthophosphate, and total phosphorus (P)), and TSS were analyzed according to methods described in Fishman (1993), U.S. Environmental Protection Agency (1993), and Patton and Truitt (2000). Measurement of FIB, including *E. coli* and enterococci, was completed using IDEXX Quanti-Tray® technology with Colisure® and Enterolert®, respectively (IDEXX Laboratories, Inc., 2011). Laboratory measurements of FIB are reported as most probable number (MPN) per gram (g) for soil samples and MPN per 100 mL for wastewater and water samples. Some of the measured concentrations of *E. coli* and enterococci are reported as either a lower "<" or upper ">" censored value. The specific censoring levels varied among the samples because of differences in sample dilutions associated with the bacteria analyses. The FIB results are published in this report but are not contained in the USGS National Water Information System database.

Quality-control samples, including field blanks, equipment blanks, and replicate samples, were collected in order to document potential bias and variability in data that may result during the collection, processing, shipping, and handling of environmental samples (U.S. Geological Survey, variously dated). Field blanks were collected and processed in the field with the same equipment used for the environmental samples to help identify potential contamination resulting from field sampling activities and exposure. Equipment blanks were processed in the USGS North Carolina Water Science Center laboratory in Raleigh to help identify potential contamination resulting from sample collection and processing equipment (bottles, filters, preservatives, and pump tubing). Replicate samples were collected to help document the variability in data results associated with sample collection, processing, and laboratory analysis.

Data Summary

Analytical results for nutrients, TSS, and FIB and hydrologic data collected at the LWRFL study area during October 2009 to January 2011 are presented in this section. The analytical data for environmental samples collected during the study provide information on the occurrence of nutrients, TSS, and (or) FIB in swine wastewater, spray field soils, field runoff, and the receiving stream.

Nutrient and Bacteria Concentrations in Swine Wastewater Samples

The analytical results for samples of wastewater collected during December 2009 to November 2010 along the waste-stream flowpath at the swine facility for sites SHO1, SL1, and SL2 are given in table 3, and results for site SF1 are given in table 4. Ammonia was the dominant species of nitrogen measured in the wastewater samples. Overall, there tended to be a decrease in specific conductance and concentrations of TSS, ammonia + organic N, ammonia, and total P along the flow path from pipe outfall location SHO1 to secondary lagoon SL2 (table 3). Nitrate + nitrite concentrations did not follow a consistent pattern. Nutrient concentrations for samples collected in the spray field (table 4) were similar to the samples collected directly from lagoon SL2, which was used as the source for spraying to the application fields. Results of the FIB analyses also indicated a decrease in concentrations of *E. coli* and enterococci from site SHO1 to SL2. In general, measured concentrations of *E. coli* were typically higher than enterococci concentrations in the wastewater samples.

Bacteria Concentrations in Spray-Field Soil Samples

The bacteria analytical results for soil samples collected from the Bermuda field on April 12, 2010, when wastewater was spray applied to the field (table 2) and for samples collected 1, 3, 7, 14, and 28 days following the application are presented in table 5. Soil concentrations of enterococci generally were higher than *E. coli*. In most of the soil samples, concentrations of *E. coli* typically were less than 100 MPN/g. This contrasts with the results observed for the wastewater samples where *E. coli* concentrations commonly were higher than enterococci concentrations.

In many cases, enterococci concentrations were higher in soil samples collected from 0.0 to 0.5 ft relative to samples from 0.5 to 1.0 ft. Although enterococci concentrations in soil did not follow a consistent pattern with time following the wastewater application, the concentrations generally were highest in the set of samples collected 3 days after the application.

Hydrologic and Water-Quality Data for Field Runoff and Stream Sites

Information on hydrologic data and water-quality samples collected at in-field runoff sites BR1, SR1, and SR2, and stream sites ST1A, ST1B, ST1C, and ST1D between October 2009 and January 2011 are summarized in this section. Laboratory results of nutrient, TSS, and bacteria analyses of samples collected during stormflow and base-flow conditions at the runoff and stream sites also are presented.

Hydrologic Conditions during Sample Collection

Daily precipitation measured at the USGS raingage (site ST1A, fig. 1) during the study period (October 2009 to January 2011) is shown in figure 3. Supplemental precipitation data obtained through the CRONOS database for the LAKE weather station (State Climate Office of North Carolina, 2011) also are included in figure 3 for days when data were missing from the USGS precipitation record (Appendix 1).

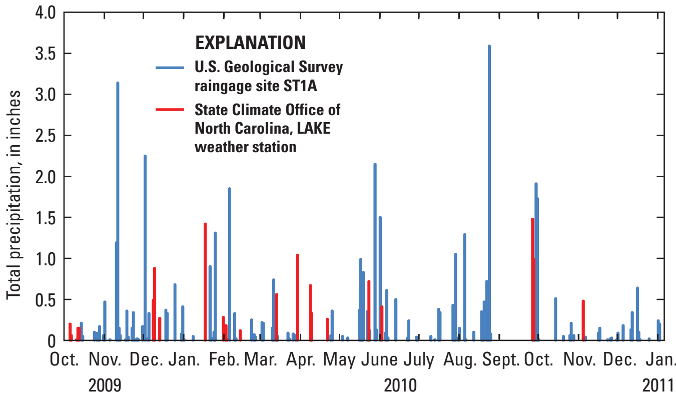

Figure 3. Daily total precipitation at the LWRFL study area in North Carolina.

After the three in-field runoff sites (BR1, SR1, and SR2) and two stream sites (ST1A and ST1D) were equipped with automated water-quality samplers in March 2010, daily precipitation occasionally exceeded 1 inch; however, because of antecedent soil moisture conditions, there were a minimal number of storm events where the amount of generated stormflow at the sites was sufficient for collecting samples for laboratory analyses. The relatively dry runoff conditions encountered during the study period were reflected in the daily maximum water stage recorded at each site (fig. 4). Gaps in the plotted stage data represent periods of missing data caused by equipment malfunctions or icing conditions during winter weather.

Water-quality samples were collected at sites BR1, SR1, SR2, ST1A, and ST1D from December 2009 to September 2010 during four storm events (table 6). The number of samples collected for laboratory analysis of nutrients and bacteria varied among the sites on the basis of the magnitude of stormflow during each sampled event. For storm sampling events 2, 3, and 4, automated samplers were used to collect between 1 and 5 samples for each event and site for analysis of nutrients and bacteria. Samples were collected during rising, peak, and (or) falling stage conditions throughout the event. Minimal samples were collected at site BR1 during event 2 and at sites BR1 and SR2 during event 3 (table 6) because of limited stormflow at these locations. For comparison, the stormflow samples collected at each site are plotted along the discharge hydrograph for events 2 (fig. 5), 3 (fig. 6), and 4 (fig. 7). The daily mean values of discharge compiled for each site during the study are presented as Appendix 2. Where available, the values for instantaneous discharge at those times when samples were collected are presented with the analytical results in the following sections.

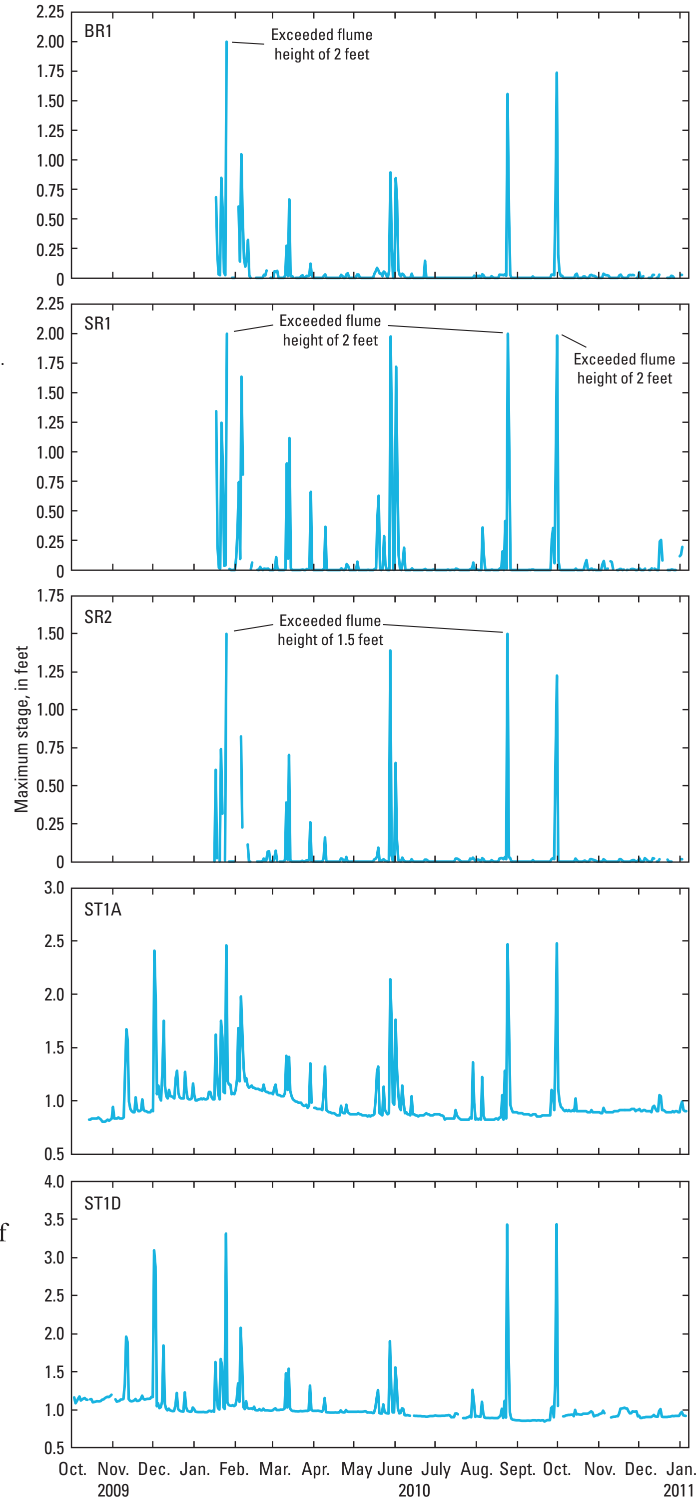

Figure 4. Daily maximum stage at sites BR1, SR1, SR2, ST1A, and ST1D at the LWRFL study area in North Carolina.

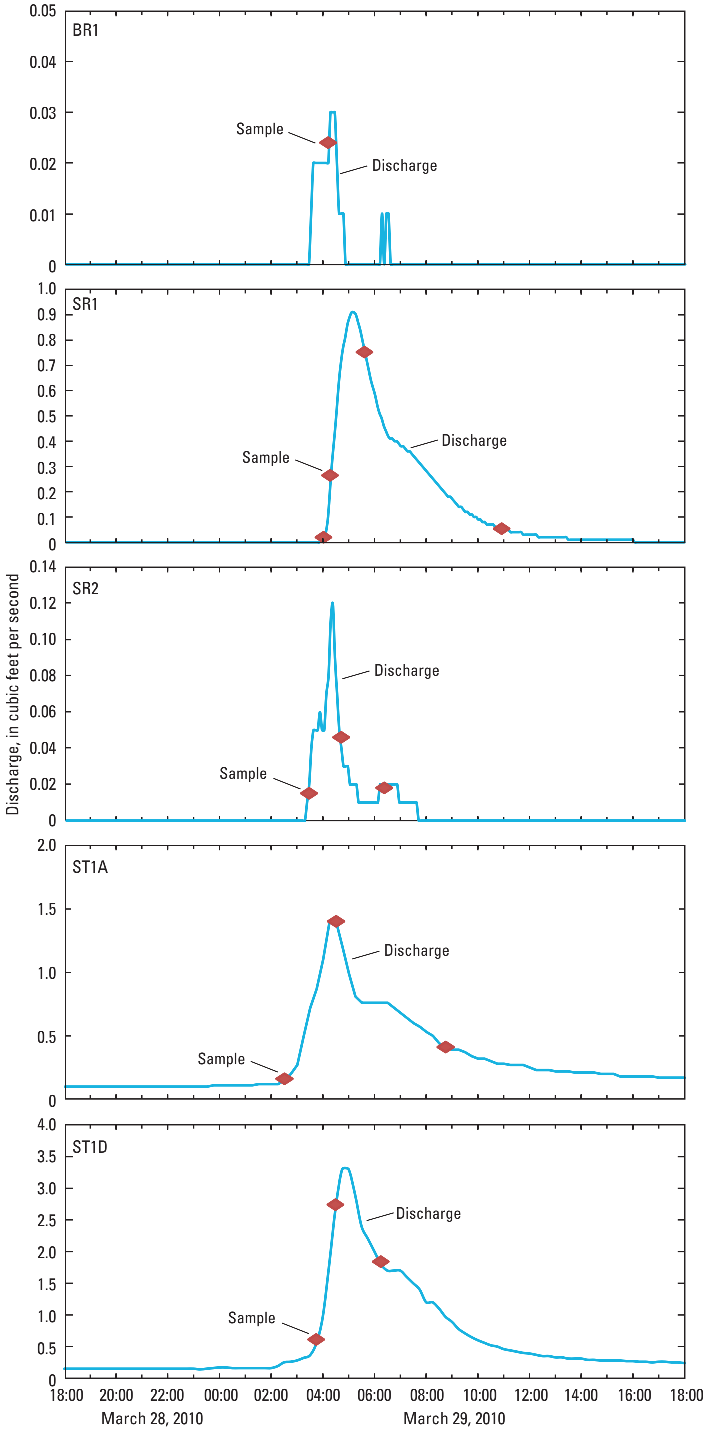

Figure 5. Discharge hydrographs at sites BR1, SR1, SR2, ST1A, and ST1D for sampling event 2 on March 29, 2010, at the LWRFL study area in North Carolina.

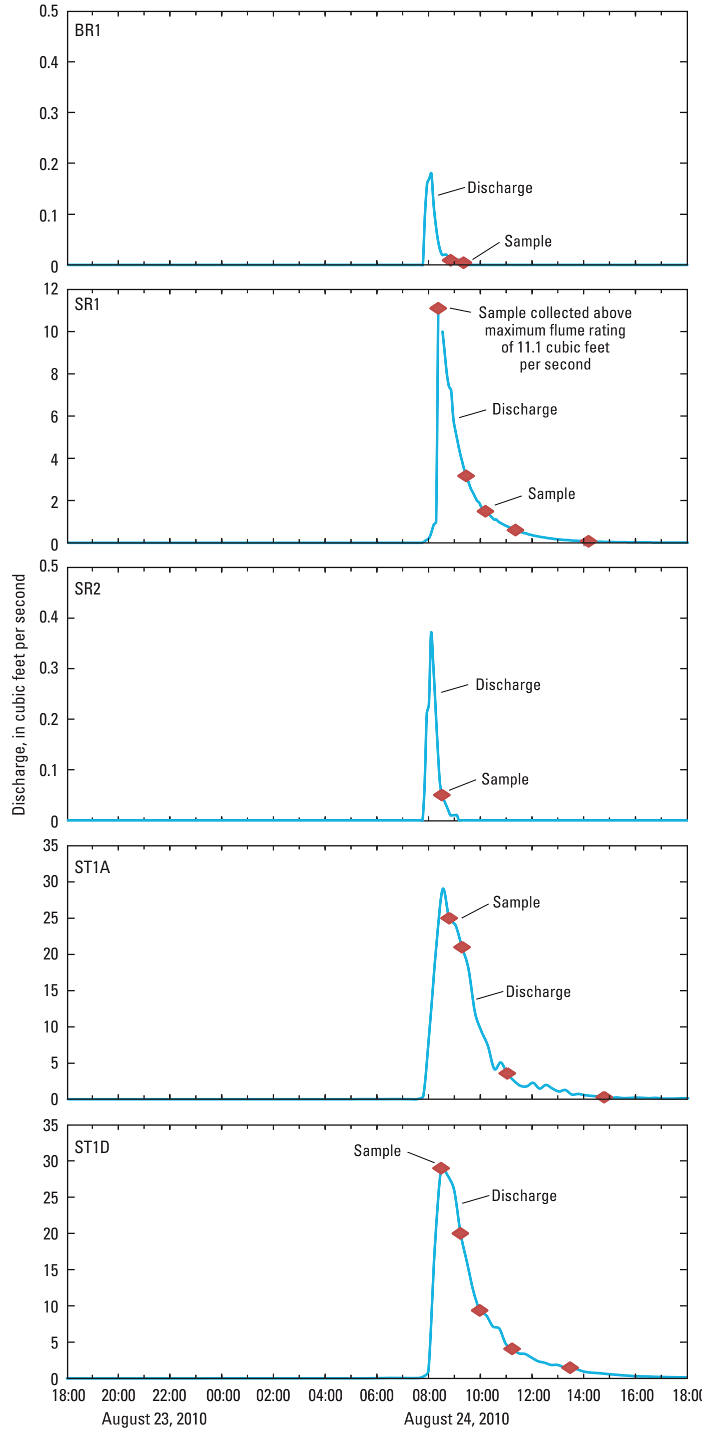

Figure 6. Discharge hydrographs at sites BR1, SR1, SR2, ST1A, and ST1D for sampling event 3 on August 24, 2010, at the LWRFL study area in North Carolina.

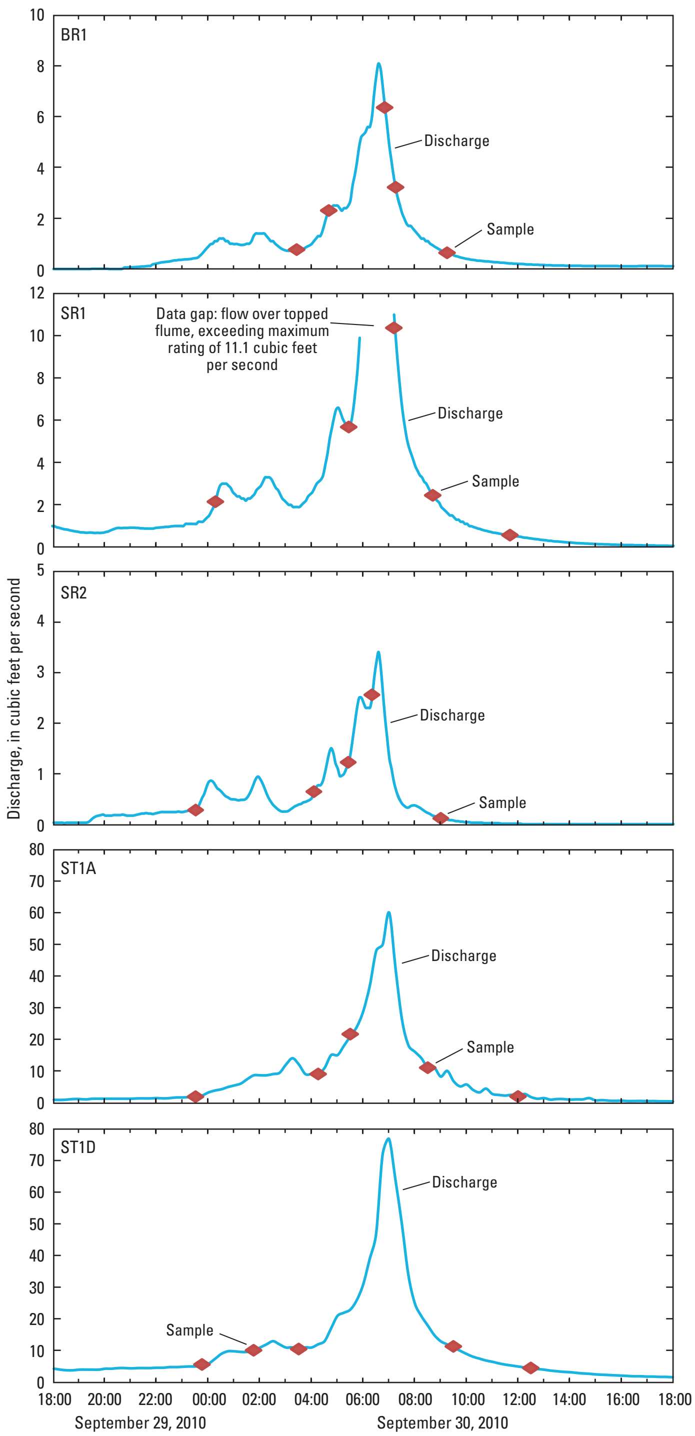

Figure 7. Discharge hydrographs at sites BR1, SR1, SR2, ST1A, and ST1D for sampling event 4 on September 29–30, 2010, at the LWRFL study area in North Carolina.

Nutrient and Bacteria Concentrations in Field Runoff Samples

Results of field measurements and laboratory analyses of nutrients, TSS, and bacteria for water-quality samples collected during storm events are given for background runoff site BR1 (table 7) and spray-field runoff sites SR1 (table 8) and SR2 (table 9). Examination of the laboratory results reported for the field runoff sites indicates that in some samples, dissolved concentrations of ammonia + organic N were higher than total concentrations of ammonia + organic N. A similar observation was also noted in the equipment blank processed for site SR2 on March 30, 2010, where the dissolved concentration of 0.26 mg/L for ammonia + organic N was higher than the total concentration having an estimated value of 0.06 mg/L (table 9). Differences up to 0.2 to 0.3 mg/L between the reported dissolved and total concentrations of ammonia + organic N are considered to be within the precision of the analytical method. Larger observed differences may indicate that low-level contamination of ammonia + organic N occurred in samples during processing, possibly during the filtering of dissolved samples. Similar observations are noted in some of the ammonia + organic N results for stream samples presented in the following section.

For the field runoff sites, the highest concentrations of nitrite + nitrate (4.73 mg/L) and total N (11 mg/L) were detected in the sample collected on March 29, 2010, at background site BR1 (table 7). It is worth noting that during a site visit on March 17, 2010, USGS personnel were informed by staff at the LWRFL that residual swine feed had been disposed of by spreading on a small area of the fescue field upgradient from the BR1 monitoring station. Runoff from this residual swine feed material may have influenced the water-quality results of the stormflow sample collected on March 29, 2010, at site BR1. Concentrations of total P in all stormflow samples collected at runoff sites BR1 and SR1 were less than 1 mg/L, whereas samples collected from site SR2 had total P concentrations ranging from 1.66 to 3.41 mg/L (tables 7–9).

Results of the FIB analyses indicate variable concentrations of *E. coli* and enterococci among runoff sites BR1, SR1, and SR2. In general, measured concentrations of enterococci were higher than *E. coli* in stormflow samples at the field runoff sites (tables 7–9), similar to what was observed in the soil samples collected from the Bermuda spray field (table 5). Concentrations of *E. coli* in stormflow samples at SR2 generally were lower than those at sites BR1 and SR1.

Nutrient and Bacteria Concentrations in Stream Samples

Results of field measurements and laboratory analyses for water-quality samples collected during base flow and (or) stormflow are given for stream sites ST1A (table 10), ST1B and ST1C (table 11), and ST1D (table 12). Nutrient, TSS, and bacteria results in samples collected during both base-flow and stormflow conditions are provided for upstream site ST1A and downstream site ST1D. Bacteria results in samples collected during base-flow conditions are provided for intermediate stream sites ST1B and ST1C.

Analytical results at stream sites ST1A (table 10) and ST1D (table 12) for samples collected during base-flow conditions indicate a general increase in DO, pH, specific conductance, nitrite + nitrate, and total N and a decrease in ammonia from upstream to downstream. Concentrations of TSS, ammonia + organic N, organic N, and total P were elevated in samples collected at sites ST1A and ST1D during stormflow relative to samples collected during base flow.

Results of the bacteria analyses indicate variable concentrations of *E. coli* and enterococci among stream sites ST1A, ST1B, ST1C, and ST1D (tables 10–12) with no consistent pattern noted in samples collected during either base-flow or stormflow conditions. At both sites ST1A and ST1D, concentrations of *E. coli* and enterococci were elevated in samples collected during stormflow relative to base flow. In general, however, measured concentrations of enterococci were higher than *E. coli* for all samples collected at the stream sites. Although beyond the scope of this report, a more thorough analysis of the water-quality data that incorporates adjustments for flow would be necessary for evaluating nutrient and bacteria loadings among the field runoff and stream monitoring sites.

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Table 1. Data-collection network at the Lake Wheeler Road Field Laboratory (LWRFL) study area, Wake County, North Carolina, 2009–2011.

[USGS, U.S. Geological Survey; NCSU, North Carolina State University; trib, tributary]

USGS station name	Local name (locations in fig. 1)	USGS site number	Type of data collected	Period of collection
Wastewater sites				
Swine house outflow site 1 at NCSU Research Unit at Raleigh	SHO1	354348078403801	Water-quality samples (wastewater)	12/07/09–11/08/10
Swine lagoon 1 at NCSU Research Unit at Raleigh	SL1	354347078403501	Water-quality samples (wastewater)	12/07/09–11/08/10
Swine lagoon 2 at NCSU Research Unit at Raleigh	SL2	354349078403101	Water-quality samples (wastewater)	12/07/09–11/08/10
Swine spray field at NCSU Research Unit at Raleigh	SF1	354346078402101	Water-quality samples (wastewater)	12/07/09–11/08/10
			Soil samples	04/12/10–05/10/10
In-field runoff sites				
Background runoff site 1 at NCSU Research Unit at Raleigh	BR1	354355078401401	Discharge	01/15/10–01/05/11
			Water-quality samples (runoff only)	12/09/09–09/30/10
Swine runoff site 1 at NCSU Research Unit at Raleigh	SR1	354349078402801	Discharge	01/15/10–01/05/11
			Water-quality samples (runoff only)	12/09/09–09/30/10
Swine runoff site 2 at NCSU Research Unit at Raleigh	SR2	354347078401501	Discharge	01/15/10–01/05/11
			Water-quality samples (runoff only)	12/09/09–09/30/10
Stream sites				
Unnamed trib to Swift Creek near Yates Mill Pond	ST1A	0208762750	Precipitation	10/14/09–01/05/11
			Discharge	10/14/09–01/05/11
			Water-quality samples (baseflow and runoff)	11/03/09–01/04/11
Intermediate site ST1B on unnamed trib to Swift Creek at NCSU farm	ST1B	354353078402801	Water-quality samples (baseflow only)	11/03/09–01/04/11
Intermediate site ST1C on unnamed trib to Swift Creek at NCSU farm	ST1C	354352078402001	Water-quality samples (baseflow only)	11/03/09–01/04/11
Unnamed trib to Swift Creek at NCSU Research Unit at Raleigh	ST1D	0208762755	Discharge	10/02/09–01/05/11
			Water-quality samples (baseflow and runoff)	11/03/09–01/04/11

Table 2. Summary of wastewater applications to the spray fields at the LWRFL study area in North Carolina (Curtis Powell, NCSU, LWRFL, written commun., June 2011).

[PAN, plant available nitrogen; gal, gallon; lb, pound; na, not applicable]

Date	Fescue field 50 (6.02 acres) Grid blocks: 3, 9–14		Fescue field 52B (6.49 acres) Grid blocks: 1,2, 4–8		Bermuda field 52A1 (6.02 acres) Grid blocks: 15–17, 20–22, 25–27		Bermuda field 52A2 (6.76 acres) Grid blocks: 17–19, 22–24, 27–29		Summary of grid blocks (locations in fig. 2) sampled during spray applications
	Volume applied (gal/acre)	PAN applied (lb/acre)	Volume applied (gal/acre)	PAN applied (lb/acre)	Volume applied (gal/acre)	PAN applied (lb/acre)	Volume applied (gal/acre)	PAN applied (lb/acre)	
12/07/09	5,143	0.72	10,256	1.44	na	na	na	na	Sampled blocks 4 and 8 (field 52B), and 10 (field 50)
01/13/10	6,498	0.91	6,480	0.91	na	na	na	na	
01/14/10	16,246	2.27	16,200	2.26	na	na	na	na	
01/15/10	6,498	0.91	6,480	0.91	na	na	na	na	
02/05/10	12,997	1.82	12,960	1.81	na	na	na	na	
02/12/10	12,997	1.82	12,960	1.81	na	na	na	na	
02/15/10	12,997	1.82	12,960	1.81	na	na	na	na	
03/10/10	12,997	2.34	12,960	2.33	na	na	na	na	Sampled blocks 2 and 5 (field 52B), and 9 (field 50)
03/19/10	25,994	4.68	25,920	4.66	na	na	na	na	
04/05/10	na	na	na	na	na	na	12,731	2.16	
04/12/10	na	na	na	na	6,498	1.10	12,997	2.21	Sampled blocks 19, 23, and 28 (field 52A2)
04/29/10	na	na	na	na	22,745	3.87	na	na	
07/06/10	na	na	na	na	12,997	2.21	na	na	
07/08/10	na	na	na	na	12,997	2.21	na	na	
07/14/10	na	na	na	na	na	na	25,462	2.54	
08/03/10	na	na	na	na	na	na	12,731	1.27	Sampled blocks 18, 23, and 24 (field 52A2)
10/18/10	9,748	0.97	na	na	9,748	0.97	na	na	
10/21/10	19,495	1.95	na	na	19,495	1.95	na	na	
10/22/10	12,997	1.30	na	na	12,997	1.30	na	na	
11/02/10	12,997	2.34	12,960	2.33	na	na	na	na	
11/03/10	12,997	2.34	12,960	2.33	na	na	na	na	
11/08/10	12,997	2.34	12,960	2.33	na	na	na	na	Sampled blocks 4 and 6 (field 52B), and 14 (field 50)
11/09/10	6,498	1.17	6,480	1.17	na	na	na	na	
11/10/10	6,498	1.17	6,480	1.17	na	na	na	na	

Table 3. Analytical results for wastewater sites SHO1, SL1, and SL2 at the LWRFL study area in North Carolina.

[mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; N, nitrogen; P, phosphorus; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than; >, greater than; E, estimated; italics indicate quality-control samples]

Date	Time	Sample type	Barometric pressure, mm Hg	Temperature, air, °C	Dissolved oxygen, mg/L	Dissolved oxygen percent of saturation	pH, standard units	Specific conductance, µS/cm at 25 °C	Temperature, water, °C
				Site SHO1					
12/07/09	1025	Wastewater	--	8.0	--	--	--	--	--
03/09/10	*1215*	*Field blank*	--	--	--	--	--	--	--
03/09/10	1235	Wastewater	--	21.5	--	--	--	--	--
04/12/10	1020	Wastewater	--	19.5	--	--	--	--	--
08/03/10	*0940*	*Field blank*	*759*	*28*	--	--	--	--	--
08/03/10	1020	Wastewater	759	29.0	3.4	43	7.6	2,070	26.7
11/08/10	1040	Wastewater	756	13.0	6.6	63	7.6	2,130	12.4
				Site SL1					
12/07/09	1100	Wastewater	--	8.0	--	--	--	--	--
03/09/10	1310	Wastewater	--	22.0	--	--	--	--	--
04/12/10	1035	Wastewater	763	19.5	0.2	2	7.5	2,290	20.1
08/03/10	1110	Wastewater	759	29.0	0.9	10	7.8	2,040	30.6
11/08/10	1115	Wastewater	756	13.5	1.3	13	7.5	2,030	13.7
				Site SL2					
12/07/09	1130	Wastewater	--	9.0	--	--	--	--	--
03/09/10	1345	Wastewater	--	22.0	--	--	--	--	--
04/12/10	1110	Wastewater	768	20.0	28.2	326	8.7	1,450	22.3
08/03/10	1315	Wastewater	759	34.0	17.7	245	8.7	1,400	32.0
11/08/10	1315	Wastewater	753	17.0	6.4	62	7.1	1,550	13.6

Table 3. Analytical results for wastewater sites SHO1, SL1, and SL2 at the LWRFL study area in North Carolina.—Continued

[mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; N, nitrogen; P, phosphorus; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than; >, greater than; E, estimated; italics indicate quality-control samples]

Date	Time	Sample type	Suspended solids, unfiltered, mg/L	Ammonia + organic N, filtered, mg/L as N	Ammonia + organic N, unfiltered, mg/L as N	Ammonia, filtered, mg/L as N	Nitrate + nitrite, filtered, mg/L as N	Organic nitrogen, filtered, mg/L as N	Organic nitrogen, unfiltered, mg/L as N
				Site SHO1					
12/07/09	1025	Wastewater	--	--	--	--	--	--	--
03/09/10	*1215*	*Field blank*	--	*<0.1*	*<0.1*	*<0.02*	*E0.03*	*<0.1*	*<0.1*
03/09/10	1235	Wastewater	150	240	330	192	2.63	50	140
04/12/10	1020	Wastewater	--	--	--	--	--	--	--
08/03/10	*0940*	*Field blank*	--	*<0.1*	*0.18*	*0.05*	*<0.04*	*<0.05*	*0.13*
08/03/10	1020	Wastewater	309	100	140	89.2	0.14	10	49
11/08/10	1040	Wastewater	104	140	150	109	0.07	27	38
				Site SL1					
12/07/09	1100	Wastewater	--	--	--	--	--	--	--
03/09/10	1310	Wastewater	<150	120	170	106	<0.04	14	59
04/12/10	1035	Wastewater	--	--	--	--	--	--	--
08/03/10	1110	Wastewater	333	91	140	79.6	<0.04	11	60
11/08/10	1115	Wastewater	84	110	120	90.2	0.05	15	27
				Site SL2					
12/07/09	1130	Wastewater	--	--	--	--	--	--	--
03/09/10	1345	Wastewater	<150	43	55	32.9	0.42	10	22
04/12/10	1110	Wastewater	--	--	--	--	--	--	--
08/03/10	1315	Wastewater	76	26	38	14.6	E0.03	12	24
11/08/10	1315	Wastewater	44	35	41	26.8	6.36	7.9	14

Table 3. Analytical results for wastewater sites SHO1, SL1, and SL2 at the LWRFL study area in North Carolina.—Continued

[mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; N, nitrogen; P, phosphorus; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than; >, greater than; E, estimated; italics indicate quality-control samples]

Date	Time	Sample type	Orthophosphate, filtered, mg/L as P	Phosphorus, unfiltered, mg/L as P	Total nitrogen, filtered, mg/L as N	Total nitrogen, unfiltered, mg/L as N	E. coli, MPN/100 mL	Enterococci, MPN/100 mL
				Site SHO1				
12/07/09	1025	Wastewater	--	--	--	--	>2,419,600	2,000
03/09/10	*1215*	*Field blank*	*<0.008*	*<0.02*	*<0.13*	*<0.13*	--	--
03/09/10	1235	Wastewater	37.2	69.1	240	340	>2,419,600	>2,419,600
04/12/10	1020	Wastewater	--	--	--	--	>2,419,600	97,800
08/03/10	*0940*	*Field blank*	*<0.008*	*0.286*	*<0.14*	*<0.22*	--	--
08/03/10	1020	Wastewater	34.0	81.8	100	140	579,400	307,600
11/08/10	1040	Wastewater	47.7	74.0	140	150	>2,419,600	>2,419,600
				Site SL1				
12/07/09	1100	Wastewater	--	--	--	--	31,300	4,170
03/09/10	1310	Wastewater	29.9	54.4	<120	<170	139,600	22,800
04/12/10	1035	Wastewater	--	--	--	--	8,664	259,500
08/03/10	1110	Wastewater	16.8	75.2	<91	<140	33,100	15,800
11/08/10	1115	Wastewater	44.9	72.3	110	120	517,200	461,100
				Site SL2				
12/07/09	1130	Wastewater	--	--	--	--	6,300	2,030
03/09/10	1345	Wastewater	28.5	44.1	43	55	52	<10
04/12/10	1110	Wastewater	--	--	--	--	9,804	8,297
08/03/10	1315	Wastewater	20.6	34.3	E26	E38	830	40,200
11/08/10	1315	Wastewater	65.7	62.2	41	47	7,701	435,200

Table 4. Analytical results for wastewater site SF1 at the LWRFL study area in North Carolina.

[mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; N, nitrogen; P, phosphorus; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than; italics indicate quality-control samples]

Date	Time	Sample type	Grid block number	Barometric pressure, mm Hg	Tempera-ture, air, °C	Dissolved oxygen, mg/L	Dissolved oxygen percent of saturation	pH, standard units	Specific conduc-tance, uS/cm at 25 °C	Tempera-ture, water, °C
12/07/09	1355	Wastewater	4	--	11.0	--	--	--	--	--
12/07/09	1405	Wastewater	8	--	11.0	--	--	--	--	--
12/07/09	1415	Wastewater	10	--	11.0	--	--	--	--	--
03/09/10	*1115*	*Field blank*	--	--	--	--	--	--	--	--
03/10/10	1130	Wastewater	2, 5, 9[a]	756	17.0	9.8	107	8.4	1,610	18.9
03/10/10	1130	Wastewater	2	--	--	--	--	--	--	--
03/10/10	1135	Wastewater	5	--	--	--	--	--	--	--
03/10/10	1140	Wastewater	9	--	--	--	--	--	--	--
04/12/10	1210	Wastewater	19	764	22.0	12.0	148	8.4	1,530	25.9
04/12/10	1220	Wastewater	23	764	22.5	10.3	125	8.3	1,560	24.9
04/12/10	1235	Wastewater	28	764	22.5	14.4	182	8.5	1,540	27.0
08/03/10	1200	Wastewater	18	759	32.0	15.8	230	8.5	1,490	35.0
08/03/10	1215	Wastewater	23	759	32.0	17.5	256	8.6	1,470	35.2
08/03/10	1230	Wastewater	24	759	34.0	16.3	240	8.6	1,460	35.7
08/03/10	1235	Wastewater	18, 23, 24[a]	759	34.0	16.6	242	8.6	1,470	35.3
11/08/10	1215	Wastewater	4	755	13.0	--	--	--	--	--
11/08/10	1220	Wastewater	6	755	13.0	10.1	100	7.8	1,600	14.4
11/08/10	1225	Wastewater	14	755	13.0	10.2	101	7.8	1,600	14.5
11/08/10	1230	Wastewater	4, 6, 14[a]	755	13.0	10.2	101	7.8	1,600	14.4

Table 4. Analytical results for wastewater site SF1 at the LWRFL study area in North Carolina.—Continued

[mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; N, nitrogen; P, phosphorus; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than; italics indicate quality-control samples]

Date	Time	Sample type	Suspended solids, unfiltered, mg/L	Ammonia + organic N, filtered, mg/L as N	Ammonia + organic N, unfiltered, mg/L as N	Ammonia, filtered, mg/L as N	Nitrate + nitrite, filtered, mg/L as N	Organic nitrogen, filtered, mg/L as N	Organic nitrogen, unfiltered, mg/L as N
12/07/09	1355	Wastewater	--	--	--	--	--	--	--
12/07/09	1405	Wastewater	--	--	--	--	--	--	--
12/07/09	1415	Wastewater	--	--	--	--	--	--	--
03/09/10	*1115*	*Field blank*	--	--	--	--	--	--	--
03/10/10	1130	Wastewater	<150	46	54	33.3	0.14	13	21
03/10/10	1130	Wastewater	--	--	--	--	--	--	--
03/10/10	1135	Wastewater	--	--	--	--	--	--	--
03/10/10	1140	Wastewater	--	--	--	--	--	--	--
04/12/10	1210	Wastewater	--	--	--	--	--	--	--
04/12/10	1220	Wastewater	--	--	--	--	--	--	--
04/12/10	1235	Wastewater	--	--	--	--	--	--	--
08/03/10	1200	Wastewater	--	--	--	--	--	--	--
08/03/10	1215	Wastewater	--	--	--	--	--	--	--
08/03/10	1230	Wastewater	--	--	--	--	--	--	--
08/03/10	1235	Wastewater	169	23	37	12.2	<0.04	11	24
11/08/10	1215	Wastewater	--	--	--	--	--	--	--
11/08/10	1220	Wastewater	--	--	--	--	--	--	--
11/08/10	1225	Wastewater	--	--	--	--	--	--	--
11/08/10	1230	Wastewater	15	35	39	23.9	6.79	11	15

Table 4. Analytical results for wastewater site SF1 at the LWRFL study area in North Carolina.—Continued

[mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; N, nitrogen; P, phosphorus; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than; italics indicate quality-control samples]

Date	Time	Sample type	Orthophosphate, filtered, mg/L as P	Phosphorus, unfiltered, mg/L as P	Total nitrogen, filtered, mg/L as N	Total nitrogen, unfiltered, mg/L as N	E. coli, MPN/100 mL	Enterococci, MPN/100 mL
12/07/09	1355	Wastewater	--	--	--	--	34,480	5,860
12/07/09	1405	Wastewater	--	--	--	--	46,110	7,000
12/07/09	1415	Wastewater	--	--	--	--	48,840	4,480
03/09/10	*1115*	*Field blank*	--	--	--	--	*<10*	*<10*
03/10/10	1130	Wastewater	34.1	47.2	46	55	--	--
03/10/10	1130	Wastewater	--	--	--	--	197	10
03/10/10	1135	Wastewater	--	--	--	--	84	<10
03/10/10	1140	Wastewater	--	--	--	--	52	<10
04/12/10	1210	Wastewater	--	--	--	--	4,106	84
04/12/10	1220	Wastewater	--	--	--	--	2,489	<10
04/12/10	1235	Wastewater	--	--	--	--	3,130	<10
08/03/10	1200	Wastewater	--	--	--	--	457	199
08/03/10	1215	Wastewater	--	--	--	--	345	20
08/03/10	1230	Wastewater	--	--	--	--	201	20
08/03/10	1235	Wastewater	24.9	49.6	<23	<37	--	--
11/08/10	1215	Wastewater	--	--	--	--	1,726	129,600
11/08/10	1220	Wastewater	--	--	--	--	2,481	178,500
11/08/10	1225	Wastewater	--	--	--	--	1,935	172,300
11/08/10	1230	Wastewater	65.7	64.4	42	46	--	--

[a]Composite sample from the three grid blocks sampled on this date were analyzed for nutrients.

Table 5. Concentrations of fecal indicator bacteria in soil samples collected from the Bermuda spray field at the LWRFL study area in North Carolina.

[MPN/g, most probable number per gram; <, less than]

Days after application[a]	Date	Time	Grid block number (locations in fig. 2)	Soil depth: 0.0–0.5 feet		Soil depth: 0.5–1.0 feet	
				E. coli, MPN/g	Enterococci, MPN/g	E. coli, MPN/g	Enterococci, MPN/g
pre-application	04/12/10	0755	18	<100	<10,000	<100	100
pre-application	04/12/10	0830	23	<100	2,660	<100	6,290
pre-application	04/12/10	0855	28	<100	51,000	<100	62,000
post-application	04/12/10	1245	28	9,804,000	<10,000	100	5,690
post-application	04/12/10	1310	23	200	13,080	100	10,000
post-application	04/12/10	1340	19	<100	21,410	<100	41,000
1	04/13/10	1055	23	<100	<10,000	<100	<10,000
1	04/13/10	1125	24	<100	141,360	<100	98,040
1	04/13/10	1155	29	100	41,000	100	<10,000
3	04/15/10	0930	23	<100	147,000	<100	223,000
3	04/15/10	1000	28	100	346,000	<100	51,000
3	04/15/10	1025	29	200	1,063,000	<100	185,000
7	04/19/10	0940	19	<100	10,000	<100	<10,000
7	04/19/10	1010	24	<100	<10,000	<100	<10,000
7	04/19/10	1045	29	<100	10,000	<100	10,000
14	04/26/10	1035	19	<100	10,000	<100	<10,000
14	04/26/10	1105	23	<100	20,000	<100	10,000
14	04/26/10	1135	24	<100	309,000	<100	<10,000
28	05/10/10	0935	18	<100	20,000	<100	<10,000
28	05/10/10	1020	19	<100	10,000	<100	241,960
28	05/10/10	1130	29	<100	<10,000	<100	10,000

[a]Swine lagoon wastewater was spray-applied to the Bermuda field on April 12, 2010, beginning at 0950 and ending at 1150.

Table 6. Summary of stormflow samples collected for field-runoff sites (BR1, SR1, and SR2) and stream sites (ST1A and ST1D) at the LWRFL study area in North Carolina.

Sample site (locations in fig. 1)	Event 1[a] December 9, 2009		Event 2 March 29, 2010		Event 3 August 24, 2010		Event 4 September 29–30, 2010	
	Number nutrient samples	Number bacteria samples	Number nutrient samples	Number bacteria samples	Number nutrient samples	Number bacteria samples	Number nutrient samples	Number bacteria samples
BR1	0	1	1[b]	1[b]	2[b]	2[b]	5	5
SR1	0	1	4	4	5	5	5	5
SR2	0	1	3	3	1[b]	1[b]	5	5
ST1A	0	1	3	3	4	4	5[c]	5[c]
ST1D	0	1	3	3	5	5	5[c]	5[c]

[a]At each site, a manual grab sample only was collected for bacteria analyses.
[b]Minimal runoff at this site during the storm event limited the number of samples collected for analyses.
[c]Equipment malfunction prohibited collection of samples during peak flow.

Table 7. Analytical results for background runoff site BR1 at the LWRFL study area in North Carolina.

[ft³/s, cubic feet per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; N, nitrogen; P, phosphorus; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than; E, estimated]

Date	Time	Instantaneous discharge, ft³/s	Specific conductance, µS/cm at 25 °C	Suspended solids, unfiltered, mg/L	Ammonia + organic N, filtered, mg/L as N	Ammonia + organic N, unfiltered, mg/L as N	Ammonia, filtered, mg/L as N	Nitrate + nitrite, filtered, mg/L as N	Organic nitrogen, filtered, mg/L as N	Organic nitrogen, unfiltered, mg/L as N
12/09/09	1350	0.14	45	--	--	--	--	--	--	--
03/29/10	0411	0.02	81	93	5.3	6.0	3.47	4.73	1.8	2.5
08/24/10	0850	0.01	50	<30	1.1	1.5	0.022	1.03	1.1	1.4
08/24/10	0920	0.00	54	218	1.1	2.1	E0.018	0.79	E1.1	E2.1
09/30/10	0325	0.76	72	<15	2.2	1.8	0.044	1.03	2.1	1.7
09/30/10	0440	2.3	60	<15	2.0	1.6	0.031	0.71	1.9	1.5
09/30/10	0650	6.4	50	<15	1.4	1.2	0.035	0.57	1.4	1.2
09/30/10	0715	3.2	52	<15	1.5	1.2	0.037	0.53	1.4	1.2
09/30/10	0915	0.63	66	<15	1.6	1.5	0.036	0.61	1.6	1.4

Table 7. Analytical results for background runoff site BR1 at the LWRFL study area in North Carolina.—Continued

[ft³/s, cubic feet per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; N, nitrogen; P, phosphorus; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than; E, estimated]

Date	Time	Orthophosphate, filtered, mg/L as P	Phosphorus, unfiltered, mg/L as P	Total nitrogen, filtered, mg/L as N	Total nitrogen, unfiltered, mg/L as N	E. coli, MPN/ 100 mL	Enterococci, MPN/ 100 mL
12/09/09	1350	--	--	--	--	327	6,167
03/29/10	0411	0.027	0.272	10	11	4,352	1,169
08/24/10	0850	0.151	0.328	2.1	2.5	41,700	113,900
08/24/10	0920	0.203	0.392	1.9	2.9	8,164	41,100
09/30/10	0325	0.646	0.710	3.2	2.8	2,909	104,600
09/30/10	0440	0.578	0.616	2.7	2.3	2,098	86,200
09/30/10	0650	0.654	0.691	2.0	1.8	5,475	86,000
09/30/10	0715	0.624	0.663	2.0	1.8	4,611	83,900
09/30/10	0915	0.675	0.735	2.2	2.1	2,851	5,172

Table 8. Analytical results for spray-field runoff site SR1 at the LWRFL study area in North Carolina.

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; N, nitrogen; P, phosphorus; MPN, most probable number, mL, milliliter; --, not analyzed; >, greater than; <, less than]

Date	Time	Instantaneous discharge, ft^3/s	Specific conductance, µS/cm at 25 °C	Suspended solids, unfiltered, mg/L	Ammonia + organic N, filtered, mg/L as N	Ammonia + organic N, unfiltered, mg/L as N	Ammonia, filtered, mg/L as N	Nitrate + nitrite, filtered, mg/L as N	Organic nitrogen, filtered, mg/L as N	Organic nitrogen, unfiltered, mg/L as N
12/09/09	1305	0.30	56	--	--	--	--	--	--	--
03/29/10	0401	0.02	70	332	1.9	3.6	0.392	0.63	1.5	3.2
03/29/10	0417	0.26	73	126	2.3	2.7	0.417	0.77	1.9	2.3
03/29/10	0536	0.75	70	42	1.4	1.4	0.178	0.40	1.2	1.3
03/29/10	1056	0.05	69	32	1.9	1.8	0.066	0.19	1.8	1.8
08/24/10	0820	>11	53	160	0.97	1.9	0.073	0.48	0.90	1.8
08/24/10	0925	3.2	46	38	0.90	1.2	0.034	0.50	0.86	1.2
08/24/10	1010	1.5	53	<30	0.96	1.3	0.026	0.57	0.94	1.2
08/24/10	1120	0.60	61	<30	1.1	1.5	0.024	0.72	1.1	1.5
08/24/10	1410	0.07	71	<30	1.5	1.6	0.031	0.48	1.5	1.6
09/30/10	0014	2.1	89	<30	2.0	1.6	0.039	1.06	2.0	1.6
09/30/10	0526	5.7	66	<24	1.6	1.3	0.039	0.67	1.6	1.3
09/30/10	0712	10	48	<15	1.3	0.94	0.045	0.53	1.2	0.9
09/30/10	0840	2.5	64	<15	1.4	1.2	0.041	0.64	1.4	1.2
09/30/10	1140	0.56	81	<15	1.8	1.5	0.037	0.56	1.7	1.4

Table 8. Analytical results for spray-field runoff site SR1 at the LWRFL study area in North Carolina.—Continued

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; N, nitrogen; P, phosphorus; MPN, most probable number, mL, milliliter; --, not analyzed; >, greater than; <, less than]

Date	Time	Orthophosphate, filtered, mg/L as P	Phosphorus, unfiltered, mg/L as P	Total nitrogen, filtered, mg/L as N	Total nitrogen, unfiltered, mg/L as N	E. coli, MPN/100 mL	Enterococci, MPN/100 mL
12/09/09	1305	--	--	--	--	2,046	1,242
03/29/10	0401	0.339	0.950	2.5	4.2	3,873	10,462
03/29/10	0417	0.567	0.960	3.1	3.5	4,611	19,863
03/29/10	0536	0.324	0.605	1.8	1.8	14,136	17,329
03/29/10	1056	0.290	0.603	2.1	2.0	2,352	9,084
08/24/10	0820	0.599	0.930	1.5	2.4	218	1,413,600
08/24/10	0925	0.607	0.817	1.4	1.7	4,674	14,400
08/24/10	1010	0.605	0.818	1.5	1.8	8,164	55,200
08/24/10	1120	0.554	0.785	1.9	2.2	8,164	172,600
08/24/10	1410	0.466	0.646	2.0	2.1	2,142	60,200
09/30/10	0014	0.817	0.880	3.1	2.7	1,553	4,374
09/30/10	0526	0.767	0.812	2.3	2.0	1,785	17,900
09/30/10	0712	0.575	0.637	1.8	1.5	1,333	<1,000
09/30/10	0840	0.710	0.748	2.1	1.9	1,935	27,200
09/30/10	1140	0.660	0.683	2.3	2.0	--	14,400

Table 9. Analytical results for spray-field runoff site SR2 at the LWRFL study area in North Carolina.

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; N, nitrogen; P, phosphorus; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than; E, estimated; italics indicate quality-control sample]

Date	Time	Sample type	Instantaneous discharge, ft^3/s	Specific conductance, µS/cm at 25 °C	Suspended solids, unfiltered, mg/L	Ammonia + organic N, filtered, mg/L as N	Ammonia + organic N, unfiltered, mg/L as N	Ammonia, filtered, mg/L as N	Nitrate + nitrite, filtered, mg/L as N
12/09/09	1215	Water	0.02	110	--	--	--	--	--
03/29/10	0324	Water	0.01	103	142	2.0	3.1	0.232	1.30
03/29/10	0438	Water	0.05	85	30	1.6	2.0	0.122	0.67
03/29/10	0619	Water	0.02	97	36	2.1	2.4	0.105	0.70
03/30/10	*0940*	*Equipment blank*	--	--	--	*0.26*	*E0.06*	*E0.014*	*<0.04*
08/24/10	0830	Water	0.05	52	240	0.75	1.2	0.024	E0.02
09/29/10	2329	Water	0.28	97	<15	1.4	1.2	0.026	E0.02
09/30/10	0406	Water	0.64	83	<15	1.1	1.0	0.024	<0.04
09/30/10	0526	Water	1.2	72	<15	1.2	0.89	0.031	<0.04
09/30/10	0621	Water	2.5	49	<15	0.81	0.66	0.022	<0.04
09/30/10	0900	Water	0.11	89	<15	1.2	1.0	0.029	<0.04

Table 9. Analytical results for spray-field runoff site SR2 at the LWRFL study area in North Carolina.—Continued

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; N, nitrogen; P, phosphorus; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than; E, estimated; italics indicate quality-control sample]

Date	Time	Sample type	Organic nitrogen, filtered, mg/L as N	Organic nitrogen, unfiltered, mg/L as N	Orthophosphate, filtered, mg/L as P	Phosphorus, unfiltered, mg/L as P	Total nitrogen, filtered, mg/L as N	Total nitrogen, unfiltered, mg/L as N	E. coli, MPN/100 mL	Enterococci, MPN/100 mL
12/09/09	1215	Water	--	--	--	--	--	--	6,131	505
03/29/10	0324	Water	1.8	2.9	1.32	1.98	3.3	4.4	30	11,199
03/29/10	0438	Water	1.5	1.9	1.43	1.75	2.3	2.7	10	1,887
03/29/10	0619	Water	2.0	2.3	1.41	1.73	2.8	3.1	<10	4,996
03/30/10	*0940*	*Equipment blank*	*E0.25*	*E0.04*	*<0.008*	*<0.008*	*<0.3*	*<0.1*	--	--
08/24/10	0830	Water	0.73	1.2	2.03	2.19	E0.78	E1.3	457	189,200
09/29/10	2329	Water	1.4	1.2	3.61	3.41	E1.4	E1.2	24,600	25,300
09/30/10	0406	Water	1.1	1.0	3.09	2.92	<1.1	<1.1	30	28,800
09/30/10	0526	Water	1.1	0.86	2.72	2.52	<1.2	<0.93	512	27,500
09/30/10	0621	Water	0.78	0.64	1.70	1.66	<0.85	<0.70	336	38,900
09/30/10	0900	Water	1.2	0.97	3.36	3.36	<1.2	<1.0	733	23,800

Table 10. Analytical results for upstream site ST1A at the LWRFL study area in North Carolina.

[mm Hg, millimeters of mercury; °C, degrees Celsius; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; N, nitrogen; P, phosphorus; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than; E, estimated; italics indicate quality-control samples; shading indicates samples collected during storm-runoff events]

Date	Time	Sample type	Barometric pressure, mm Hg	Tempera-ture, air, °C	Instantaneous discharge, ft^3/s	Dissolved oxygen, mg/L	Dissolved oxygen percent of saturation	pH, standard units	Specific conductance, µS/cm at 25 °C	Temperature, water, °C
11/03/09	1020	Water	761	16.0	0.04	7.7	75	6.1	86	13.9
11/17/09	0910	Water	761	13.0	0.08	8.3	80	6.0	89	13.4
12/07/09	1215	Water	--	10.0	0.10	--	--	--	--	--
12/09/09	1045	Water	745	14.5	4.2	10.8	95	6.1	47	9.4
01/12/10	1105	Water	762	4.0	0.14	11.1	91	5.4	65	6.6
02/17/10	1055	Water	751	4.5	0.13	10.3	86	5.5	68	7.1
03/10/10	0930	Water	760	13.0	0.12	10.5	96	5.6	70	11.1
03/22/10	0955	Water	751	14.0	0.12	9.6	94	5.8	70	13.8
03/29/10	0232	Water	--	--	0.16	--	--	--	77	--
03/29/10	0423	Water	--	--	1.4	--	--	--	62	--
03/29/10	0844	Water	--	--	0.41	--	--	--	60	--
04/07/10	1055	Water	756	24.5	0.08	9.1	97	5.9	77	18.2
05/04/10	1015	Water	755	26.0	0.07	6.4	70	5.9	83	18.6
05/04/10	*1020*	*Replicate*	--	--	--	--	--	--	--	--
06/14/10	1040	Water	755	29.0	0.06	6.5	74	5.9	84	21.2
07/12/10	1045	Water	754	28.0	0.03	6.5	73	6.0	89	20.8
08/02/10	1025	Water	759	24.0	0.04	6.7	74	6.1	90	20.2
08/24/10	0845	Water	--	--	25	--	--	--	48	--
08/24/10	0915	Water	--	--	21	--	--	--	55	--
08/24/10	1100	Water	--	--	3.6	--	--	--	76	--
08/24/10	1445	Water	--	--	0.32	--	--	--	101	--
09/20/10	1010	Water	756	27.5	0.03	6.1	66	6.0	89	19.2
09/29/10	2333	Water	--	--	1.8	--	--	--	78	--
09/30/10	0408	Water	--	--	9.0	--	--	--	78	--
09/30/10	0533	Water	--	--	22	--	--	--	74	--
09/30/10	0830	Water	--	--	11.0	--	--	--	64	--
09/30/10	1200	Water	--	--	1.9	--	--	--	75	--
10/12/10	*1020*	*Field blank*	--	--	--	--	--	--	--	--
10/12/10	1050	Water	753	25.0	0.06	6.5	68	5.9	91	17.3
11/29/10	1140	Water	768	10.5	0.06	7.7	70	6.0	84	10.9
01/04/11	1205	Water	758	9.0	0.07	8.8	76	5.8	83	8.9

Table 10. Analytical results for upstream site ST1A at the LWRFL study area in North Carolina.—Continued

[mm Hg, millimeters of mercury; °C, degrees Celsius; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; N, nitrogen; P, phosphorus; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than; E, estimated; italics indicate quality-control samples; shading indicates samples collected during storm-runoff events]

Date	Time	Sample type	Suspended solids, unfiltered, mg/L	Ammonia + organic N, filtered, mg/L as N	Ammonia + organic N, unfiltered, mg/L as N	Ammonia, filtered, mg/L as N	Nitrate + nitrite, filtered, mg/L as N	Organic nitrogen, filtered, mg/L as N	Organic nitrogen, unfiltered, mg/L as N
11/03/09	1020	Water	<15	0.38	0.25	0.041	1.28	0.34	0.21
11/17/09	0910	Water	--	--	--	--	--	--	--
12/07/09	1215	Water	--	--	--	--	--	--	--
12/09/09	1045	Water	--	--	--	--	--	--	--
01/12/10	1105	Water	--	--	--	--	--	--	--
02/17/10	1055	Water	--	--	--	--	--	--	--
03/10/10	0930	Water	<15	0.50	0.42	0.150	1.16	0.35	0.27
03/22/10	0955	Water	--	--	--	--	--	--	--
03/29/10	0232	Water	476	1.0	1.5	0.224	1.07	0.80	1.3
03/29/10	0423	Water	132	0.92	1.7	0.121	0.53	0.80	1.6
03/29/10	0844	Water	<30	0.72	0.86	0.089	0.76	0.63	0.77
04/07/10	1055	Water	--	--	--	--	--	--	--
05/04/10	1015	Water	<15	0.62	0.59	0.219	2.71	0.40	0.37
05/04/10	*1020*	*Replicate*	*<15*	*0.63*	*0.61*	*0.207*	*3.3*	*0.42*	*0.41*
06/14/10	1040	Water	<15	0.63	0.64	0.210	1.36	0.42	0.42
07/12/10	1045	Water	--	--	--	--	--	--	--
08/02/10	1025	Water	--	--	--	--	--	--	--
08/24/10	0845	Water	32	0.85	1.6	0.046	1.21	0.80	1.6
08/24/10	0915	Water	<150	0.91	1.6	0.045	1.48	0.86	1.5
08/24/10	1100	Water	<30	1.2	1.5	0.028	2.12	1.1	1.5
08/24/10	1445	Water	88	0.96	1.2	0.029	2.62	0.93	1.1
09/20/10	1010	Water	--	--	--	--	--	--	--
09/29/10	2333	Water	52	1.6	1.2	E0.018	1.12	E1.6	E1.2
09/30/10	0408	Water	36	1.6	1.5	E0.019	1.56	E1.6	E1.5
09/30/10	0533	Water	37	1.7	1.6	0.027	1.44	1.7	1.5
09/30/10	0830	Water	49	1.3	1.2	0.024	1.14	1.3	1.2
09/30/10	1200	Water	<25	1.4	1.2	0.023	1.13	1.4	1.2
10/12/10	*1020*	*Field blank*	--	*0.14*	*<0.05*	*<0.01*	*<0.02*	*<0.14*	*<0.05*
10/12/10	1050	Water	<15	0.63	0.41	0.242	1.61	0.39	0.17
11/29/10	1140	Water	<15	0.27	0.32	0.154	1.67	0.12	0.16
01/04/11	1205	Water	--	--	--	--	--	--	--

Table 10. Analytical results for upstream site ST1A at the LWRFL study area in North Carolina.—Continued

[mm Hg, millimeters of mercury; °C, degrees Celsius; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; N, nitrogen; P, phosphorus; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than; E, estimated; italics indicate quality-control samples; shading indicates samples collected during storm-runoff events]

Date	Time	Sample type	Orthophosphate, filtered, mg/L as P	Phosphorus, unfiltered, mg/L as P	Total nitrogen, filtered, mg/L as N	Total nitrogen, unfiltered, mg/L as N	E. coli, MPN/100 mL	Enterococci, MPN/100 mL
11/03/09	1020	Water	E0.007	0.023	1.7	1.5	--	--
11/17/09	0910	Water	--	--	--	--	--	--
12/07/09	1215	Water	--	--	--	--	<10	<10
12/09/09	1045	Water	--	--	--	--	1,246	30
01/12/10	1105	Water	--	--	--	--	73	528
02/17/10	1055	Water	--	--	--	--	30	320
03/10/10	0930	Water	E0.008	0.014	1.7	1.6	199	40
03/22/10	0955	Water	--	--	--	--	404	605
03/29/10	0232	Water	0.008	0.476	2.1	2.6	345	2,987
03/29/10	0423	Water	E0.015	0.404	1.5	2.2	4,884	29,200
03/29/10	0844	Water	0.013	0.089	1.5	1.6	1,291	6,294
04/07/10	1055	Water	--	--	--	--	199	84
05/04/10	1015	Water	0.014	0.035	3.3	3.3	63	341
05/04/10	*1020*	*Replicate*	*0.014*	*0.036*	*3.9*	*3.9*	--	--
06/14/10	1040	Water	0.019	0.023	2.0	2.0	637	2,595
07/12/10	1045	Water	--	--	--	--	213	2,064
08/02/10	1025	Water	--	--	--	--	414	1,081
08/24/10	0845	Water	0.239	0.709	2.1	2.8	29,900	517,200
08/24/10	0915	Water	0.253	0.685	2.4	3.1	20,100	435,200
08/24/10	1100	Water	0.277	0.508	3.3	3.7	12,200	307,600
08/24/10	1445	Water	0.144	0.269	3.6	3.8	8,664	41,700
09/20/10	1010	Water	--	--	--	--	12,033	7,270
09/29/10	2333	Water	0.179	0.316	2.7	2.3	18,700	48,800
09/30/10	0408	Water	0.364	0.476	3.2	3.1	12,100	57,100
09/30/10	0533	Water	0.495	0.721	3.1	3.0	5,475	56,500
09/30/10	0830	Water	0.421	0.513	2.5	2.4	6,488	2,037
09/30/10	1200	Water	0.300	0.366	2.5	2.4	2,755	1,456
10/12/10	*1020*	*Field blank*	*<0.004*	*<0.004*	*<0.16*	*<0.07*	--	--
10/12/10	1050	Water	0.013	0.024	2.2	2.0	176	512
11/29/10	1140	Water	0.016	0.017	1.9	2.0	31	52
01/04/11	1205	Water	--	--	--	--	41	8,664

Table 11. Analytical results for intermediate stream sites ST1B and ST1C at the LWRFL study area in North Carolina.

[mm Hg, millimeters of mercury; °C, degrees Celsius; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than]

Date	Time	Barometric pressure, mm Hg	Temperature, air, °C	Instantaneous discharge, ft^3/s	Dissolved oxygen, mg/L	Dissolved oxygen percent of saturation	pH, standard units	Specific conductance, µS/cm at 25 °C	Temperature, water, °C	E. coli, MPN/ 100 mL	Enterococci, MPN/ 100 mL
						Site ST1B					
11/03/09	1135	760	16.0	0.05	6.9	67	6.0	185	13.7	--	--
11/17/09	1000	761	14.5	0.09	8.4	80	6.0	167	13.1	--	--
01/12/10	1150	761	4.5	0.14	10.6	87	5.8	149	7.0	<10	2,415
02/17/10	1140	752	4.0	0.15	10.2	85	5.6	140	6.9	<10	20
03/22/10	1040	751	16.0	0.15	8.9	87	5.9	149	13.9	52	420
04/07/10	1135	756	27.0	0.10	8.0	84	5.8	166	17.0	41	93
05/04/10	1120	755	24.5	0.07	6.4	69	5.8	183	18.2	75	432
06/14/10	1135	755	29.0	0.04	6.9	77	5.8	178	20.3	199	7,701
07/12/10	1130	754	27.0	0.09	6.6	74	6.0	226	20.4	345	1,354
08/02/10	1100	760	24.5	0.09	7.0	77	6.1	219	20.0	323	889
09/20/10	1045	757	27.0	0.04	7.2	78	6.0	223	18.7	309	4,884
10/12/10	1150	754	23.0	0.12	7.5	78	5.9	204	16.8	160	3,255
11/29/10	1235	768	11.0	--	7.9	70	6.1	194	10.1	<10	132
01/04/11	1240	757	10.0	0.09	8.8	75	5.8	186	8.2	10	399
						Site ST1C					
11/03/09	1235	760	18.5	0.05	8.7	84	6.8	174	13.2	--	--
11/17/09	1115	760	15.0	0.12	9.8	94	6.7	166	13.1	--	--
01/12/10	1240	761	4.0	0.15	12.1	98	6.9	150	6.2	109	2,142
02/17/10	1255	752	6.5	0.13	11.1	92	6.3	139	6.8	<10	211
03/22/10	1130	751	16.5	0.22	11.0	108	6.5	147	13.8	122	383
04/07/10	1215	756	26.0	0.12	9.8	105	6.5	161	18.1	160	708
05/04/10	1200	755	24.0	0.07	8.0	87	6.5	178	18.9	134	1,029
06/14/10	1225	755	31.0	0.01	8.0	93	6.5	171	21.9	404	3,968
07/12/10	1240	754	28.5	0.07	8.1	95	6.8	212	22.2	75	933
08/02/10	1200	760	24.5	0.08	8.3	94	6.8	204	21.1	199	909
09/20/10	1130	757	27.5	0.08	8.6	94	6.7	209	19.2	161	1,935
10/12/10	1235	753	26.0	0.12	8.9	94	6.6	197	17.0	404	1,374
11/29/10	1305	768	12.0	--	9.9	86	6.7	190	9.1	41	122
01/04/11	1335	757	11.0	0.09	11.0	91	6.4	176	7.2	199	663

Table 12. Analytical results for downstream site ST1D at the LWRFL study area in North Carolina.

[mm Hg, millimeters of mercury; °C, degrees Celsius; ft³/s, cubic feet per second; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; N, nitrogen; P, phosphorus; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than; E, estimated; italics indicate quality-control samples; shading indicates samples collected during storm-runoff events]

Date	Time	Sample type	Barometric pressure, mm Hg	Tempera-ture, air, °C	Instantaneous discharge, ft³/s	Dissolved oxygen, mg/L	Dissolved oxygen percent of saturation	pH, standard units	Specific conductance, µS/cm at 25 °C	Tempera-ture, water, °C
11/03/09	1315	Water	759	19.0	0.06	7.5	73	6.6	165	13.4
11/17/09	1225	Water	760	16.5	0.12	9.2	89	6.5	159	13.4
12/07/09	1300	Water	--	11.0	0.21	--	--	--	--	--
12/09/09	1135	Water	743	16.5	5.0	10.8	97	6.3	64	10.2
01/12/10	1335	Water	761	3.5	0.25	12.8	104	6.6	145	6.1
02/17/10	1405	Water	751	6.5	0.26	11.2	94	6.3	136	7.0
03/08/10	1015	Water	759	13.0	0.20	13.8	116	6.3	141	7.7
03/08/10	1230	Water	759	17.0	0.20	14.8	130	6.5	140	9.6
03/10/10	1025	Water	757	16.0	0.26	12.7	116	6.6	142	11.0
03/22/10	1230	Water	751	18.5	0.21	12.8	130	6.6	140	15.1
03/29/10	0347	Water	--	--	0.61	--	--	--	134	--
03/29/10	0431	Water	--	--	2.7	--	--	--	104	--
03/29/10	0612	Water	--	--	1.8	--	--	--	72	--
04/07/10	1300	Water	756	30.5	0.19	11.1	121	6.6	154	19.0
05/04/10	1245	Water	755	24.0	0.10	7.2	79	6.4	167	18.8
06/14/10	1315	Water	755	32.0	0.11	7.7	89	6.5	162	22.5
07/12/10	1330	Water	753	28.5	0.04	7.6	89	6.7	200	22.7
08/02/10	1245	Water	760	26.0	0.08	8.2	93	6.8	193	21.8
08/24/10	0830	Water	--	--	29	--	--	--	48	--
08/24/10	0915	Water	--	--	20	--	--	--	52	--
08/24/10	1000	Water	--	--	9.4	--	--	--	61	--
08/24/10	1115	Water	--	--	4.1	--	--	--	75	--
08/24/10	1330	Water	--	--	1.5	--	--	--	93	--
09/20/10	1225	Water	757	27.5	0.03	8.2	91	6.7	199	20.1
09/29/10	2352	Water	--	--	5.6	--	--	--	90	--
09/30/10	0146	Water	--	--	10	--	--	--	79	--
09/30/10	0337	Water	--	--	10	--	--	--	84	--
09/30/10	0925	Water	--	--	11	--	--	--	74	--
09/30/10	1225	Water	--	--	4.5	--	--	--	92	--
09/30/10	*2100*	*Equipment blank*	--	--	--	--	--	--	--	--
10/12/10	1320	Water	754	27.0	0.11	8.7	92	6.5	184	17.4
10/12/10	*1325*	*Replicate*	--	--	--	--	--	--	--	--
11/29/10	1330	Water	768	12.5	0.13	9.1	79	6.7	177	9.0
12/13/10	1015	Water	740	1.5	0.17	9.3	77	6.0	160	5.8
01/04/11	1420	Water	757	10.0	0.19	10.9	91	6.5	165	7.3

Table 12. Analytical results for downstream site ST1D at the LWRFL study area in North Carolina.—Continued

[mm Hg, millimeters of mercury; °C, degrees Celsius; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; N, nitrogen; P, phosphorus; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than; E, estimated; italics indicate quality-control samples; shading indicates samples collected during storm-runoff events]

Date	Time	Sample type	Suspended solids, unfiltered, mg/L	Ammonia + organic N, filtered, mg/L as N	Ammonia + organic N, unfiltered, mg/L as N	Ammonia, filtered, mg/L as N	Nitrate + nitrite, filtered, mg/L as N	Organic nitrogen, filtered, mg/L as N	Organic nitrogen, unfiltered, mg/L as N
11/03/09	1315	Water	<15	0.51	0.24	<0.020	2.39	<0.51	<0.24
11/17/09	1225	Water	--	--	--	--	--	--	--
12/07/09	1300	Water	--	--	--	--	--	--	--
12/09/09	1135	Water	--	--	--	--	--	--	--
01/12/10	1335	Water	--	--	--	--	--	--	--
02/17/10	1405	Water	--	--	--	--	--	--	--
03/08/10	1015	Water	--	--	--	<0.020	2.85	--	<0.16
03/08/10	1230	Water	--	--	--	--	--	--	--
03/10/10	1025	Water	<15	0.32	0.28	<0.020	2.74	<0.32	<0.28
03/22/10	1230	Water	--	--	--	--	--	--	--
03/29/10	0347	Water	32	0.54	0.71	0.096	2.43	0.44	0.61
03/29/10	0431	Water	174	0.81	1.7	0.183	1.30	0.63	1.5
03/29/10	0612	Water	66	1.0	1.1	0.111	0.79	0.91	1.0
04/07/10	1300	Water	--	--	--	--	--	--	--
05/04/10	1245	Water	<15	0.30	0.29	0.035	1.11	0.26	0.26
06/14/10	1315	Water	<15	0.40	0.25	0.022	3.02	0.38	0.23
07/12/10	1330	Water	--	--	--	--	--	--	--
08/02/10	1245	Water	--	--	--	--	--	--	--
08/24/10	0830	Water	648	0.95	4.3	0.077	0.71	0.87	4.2
08/24/10	0915	Water	324	0.89	1.9	0.054	1.19	0.83	1.8
08/24/10	1000	Water	184	0.94	1.6	0.054	1.44	0.88	1.6
08/24/10	1115	Water	76	1.0	1.5	0.040	1.75	1.0	1.4
08/24/10	1330	Water	<30	1.2	1.2	0.055	2.15	1.2	1.2
09/20/10	1225	Water	--	--	--	--	--	--	--
09/29/10	2352	Water	72	1.8	1.9	E0.019	1.29	E1.8	E1.9
09/30/10	0146	Water	140	1.7	1.8	0.027	1.37	1.6	1.7
09/30/10	0337	Water	45	1.7	1.5	0.030	1.68	1.7	1.4
09/30/10	0925	Water	81	1.1	1.4	0.027	1.46	1.1	1.3
09/30/10	1225	Water	43	1.4	1.3	0.043	1.75	1.4	1.2
09/30/10	*2100*	*Equipment blank*	--	*0.12*	*<0.1*	*<0.02*	*<0.04*	*<0.12*	*<0.1*
10/12/10	1320	Water	<15	0.80	0.17	0.037	3.53	0.76	0.13
10/12/10	*1325*	*Replicate*	*<15*	*0.92*	*0.22*	*0.041*	*3.57*	*0.88*	*0.18*
11/29/10	1330	Water	<15	0.17	0.18	0.011	3.31	0.16	0.17
12/13/10	1015	Water	--	--	--	<0.010	2.82	--	<0.21
01/04/11	1420	Water	--	--	--	--	--	--	--

Table 12. Analytical results for downstream site ST1D at the LWRFL study area in North Carolina.—Continued

[mm Hg, millimeters of mercury; °C, degrees Celsius; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; N, nitrogen; P, phosphorus; MPN, most probable number; mL, milliliter; --, not analyzed; <, less than; E, estimated; italics indicate quality-control samples; shading indicates samples collected during storm-runoff events]

Date	Time	Sample type	Orthophosphate, filtered, mg/L as P	Phosphorus, unfiltered, mg/L as P	Total nitrogen, filtered, mg/L as N	Total nitrogen, unfiltered, mg/L as N	E. coli, MPN/ 100 mL	Enterococci, MPN/ 100 mL
11/03/09	1315	Water	E0.006	0.018	2.9	2.6	--	--
11/17/09	1225	Water	--	--	--	--	--	--
12/07/09	1300	Water	--	--	--	--	10	30
12/09/09	1135	Water	--	--	--	--	613	379
01/12/10	1335	Water	--	--	--	--	41	1,918
02/17/10	1405	Water	--	--	--	--	<1,000	86
03/08/10	1015	Water	0.011	0.017	--	--	285	1,236
03/08/10	1230	Water	--	--	--	--	na	na
03/10/10	1025	Water	0.010	0.016	3.1	3.0	420	10
03/22/10	1230	Water	--	--	--	--	135	20
03/29/10	0347	Water	0.013	0.081	3.0	3.1	624	1,904
03/29/10	0431	Water	0.014	0.416	2.1	3.0	8,664	18,500
03/29/10	0612	Water	0.123	0.354	1.8	1.9	8,164	13,200
04/07/10	1300	Water	--	--	--	--	161	291
05/04/10	1245	Water	0.022	0.035	1.4	1.4	74	1,725
06/14/10	1315	Water	0.029	0.033	3.4	3.3	327	2,851
07/12/10	1330	Water	--	--	--	--	122	10
08/02/10	1245	Water	--	--	--	--	161	536
08/24/10	0830	Water	0.199	1.03	1.7	5.0	53,800	1,203,300
08/24/10	0915	Water	0.258	0.889	2.1	3.1	17,100	547,500
08/24/10	1000	Water	0.274	0.698	2.4	3.0	16,000	3,448
08/24/10	1115	Water	0.270	0.526	2.8	3.2	18,300	250,000
08/24/10	1330	Water	0.229	0.418	3.4	3.4	12,997	110,600
09/20/10	1225	Water	--	--	--	--	160	2,613
09/29/10	2352	Water	0.361	0.513	3.1	3.2	3,873	37,900
09/30/10	0146	Water	0.420	0.659	3.0	3.1	6,867	56,500
09/30/10	0337	Water	0.439	0.638	3.4	3.1	5,794	29,800
09/30/10	0925	Water	0.429	0.595	2.6	2.8	2,613	25,600
09/30/10	1225	Water	0.302	0.379	3.2	3.0	4,106	44,800
09/30/10	*2100*	*Equipment blank*	*<0.008*	*<0.008*	*<0.16*	*<0.14*	--	--
10/12/10	1320	Water	0.015	0.030	4.3	3.7	216	906
10/12/10	*1325*	*Replicate*	*0.012*	*0.028*	*4.5*	*3.8*	--	--
11/29/10	1330	Water	0.016	0.013	3.5	3.5	98	<10
12/13/10	1015	Water	0.016	0.017	--	--	--	--
01/04/11	1420	Water	--	--	--	--	160	98

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