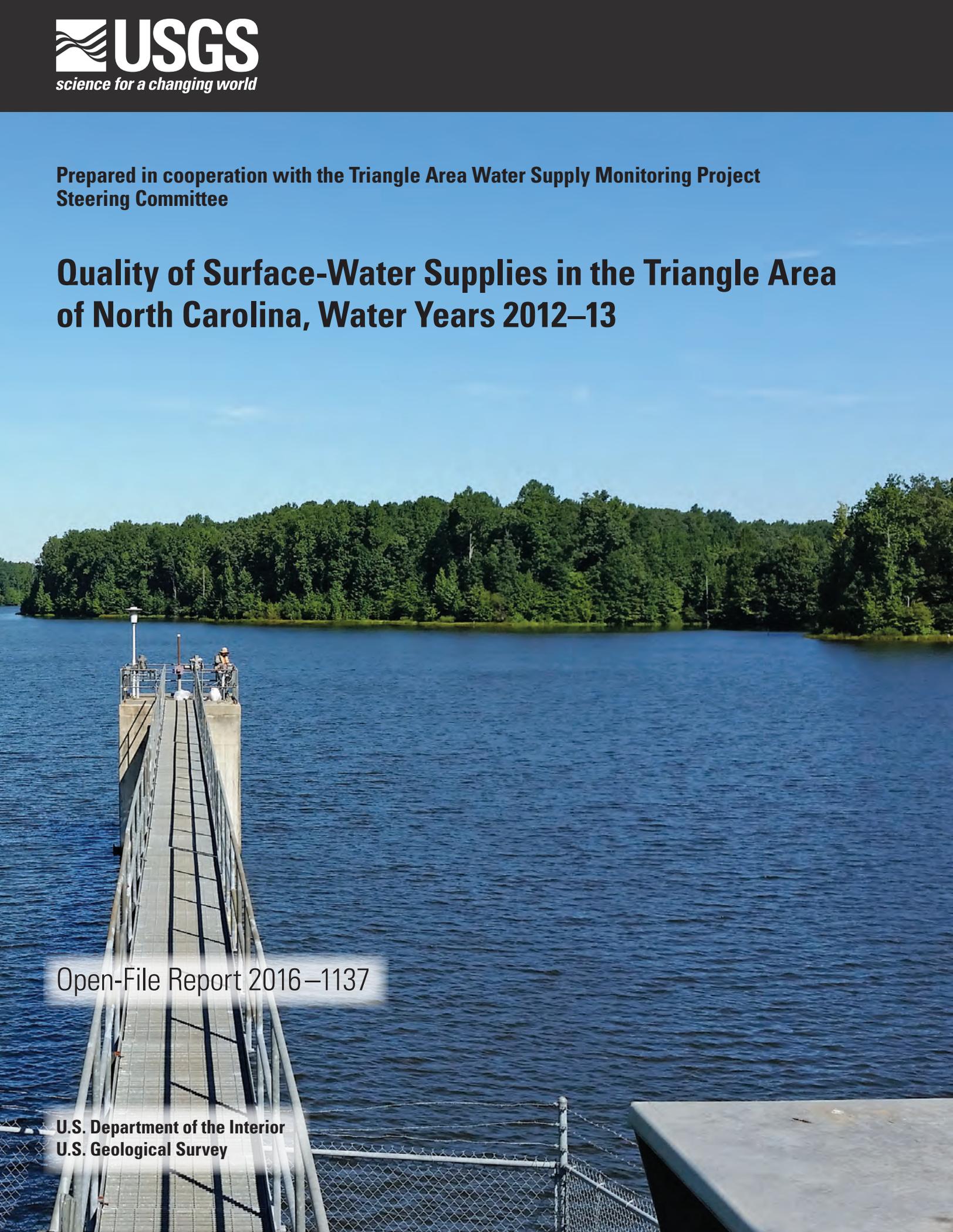


Prepared in cooperation with the Triangle Area Water Supply Monitoring Project
Steering Committee

Quality of Surface-Water Supplies in the Triangle Area of North Carolina, Water Years 2012–13

Open-File Report 2016–1137

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



Cover. West Fork Eno Reservoir at dam near Cedar Grove, North Carolina (photograph by Ryan B. Rasmussen, U.S. Geological Survey).

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By C.A. Pfeifle, J.L. Cain, and R.B. Rasmussen

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

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

U.S. Geological Survey
Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 2016

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[Available for downloading from <http://dx.doi.org/10.3133/ofr20161137>]

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- Appendix 4. Chemical constituents and physical properties analyzed by the U.S. Geological Survey National Water Quality Laboratory for the Triangle Area Water Supply Monitoring Project, and the methods used for sample analyses, October 2011 through September 2013

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
	Flow rate	
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m ³ /s)

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

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32.$$

Datum

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

Supplemental Information

Water year is defined as the period from October 1 to September 30 and is identified by the year in which the period ends. For example, water year 2012 is October 1, 2011, to September 30, 2012.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter ($\mu\text{g}/\text{L}$).

Previous North Carolina state agency names in existence at the time of data collection—the North Carolina Division of Water Quality (NCDWQ) and the Department of Environment and Natural Resources (DENR)—are used in this report. The North Carolina Division of Water Quality (NCDWQ) became the North Carolina Division of Water Resources (NCDWR) in August 2013, and the Department of Environment and Natural Resources (DENR) became the Department of Environmental Quality (DEQ) in September 2015.

Abbreviations

DENR	Department of Environment and Natural Resources
MCL	maximum contaminant level
NCDWQ	North Carolina Division of Water Quality
NWISWeb	USGS National Water Information System
SDWR	secondary drinking-water regulation
TAWSSMP	Triangle Area Water Supply Monitoring Project
USGS	U.S. Geological Survey

Quality of Surface-Water Supplies in the Triangle Area of North Carolina, Water Years 2012–13

By C.A. Pfeifle, J.L. Cain, and R.B. Rasmussen

Abstract

Surface-water supplies are important sources of drinking water for residents in the Triangle area of North Carolina, which is located within the upper Cape Fear and Neuse River Basins. Since 1988, the U.S. Geological Survey and a consortium of local governments have tracked water-quality conditions and trends in several of the area's water-supply lakes and streams. This report summarizes data collected through this cooperative effort, known as the Triangle Area Water Supply Monitoring Project, during October 2011 through September 2012 (water year 2012) and October 2012 through September 2013 (water year 2013). Major findings for this period include:

- Annual precipitation was approximately 2 percent above the long-term mean (average) annual precipitation in 2012 and approximately 3 percent below the long-term mean in 2013.
- In water year 2012, streamflow was generally below the long-term mean during most of the period for the 10 project streamflow gaging stations. Streamflow was near or above the long-term mean at the same streamflow gaging stations during the 2013 water year.
- More than 7,000 individual measurements of water quality were made at a total of 17 sites—6 in the Neuse River Basin and 11 in the Cape Fear River Basin. Forty-three water-quality properties or constituents were measured; State water-quality standards exist for 23 of these.
- All observations met State water-quality standards for pH, temperature, hardness, chloride, fluoride, sulfate, nitrate, arsenic, cadmium, chromium, lead, nickel, and selenium.
- North Carolina water-quality standards were exceeded one or more times for dissolved oxygen, dissolved-oxygen percent saturation, turbidity, chlorophyll *a*, copper, iron, manganese, mercury, silver, and zinc. Exceedances occurred at all 17 sites.
- Stream samples collected during storm events contained elevated concentrations of 19 water-quality constituents relative to non-storm events.

Introduction

The Triangle area, located within the upper Cape Fear and Neuse River Basins, is one of the most rapidly developing areas of North Carolina. Population growth continues to increase demands for water from public suppliers, the majority of which draw water from streams and lakes in the region. Growth also brings the threat of greater loads of pollutants and new contaminant sources which, if not properly managed, could adversely affect water quality.

For more than 25 years, the Triangle Area Water Supply Monitoring Project (TAWSSMP) has tracked water-quality conditions and long-term trends in many of the area's water-supply lakes, rivers, and tributaries. The project has progressed in phases, allowing for flexibility in the monitoring network and partners and for timely response to emerging water-quality concerns (<http://nc.water.usgs.gov/projects/triangle/overview.html>). Objectives of the project for water years 2012 and 2013:

- Extend the existing water-quality database for nutrients, sediment, major ions, and metals and trace elements to track spatial variations in water quality, loads to reservoirs, and long-term water-quality trends.
- Continue monitoring at tributary sites during high-flow events to increase the understanding of constituent concentrations and loads during extreme hydrologic conditions.
- Maintain a network of 10 continuous streamflow gaging stations in the study area.

Pursuant to an agreement with several local governments, the U.S. Geological Survey (USGS) monitors hydrologic conditions and collects water-quality samples. One site in the Triangle area consists only of a streamflow gage. Continuous streamflow is recorded at almost all of the stream sites and is funded through the TAWSSMP and other USGS programs. The USGS is responsible for data quality assurance, analysis, and interpretation, providing the data to the public and maintaining the data in perpetuity. Funding for the project is provided by local government partners (see sidebar) and by the USGS cooperative matching funds (<http://water.usgs.gov/coop/>). The Triangle J Council of Governments provides organizational support services for the TAWSSMP.

Triangle Area Water Supply Monitoring Project Partners, 2012–13

Chatham County
Orange County
Town of Apex
Town of Cary
City of Durham
Town of Hillsborough
Town of Morrisville
Orange Water and Sewer Authority
Triangle J Council of Governments
U.S. Geological Survey

For more information on the project, go to
<http://nc.water.usgs.gov/projects/triangle/overview.html>.

This report summarizes monitoring activities and data collected by the USGS for the TAWSMP during October 2011 through September 2013, also referred to as water years 2012 (October 2011 to September 2012) and 2013 (October 2012 to September 2013). Hydrologic conditions in the Triangle area are described. Ranges of concentrations for water-quality field parameters, major ions, nutrients, metals and trace elements, organic carbon, and suspended sediment are presented for each site sampled during this period. The supporting data for this report are available at Pfeifle and others (2016; <http://dx.doi.org/10.5066/F77M061X>).

Monitoring Network

Since the project began in 1988, several adjustments have been made to sampling locations, sampling frequency, and constituents that are sampled. During 2012–13, the TAWSMP monitoring network was composed of 22 sites, including streamflow gaging stations and stream and lake water-quality sampling sites (fig. 1). Water-quality samples were collected at 17 sites during this period. Beginning in October 2011, turbidity was recorded at all lake sites by using a handheld turbidity meter. Lake samples collected at the mid-depth were discontinued at all the lake sites in October 2011. Analyses were discontinued for color (platinum cobalt units) and nitrite (filtered as milligram per liter). Beginning in July 2012, the goal to collect storm-runoff samples was reduced to 10 samples per year. Project sampling and analytical methods and quality-assurance practices are described by Oblinger (2004).

Streamflow Gaging Stations

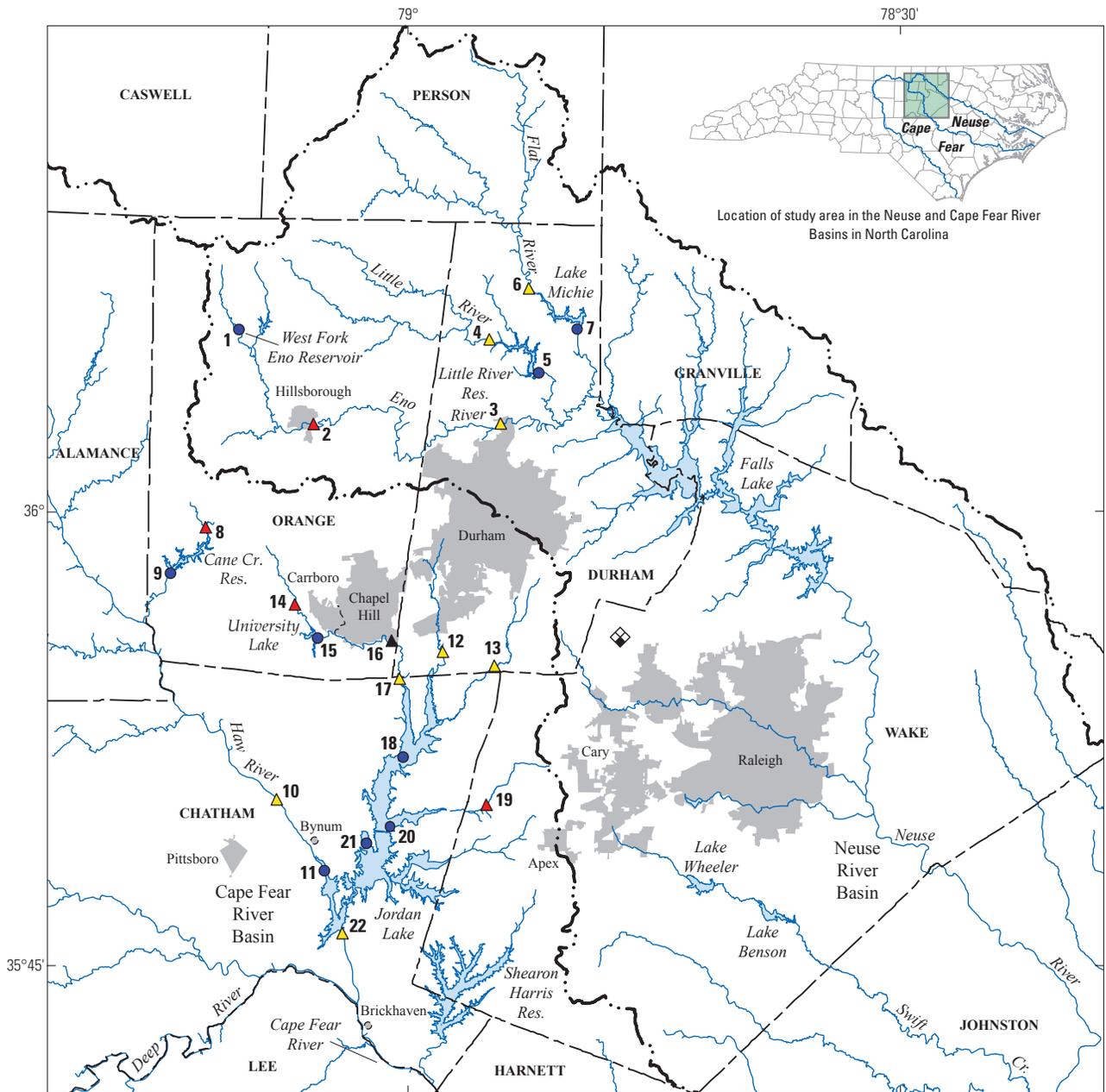
Streamflow records are useful for managing water supplies and are essential for determining in-stream loads of sediment, nutrients, and other constituents and interpreting water-quality

trends. The USGS operates 10 continuous-record streamflow gaging stations that are funded through the TAWSMP (table 1). These gages record water level and discharge at 15-minute intervals and display them in near-real time through the USGS National Water Information System (NWISWeb) interface (<http://waterdata.usgs.gov/nc/nwis/current/?type=flow>). Precipitation and streamflow data for additional sites in the study area are available through other USGS programs (table 1).

Water-Quality Sites and Constituents

Water-quality data are used to track current conditions and to analyze long-term water-quality trends and pollutant loads in the Triangle area. The USGS monitored water quality at 17 sites in the TAWSMP study area during water years 2012 and 2013. More than 7,000 individual measurements of water quality were made, not including lake vertical-profile data. The measurements were made at 6 sites in the Neuse River Basin and 11 sites in the Cape Fear River Basin. USGS water-quality data as shown in appendix 1 are available to project partners and the public via the USGS NWISWeb (<http://nwis.waterdata.usgs.gov/nc/nwis/qwdata>) or by request from the USGS South Atlantic Water Science Center (<http://www.usgs.gov/water/southatlantic/>).

Six public water-supply lakes at nine sites were sampled including West Fork Eno Reservoir (site 1), Little River Reservoir (site 5), and Lake Michie (site 7) in the Neuse River Basin, and Cane Creek Reservoir (site 9), University Lake (site 15), and Jordan Lake (sites 11, 18, 20, 21) in the Cape Fear River Basin (table 1; fig. 1). Jordan Lake is a large, multipurpose reservoir managed by the U.S. Army Corps of Engineers. The USGS sampled four sites in Jordan Lake bimonthly during water years 2012 and 2013. The five smaller reservoirs are used primarily for water supplies although most also provide recreational access. One site in each of the smaller lakes was sampled four times (October, April, June, and August) per year. Lake samples were collected at multiple depths, but only near-surface samples were summarized in this report. Vertical profiles of field parameters (water temperature, dissolved oxygen, specific conductance, and pH) were measured at 1-meter (m) depth intervals at the sampling location, along with water transparency by Secchi disk depth. Water samples were collected for analysis of acid neutralizing capacity, turbidity, nutrients (ammonia plus organic nitrogen, ammonia, nitrate plus nitrite, orthophosphate, and phosphorus), major ions (calcium, magnesium, sodium, potassium, chloride, fluoride, sulfate, and silica), unfiltered iron and manganese, total organic carbon, phytoplankton, and chlorophyll *a* during each sampling trip (Oblinger, 2004). In this report, ammonia plus organic nitrogen, ammonia, and nitrate plus nitrite are reported in milligrams per liter as nitrogen (mg/L as N), and orthophosphate and phosphorus are reported in milligrams per liter as phosphorus (mg/L as P). Additional water samples were collected for unfiltered metals and trace elements (aluminum, arsenic, cadmium, chromium, cobalt, copper, zinc, lead, mercury, molybdenum, nickel, selenium, and silver) twice per year.



Base from digital files of:
 U.S. Department of Commerce, Bureau of Census,
 1990 Precensus TIGER/Line Files-Political boundaries, 1991
 U.S. Environmental Protection Agency, River File 3
 U.S. Geological Survey, 1:100,000 scale

EXPLANATION

- 16 ▲ Basin boundary
- 21 ● Streamgauge and number
- 14 ▲ Lake site and number
- 22 ▲ Stream site and number
- ▲ Runoff-only stream site and number
- ◆ National Weather Service precipitation station (KRDU)



Figure 1. Location of Triangle Area Water Supply Monitoring Project data-collection sites in the upper Cape Fear and Neuse River Basins, North Carolina, October 2011 through September 2013.

4 Quality of Surface-Water Supplies in the Triangle Area of North Carolina, Water Years 2012–13

Table 1. Water-quality and streamflow monitoring sites for the Triangle Area Water Supply Monitoring Project, North Carolina, October 2011 through September 2013.

[Site type: Lake, lake sites that were sampled bimonthly; Stream (runoff), stream sites that were sampled only during runoff events; Stream (routine), stream sites that were sampled bimonthly and during runoff. Abbreviations: no., number; USGS, U.S. Geological Survey; n/a, not applicable for lake sites; USACE, U.S. Army Corps of Engineers; —, data were not collected (refer to footnote)]

Map no. (fig. 1)	Site location in North Carolina, USGS station number (in downstream order)	Data collected during October 2011–September 2013			
		Site type	Water quality	Continuous streamflow	Period of record for continuous stream sites
Neuse River Basin					
1	West Fork Eno Reservoir at Dam near Cedar Grove, 0208480275	Lake	Yes	n/a	n/a
2	Eno River at Hillsborough, 02085000	Stream (routine)	Yes	Yes	1928–2013
3	Eno River near Durham, 02085070	Stream (runoff)	No	Yes	1963–2013
4	Little River at SR 1461 near Orange Factory, 0208521324	Stream (runoff)	Yes	Yes	1987–2013
5	Little River Reservoir at dam near Bahama, 0208524845	Lake	Yes	n/a	n/a
6	Flat River at Bahama, 02085500	Stream (runoff)	Yes	Yes	1925–2013
7	Lake Michie at dam near Bahama, 02086490	Lake	Yes	n/a	n/a
Cape Fear River Basin					
8	Cane Creek near Orange Grove, 02096846	Stream (routine)	Yes	Yes	1989–2013
9	Cane Creek Reservoir at dam near White Cross, 0209684980	Lake	Yes	n/a	n/a
10	Haw River near Bynum, 02096960	Stream (runoff)	No	(USACE) ¹	1974–2013
11	B. Everett Jordan Lake, Haw River arm near Hanks Chapel, 0209699999	Lake	Yes	n/a	n/a
12	New Hope Creek near Blands, 02097314	Stream (runoff)	Yes	Yes	1983–2013
13	Northeast Creek at SR 1100 near Genlee, 0209741955	Stream (runoff)	Yes	Yes	1983–2013
14	Morgan Creek near White Cross, 02097464	Stream (routine)	Yes	Yes	1989–2013
15	University Lake at intakes near Chapel Hill, 0209749990	Lake	Yes	n/a	n/a
16	Morgan Creek near Chapel Hill, 02097517	Streamflow only	n/a	Yes	1983–2013
17	Morgan Creek near Farrington, 02097521	Stream (runoff)	No	— ²	1989–95, 2009
18	B. Everett Jordan Lake at buoy 12 at Farrington, 0209768310	Lake	Yes	n/a	n/a
19	White Oak Creek at mouth near Green Level, 0209782609	Stream (routine)	Yes	Yes	2000–2013
20	B. Everett Jordan Lake above U.S. Highway 64 at Wilsonville, 0209799150	Lake	Yes	n/a	n/a
21	B. Everett Jordan Lake at Bells Landing near Griffins Crossroads, 0209801100	Lake	Yes	n/a	n/a
22	Haw River below B. Everett Jordan Lake dam near Moncure, 02098198	Stream (runoff)	No	— ³	1966–2013

¹Gage funded through separate agreement with agency shown in parentheses.

²Streamflow from nearby gage, USGS station 02097517.

³Streamflow computed from USACE releases from the Jordan Lake dam.

Four stream sites were sampled by the USGS on a bimonthly basis for field parameters, nutrients, major ions, total organic carbon, and suspended sediment, and twice per year for metals and trace elements. These sites include Eno River at Hillsborough (site 2), Cane Creek near Orange Grove (site 8), Morgan Creek near White Cross (site 14), and White Oak Creek (site 19; fig. 1; table 1). Samples were collected at multiple locations along a transect and were composited. Sampling is not conducted during zero-flow conditions, which occasionally occurs at the smaller streams.

In addition to the bimonthly sampling at the four stream sites, an additional eight stream sites in the TAWSMP network were considered for sampling only during storm-runoff events when the water level was rapidly increasing due to a localized rainfall event (appendix 1). Although eight stream sites were targeted, the actual number of sites where storm samples were collected varies from year to year and includes four sites during this period (table 1; fig. 1). During 2012–13, four additional stream sites were sampled by the USGS during selected storm-runoff events. These higher-flow samples supplement fixed-interval data collected by the North Carolina Division of Water Quality (NCDWQ) as part of the Ambient Monitoring System (<http://deq.nc.gov/about/divisions/water-resources>).

Only four runoff samples were collected using a portable refrigerated automatic sampler at Cane Creek (site 8) according to USGS protocols (U.S. Geological Survey, 2006). Once the pre-programmed water-level condition for the stream was met, seven individual 1-liter (L) polyethylene bottles were consecutively filled with sample water by the automatic sampler. After sampling was completed, the refrigerated automatic sampler maintained the samples at a temperature of 3 degrees Celsius (plus or minus 1 degree Celsius). The seven individual 1-L bottles were retrieved and all the contents in the bottles were composited into an 8-L plastic churn splitter. The samples were processed within 24 hours of collection using the same processing techniques as used for manual or routine samples (Wilde and others, 2004). Because the delay between collection and processing allowed conditions within the collection bottles to deviate from those measured in-stream, dissolved oxygen and water temperature measurements from the composite samples were not recorded. If the automatic sampler did not collect enough water, some constituents were not analyzed at the laboratory.

Acid neutralizing capacity was determined in the field at the time of sampling, using USGS standard methods (Rounds, 2012). Nutrient, major ions, and trace element analyses were performed at the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado. Chlorophyll *a* analyses were performed by Meritech, Inc., in Reidsville, N.C. Meritech, Inc., participated in the chlorophyll *a* inter-laboratory performance comparisons (round robins) sponsored by the NCDWQ during 2012 and 2013. Water samples were analyzed for suspended sediment concentrations at the USGS Eastern Region Sediment Laboratory in Louisville, Kentucky.

During water years 2012 and 2013, routine sampling of the 9 lake sites and the 4 bimonthly stream sites was conducted on schedule with a few exceptions. Cane Creek (site 8), Morgan Creek near White Cross (site 14), and White Oak Creek (site 19) were not sampled during some months due to zero-flow conditions. The April 2013 samples for Little River Reservoir (site 5) and Lake Michie (site 7) were collected on May 1, 2013. A total of 16 runoff-event samples were collected at the four routine stream sites and four runoff-only stream sites (appendix 1). It is important to note that results for the four streams sampled only during runoff events likely do not represent typical water-quality conditions for these streams.

Quality Assurance

Quality-control samples, consisting of sampling-equipment blanks, sampling-vehicle (ambient) blanks, field blanks, and replicate samples, were collected and reviewed throughout the period to ensure that project data-quality objectives were met (appendixes 2, 3; Oblinger, 2004). Deionized water was produced in the USGS Raleigh, N.C., laboratory and was used to clean sampling equipment. The source solution for sampling-equipment, sampling-vehicle, and field blanks was inorganic-blank or organic-blank water (depending on the constituents being analyzed) obtained from the USGS National Field Service Supply. Approximately 16 percent of the sample load consisted of quality-control samples. Quality-control samples and collection procedures are described in Chapter 4 of the USGS National Field Manual (U.S. Geological Survey, 2006).

During October 2011 through September 2013, 3 sampling-equipment blanks, 7 sampling-vehicle blanks, and 13 field blanks were collected and analyzed for major ions, nutrients, trace metals, and total organic carbon (appendix 2). In all, 29 constituents were analyzed and 505 blank results were generated. Almost 96 percent of the results were below censoring levels, indicating minimal contamination during this period. Overall, 18 quantified blank results were detected (results above constituent censoring levels), which represented approximately 4 percent of the results. Five of these were low-level detections of ammonia; the remaining 13 detections were distributed among 10 different constituents.

Sampling-equipment blanks had only one low quantified detection (silver at 0.016 micrograms per liter ($\mu\text{g/L}$), just above the censoring level of 0.015 $\mu\text{g/L}$). Therefore, contamination due to the equipment cleaning process or laboratory analysis was unlikely. Six vehicle blanks and five field blanks had quantified detections of one or more constituents indicating that contamination would be more likely to occur during field sampling and processing (appendix 2). Even so, the number of detections overall was very low, and most of the detections were at or near constituent censoring levels, indicating negligible systematic positive bias.

6 Quality of Surface-Water Supplies in the Triangle Area of North Carolina, Water Years 2012–13

A detection rate of less than 10 percent was deemed acceptable for this study. If a constituent was detected in greater than 10 percent of the combined equipment, vehicle, and field blanks, then the results were assessed for the potential to positively bias the environmental results. Only four constituents exceeded the 10 percent blank-detection threshold, including unfiltered ammonia plus organic nitrogen (11 percent), ammonia (28 percent), nitrate plus nitrite (11 percent), and total organic carbon (12 percent) (table 2). For these constituents, blank detections were further evaluated based on proximity to censoring levels and relevance to corresponding environmental concentrations. Environmental concentrations less than five times the median of the quantified blank detections generally were considered to have some potential for contamination.

A threshold value of five times the median blank detection was deemed overly conservative for ammonia plus organic nitrogen during this reporting period. The two field-blank detections for ammonia plus organic nitrogen were 0.08 mg/L, which is near the censoring level of 0.07 mg/L, and an atypically high value of 0.23 mg/L. This extreme value resulted in a median detection value of 0.155 mg/L, which, in turn, caused the evaluation threshold to be 0.78 mg/L. The remaining 16 blanks were less than 0.07 mg/L. In comparison, concentrations of ammonia plus organic nitrogen in environmental samples ranged from 0.25 to 2.6 mg/L. Despite the magnitude, this one relatively high value of ammonia plus organic nitrogen in a field blank likely does not represent a systematic positive bias given how atypical the value was.

Ammonia was detected in three vehicle blanks and two field blanks with a median detection concentration of 0.01 mg/L. Therefore, environmental ammonia concentrations greater than or equal to 0.01 and less than 0.05 mg/L

were considered potentially biased due to contamination during field sampling activities. During water years 2012–13, approximately 52 percent of the ammonia concentrations were within this range and should be interpreted with caution. Ammonia concentrations less than 0.01 mg/L (censored values) were not considered to be positively biased because they were reported as non-detections.

Nitrate plus nitrite was detected in one vehicle blank and one field blank with a median detection concentration of 0.015 mg/L. Thus, environmental nitrate plus nitrite concentrations greater than or equal to 0.01 and less than 0.08 mg/L were considered potentially biased due to contamination during field sampling activities. During water years 2012–13, approximately 24 percent of the nitrate plus nitrite concentrations were within this range and should be interpreted with caution. Nitrate plus nitrite concentrations less than 0.01 mg/L were not considered to be positively biased because they were censored and reported as non-detections.

Total organic carbon was detected in one vehicle blank and one field blank. The median detection was 1.1 mg/L; therefore, a potential-contamination threshold of 5.5 mg/L was computed. Concentrations in environmental samples for total organic carbon ranged from 3.6 to 36.8 mg/L (appendix 1). Approximately 10 percent of the samples had concentrations less than the threshold and may be biased by sampling artifacts.

The variability of sampling and analysis was assessed with 21 sets of field replicates (appendix 3). Among the 21 sets of field replicates, there were a total of 239 replicate-result pairs. Paired concentrations with a relative percent difference (RPD, absolute difference times 100 divided by the average) less than 25 percent were considered to demonstrate acceptable reproducibility. Of the 239 replicate set pairs, approximately 97 percent had RPDs less than 25 percent.

Table 2. Summary of selected constituent data observed in equipment, vehicle, and field blanks and environmental samples from the Triangle Area Water Supply Monitoring Project, North Carolina, October 2011 through September 2013.

[mg/L, milligram per liter; N, nitrogen; <, less than]

Constituent	Unit	Censoring level	Number of blanks analyzed	Blanks				Environmental samples	
				Blanks with detections			5 times the median quantified detection	Range of values	Percent less than 5 times the median concentration detected in a blank
				Number	Percent	Range of quantified detections			
Ammonia, filtered	mg/L as N	0.01	18	5	27.8	0.01–0.02	0.05	<0.01–0.21	52
Nitrate plus nitrite, unfiltered	mg/L as N	0.01	18	2	11.1	0.01–0.02	0.08	<0.01–0.96	24
Total organic carbon, unfiltered	mg/L	0.5	17	2	11.8	1.1	5.5	3.6–36.8	10

Orthophosphate, cobalt, copper, and nickel each had a single replicate set with a RPD greater than 25 percent, and ammonia and total phosphorus each had two replicate sets with RPDs greater than 25 percent (appendix 3). The occurrences of high RPDs for orthophosphate, copper, and nickel were isolated and not representative of the dataset as a whole. Large RPD values are common and accepted without further discussion when they result from small absolute differences near the constituent censoring level. For example, two ammonia replicate sets had RPDs of 28.6; however, the absolute differences were 0.01 mg/L, and the censoring level was 0.01 mg/L, thus the difference is considered to be negligible.

When the absolute concentration difference is greater than or equal to three times the censoring level and is associated with a large RPD, high variability is indicated. Only one of the replicate pairs for total phosphorus met these criteria, with a RPD of 88 percent and an absolute difference of 0.085 mg/L. The large absolute difference appears to be a random occurrence. The cobalt replicate pair with an RPD of 62 percent and an absolute difference of 0.08 mg/L appears to be an isolated occurrence during this period. Unfiltered constituents are often difficult to replicate because much of the total phosphorus and cobalt are associated with particles that are not homogeneously distributed in the water. Overall, total phosphorus and cobalt generally showed acceptable reproducibility, but replicate sets will continue to be closely monitored. In general, results for replicate pairs indicated acceptable reproducibility for all water-quality constituents measured during this period.

Precipitation and Streamflow

Precipitation measured at the Raleigh-Durham International Airport, North Carolina (National Weather Service station KRDU; fig. 1), from October 2011 through September 2012 totaled 44.3 inches, which is approximately 2 percent above the long-term mean annual precipitation of 43.3 inches (National Oceanic and Atmospheric

Administration, 2015; State Climate Office of North Carolina, 2015b). From October 2012 through September 2013, precipitation at the Raleigh-Durham Airport measured 44.8 inches, which is approximately 3 percent above the long-term mean annual precipitation. The highest monthly precipitation for the 2-year period occurred in June 2013 (10.1 inches; fig. 2) as a result of precipitation associated with Tropical Storm Andrea (http://www.nhc.noaa.gov/data/tcr/AL012013_Andrea.pdf).

Another indication of hydrologic conditions is provided by the monthly Palmer Hydrological Drought Index scores for water years 2012 and 2013 (fig. 3; State Climate Office of North Carolina, 2015a). This index reflects the long-term, cumulative impacts of drought on hydrologic characteristics such as reservoir levels and streamflow. Negative values indicate dry periods, and positive values indicate wet periods. The Palmer Hydrological Drought Index is separated into 11 categories as defined by Palmer (1965). Among these categories are values greater than or equal to 4.00, which are classified as extremely wet. Near normal conditions are considered to be from 0.49 to -0.49 , and extreme drought conditions are considered to be less than or equal to -4.00 . The Palmer Hydrological Drought Index indicated that incipient drought to mild drought conditions persisted throughout the northern Piedmont (including Orange and Durham Counties) until January 2013. For the remainder of water year 2013, near normal to moderately wet conditions were seen in the area. In the central Piedmont (including Chatham and Wake Counties) of North Carolina (fig. 3), mild drought to moderate drought conditions were observed in the area through February 2013. Incipient drought conditions were seen in the region from March 2013 through May 2013. During June 2013 through September 2013, slight wet to very wet conditions were seen in the central Piedmont.

Streamflow data collected at all 10 TAWSMP gaging stations were reviewed, quality assured, and published in the USGS Water Data Reports for water years 2012 and 2013 (<http://nc.water.usgs.gov/reports/WDR/>). Detailed data also are available online via the USGS NWISWeb (<http://waterdata.usgs.gov/nc/nwis/>).

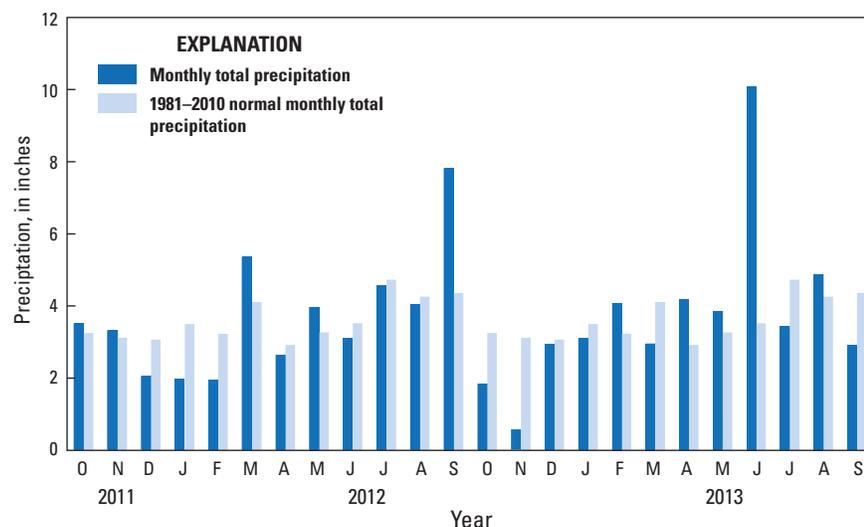


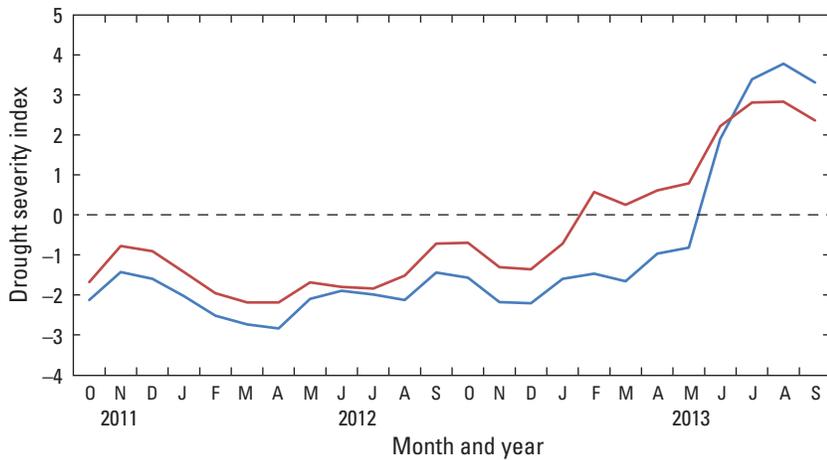
Figure 2. Monthly precipitation at the Raleigh-Durham International Airport, North Carolina (National Weather Service station KRDU), October 2011 through September 2013, and normal monthly total precipitation for the period 1981–2010. Location is shown in figure 1.

8 Quality of Surface-Water Supplies in the Triangle Area of North Carolina, Water Years 2012–13

Annual runoff in water year 2012 was below the long-term mean at nine gaging stations and slightly below the long-term mean at Northeast Creek near Genlee (site 13) (fig. 4A). Among the 10 stations, annual runoff ranged from 4.03 to 19.79 inches during water year 2012. In water year 2013, annual runoff at two stations was above the long-term mean—New Hope Creek near Blands (site 12) and Northeast Creek near Genlee (site 13). The remaining stations were below the long-term mean. At the 10 gaging stations, annual runoff in water year 2013 ranged from 8.58 to 24.22 inches (fig. 4B). At some sites, including New Hope Creek near Blands (site 12), Northeast Creek near Genlee (site 13), and Morgan Creek near Chapel Hill (site 16), a significant percentage of the in-stream flow consists of treated effluent from municipal water reclamation facilities. These continuous

inputs contribute to higher in-stream flows and tend to mitigate effects of drought on annual runoff (fig. 4).

During water year 2012, streamflow was generally below the normal range as illustrated by 7-day average hydrographs for the Eno River at Hillsborough (site 2) in the Neuse River Basin and the Haw River near Bynum (site 10) in the Cape Fear River Basin (fig. 5). During the late summer of 2012, streamflow briefly rose into the normal range. Streamflow was well below normal during November 2012 to January 2013, below to near normal during spring 2013, and within the normal range during summer 2013 (fig. 5). Three streams in the study area had periods of zero flow during water years 2012 and 2013: Cane Creek near Orange Grove (site 8), Morgan Creek near White Cross (site 14), and White Oak Creek (site 19).



EXPLANATION

- Orange and Durham Counties in northern Piedmont
- Chatham and Wake Counties in central Piedmont

Figure 3. Palmer Hydrological Drought Index for Orange and Durham Counties in the northern Piedmont and Chatham and Wake Counties in the central Piedmont climate divisions of North Carolina, October 2011 through September 2013. Values above zero indicate wet periods, and values below zero indicate dry periods.

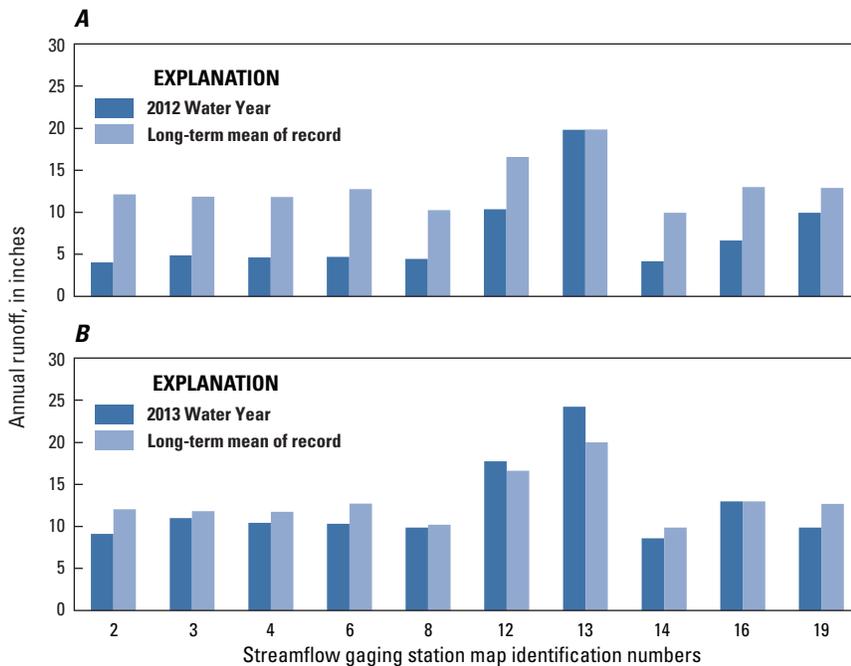


Figure 4. Annual runoff measured from (A) October 2011 through September 2012 and (B) October 2012 through September 2013 and the long-term mean runoff for the period of record at 10 streamflow gaging stations in the Triangle area of North Carolina. Map identification numbers and the periods of record, which vary among stations, are given in table 1.

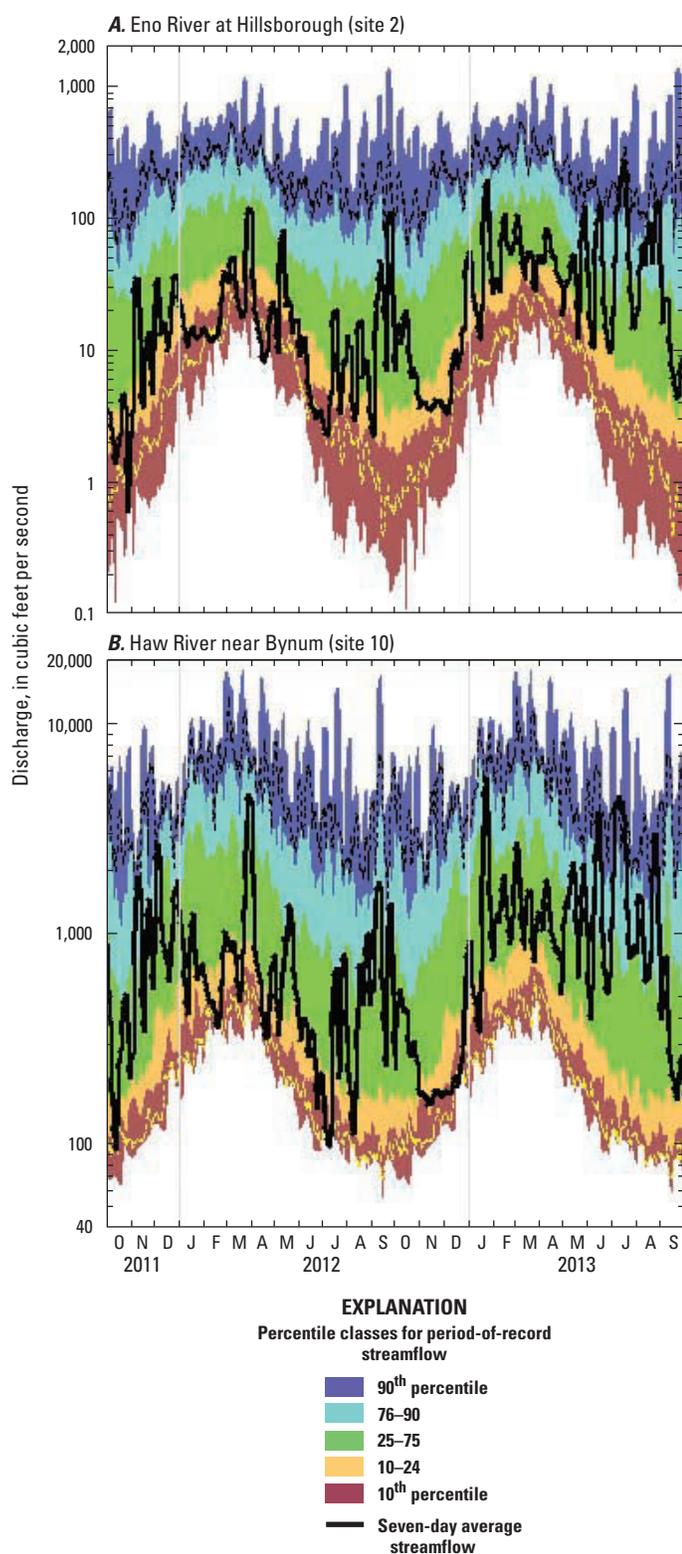


Figure 5. Seven-day average streamflow, in cubic feet per second, overlaid on period-of-record flow percentiles at (A) site 2, Eno River at Hillsborough in the Neuse River Basin; and (B) site 20, Haw River near Bynum in the Cape Fear River Basin, for the period October 2011 through September 2013. Locations are shown in figure 1, and site information is given in table 1.

Water Quality

Water-quality data were reviewed, quality assured, and published in the USGS 2012 and 2013 Water Data Reports (<http://nc.water.usgs.gov/reports/WDR/>). The data are presented in appendix 1 and also are available online via the USGS NWISWeb (<http://waterdata.usgs.gov/nc/nwis/>). Ranges of concentrations observed at each site for 43 properties or constituents are presented (table 3). Analytical methods for all measured properties and constituents are presented in appendix 4. Dissolved-oxygen percent saturation, hardness, and total nitrogen were computed by using USGS National Water Information System (NWIS) algorithms. Although the lake sites were sampled at multiple depths, only results from near-surface waters are included in this report. Additional data for lake samples collected in near-bottom waters may be obtained from the USGS NWISWeb or by request to the USGS South Atlantic Water Science Center.

In-stream water-quality thresholds have been adopted by the North Carolina Division of Water Quality for 23 constituents monitored by the TAWSMP (table 3). All project sampling sites are classified for water-supply use; therefore, applicable standards are the most stringent values established to protect freshwater aquatic life, water supply, or human health (North Carolina Department of Natural Resources, Division of Water Quality, 2007). Individual observations that do not meet water-quality thresholds do not constitute violations of the standards nor indicate that the body of water is impaired; however, the thresholds are useful for comparative purposes.

Concentration ranges that are shown in table 3 in bold font indicate that at least one sample for the constituent exceeded a North Carolina water-quality threshold at that location. Exceedances of water-quality thresholds occurred at every site for at least one constituent. Maximum Contaminant Levels (MCLs) and Secondary Drinking Water Regulations (SDWRs) have been established by the U.S. Environmental Protection Agency for 17 of the monitored constituents (<http://www.epa.gov/safewater/contaminants/index.html>) (U.S. Environmental Protection Agency, 2015). These criteria are applicable only to treated potable water—not to raw water supplies—and are provided solely for reference.

No exceedances of State water-quality thresholds were observed for 13 constituents: pH, temperature, hardness, chloride, fluoride, sulfate, nitrate plus nitrite, arsenic, cadmium, chromium, lead, nickel, and selenium (table 3). Values exceeded thresholds for 10 water-quality constituents: dissolved oxygen, dissolved-oxygen percent saturation, turbidity, chlorophyll a, copper, iron, manganese, mercury, silver, and zinc (table 3).

Stream samples collected during storm-runoff events generally contained more particulate material than samples collected during routine sampling events. Storm-runoff samples had higher turbidity and higher concentrations of unfiltered constituents, including total nitrogen, ammonia plus organic nitrogen, phosphorus, and total organic carbon;

arsenic; total recoverable aluminum, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, silver, and zinc; and suspended sediment. In addition, some filtered constituents including potassium and orthophosphate were relatively higher in runoff samples than in routine samples. Comparisons were based on the Wilcoxon rank test ($p < 0.05$).

Dissolved Oxygen, pH, Specific Conductance, and Turbidity

Dissolved-oxygen concentrations less than the State daily-average minimum threshold of 5 mg/L were observed occasionally at four lake sites and two stream sites in the study area (table 3; appendix 1; fig. 6A). Dissolved-oxygen concentrations less than the instantaneous minimum threshold of 4.0 mg/L were recorded at Lake Michie (site 7) in October 2011 (3.9 mg/L) and June 2013 (3.7 mg/L), Northeast Creek near Genlee (site 13) in September 2012 (3.6 mg/L), University Lake (site 15) in October 2012 (3.5 mg/L) and June 2013 (3.5 mg/L), Jordan Lake at Buoy 12 (site 18) in August 2012 (3.7 mg/L), and at White Oak Creek near Green Level (site 19) in August 2013 (1.4 mg/L) (appendix 1).

Dissolved-oxygen concentrations are dynamic in lakes and rivers, fluctuating with temperature, atmospheric pressure, and biological activity. When dissolved oxygen in water is in equilibrium with the air, the water is considered saturated. Under certain conditions, algae and aquatic plants produce oxygen through photosynthesis more rapidly than can be equilibrated with the atmosphere, resulting in supersaturated conditions. Supersaturation is commonly observed in biologically productive lakes, especially during summer months. Dissolved-oxygen saturation values greater than 110 percent exceed the State dissolved-gases threshold; such values were recorded at five reservoir sites during water years 2012 and 2013 (table 3; fig. 6B). A dissolved-oxygen saturation value greater than 110 percent also was measured at Cane Creek near Orange Grove (site 8; 121 percent, February 2, 2012, appendix 1). Though high dissolved-oxygen saturation values can be accompanied by high pH values, recorded pH values were within the State's acceptable range of 6.0 to 9.0 standard units.

In North Carolina, the State standard for turbidity differs for various classes of water resources. No sites are designated trout waters so the threshold is 25 nephelometric turbidity units (NTU) for lakes and reservoirs and 50 NTU for streams (see table 3, footnote 1). Study results are in nephelometric turbidity ratio units (NTRU), which are not significantly different from NTU. During the water years 2012 and 2013, State turbidity thresholds were exceeded at two lake sites and seven stream sites (table 3; appendix 1; fig. 6C). Turbidity values were greater than 25 NTU at Jordan Lake, Haw River (site 11) and Jordan Lake at Buoy 12 (site 18). The maximum turbidity value for a lake site was observed on December 2, 2011, at Jordan Lake at Buoy 12 (site 18, 39 NTRU), and the minimum lake value was 1.7 NTRU at West Fork Eno Reservoir (site 1) on June 12, 2012. The State

turbidity threshold for streams was exceeded at seven stream sites: Eno River at Hillsborough (site 2), Little River (site 4), Cane Creek near Orange Grove (site 8), New Hope Creek (site 12), Northeast Creek (site 13), Morgan Creek near White Cross (site 14), and White Oak Creek (site 19). The maximum turbidity value for a stream site was 420 NTRU recorded at Cane Creek near Orange Grove (site 8; June 7, 2013). The minimum turbidity value was observed at Morgan Creek near White Cross in December 2012 (site 14; 2.6 NTRU). It should be noted that the only time the stream sites exceeded the turbidity threshold was in June 2013. These storm-event samples were collected during high flow conditions that followed the passage of Tropical Storm Andrea.

Although no standard has been adopted for specific conductance, this constituent continued to show interesting variations among sites (table 3; appendix 1). The highest conductance value of 260 microsiemens per centimeter ($\mu\text{S}/\text{cm}$) at 25 degrees Celsius was recorded at Jordan Lake, Haw River Arm (site 11) on December 5, 2012. Cane Creek near Orange Grove (site 8) had the lowest conductance value of 45 $\mu\text{S}/\text{cm}$ on June 7, 2013.

West Fork Eno Reservoir (site 1) had the greatest water transparency in water years 2012 (2.60 m, August 24, 2012) and 2013 (2.10 m, October 2, 2012). This is in keeping with the lowest observed turbidity value recorded at this site 2 months earlier in June 2012.

Metals and Trace Elements

During 2012–13, State water-quality thresholds were 1,000 $\mu\text{g}/\text{L}$ for total recoverable iron and 200 $\mu\text{g}/\text{L}$ for total recoverable manganese. It is of note that the U.S. Environmental Protection Agency subsequently approved NCDWQ's request to remove these thresholds (U.S. Environmental Protection Agency, 2016). Iron concentrations exceeded 1,000 $\mu\text{g}/\text{L}$ at eight streams and one lake site in the study area during water years 2012 and 2013 (table 3; fig. 7A). As seen in previous water years, runoff samples consistently exceeded the threshold. Except for selected samples collected at Jordan Lake, Haw River arm (site 11; table 3), iron concentrations in lake surface waters were less than 1,000 $\mu\text{g}/\text{L}$. Total recoverable manganese occasionally exceeded the 200 $\mu\text{g}/\text{L}$ water-supply threshold at seven lake sites and five streams sites during 2012 and 2013 (table 3; fig. 7B). Iron and manganese tend to be substantially higher in lake bottom waters than near-surface samples during summer stratification (U.S. Geological Survey, 2015). Iron and manganese generally are higher in streams during run-off events compared to base-flow conditions.

Four stream and five lake sites had total recoverable mercury concentrations above the State threshold of 0.012 $\mu\text{g}/\text{L}$ (table 3; fig. 7C). A maximum concentration of 0.184 $\mu\text{g}/\text{L}$ was recorded at Lake Michie (site 7) on April 12, 2012 (appendix 1). All mercury concentrations were less than the Federal drinking-water MCL of 2 $\mu\text{g}/\text{L}$.

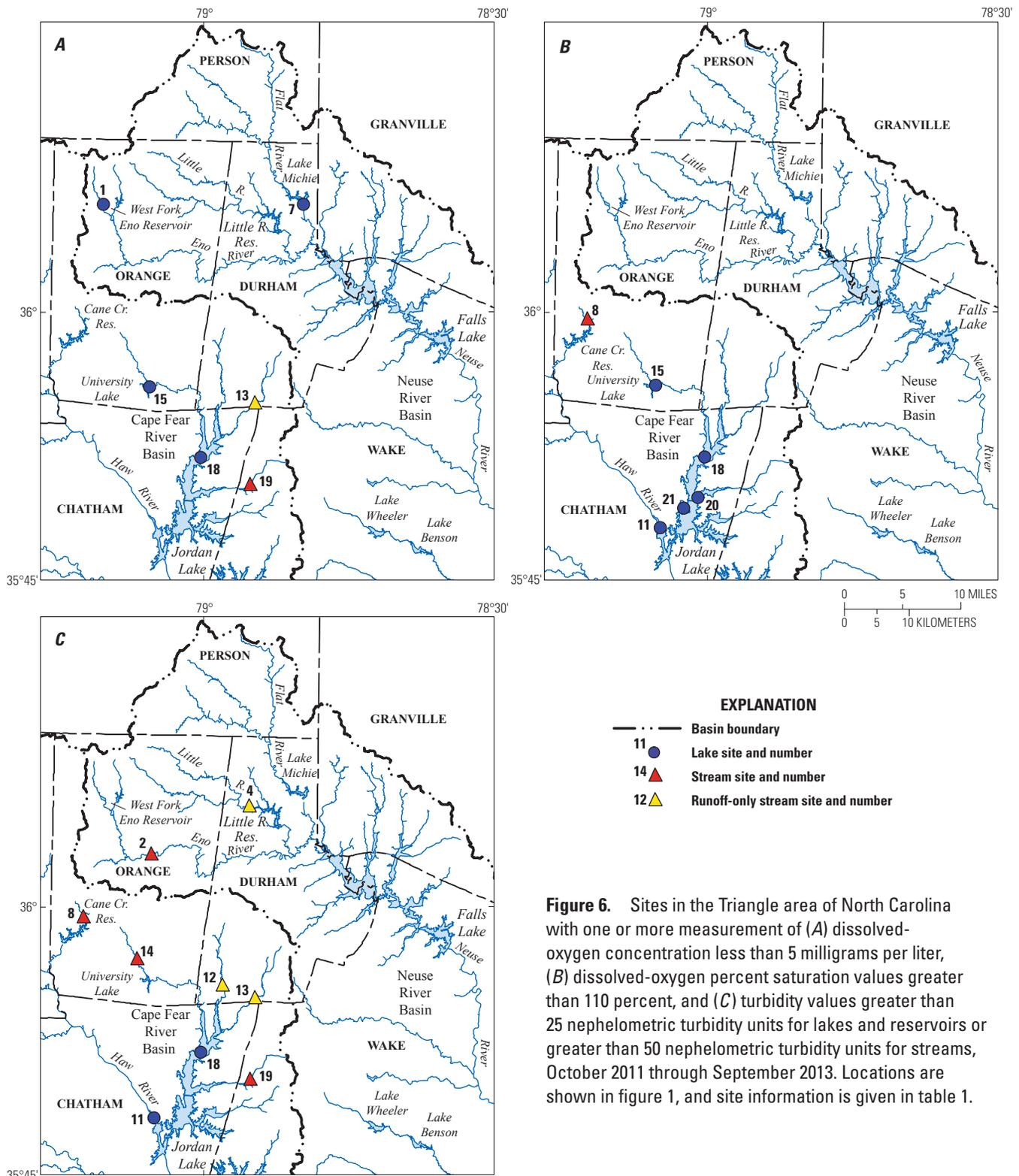


Figure 6. Sites in the Triangle area of North Carolina with one or more measurement of (A) dissolved-oxygen concentration less than 5 milligrams per liter, (B) dissolved-oxygen percent saturation values greater than 110 percent, and (C) turbidity values greater than 25 nephelometric turbidity units for lakes and reservoirs or greater than 50 nephelometric turbidity units for streams, October 2011 through September 2013. Locations are shown in figure 1, and site information is given in table 1.

Base from digital files of:
 U.S. Environmental Protection Agency, River File 3
 U.S. Geological Survey, 1:100,000 scale

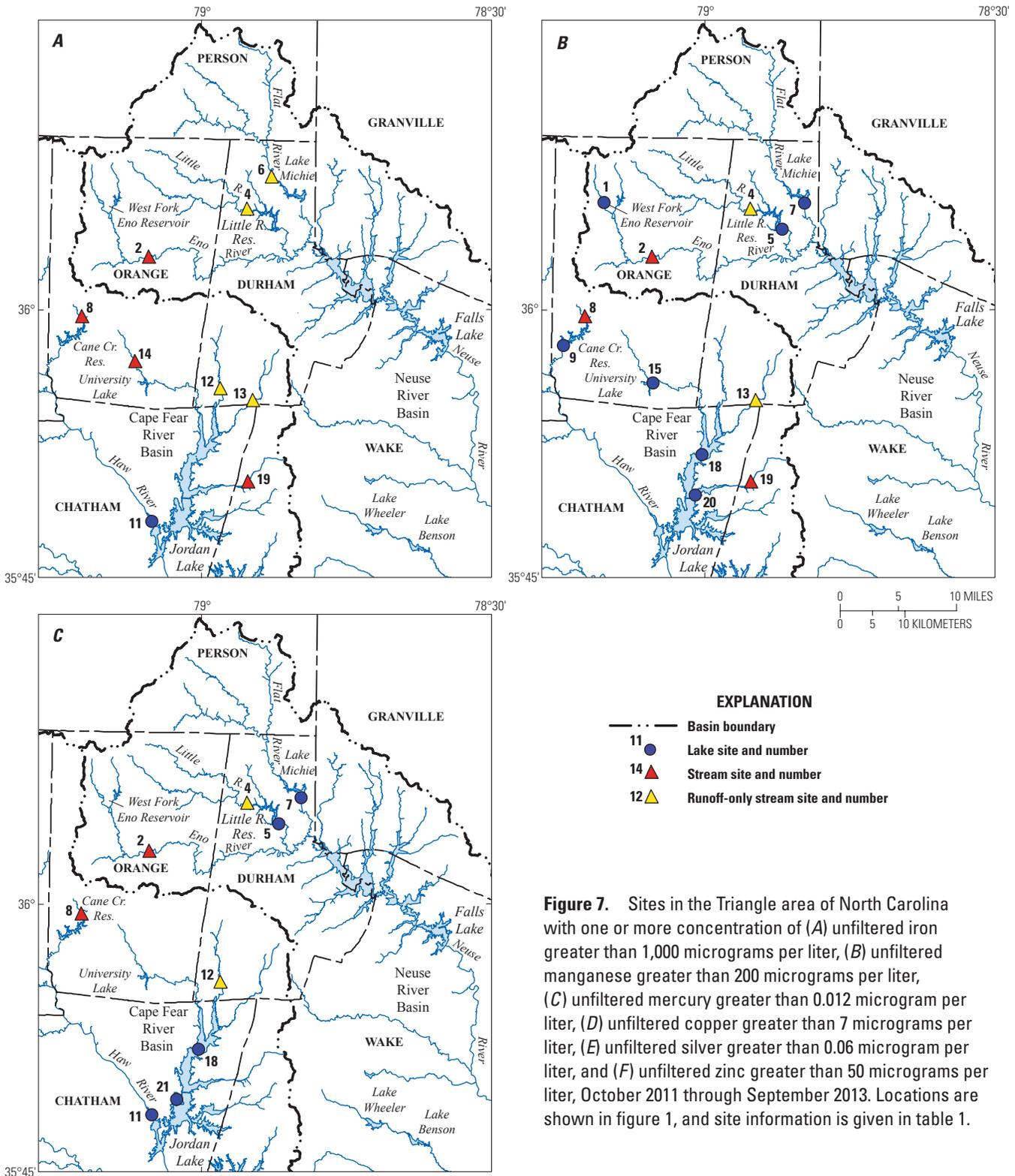


Figure 7. Sites in the Triangle area of North Carolina with one or more concentration of (A) unfiltered iron greater than 1,000 micrograms per liter, (B) unfiltered manganese greater than 200 micrograms per liter, (C) unfiltered mercury greater than 0.012 microgram per liter, (D) unfiltered copper greater than 7 micrograms per liter, (E) unfiltered silver greater than 0.06 microgram per liter, and (F) unfiltered zinc greater than 50 micrograms per liter, October 2011 through September 2013. Locations are shown in figure 1, and site information is given in table 1.

Base from digital files of:
 U.S. Environmental Protection Agency, River File 3
 U.S. Geological Survey, 1:100,000 scale

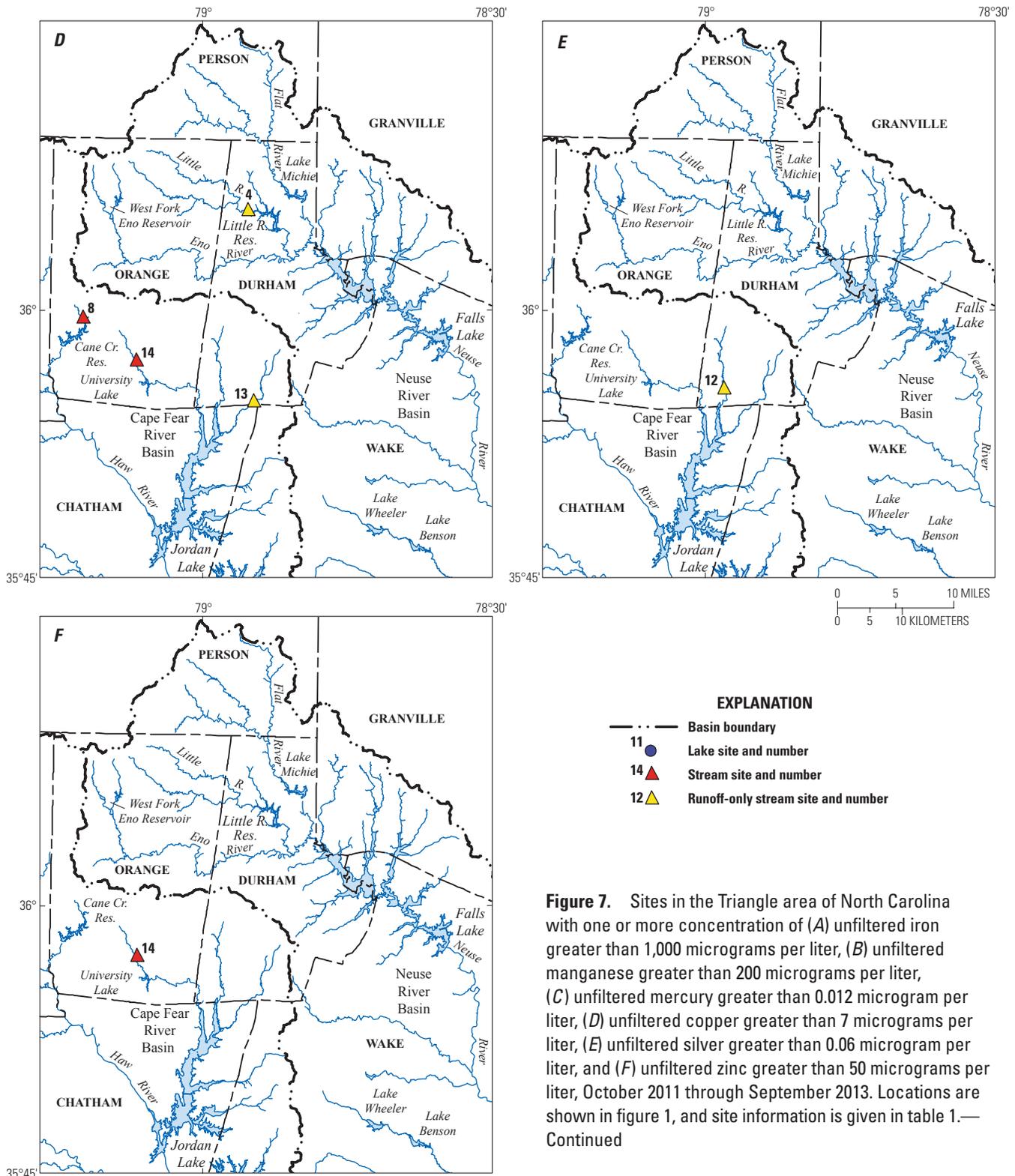


Figure 7. Sites in the Triangle area of North Carolina with one or more concentration of (A) unfiltered iron greater than 1,000 micrograms per liter, (B) unfiltered manganese greater than 200 micrograms per liter, (C) unfiltered mercury greater than 0.012 microgram per liter, (D) unfiltered copper greater than 7 micrograms per liter, (E) unfiltered silver greater than 0.06 microgram per liter, and (F) unfiltered zinc greater than 50 micrograms per liter, October 2011 through September 2013. Locations are shown in figure 1, and site information is given in table 1.— Continued

Base from digital files of:
U.S. Environmental Protection Agency, River File 3
U.S. Geological Survey, 1:100,000 scale

Copper concentrations greater than the State water-quality action level of 7 µg/L were measured at four stream sites, but no lake sites (table 3; fig. 7D). A maximum copper concentration of 33.1 µg/L was recorded at Morgan Creek near White Cross on April 1, 2013, following a series of rain events (appendix 1).

A single concentration of zinc above the State water-quality action level of 50 µg/L was observed at Morgan Creek near White Cross (site 14) on April 25, 2012 (90.8 µg/L). New Hope Creek was the only site to exceed the State water-quality action level of 0.06 µg/L for silver (0.067 µg/L on September 19, 2012). No exceedances for zinc or silver were observed at any lake or reservoir sites in the 2-year study period.

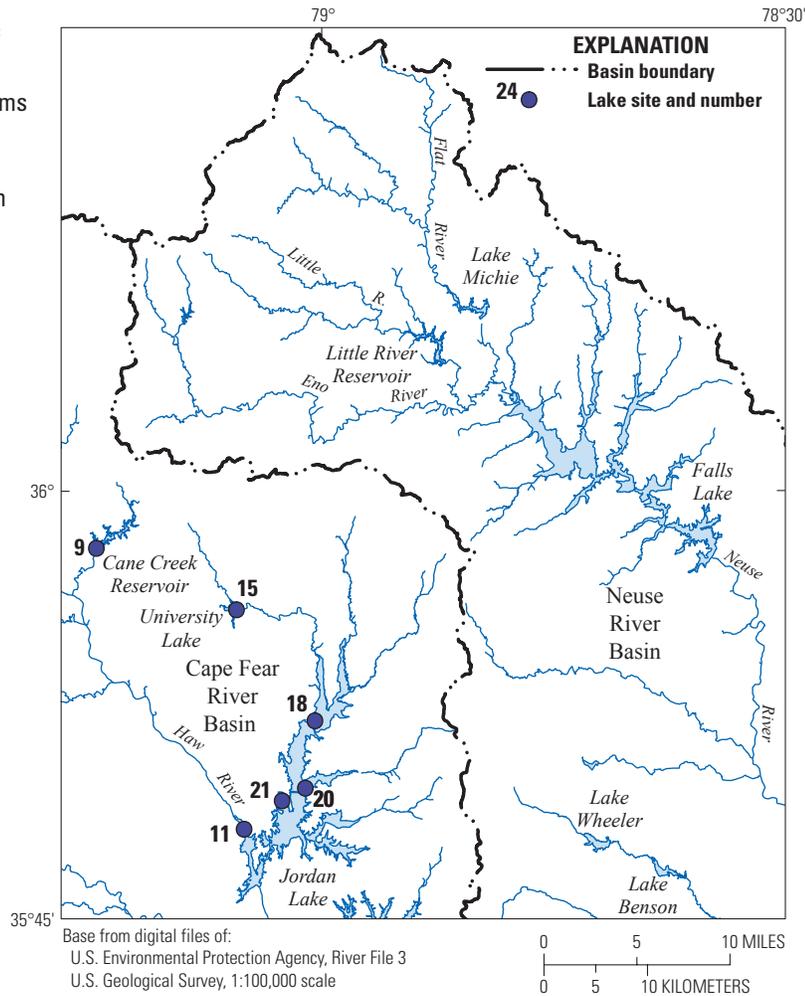
With the exception of aluminum, iron, and manganese, all metal and trace element concentrations were less than Federal drinking-water MCLs or SDWRs (table 3) during 2012 and 2013. As noted previously, MCLs and SDWRs are applicable to treated drinking water rather than untreated source water and

are included for reference in this report. Aluminum, iron, and manganese frequently exceeded SDWRs (table 3), although concentrations were similar to those observed in the study area during previous years (<http://nc.water.usgs.gov/reports/WDR/>).

Chlorophyll *a*

Chlorophyll *a* was measured only at lake sites. During water years 2012 and 2013, concentrations greater than the North Carolina water-quality standard of 40 µg/L were observed at least once at six of the nine lake sites, including Cane Creek Reservoir (site 9), University Lake (site 15), and all four sites in Jordan Lake (sites 11, 18, 20, 21) (table 3; fig. 8). A maximum chlorophyll *a* value of 72.2 µg/L was recorded at University Lake (site 15) on October 20, 2011. West Fork Eno Reservoir (site 1) had the three lowest values of chlorophyll *a* values (2.9 µg/L, April 10, 2013; 3.1 µg/L, August 24, 2012; 3.7 µg/L, October 14, 2011).

Figure 8. Sites in the Triangle area of North Carolina with concentrations of chlorophyll *a* greater than 40 micrograms per liter, October 2011 through September 2013. Locations are shown in figure 1, and site information is given in table 1.



Nitrogen and Phosphorus

The USGS collected nutrient samples six times per year at four routine stream sites, four to six times per year at nine lake sites, and during every sampling of runoff stream sites. Nutrient species that were analyzed included total ammonia plus organic nitrogen (also known as total Kjeldahl nitrogen), ammonia, nitrate plus nitrite, orthophosphate, and total phosphorus. A State water-quality standard exists only for nitrate plus nitrite (10 mg/L) and was never exceeded. The standard is well above the maximum observed concentration of nitrate plus nitrite of 0.96 mg/L.

Total ammonia plus organic nitrogen concentrations ranged from 0.25 mg/L at Morgan Creek near White Cross (site 14) to 2.6 mg/L at Cane Creek near Orange Grove (site 8) and varied widely among sites and sampling dates (table 3).

Nitrate plus nitrite concentrations ranged from <0.01 mg/L at several lake sites to 0.96 mg/L at Cane Creek near Orange Grove (site 8; table 3).

Total nitrogen values were computed by summing ammonia plus organic nitrogen and nitrate plus nitrite. These computations were performed automatically by algorithms embedded in the USGS NWIS database. The left-censored (<) remark code was retained with the computed total nitrogen value if one of the constituents used in the algorithm was below 0.07 mg/L for ammonia plus organic nitrogen or below 0.01 mg/L for nitrate plus nitrite. The censoring level associated with nitrate plus nitrite (0.01 mg/L) has minimal significance on the computed values for total nitrogen. In comparison, the minimum ammonia plus organic nitrogen concentration was 0.26 mg/L, which is an order of magnitude greater. The < remark codes were disregarded for the purpose of data assessment (fig. 9).

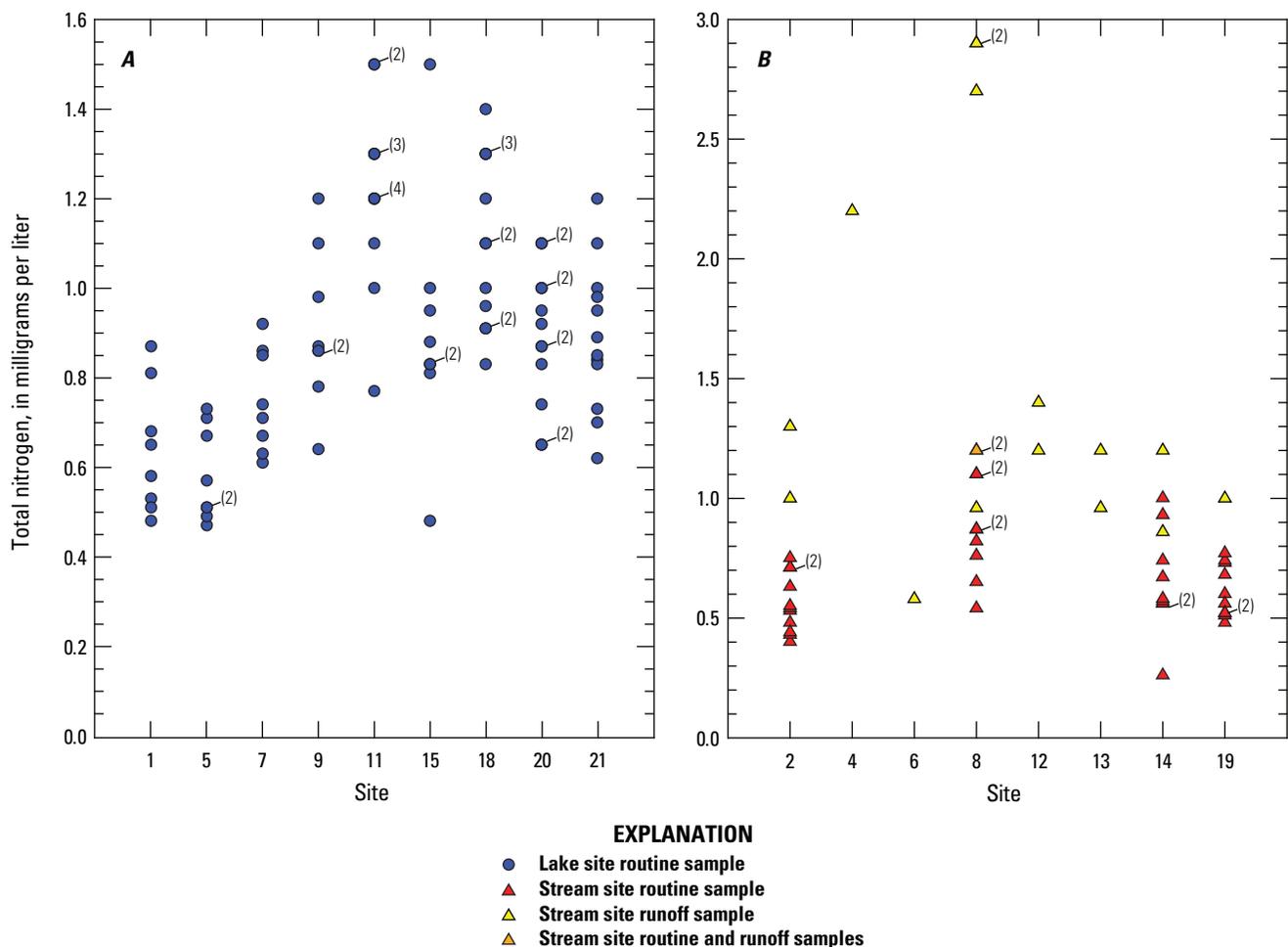


Figure 9. Concentrations of (A) total nitrogen for lakes and (B) total nitrogen for streams at sites in the Triangle Area Water Supply Monitoring Project study area, October 2011 through September 2013. Locations are shown in figure 1, and site information is given in table 1. To denote multiple samples with the same value, the number of occurrences is shown in parentheses next to the symbol.

Among lake sites, the highest concentration of total nitrogen (1.5 mg/L) was observed at University Lake (site 15, October 20, 2011) and Jordan Lake, Haw River arm (site 11, February 15, 2012 and December 5, 2012) and University Lake (site 15) (table 3; appendix 1; fig. 9A). Cane Creek near Orange Grove (site 8) had the highest concentration of total nitrogen observed among stream sites (2.9 mg/L in November 2011 and June 2013; table 3; appendix 1; fig. 9B).

Total phosphorus concentrations ranged from 0.012 mg/L at West Fork Eno Reservoir (site 1, fig. 10A) to 0.867 mg/L at Cane Creek near Orange Grove (site 8, fig. 10B). Among lake sites, some of the higher concentrations of total phosphorus generally were observed at Jordan Lake, Haw River arm and Jordan Lake at Buoy 12 (sites 11 and 18, fig. 10A). Storm-event samples frequently had concentrations greater than 0.20 mg/L (fig. 10B). Relatively lower concentrations (less than or equal to 0.05 mg/L) generally were recorded at the four routine stream sites, several small reservoirs, and three sites in Jordan Lake (fig. 10).

Concentrations of dissolved ammonia, nitrate plus nitrite, and orthophosphate were less than laboratory censoring levels in 26, 26, and 54 percent of samples, respectively

(appendix 1). The highest concentration reported for ammonia was 0.21 mg/L at Jordan Lake at U.S. Highway 64 (site 20) on December 2, 2011. For nitrate plus nitrite, the highest concentration in the study area (0.96 mg/L) was observed on February 7, 2013, at Cane Creek near Orange Grove (site 8). The maximum concentrations of orthophosphate (0.258 mg/L) and total phosphorus (0.867 mg/L) were observed at Cane Creek near Orange Grove (site 10, September 18, 2012).

As in previous years, lake sites generally had low concentrations of dissolved ammonia, nitrate plus nitrite, and orthophosphate near the water surface during summer months, when these inorganic nutrient species tend to be taken up by phytoplankton. The somewhat riverine site 11, Jordan Lake Haw River arm, was an exception. Nitrate plus nitrite was above censoring levels during 10 of the 12 sampling events, ranging from 0.15 to 0.95 mg/L (appendix 1). Though not included in this report, bottom-water concentrations of ammonia, orthophosphate, and total phosphorus are noted for context and comparison as being higher than near-surface concentrations during summer, when lakes were thermally stratified. This is also consistent with results from previous years (<http://nc.water.usgs.gov/reports/WDR/>).

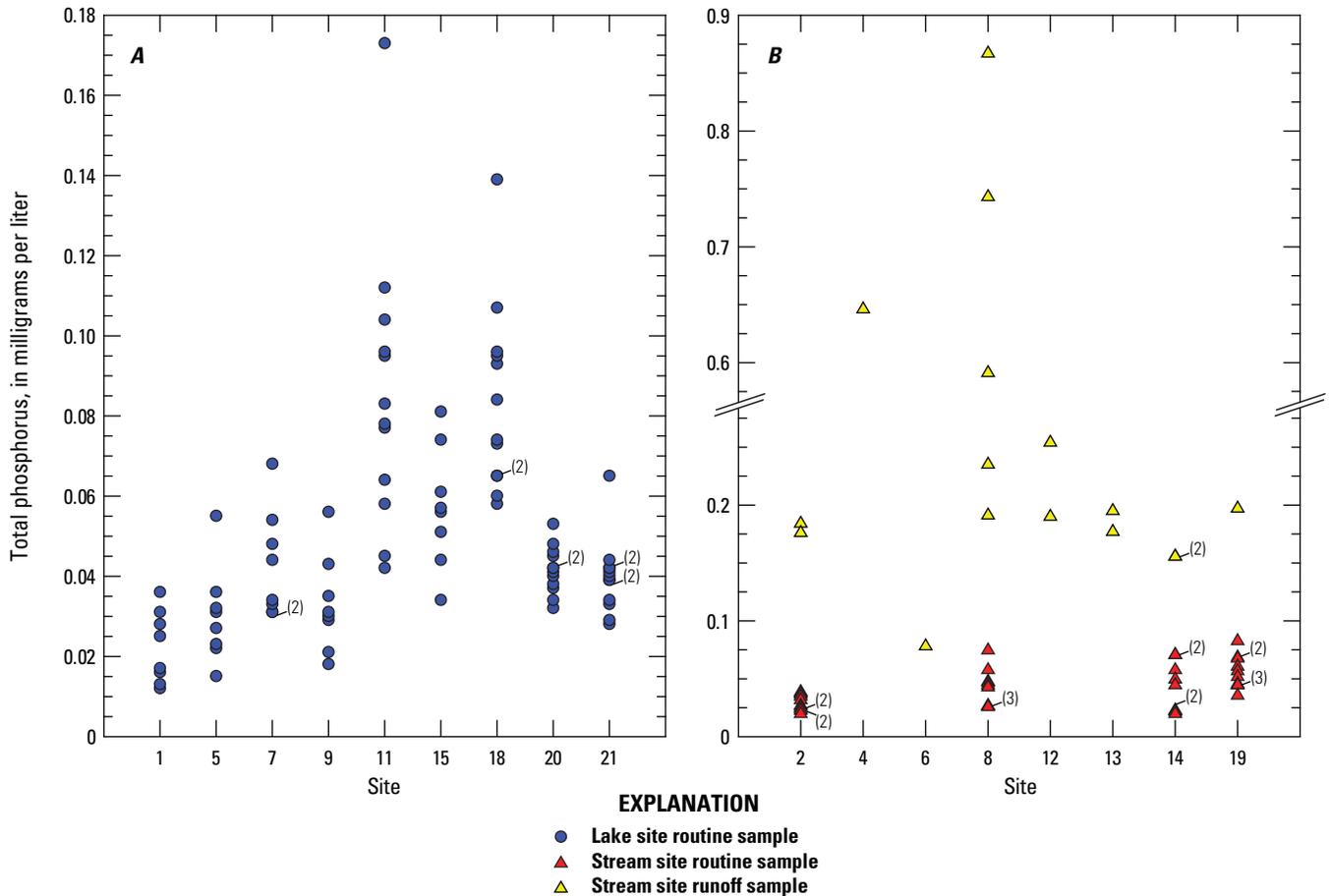


Figure 10. Concentrations of (A) total phosphorus for lakes and (B) total phosphorus for streams at sites in the Triangle Area Water Supply Monitoring Project study area, October 2011 through September 2013. Locations are shown in figure 1, and site information is given in table 1. To denote multiple samples with the same value, the number of occurrences is shown in parentheses next to the symbol.

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