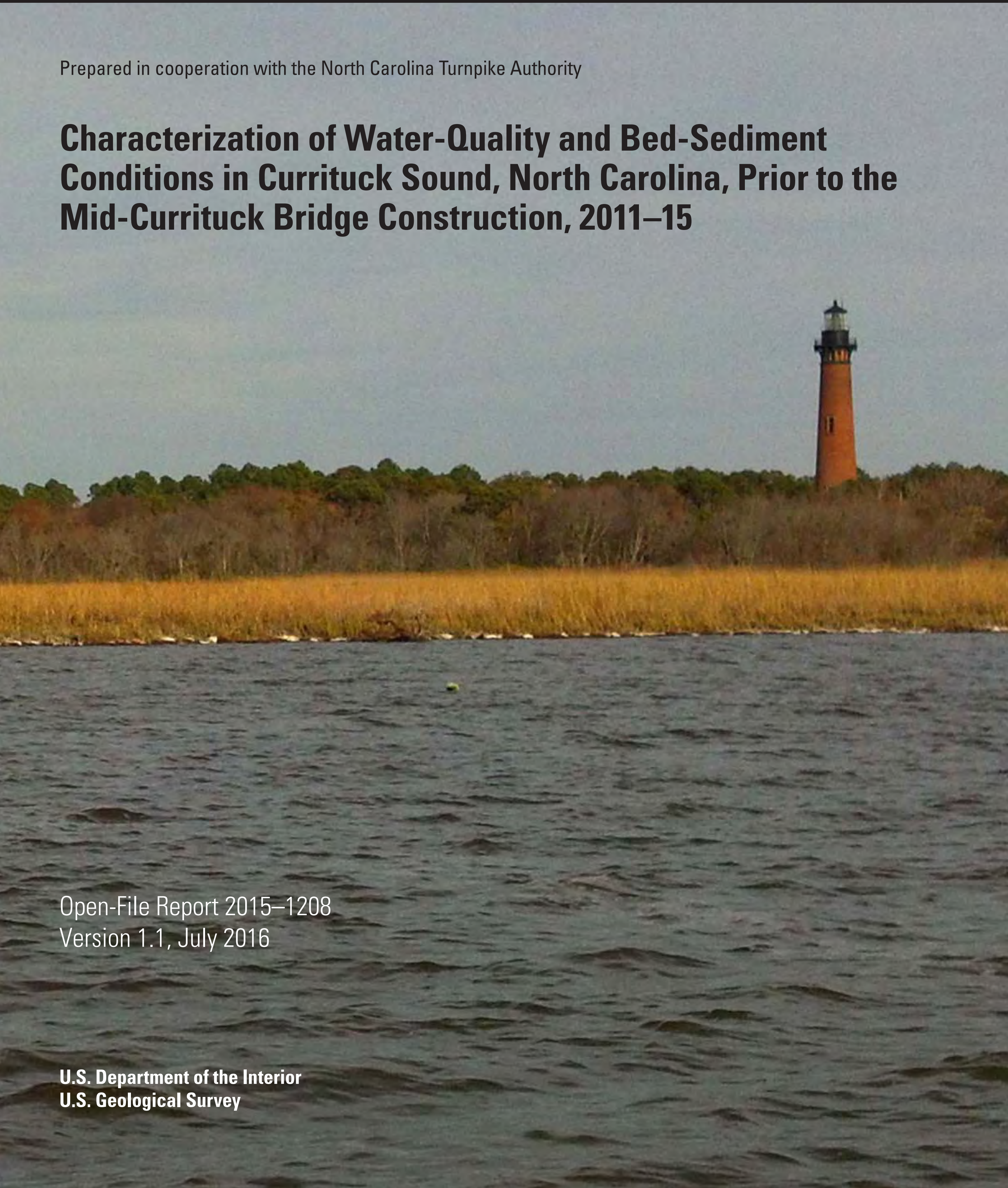
Prepared in cooperation with the North Carolina Turnpike Authority

Characterization of Water-Quality and Bed-Sediment Conditions in Currituck Sound, North Carolina, Prior to the Mid-Currituck Bridge Construction, 2011–15



Open-File Report 2015–1208
Version 1.1, July 2016

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

Front and back cover: View from Currituck Sound, North Carolina, showing the Currituck Lighthouse and U.S. Geological Survey water-level and wind gages at the end of a boat dock. Photograph by Chad Wagner, U.S. Geological Survey

Characterization of Water-Quality and Bed-Sediment Conditions in Currituck Sound, North Carolina, Prior to the Mid-Currituck Bridge Construction, 2011–15

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SALLY JEWELL, Secretary

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Contents

Figures

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Conversion Factors

[Inch/Pound to International System of Units]

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
ounce, fluid (fl oz)	29.57	milliliter (mL)
ounce, fluid (fl. oz)	0.02957	liter (L)
gallon (gal)	3.785	liter (L)
cubic inch (in^3)	0.01639	liter (L)
Velocity		
mile per hour (mi/h, mph)	1.609	kilometer per hour (km/h)
Mass		
ounce, avoirdupois (oz)	2.835×107	microgram (µg)
ounce, avoirdupois (oz)	2.835×104	milligram (mg)
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)

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

Supplemental Information

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 in either milligrams per liter (mg/L) or micrograms per liter (µg/L)

Abbreviations

ADCP	acoustic Doppler current profiler
DCP	data collection platform
ECSU	Elizabeth City State University
EPA	U.S. Environmental Protection Agency
FEIS	Final Environmental Impact Study or Statement
GPS	global positioning system
MPN	most probable number
NCDOT	North Carolina Department of Transportation
NCTA	North Carolina Turnpike Authority
NERR	National Estuarine Research Reserve
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
PAH	polycyclic aromatic hydrocarbon
POC	parameter of concern
QA/QC	quality assurance and quality control
RPD	relative percent difference
SAV	submerged aquatic vegetation
TN	total nitrogen
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

Characterization of Water-Quality and Bed-Sediment Conditions in Currituck Sound, North Carolina, Prior to the Mid-Currituck Bridge Construction, 2011–15

By Chad Wagner, Sharon Fitzgerald, and Dominick Antolino

Abstract

The North Carolina Turnpike Authority, a division of the North Carolina Department of Transportation, is planning to make transportation improvements in the Currituck Sound area by constructing a two-lane bridge from U.S. Highway 158 just south of Coinjock, North Carolina, to State Highway 12 on the Outer Banks just south of Corolla, North Carolina. The results of the Final Environmental Impact Study associated with the bridge and existing roadway improvements indicated potential water-quality and habitat impacts to Currituck Sound related to stormwater runoff, altered light levels, introduction of piles as hard substrate, and localized turbidity and siltation during construction.

The primary objective of this initial study phase was to establish baseline water-quality conditions and bed-sediment chemistry of Currituck Sound in the vicinity of the planned alignment of the Mid-Currituck Bridge. These data will be used to evaluate the impacts associated with the bridge construction and bridge deck stormwater runoff. Between 2011 and 2015, discrete water-quality samples were collected monthly and after selected storm events from five locations in Currituck Sound. The sampling locations were distributed along the proposed alignment of the Mid-Currituck Bridge. Water samples were analyzed for physical parameters and water-quality constituents associated with bridge deck stormwater runoff and important in identifying impaired waters designated as “SC” (saltwater-aquatic life propagation/protection and secondary recreation) under North Carolina’s water-quality classifications. Bed-sediment chemistry was also measured three times during the study at the five sampling locations. Continuous water-level and wind speed and direction data in Currituck Sound were also collected by the U.S. Geological Survey during the study period.

For the water samples, measured concentrations were greater than water-quality thresholds on 52 occasions. In addition, there were 190 occurrences of censored results having a reporting level higher than specific thresholds. All 52 occurrences of concentrations greater than water-quality thresholds were confined to seven different physical properties or constituents, namely pH (25), turbidity (8), total recoverable chromium (6), total recoverable copper (6), dissolved copper (3), total recoverable mercury (2), and total recoverable nickel (2). Concentrations of 17 other constituents were never measured to be greater than their established water-quality thresholds during the study.

The focus of the water-quality characterization was on concentrations of constituents identified as parameters of concern in a 2011 collaborative U.S. Geological Survey/North Carolina Department of Transportation study that characterized bridge deck stormwater runoff across North Carolina. The occurrence and distribution of parameters of concern identified in the 2011 study, including pH, nutrients, total recoverable and dissolved metals, and polycyclic aromatic hydrocarbons, and some additional pertinent physical properties (dissolved oxygen, specific conductance, and turbidity), were analyzed in water and bed-sediment samples. Statistical differences were identified between monthly and storm samples for the following physical properties and constituents: pH, dissolved oxygen, specific conductance, turbidity, *Escherichia coli* bacteria, total recoverable aluminum, and total recoverable iron. Seasonality was observed in pH, specific conductance, dissolved oxygen, turbidity, total phosphorus, and total nitrogen, and total recoverable aluminum, arsenic, iron, lead, and manganese during the study period. The volume and residence time of the water in Currituck Sound are such that the water chemistry is relatively uniform spatially, but variable temporally.

One of the most variable constituents in bed sediments was the fraction of fines, those sediments less than 63 micrometers in diameter. Because most, if not all, of the measured constituents were presumably associated with this fraction, bulk-sediment concentrations are determined largely by the amount of fines present. Only four constituents were greater than bed-sediment thresholds: tin (5 samples), barium (4 samples), aluminum (2 samples), and diethyl phthalate (1 sample). The occurrences of concentrations being greater than referenced thresholds could be underestimated for diethyl phthalate, because the reporting level exceeded the threshold

in nine samples. Thirty-five constituents had sampled concentrations that were never greater than quality thresholds, although 21 of these constituents (154 instances) had at least one sample with a reporting level that was greater than the corresponding threshold. Finally, 33 constituents had no quality thresholds.

This study and previous studies of bed-sediment quality in Currituck Sound, although few, indicate that sedimentation in Currituck Sound near the proposed alignment of the Mid-Currituck Bridge is characterized overall by low and transient input, frequent wind-driven resuspension, and little long-term deposition of fines. To the extent that it might alter water depths along the alignment, bridge construction might also alter the deposition and resuspension rates of fine sediments in Currituck Sound in the vicinity of the bridge.

The characterization of water-quality and bed-sediment chemistry in Currituck Sound along the proposed alignment of the Mid-Currituck Bridge summarized herein provides a baseline for determining the effect of bridge construction and bridge deck runoff on environmental conditions in Currituck Sound.

Introduction

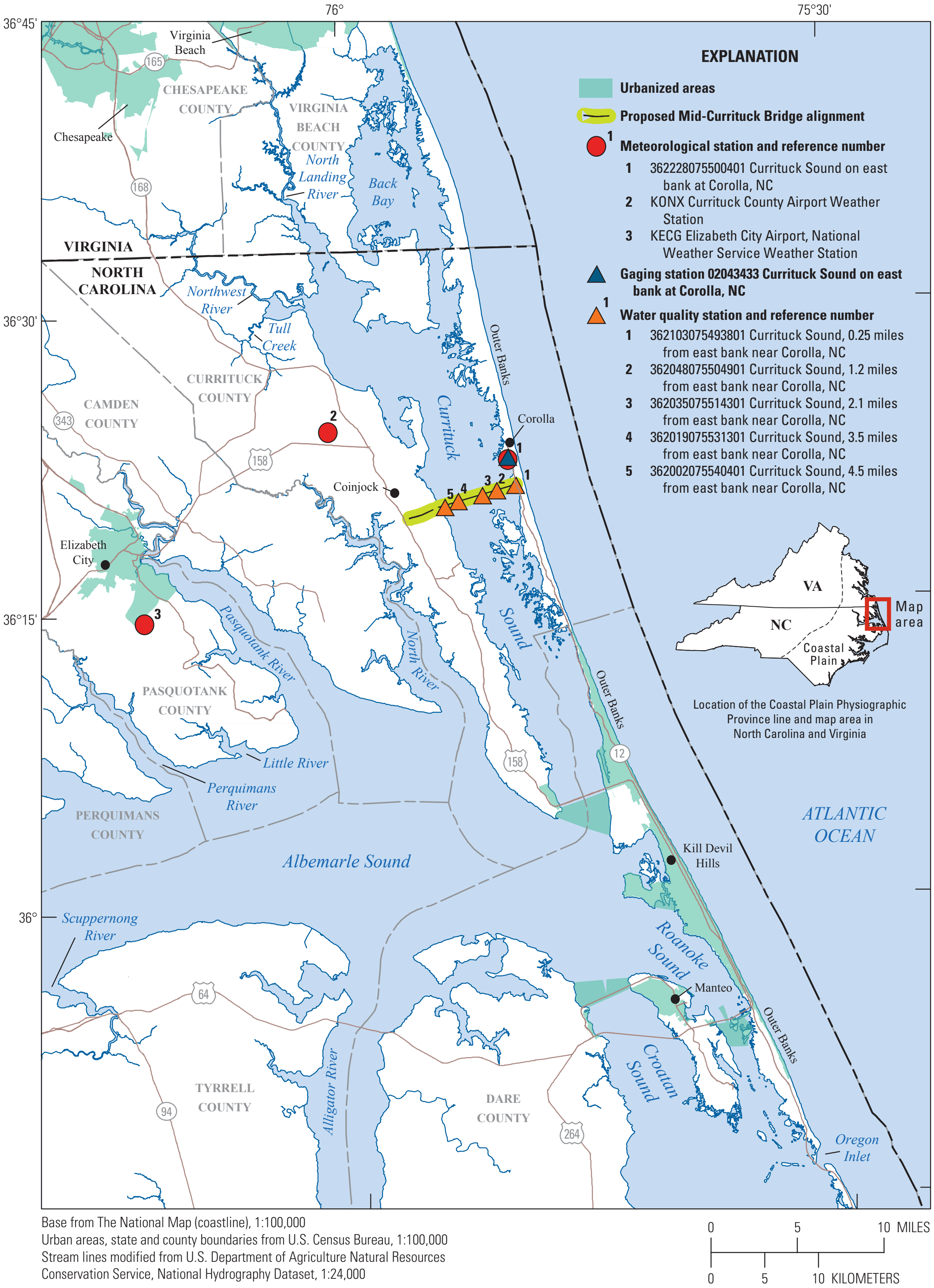
Ecological conditions in and around Currituck Sound in northeastern North Carolina and southeastern Virginia have changed substantially since at least the 1980s. Fish-population surveys have indicated a decrease in freshwater species and an increase in estuarine species. These changes are attributed to an increase in salinity in the sound (Southwick and Norman, 1991). It has further been hypothesized (U.S. Army Corps of Engineers, 2001) that the change in the salinity regime is associated with a substantial decline in submerged aquatic vegetation (SAV), although other factors may be responsible for the SAV declines. Beds of SAV provide food for migratory waterfowl, in addition to spawning and nursery habitats for fish species. A decline in SAV beds also contributes to a decline in water quality, in that a decrease in SAV root systems and underwater biomass allows increased resuspension of fine sediments and associated nutrients during wind events (U.S. Army Corps of Engineers, 2001). In 2001, the U.S. Army Corps of Engineers conducted a reconnaissance study of Currituck Sound under Section 905(b) of the Water Resources Development Act of 1986. The purpose of the study was “to determine whether planning for the improvement of water quality, environmental restoration and protection, and related purposes for Currituck Sound should proceed further” (U.S. Army Corps of Engineers, 2001). Among other findings, one conclusion from the study was that Currituck Sound is a “threatened resource” (Fine, 2008).

In 2005, a team of scientists was assembled to begin an investigation of the hydrologic and water-quality characteristics of Currituck Sound and its major tributaries. The objectives of the investigation were to document water-quality trends in the sound and collect the data needed for the development of a coupled hydrodynamic and water-quality model. The U.S. Geological Survey (USGS), Elizabeth City State University (ECSU), North Carolina National Estuarine Research Reserve (NERR), and the U.S. Fish and Wildlife Service (USFWS) partnered in data-collection efforts in and around Currituck Sound during 2006 and 2007. Data were collected at nine locations and included continuous measurements of water elevation, velocity, discharge, water temperature, specific conductance, dissolved oxygen, pH, turbidity, and chlorophyll *a* (at a subset of the nine sites). Water-quality samples also were collected at selected sites in the sound. All data can be obtained through the National Water Information System (NWIS) Web interface at http://waterdata.usgs.gov/nc/nwis or in the USGS annual water-resources data reports (U.S. Geological Survey, 2007, 2008). The USGS also collected data to define the hydrologic and salinity characteristics of the upper Currituck Sound and selected tributaries from 1998 to 1999. The results of this analysis are presented in Caldwell (2001).

The North Carolina Turnpike Authority (NCTA), a division of the North Carolina Department of Transportation (NCDOT), is planning to make transportation improvements in the Currituck Sound area by constructing a two-lane bridge from U.S. Highway 158 just south of Coinjock, North Carolina, to State Highway 12 on the Outer Banks just south of Corolla, N.C. (fig. 1). The results of the Final Environmental Impact Study (FEIS) associated with the bridge and existing roadway improvements indicated potential water-quality and habitat impacts to Currituck Sound related to stormwater runoff, altered light levels, introduction of piles as hard substrate, and localized turbidity and siltation during construction (North Carolina Turnpike Authority, 2010).

Several studies have shown that bridge deck runoff contains a relatively high load of constituents, such as nutrients, solids, pesticides, metals, and polycyclic aromatic hydrocarbons (PAHs) (Driscoll and others, 1988; Dupuis, 2002; Malina and others, 2005; Marsalek and others, 1997; McKenzie and Irwin, 1983; URS Corporation, 2010; Wagner and others, 2011). These substances have the potential to adversely affect aquatic life by directly or indirectly interfering with various biological processes and cycles; however, the actual impacts of stormwater runoff from bridges are highly site-specific (URS Corporation, 2010; Wagner and others, 2011). Constituents in stormwater runoff or from a hazardous spill incident discharged into Currituck Sound could dissipate slowly because of limited water circulation and may result in bioaccumulation and higher sediment contamination levels than in receiving waters having better circulation and higher flow rates.

The primary objective of this initial study phase was to establish baseline water-quality conditions and bed-sediment chemistry of Currituck Sound in the vicinity of the planned alignment of the Mid-Currituck Bridge. The data collected can then be used to evaluate the impacts associated with the bridge construction and bridge deck stormwater runoff.



Base from The National Map (coastline), 1:100,000
Urban areas, state and county boundaries from U.S. Census Bureau, 1:100,000
Stream lines modified from U.S. Department of Agriculture Natural Resources Conservation Service, National Hydrography Dataset, 1:24,000

Figure 1. Location of the study area in Currituck Sound, North Carolina.

Purpose and Scope

The purpose of this report is to document the USGS data-collection efforts to characterize the baseline water-quality and bed-sediment conditions in Currituck Sound in the vicinity of the proposed Mid-Currituck Bridge. In addition to describing the methods used for data collection and quality assurance, this report also provides a summary of the baseline water-quality conditions in Currituck Sound in the vicinity of the proposed Mid-Currituck Bridge.

Between 2011 and 2015, discrete water-quality samples were collected monthly and after selected storm events from five locations in Currituck Sound. These sampling locations are distributed along the proposed alignment of the Mid-Currituck Bridge. Water samples were analyzed for physical properties and water-quality constituents associated with bridge deck stormwater runoff (Wagner and others, 2011) and important in identifying impaired waters designated as “SC” (saltwater – aquatic life propagation/protection and secondary recreation) under North Carolina’s water-quality classifications by the North Carolina Department of Environmental Quality (North Carolina Department of Environment and Natural Resources, 2008). The occurrence and distribution of parameters of concern (POCs) identified in Wagner and others (2011), including pH, nutrients, total recoverable and dissolved metals, and PAHs, and some additional pertinent physical parameters (dis-solved oxygen, specific conductance, and turbidity) were analyzed in water and bed-sediment samples. Bed-sediment chemistry was also measured three times during the study at the five sampling locations. Continuous water-level and wind speed and direction data in Currituck Sound were also collected by the USGS during the water-quality sampling period. The circulation dynamics of the sound in the vicinity of the planned bridge were measured for each sampling event using an acoustic Doppler current profiler (ADCP) integrated with a differentially corrected global positioning system (GPS). The ADCP velocity data can be used to characterize and compare the circulation dynamics and how they relate to water quality in the vicinity of the bridge at the time of each sampling event before and after bridge construction.

Study Area

Currituck Sound is a 153-square-mile (mi^2) oligohaline estuary in the northeastern part of the Coastal Plain Physiographic Province of North Carolina (fig. 1). The drainage area of the entire Currituck Sound is estimated to be 733 mi^2, of which almost one-third is open water. Most of the land that drains into Currituck Sound is in the cities of Virginia Beach and Chesapeake, Virginia, and in northwestern Currituck County, N.C. The exact drainage area of Currituck Sound is uncertain because the water in several canals that connect Currituck Sound to Chesapeake Bay can flow northward or southward and because the basin has low topographic relief (Fine, 2008).

The climate of the study area is temperate and oceanic. The average annual precipitation is about 45 inches (in.), and monthly totals typically are greatest during July and August (Norman, 1991). Flood-producing rainfall and high winds associated with hurricanes or tropical storms and (or) convective thunderstorms generally occur during the summer or fall. In addition, nor’easters—storms that generate strong winds, heavy rainfall, and high water elevations or flooding—generally occur during fall and winter months. Water circulation patterns in Currituck Sound are primarily wind-driven rather than tidally driven because of the relatively long distance between the sound and its connection with the Atlantic Ocean at Oregon Inlet, N.C. (Fine, 2008) (fig. 1).

The data collected by the USGS in Currituck Sound from 2006 to 2007 indicate that, most of the time, the circulation and movement of water in the sound are dominated by wind events. Freshwater inflows into the upper Currituck Sound are small and the tidal effect is minimal, typically resulting in a less than 0.5-ft difference between daily maximum and minimum water level (Caldwell, 2001) in the vicinity of the planned bridge alignment. Therefore, the most appreciable changes in water quality occur during wind events. Southwestern winds are dominant in spring and summer and push more saline water up from the south into the sound, thereby increasing water levels and conductivity/salinity. North winds are dominant in fall and winter and tend to push water out of the sound, decreasing water levels and conductivity/salinity. Average surface-water depth in Currituck Sound during the study period of 2011–15 at the five sampling locations (fig. 1) varied as follows:

- Station at 0.25 miles (mi) from the east bank of Currituck Sound (station 1): 2.0 ft
- Station at 1.2 mi from the east bank of Currituck Sound (station 2): 6.2 ft
- Station at 2.1 mi from the east bank of Currituck Sound (station 3): 6.4 ft
- Station at 3.5 mi from the east bank of Currituck Sound (station 4): 8.1 ft
- Station at 4.5 mi from the east bank of Currituck Sound (station 5): 4.4 ft

The spatial mean of depth-averaged water velocity magnitudes and directions were computed from the ADCP three-dimensional velocity data over 400-ft sections of the proposed bridge alignment that were centered on each of the five water quality stations and summarized for the sampling events in table 1. The relatively high standard deviations shown in table 1 indicate that the water-velocity magnitudes and directions are highly variable both spatially and temporally in the vicinity of the proposed Mid-Currituck Bridge.

Three major tributaries supply most of the freshwater to Currituck Sound—North Landing River, Northwest River, and Tull Creek (fig. 1). Northwest River and Tull Creek drain mostly agricultural lands and have drainage areas of 196 mi^2 and 52 mi^2, respectively. The drainage area of North Landing River at the Virginia-North Carolina State line is about 117 mi^2.

Table 1. Summary of spatially and depth-averaged water-velocity magnitude and direction in the vicinity of the water-quality sampling locations in Currituck Sound, North Carolina.

[Dates are shown as month, day, year. ft/s, foot per second; std dev, standard deviation; deg, degrees; --, no valid velocity data available; GPS, global positioning system]

Date	362103075493801				362048075504901				362035075514301			
	0.25 miles from east bank of Currituck Sound				1.2 miles from east bank of Currituck Sound				2.1 miles from east bank of Currituck Sound			
	Average velocity magnitude (ft/s)	Std dev velocity magnitude (ft/s)	Average velocity direction (deg from 0, north)	Std dev velocity direction (deg from 0, north)	Average velocity magni tude (ft/s)	Std dev velocity magnitude (ft/s)	Average velocity direction (deg from 0, north)	Std dev velocity direction (deg from 0, north)	Average velocity magnitude (ft/s)	Std dev velocity magnitude (ft/s)	Average velocity direction (deg from 0, north)	Std dev velocity direction (deg from 0, north)
Monthly measurements												
9/28/2011	No valid GPS data											
10/18/2011	0.05	0.41	275.1	105.9	0.15	0.36	234.6	94.7	0.05	0.40	8.7	109.4
11/15/2011	0.59	0.32	17.2	147.1	0.35	0.22	309.8	101.4	0.19	0.37	321.4	121.9
12/20/2011	--	--	--	--	0.19	0.15	247.6	60.3	0.14	0.12	245.5	80.4
1/24/2012	0.44	0.44	63.2	104.0	0.10	0.17	297.9	112.4	0.16	0.14	1.3	135.5
2/22/2012	0.23	0.20	189.0	83.7	0.27	0.17	289.2	74.8	0.15	0.19	347.2	128.3
3/21/2012	0.21	0.12	14.3	87.4	0.08	0.28	5.4	114.1	0.13	0.38	65.3	103.7
4/17/2012	0.42	0.26	174.2	44.1	0.09	0.14	147.7	78.1	0.11	0.09	154.7	72.0
6/20/2012	0.41	0.24	63.4	75.6	0.15	0.22	250.3	86.6	0.07	0.17	269.1	99.8
7/18/2012	1.26	0.11	91.2	5.7	0.03	0.30	270.2	100.0	0.12	0.18	74.9	98.9
8/15/2012	0.29	0.25	166.4	67.5	0.12	0.27	296.5	99.7	0.18	0.22	2.3	131.9
9/12/2012	0.40	0.14	50.2	66.1	0.30	0.18	44.7	101.7	0.14	0.18	28.3	118.6
11/15/2012	0.25	0.05	162.7	28.2	0.17	0.37	149.5	80.9	0.55	0.93	200.9	66.7
12/18/2012	--	--	--	--	--	--	--	--	--	--	--	--
1/17/2013	0.32	0.56	167.4	83.0	0.16	0.45	40.0	107.2	0.07	0.47	109.9	105.0
3/20/2012	0.10	0.40	320.0	118.1	0.14	0.20	349.1	122.8	0.06	0.23	280.4	104.9
4/9/2013	No valid GPS data											
5/30/2013	--	--	--	--	--	--	--	--	--	--	--	--
6/26/2013	0.28	0.40	124.5	92.7	0.65	1.07	61.3	96.9	1.06	1.21	68.8	88.4
7/24/2013	0.29	0.57	205.6	81.0	0.06	0.27	231.3	99.8	0.26	0.28	113.7	78.7
8/15/2013	0.83	0.11	21.5	17.2	0.09	0.43	348.9	109.6	0.29	0.76	57.3	114.8
9/11/2013	No valid GPS data											
10/23/2013	--	--	--	--	--	--	--	--	--	--	--	--
11/21/2013	--	--	--	--	1.09	0.89	63.7	91.6	1.31	1.01	74.1	81.6
12/19/2013	0.18	0.59	81.8	96.0	0.19	0.41	289.3	105.7	0.23	0.42	46.4	103.7
Storm measurements												
8/30/2011	0.06	0.08	31.6	124.3	0.13	0.24	92.5	96.6	0.19	0.27	198.5	79.4
3/6/2012	0.32	0.21	132.5	53.6	0.03	0.22	60.8	109.9	0.05	0.31	119.1	98.8
5/31/2012	0.32	0.15	181.2	40.1	0.02	0.35	170.4	84.9	0.09	0.33	59.5	106.0
10/10/2012	--	--	--	--	0.12	0.16	265.8	90.2	0.23	0.22	319.4	113.2
2/27/2013	0.65	0.76	233.7	93.7	0.47	0.30	323.3	24.3	0.27	0.17	333.1	131.9
6/10/2013	--	--	--	--	0.25	0.51	261.0	96.2	0.28	0.52	26.1	116.9
1/25/2015	No valid GPS data											

Table 1. Summary of spatially- and depth-averaged water-velocity magnitude and direction in the vicinity of the water-quality sampling locations in Currituck Sound, North Carolina.—Continued

[Dates are shown as month, day, year. ft/s, foot per second; std dev, standard deviation; deg, degrees; --, no valid velocity data available; GPS, global positioning system]

Date	362019075531301				362002075540401			
	3.5 miles from east bank of Currituck Sound				4.5 miles from east bank of Currituck Sound			
	Average velocity magnitude (ft/s)	Std dev velocity magnitude (ft/s)	Average velocity direction (deg from 0, north)	Std dev velocity direction (deg from 0, north)	Average velocity magnitude (ft/s)	Std dev velocity magnitude (ft/s)	Average velocity direction (deg from 0, north)	Std dev velocity direction (deg from 0, north)
Monthly measurements								
9/28/2011	No valid GPS data							
10/18/2011	0.20	0.25	153.4	74.7	0.07	0.19	184.2	88.5
11/15/2011	0.36	0.19	190.3	49.0	0.35	0.27	290.9	85.8
12/20/2011	0.07	0.13	315.9	112.8	0.16	0.21	211.1	83.2
1/24/2012	0.26	0.10	335.6	92.8	0.11	0.15	234.5	86.8
2/22/2012	0.31	0.15	340.4	122.7	0.20	0.17	288.4	98.4
3/21/2012	0.32	0.42	68.8	109.8	0.15	0.29	330.4	115.9
4/17/2012	0.38	0.13	159.1	23.5	0.11	0.14	195.0	66.0
6/20/2012	0.06	0.20	179.1	85.7	0.17	0.21	211.1	79.6
7/18/2012	0.04	0.15	158.5	95.8	0.10	0.16	301.4	111.1
8/15/2012	0.11	0.17	1.1	123.3	0.31	0.27	237.1	69.9
9/12/2012	0.22	0.33	16.8	131.7	0.26	0.44	39.1	118.4
11/15/2012	0.32	0.62	298.6	123.1	0.41	0.13	94.4	37.3
12/18/2012	--	--	--	--	--	--	--	--
1/17/2013	0.18	0.37	98.7	102.3	0.44	0.63	140.1	83.4
3/20/2012	0.08	0.40	48.2	99.7	0.07	0.45	309.2	105.6
4/9/2013	No valid GPS data							
5/30/2013	0.90	0.62	169.7	57.8	0.43	0.31	135.4	76.6
6/26/2013	0.67	0.81	78.8	61.1	0.05	0.31	55.4	101.3
7/24/2013	0.36	0.19	154.6	45.0	0.17	0.22	125.9	83.5
8/15/2013	0.28	0.41	38.6	114.2	0.40	0.32	331.7	121.5
9/11/2013	No valid GPS data							
10/23/2013	--	--	--	--	--	--	--	--
11/21/2013	1.34	0.91	48.8	78.4	0.23	0.61	61.0	106.0
12/19/2013	2.06	1.42	253.6	65.8	0.67	0.39	34.7	110.8
Storm measurements								
8/30/2011	0.33	0.43	186.9	67.1	0.26	0.33	125.5	87.9
3/6/2012	0.21	0.35	91.1	96.7	0.12	0.26	108.5	93.5
5/31/2012	0.08	0.22	357.1	111.9	0.12	0.17	199.4	85.2
10/10/2012	0.38	0.13	336.9	103.7	0.13	0.16	294.1	106.4
2/27/2013	0.43	0.19	324.9	108.8	0.38	0.43	247.9	83.2
6/10/2013	0.02	0.28	279.4	105.5	0.19	0.36	12.5	121.6
1/25/2015	No valid GPS data							

Methods

The collection of water-level, wind-speed and direction, and water-quality data within Currituck Sound in the vicinity of the proposed Mid-Currituck Bridge began in August 2011 and concluded in January 2015. This section provides a discussion of the methods used for measuring water levels, wind speed and direction, and collecting and analyzing field samples.

Water Levels, Wind Speed, and Wind Direction

A USGS gaging station measuring water level (02043433) and wind speed and direction (362228075500401) was installed on the Currituck Sound on the east bank near Corolla, N.C. (fig. 1). The gaging station was equipped with a pressure transducer to measure water level, a sensor to measure wind speed and direction, and a data collection platform (DCP) to record and transmit data at 15-minute intervals to the NWIS database administered by the USGS. Water-level data were collected according to standard USGS methods (Rantz and others, 1982; Sauer and Turnipseed, 2010). Wind speed and direction data were measured using a Sutron Ultrasonic anemometer specified to have a wind speed resolution of 0.02-mile per hour and accuracy of ±2 percent, and a wind direction resolution of 1 degree and accuracy of ±3 degrees. Wind speed and direction data were collected every second and averaged over a 2-minute period just prior to being transmitted to the NWIS database at 15-minute intervals.

Water-Velocity Data

The circulation dynamics of the sound in the vicinity of the planned bridge were measured for each sampling event using an ADCP, which allows three-dimensional velocities to be measured from approximately 1.0 ft beneath the water surface to within 6 percent of the depth to the bottom. The ADCP velocity data were collected using standard USGS techniques (Mueller and others, 2013) and can be used to help characterize the circulation dynamics in the vicinity of the planned bridge at the time of each sampling event.

Water-Quality Samples

Discrete water-quality samples were collected at five selected locations from a manned boat along an approximately 4-mi transect across Currituck Sound in the vicinity of the planned bridge alignment (fig. 1). Latitude and longitude coordinates were established for each sampling location using a GPS receiver, which allowed the bed-sediment and water samples to be collected from the same locations throughout the study. Aside from bacteria, constituents in water and bed-sediment samples were analyzed at the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado. Bacteria in water samples were analyzed at the University of North Carolina at Chapel Hill Institute of Marine Sciences Laboratory on the Outer Banks, N.C. Analytical methods and instrumentation, and reporting levels are listed in table 2. Water-quality samples were collected monthly from August 2011 to December 2013. The monthly samples were supplemented with six storm-event samples that were collected within 48 hours after significant rainfall (greater than 0.5 in. within 24 hours) in the Currituck basin between August 2011 and January 2015. Vertical profiles (beginning at the surface and at 1.64-ft [0.5-meter] increments) of field parameters (water temperature, dissolved oxygen, pH, and specific conductance) were measured at each sampling location prior to sample collection. Historical water-quality data collected by the USGS indicate that the upper Currituck Sound is mostly well-mixed. If the water column was well-mixed and (or) the water was shallow (less than 6.5 ft [2 meters deep]), one sample was collected at that site. If the water column was stratified (thermally or with regard to salinity) or deeper than 6.5 ft, 2 discrete grab samples were collected: 1 about 1.64 ft below the top of the column and 1 about 1.64 ft above the bottom. Whole-water samples were collected and immediately transferred to sample bottles and placed on ice. Additional water that would be used for filtered samples was collected at each sampling location then transferred directly to a 4-liter (L) polyethylene bottle and immediately placed on ice. In order to complete all water-quality sampling and water-velocity data collection within daylight hours, USGS staff had to delay filtering water samples until they were off of the Currituck Sound and at the University of North Carolina at Chapel Hill Institute of Marine Sciences analytical laboratory, which could be up to 5 hours after the samples were collected from the field.

Bacteria samples were collected using a near-surface grab sample collected directly into sterilized bottles. Water samples were chilled, filtered when necessary, processed, and shipped to the University of North Carolina at Chapel Hill Institute of Marine Sciences analytical laboratory and analyzed for *Enterococci* and *Escherichia coli* (*E. coli*) bacteria. The samples were collected and processed using techniques described in the USGS national field manual for the collection of water-quality samples (U.S. Geological Survey, variously dated).

Bed-Sediment Samples

Surficial bed-sediment samples were collected at the same five surface-water stations on three dates. Constituents analyzed in bed sediments, method instrumentation, and reporting levels are listed in table 2. Samples collected in November 2011 were only analyzed for elements (“inorganics” hereafter), including several metals, nutrients (nitrogen and phosphorus), and carbons (total and the organically associated fraction) because of sample loss for analysis of trace organic compounds. Replacement samples for trace-organic

Table 2. Constituents measured in surface water and bed sediment collected in Currituck Sound, 2011–15.

[Analyte: N, nitrogen; Laboratory: NWQL, National Water Quality Laboratory; UNCCSI, University of North Carolina Coastal Studies Institute; USGS, U.S. Geological Survey; Ga. WSC, Georgia Water Science Center; Method instrumentation: CNS, carbon nitrogen sulfur; CS, carbon sulfur; Reporting level unit: °C, degrees Celsius; mg/L, milligram per liter; NTRU, nephelometric turbidity ratio units; µS/cm @ 25 °C, microsiemens per centimeter at 25 degrees Celsius; µg/L, microgram per liter; pct, percent; MPN/100 mL, most probable number per 100 milliliters; µg/kg, microgram per kilogram; wt %, weight percent; mg/kg, milligram per kilogram; Reporting level type: mrl, method reporting limit; ltmdl, long-term method detection limit; mdl, method detection level; irl, interim reporting level; lrl; laboratory reporting limit; Reference: EPA, Environmental Protection Agency; ASTM, American Society of Testing and Materials. --, not applicable]

Analyte	Laboratory	Method instrumentation	CASRN[1]	Reporting level			Reference
				Value	Unit	Type	
Surface water							
Temperature	Field	Thermistor	--	--	°C	--	USGS (var. dated)
Dissolved oxygen	Field	Clark cell	7782-44-7	0	mg/L	--	USGS (var. dated)
pH	Field	Glass electrode	12408-02-5	--	--	--	USGS (var. dated)
Turbidity	Field	Broad band light occlusion	--	2	NTRU	mrl	Clesceri and others (1998)
Specific conductance, field	Field	Wheatstone bridge	12408-02-5	5	µS/cm @ 25 °C	mrl	Fishman and Friedman (1989)
Specific conductance, laboratory	NWQL	Wheatstone bridge	12408-02-5	5	µS/cm @ 25 °C	mrl	Fishman and Friedman (1989)
Suspended solids	NWQL	Gravimetric	--	15	mg/L	mrl	Fishman and Friedman (1989)
Nitrogen, ammonia + organic nitrogen, total recoverable	NWQL	Colorimetry, microkjeldahl	17778-88-0	0.07	mg/L	ltmdl	Patton and Truit (2000)
Nitrogen, ammonia as N, dissolved	NWQL	Colorimetry	7664-41-7	0.01	mg/L	ltmdl	Fishman (1993)
Nitrogen, nitrite + nitrate, dissolved	NWQL	Colorimetry, cadmium reduction	14797-65-0 ($NO2^-$) + 14797-55-8 ($NO3^-$)	0.02	mg/L	ltmdl	Fishman (1993)
Nitrogen, nitrite + nitrate, dissolved	NWQL	Colorimetry, cadmium reduction, low level	14797-65-0 ($NO2^-$) + 14797-55-8 ($NO3^-$)	0.008	mg/L	ltmdl	Fishman (1993)
Nitrogen, nitrite + nitrate, dissolved	NWQL	Colorimetry, enzyme reduction	14797-65-0 ($NO2^-$) + 14797-55-8 ($NO3^-$)	0.04	mg/L	mdl	Patton and Kryskalla (2011)
Nitrogen, nitrite + nitrate, dissolved	NWQL	Colorimetry, enzyme reduction, low level	14797-65-0 ($NO2^-$) + 14797-55-8 ($NO3^-$)	0.01	mg/L	mdl	Patton and Kryskalla (2011)
Total nitrogen	NWQL	Algorithm (sum of ammonia, organic nitrogen, nitrate, and nitrite)	7727-37-9	0.008	mg/L	--	--
Total phosphorus	NWQL	Colorimetry, low level	7723-14-0	0.004	mg/L	ltmdl	U.S. EPA (1993)
Phosphorus, phosphate, ortho, dissolved	NWQL	Colorimetry	14265-44-2	0.004	mg/L	ltmdl	Fishman (1993)
Aluminum, dissolved	NWQL	Inductively coupled plasma/mass spectrometry	7429-90-5	2.2	µg/L	ltmdl	Garbarino and others (2006)
Aluminum, total recoverable	NWQL	Inductively coupled plasma/mass spectrometry	7429-90-5	3.8	µg/L	ltmdl	Garbarino and Struzeski (1998)
Arsenic, dissolved	NWQL	Collision/reaction cell inductively coupled plasma-mass spectrometry	7440-38-2	0.04	µg/L	ltmdl	Garbarino and others (2006)
Arsenic, total recoverable	NWQL	Collision/reaction cell inductively coupled plasma-mass spectrometry	7440-38-2	0.28	µg/L	ltmdl	Garbarino and others (2006)

Table 2. Constituents measured in surface water and bed sediment collected in Currituck Sound, 2011–15.—Continued

[Analyte: N, nitrogen; Laboratory: NWQL, National Water Quality Laboratory; UNCCSI, University of North Carolina Coastal Studies Institute; USGS, U.S. Geological Survey; Ga. WSC, Georgia Water Science Center; Method instrumentation: CNS, carbon nitrogen sulfur; CS, carbon sulfur; Reporting level unit: °C, degrees Celsius; mg/L, milligram per liter; NTRU, nephelometric turbidity ratio units; µS/cm @ 25 °C, microsiemens per centimeter at 25 degrees Celsius; µg/L, microgram per liter; pct, percent; MPN/100 mL, most probable number per 100 milliliters; µg/kg, microgram per kilogram; wt %, weight percent; mg/kg, milligram per kilogram; Reporting level type: mrl, method reporting limit; ltmdl, long-term method detection limit; mdl, method detection level; irl, interim reporting level; lrl; laboratory reporting limit; Reference: EPA, Environmental Protection Agency; ASTM, American Society of Testing and Materials. --, not applicable]

Analyte	Laboratory	Method instrumentation	CASRN[1]	Reporting level			Reference
				Value	Unit	Type	
Cadmium, dissolved	NWQL	Inductively coupled plasma/mass spectrometry	7440-43-9	0.016	µg/L	ltmdl	Garbarino and others (2006)
Cadmium, total recoverable	NWQL	Inductively coupled plasma/mass spectrometry	7440-43-9	0.016	µg/L	ltmdl	Garbarino and Struzeski (1998)
Chromium, dissolved	NWQL	Collision/reaction cell inductively coupled plasma-mass spectrometry	7440-47-3	0.07	µg/L	ltmdl	Garbarino and others (2006)
Chromium, total recoverable	NWQL	Collision/reaction cell inductively coupled plasma-mass spectrometry	7440-47-3	0.3	µg/L	ltmdl	Garbarino and others (2006)
Copper, dissolved	NWQL	Collision/reaction cell inductively coupled plasma-mass spectrometry	7440-50-8	0.8	µg/L	ltmdl	Garbarino and others (2006)
Copper, total recoverable	NWQL	Collision/reaction cell inductively coupled plasma-mass spectrometry	7440-50-8	0.7	µg/L	ltmdl	Garbarino and others (2006)
Iron, dissolved	NWQL	Inductively coupled plasma/atomic emission spectrometry	7439-89-6	4	µg/L	ltmdl	Fishman (1993)
Iron, total recoverable	NWQL	Inductively coupled plasma/atomic emission spectrometry	7439-89-6	4.6	µg/L	ltmdl	Garbarino and Struzeski (1998)
Lead, dissolved	NWQL	Inductively coupled plasma/mass spectrometry	7439-92-1	0.025	µg/L	ltmdl	Garbarino and others (2006)
Lead, total recoverable	NWQL	Inductively coupled plasma/mass spectrometry	7439-92-1	0.04	µg/L	ltmdl	Garbarino and Struzeski (1998)
Manganese, dissolved	NWQL	Inductively coupled plasma/mass spectrometry	7439-96-5	0.15	µg/L	ltmdl	Garbarino and others (2006)
Manganese, total recoverable	NWQL	Inductively coupled plasma/mass spectrometry	7439-96-5	0.4	µg/L	ltmdl	Garbarino and Struzeski (1998)
Mercury, dissolved	NWQL	Atomic fluorescence cold vapor (CVAF)	7439-97-6	0.005	µg/L	ltmdl	Garbarino and Damrau (2001)
Mercury, total recoverable	NWQL	Atomic fluorescence cold vapor (CVAF)	7439-97-6	0.005	µg/L	ltmdl	Garbarino and Damrau (2001)
Nickel, dissolved	NWQL	Collision/reaction cell inductively coupled plasma-mass spectrometry	7440-02-0	0.09	µg/L	ltmdl	Garbarino and others (2006)
Nickel, total recoverable	NWQL	Collision/reaction cell inductively coupled plasma-mass spectrometry	7440-02-0	0.19	µg/L	ltmdl	Garbarino and others (2006)
Selenium, dissolved	NWQL	Collision/reaction cell inductively coupled plasma-mass spectrometry	7782-49-2	0.03	µg/L	ltmdl	Garbarino and others (2006)
Selenium, total recoverable	NWQL	Collision/reaction cell inductively coupled plasma-mass spectrometry	7782-49-2	0.05	µg/L	ltmdl	Garbarino and others (2006)

Table 2. Constituents measured in surface water and bed sediment collected in Currituck Sound, 2011–15.—Continued

[Analyte: N, nitrogen; Laboratory: NWQL, National Water Quality Laboratory; UNCCSI, University of North Carolina Coastal Studies Institute; USGS, U.S. Geological Survey; Ga. WSC, Georgia Water Science Center; Method instrumentation: CNS, carbon nitrogen sulfur; CS, carbon sulfur; Reporting level unit: °C, degrees Celsius; mg/L, milligram per liter; NTRU, nephelometric turbidity ratio units; µS/cm @ 25 °C, microsiemens per centimeter at 25 degrees Celsius; µg/L, microgram per liter; pct, percent; MPN/100 mL, most probable number per 100 milliliters; µg/kg, microgram per kilogram; wt %, weight percent; mg/kg, milligram per kilogram; Reporting level type: mrl, method reporting limit; ltmdl, long-term method detection limit; mdl, method detection level; irl, interim reporting level; lrl; laboratory reporting limit; Reference: EPA, Environmental Protection Agency; ASTM, American Society of Testing and Materials. --, not applicable]

Analyte	Laboratory	Method instrumentation	CASRN^1	Reporting level			Reference
				Value	Unit	Type	
Silver, dissolved	NWQL	Inductively coupled plasma/mass spectrometry	7440-22-4	0.005	µg/L	ltmdl	Garbarino and others (2006)
Silver, total recoverable	NWQL	Inductively coupled plasma/mass spectrometry	7440-22-4	0.015	µg/L	ltmdl	Garbarino and Struzeski (1998)
Zinc, dissolved	NWQL	Collision/reaction cell inductively coupled plasma-mass spectrometry	7440-66-6	1.4	µg/L	ltmdl	Garbarino and others (2006)
Zinc, total recoverable	NWQL	Collision/reaction cell inductively coupled plasma-mass spectrometry	7440-66-6	3	µg/L	ltmdl	Garbarino and others (2006)
Benz[*a*]anthracene, total recoverable^2	NWQL	Gas chromatography/mass spectrometry	56-55-3	0.03-0.26	µg/L	lrl	Fishman (1993)(modified)
Benzo[*a*]pyrene, total recoverable^2	NWQL	Gas chromatography/mass spectrometry	50-32-8	0.005-0.32	µg/L	lrl	Fishman (1993)(modified)
Benzo[*b*]fluoranthene, total recoverable^2	NWQL	Gas chromatography/mass spectrometry	205-99-2	0.004-0.30	µg/L	lrl	Fishman (1993)(modified)
Benzo[*k*]fluoranthene, total recoverable^2	NWQL	Gas chromatography/mass spectrometry	207-08-9	0.004-0.30	µg/L	lrl	Fishman (1993)(modified)
bis(2-Chloroethyl)ether, total recoverable^2	NWQL	Gas chromatography/mass spectrometry	111-44-4	0.01-0.30	µg/L	lrl	Fishman (1993)(modified)
bis(2-Ethylhexyl) phthalate, total recoverable^2	NWQL	Gas chromatography/mass spectrometry	117-81-7	0.5-2.6	µg/L	irl	Fishman (1993)(modified)
Chrysene, total recoverable^2	NWQL	Gas chromatography/mass spectrometry	218-01-9	0.004-0.32	µg/L	lrl	Fishman (1993)(modified)
Dibenz[*a*,*h*]anthracene, total recoverable^2	NWQL	Gas chromatography/mass spectrometry	53-70-3	0.004-0.42	µg/L	lrl	Fishman (1993)(modified)
Hexachlorobenzene, total recoverable^2	NWQL	Gas chromatography/mass spectrometry	118-74-1	0.004-0.30	µg/L	lrl	Fishman (1993)(modified)
Indeno[1,2,3-*cd*]pyrene, total recoverable^2	NWQL	Gas chromatography/mass spectrometry	193-39-5	0.004-0.38	µg/L	lrl	Fishman (1993)(modified)
N-Nitrosodimethylamine, total recoverable^2	NWQL	Gas chromatography/mass spectrometry	62-75-9	0.02-0.24	µg/L	lrl	Fishman (1993)(modified)
N-Nitrosodi-*n*-propylamine, total recoverable^2	NWQL	Gas chromatography/mass spectrometry	621-64-7	0.4	µg/L	lrl	Fishman (1993)(modified)
Pentachlorophenol, total recoverable^2	NWQL	Gas chromatography/mass spectrometry	87-86-5	0.08-0.6	µg/L	lrl	Fishman (1993)(modified)
Phenanthrene, total recoverable^2	NWQL	Gas chromatography/mass spectrometry	85-01-8	0.007-0.32	µg/L	lrl	Fishman (1993)(modified)
Nitrobenzene-*d*5 (surrogate)	NWQL	Gas chromatography/mass spectrometry	4165-60-0	--	pct	--	Fishman (1993)(modified)
p-Terphenyl-*d*14 (surrogate)	NWQL	Gas chromatography/mass spectrometry	1718-51-0	--	pct	--	Fishman (1993)(modified)
2,4,6-Tribromophenol (surrogate)	NWQL	Gas chromatography/mass spectrometry	118-79-6	--	pct	--	Fishman (1993)(modified)

Table 2. Constituents measured in surface water and bed sediment collected in Currituck Sound, 2011–15.—Continued

[Analyte: N, nitrogen; Laboratory: NWQL, National Water Quality Laboratory; UNCCSI, University of North Carolina Coastal Studies Institute; USGS, U.S. Geological Survey; Ga. WSC, Georgia Water Science Center; Method instrumentation: CNS, carbon nitrogen sulfur; CS, carbon sulfur; Reporting level unit: °C, degrees Celsius; mg/L, milligram per liter; NTRU, nephelometric turbidity ratio units; µS/cm @ 25 °C, microsiemens per centimeter at 25 degrees Celsius; µg/L, microgram per liter; pct, percent; MPN/100 mL, most probable number per 100 milliliters; µg/kg, microgram per kilogram; wt %, weight percent; mg/kg, milligram per kilogram; Reporting level type: mrl, method reporting limit; ltmdl, long-term method detection limit; mdl, method detection level; irl, interim reporting level; lrl; laboratory reporting limit; Reference: EPA, Environmental Protection Agency; ASTM, American Society of Testing and Materials. --, not applicable]

Analyte	Laboratory	Method instrumentation	CASRN[1]	Reporting level			Reference
				Value	Unit	Type	
Escherichia coli	UNCCSI	Well count with colorimetry and fluorescence	--	1	MPN/100 mL	--	Eaton and others (2005)
Enterococcus	UNCCSI	Well count with fluorescence	--	1	MPN/100 mL	--	ASTM (2014)
Bed sediment							
1,2,4-Trichlorobenzene, recoverable	NWQL	Gas chromatography/mass spectrometry	120-82-1	25	µg/kg	irl	Zaugg and others (2006)
1,2-Dimethylnaphthalene, recoverable	NWQL	Gas chromatography/mass spectrometry	573-98-8	25	µg/kg	irl	Zaugg and others (2006)
1,6-Dimethylnaphthalene, recoverable	NWQL	Gas chromatography/mass spectrometry	575-43-9	25	µg/kg	irl	Zaugg and others (2006)
1-Methyl-9*H*-fluorene, recoverable	NWQL	Gas chromatography/mass spectrometry	1730-37-6	25	µg/kg	irl	Zaugg and others (2006)
1-Methylphenanthrene, recoverable	NWQL	Gas chromatography/mass spectrometry	832-69-9	25	µg/kg	irl	Zaugg and others (2006)
1-Methylpyrene, recoverable	NWQL	Gas chromatography/mass spectrometry	2381-21-7	25	µg/kg	irl	Zaugg and others (2006)
2,3,6-Trimethylnaphthalene, recoverable	NWQL	Gas chromatography/mass spectrometry	829-26-5	25	µg/kg	irl	Zaugg and others (2006)
2,6-Dimethylnaphthalene, recoverable	NWQL	Gas chromatography/mass spectrometry	581-42-0	25	µg/kg	irl	Zaugg and others (2006)
2-Ethylnaphthalene, recoverable	NWQL	Gas chromatography/mass spectrometry	939-27-5	25	µg/kg	irl	Zaugg and others (2006)
2-Methylanthracene, recoverable	NWQL	Gas chromatography/mass spectrometry	613-12-7	25	µg/kg	irl	Zaugg and others (2006)
4*H*-Cyclopenta[*def*]phenanthrene, recoverable	NWQL	Gas chromatography/mass spectrometry	203-64-5	25	µg/kg	irl	Zaugg and others (2006)
9*H*-Fluorene, recoverable	NWQL	Gas chromatography/mass spectrometry	86-73-7	25	µg/kg	irl	Zaugg and others (2006)
Acenaphthene, recoverable	NWQL	Gas chromatography/mass spectrometry	83-32-9	25	µg/kg	irl	Zaugg and others (2006)
Acenaphthylene, recoverable	NWQL	Gas chromatography/mass spectrometry	208-96-8	25	µg/kg	irl	Zaugg and others (2006)
Anthracene, recoverable	NWQL	Gas chromatography/mass spectrometry	120-12-7	25	µg/kg	irl	Zaugg and others (2006)
Anthraquinone, recoverable	NWQL	Gas chromatography/mass spectrometry	84-65-1	25	µg/kg	irl	Zaugg and others (2006)
Benz[*a*]anthracene, recoverable	NWQL	Gas chromatography/mass spectrometry	56-55-3	25	µg/kg	irl	Zaugg and others (2006)
Benzo[*a*]pyrene, recoverable	NWQL	Gas chromatography/mass spectrometry	50-32-8	25	µg/kg	irl	Zaugg and others (2006)
Benzo[*b*]fluoranthene, recoverable	NWQL	Gas chromatography/mass spectrometry	205-99-2	25	µg/kg	irl	Zaugg and others (2006)
Benzo[*e*]pyrene, recoverable	NWQL	Gas chromatography/mass spectrometry	192-97-2	25	µg/kg	irl	Zaugg and others (2006)
Benzo[*ghi*]perylene, recoverable	NWQL	Gas chromatography/mass spectrometry	191-24-2	25	µg/kg	irl	Zaugg and others (2006)
Benzo[*k*]fluoranthene, recoverable	NWQL	Gas chromatography/mass spectrometry	207-08-9	25	µg/kg	irl	Zaugg and others (2006)
bis(2-Ethylhexyl) phthalate, recoverable	NWQL	Gas chromatography/mass spectrometry	117-81-7	25	µg/kg	irl	Zaugg and others (2006)
Carbazole, recoverable	NWQL	Gas chromatography/mass spectrometry	86-74-8	25	µg/kg	irl	Zaugg and others (2006)
Chrysene, recoverable	NWQL	Gas chromatography/mass spectrometry	218-01-9	25	µg/kg	irl	Zaugg and others (2006)
Dibenz[*a*,*h*]anthracene, recoverable	NWQL	Gas chromatography/mass spectrometry	53-70-3	25	µg/kg	irl	Zaugg and others (2006)

Table 2. Constituents measured in surface water and bed sediment collected in Currituck Sound, 2011–15.—Continued

[AAnalyte: N, nitrogen; Laboratory: NWQL, National Water Quality Laboratory; UNCCSI, University of North Carolina Coastal Studies Institute; USGS, U.S. Geological Survey; Ga. WSC, Georgia Water Science Center; Method instrumentation: CNS, carbon nitrogen sulfur; CS, carbon sulfur; Reporting level unit: °C, degrees Celsius; mg/L, milligram per liter; NTRU, nephelometric turbidity ratio units; µS/cm @ 25 °C, microsiemens per centimeter at 25 degrees Celsius; µg/L, microgram per liter; pct, percent; MPN/100 mL, most probable number per 100 milliliters; µg/kg, microgram per kilogram; wt %, weight percent; mg/kg, milligram per kilogram; Reporting level type: mrl, method reporting limit; ltmdl, long-term method detection limit; mdl, method detection level; irl, interim reporting level; lrl; laboratory reporting limit; Reference: EPA, Environmental Protection Agency; ASTM, American Society of Testing and Materials. --, not applicable]

Analyte	Laboratory	Method instrumentation	CASRN[1]	Reporting level			Reference
				Value	Unit	Type	
Dibenzothiophene, recoverable	NWQL	Gas chromatography/mass spectrometry	132-65-0	25	µg/kg	irl	Zaugg and others (2006)
Diethyl phthalate, recoverable	NWQL	Gas chromatography/mass spectrometry	84-66-2	25	µg/kg	irl	Zaugg and others (2006)
Fluoranthene, recoverable	NWQL	Gas chromatography/mass spectrometry	206-44-0	25	µg/kg	irl	Zaugg and others (2006)
Hexachlorobenzene, recoverable	NWQL	Gas chromatography/mass spectrometry	118-74-1	25	µg/kg	irl	Zaugg and others (2006)
Indeno[1,2,3-*cd*]pyrene, recoverable	NWQL	Gas chromatography/mass spectrometry	193-39-5	25	µg/kg	irl	Zaugg and others (2006)
Naphthalene, recoverable	NWQL	Gas chromatography/mass spectrometry	91-20-3	25	µg/kg	irl	Zaugg and others (2006)
Pentachloroanisole, recoverable	NWQL	Gas chromatography/mass spectrometry	1825-21-4	25	µg/kg	irl	Zaugg and others (2006)
Pentachloronitrobenzene, recoverable	NWQL	Gas chromatography/mass spectrometry	82-68-8	25	µg/kg	irl	Zaugg and others (2006)
Perylene, recoverable	NWQL	Gas chromatography/mass spectrometry	198-55-0	25	µg/kg	irl	Zaugg and others (2006)
Phenanthrene, recoverable	NWQL	Gas chromatography/mass spectrometry	85-01-8	25	µg/kg	irl	Zaugg and others (2006)
Phenanthridine, recoverable	NWQL	Gas chromatography/mass spectrometry	229-87-8	25	µg/kg	irl	Zaugg and others (2006)
Pyrene, recoverable	NWQL	Gas chromatography/mass spectrometry	129-00-0	25	µg/kg	irl	Zaugg and others (2006)
2-Fluorobiphenyl (surrogate)	NWQL	Gas chromatography/mass spectrometry	321-60-8	--	pct	--	Zaugg and others (2006)
Nitrobenzene-*d*5 (surrogate)	NWQL	Gas chromatography/mass spectrometry	4165-60-0	--	pct	--	Zaugg and others (2006)
Terphenyl-*d*14 (surrogate)	NWQL	Gas chromatography/mass spectrometry	1718-51-0	--	pct	--	Zaugg and others (2006)
Aluminum, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7429-90-5	0.1	wt %	lrl	Horowitz and others (2001)
Antimony, total	USGS Ga. WSC	Hydride generation/inductively coupled plasma/atomic emission spectrometry	7440-36-0	0.1	mg/kg	lrl	Horowitz and others (2001)
Arsenic, total	USGS Ga. WSC	Hydride generation/inductively coupled plasma/atomic emission spectrometry	7440-38-2	0.1	mg/kg	lrl	Horowitz and others (2001)
Barium, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7440-39-3	1	mg/kg	lrl	Horowitz and others (2001)
Beryllium, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7440-41-7	0.1	mg/kg	lrl	Horowitz and others (2001)
Cadmium, total	USGS Ga. WSC	Flame/atomic absorption spectrometry	7440-43-9	0.1	mg/kg	lrl	Horowitz and others (2001)
Calcium, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7440-70-2	0.1	wt %	lrl	Horowitz and others (2001)
Carbon, total	USGS Ga. WSC	CNS analyzer/thermal conductivity detection	7440-44-0	0.1	wt %	lrl	Horowitz and others (2001)
Carbon, total organic	USGS Ga. WSC	CS analyzer/infrared detection	--	0.1	wt %	lrl	Horowitz and others (2001)

Table 2. Constituents measured in surface water and bed sediment collected in Currituck Sound, 2011–15.—Continued

[Analyte: N, nitrogen; Laboratory: NWQL, National Water Quality Laboratory; UNCCSI, University of North Carolina Coastal Studies Institute; USGS, U.S. Geological Survey; Ga. WSC, Georgia Water Science Center; Method instrumentation: CNS, carbon nitrogen sulfur; CS, carbon sulfur; Reporting level unit: °C, degrees Celsius; mg/L, milligram per liter; NTRU, nephelometric turbidity ratio units; µS/cm @ 25 °C, microsiemens per centimeter at 25 degrees Celsius; µg/L, microgram per liter; pct, percent; MPN/100 mL, most probable number per 100 milliliters; µg/kg, microgram per kilogram; wt %, weight percent; mg/kg, milligram per kilogram; Reporting level type: mrl, method reporting limit; ltmdl, long-term method detection limit; mdl, method detection level; irl, interim reporting level; lrl; laboratory reporting limit; Reference: EPA, Environmental Protection Agency; ASTM, American Society of Testing and Materials. --, not applicable]

Analyte	Laboratory	Method instrumentation	CASRN[1]	Reporting level			Reference
				Value	Unit	Type	
Chromium, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7440-47-3	1	mg/kg	lrl	Horowitz and others (2001)
Cobalt, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7440-48-4	1	mg/kg	lrl	Horowitz and others (2001)
Copper, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7440-50-8	1	mg/kg	lrl	Horowitz and others (2001)
Iron, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7439-89-6	0.1	wt %	lrl	Horowitz and others (2001)
Lead, total	USGS Ga. WSC	Flame/atomic absorption spectrometry	7439-92-1	1	mg/kg	lrl	Horowitz and others (2001)
Lithium, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7439-93-2	1	mg/kg	lrl	Horowitz and others (2001)
Magnesium, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7439-95-4	0.1	wt %	lrl	Horowitz and others (2001)
Manganese, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7439-96-5	10	mg/kg	lrl	Horowitz and others (2001)
Mercury, total	USGS Ga. WSC	Cold vapor/atomic absorption spectrometry	7439-97-6	0.01	mg/kg	lrl	Horowitz and others (2001)
Molybdenum, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7439-98-7	1	mg/kg	lrl	Horowitz and others (2001)
Nickel, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7440-02-0	1	mg/kg	lrl	Horowitz and others (2001)
Nitrogen, total	USGS Ga. WSC	CNS analyzer/thermal conductivity detection	7727-37-9	0.01	wt %	lrl	Horowitz and others (2001)
Phosphorus, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7723-14-0	1	mg/kg	lrl	Horowitz and others (2001)
Potassium, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	9/7/7440	0.1	wt %	lrl	Horowitz and others (2001)
Selenium, total	USGS Ga. WSC	Hydride generation/atomic absorption spectrometry	7782-49-2	0.1	mg/kg	lrl	Horowitz and others (2001)
Silver, total	USGS Ga. WSC	Flame/atomic absorption spectrometry	7440-22-4	0.05	mg/kg	lrl	Horowitz and others (2001)
Sodium, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7440-23-5	0.1	wt %	lrl	Horowitz and others (2001)
Strontium, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7440-24-6	1	mg/kg	lrl	Horowitz and others (2001)

Table 2. Constituents measured in surface water and bed sediment collected in Currituck Sound, 2011–15.—Continued

[Analyte: N, nitrogen; Laboratory: NWQL, National Water Quality Laboratory; UNCCSI, University of North Carolina Coastal Studies Institute; USGS, U.S. Geological Survey; Ga. WSC, Georgia Water Science Center; Method instrumentation: CNS, carbon nitrogen sulfur; CS, carbon sulfur; Reporting level unit: °C, degrees Celsius; mg/L, milligram per liter; NTRU, nephelometric turbidity ratio units; µS/cm @ 25 °C, microsiemens per centimeter at 25 degrees Celsius; µg/L, microgram per liter; pct, percent; MPN/100 mL, most probable number per 100 milliliters; µg/kg, microgram per kilogram; wt %, weight percent; mg/kg, milligram per kilogram; Reporting level type: mrl, method reporting limit; ltmdl, long-term method detection limit; mdl, method detection level; irl, interim reporting level; lrl; laboratory reporting limit; Reference: EPA, Environmental Protection Agency; ASTM, American Society of Testing and Materials. --, not applicable]

Analyte	Laboratory	Method instrumentation	CASRN[1]	Reporting level			Reference
				Value	Unit	Type	
Sulfur, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7704-34-9	0.1	wt %	lrl	Horowitz and others (2001)
Thallium, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7440-28-0	50	mg/kg	lrl	Horowitz and others (2001)
Tin, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7440-31-5	0.1	mg/kg	lrl	Horowitz and others (2001)
Titanium, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7440-32-6	0.01	wt %	lrl	Horowitz and others (2001)
Uranium, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7440-61-1	50	mg/kg	lrl	Horowitz and others (2001)
Vanadium, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7440-62-2	1	mg/kg	lrl	Horowitz and others (2001)
Zinc, total	USGS Ga. WSC	Inductively coupled plasma/atomic emission spectrometry	7440-66-6	1	mg/kg	lrl	Horowitz and others (2001)

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[1] This report contains Chemical Abstracts Services Registry Numbers (CASRN). The CASRN online database provides the latest registry number information: http://www.cas.org/.

[2] Reporting level value range is for the published method and a custom method with lowered reporting levels.

analysis were collected in July 2012. All constituents were analyzed in the third set of samples collected in July 2013. Approximately 2 centimeters of the uppermost bed sediment was collected using a Teflon tube from within an Ekman dredge. Any overlying water present was first siphoned off. The wet sediment was transferred directly to cleaned, baked, 1-L, wide-mouth glass jars with Teflon-lined lids. Field replicates were collected to determine overall (sampling, handling, and analytical) variability. Bulk samples were collected for later production of split replicates and matrix spike samples. All samples were kept on ice or refrigerated during temporary storage and shipment to either the USGS Sediment Partitioning Research Laboratory in Atlanta, Georgia, or the Environmental Research Lab in the Department of Geosciences at Georgia State University for sample preparation and inorganic analysis.

At the laboratory, wet sediment samples were homogenized, rough-split into two subsamples, and then wet-sieved (mesh size less than 63 microns) under pressure using either a stainless steel sieve for trace organic compounds or a nylon/polyethylene mesh for inorganics. All inorganic and organic analyses were done on this less than 63-micron fraction (“fines” hereafter), which contains silt and clay particles. The weight percent of fines was calculated for all samples. For split replicate and matrix spike subsamples, a final splitting of the two sieved subsamples was done. A few grams of this wet-sieved sediment was dried and retained for analysis of inorganics at either the USGS Sediment Partitioning Research Laboratory in Atlanta, Ga. or the Environmental Research Lab in the Department of Geosciences at Georgia State University laboratory. Total concentration, defined as 95 percent or more of the analyzed element present, was determined because it is less operationally defined compared to total recoverable concentration (Horowitz, 1991). The remainder of the sieved wet sediment was shipped on ice in 500-mL, baked jars with Teflon-lined lids to the NWQL for analysis of trace organic compounds.

Quality Assurance and Quality Control

To ensure continued confidence in its products, all scientific work by the USGS is conducted in accordance with documented quality-assurance and quality-control (QA/QC) policies and procedures. The USGS Quality-Assurance Plan for water-resources activities in North Carolina (U.S. Geological Survey, 2010) provides a framework for defining the accuracy (bias quantification) and precision (variability quantification) of collected data. The plan is supported by a series of quality-assurance policy statements that describe responsibilities for specific functional elements, including project planning and implementation, equipment calibration and maintenance, data collection, data processing and storage, data analysis and interpretation, synthesis, reports preparation and processing, and training. Activities of the USGS North Carolina Water Science Center are systematically conducted under a hierarchy of supervision and management that is designed to ensure conformance with agency goals of quality assurance.

Each component of data collection included QA/QC procedures described in subsequent sections herein. All methods used by the USGS to collect and review scientific data are fully documented, and project data and records are archived in accordance with guidelines jointly approved by the USGS and the National Archives and Records Administration.

Potential positive bias in surface-water samples was assessed by analyzing 18 field and equipment blanks over the course of the sampling (appendix 1). (When discussing the data for constituents in water, filtered is defined as “dissolved” for inorganic constituents and unfiltered, recoverable is defined as “total recoverable” for organic constituents.) Forty-nine inorganic and organic constituents were considered, excluding total nitrogen (TN), which is the sum of other constituents, and the field parameters. This yielded a total of 666 results as opposed to 882 (18×49) results, because some constituents were not analyzed in some blanks. Overall, 94 percent (624 results) were below the respective constituent reporting levels. The 40 constituent detections in blanks (6 percent of all analyses), along with their detection frequency, magnitude, and comparison to the environmental samples, are shown in table 3. The frequency of detections in blanks was described based on the percentage of detections among all blanks analyzed for those constituents and characterized as follows: “infrequent” (less than 10 percent), “occasional” (10 to 20 percent), “moderately frequent” (21 to 30 percent), and “frequent” (greater than 30 percent). The magnitude of detections in blanks was assessed by multiplying the highest observed blank concentration by three, which was then compared to the range of results for the environmental samples. Using three times the highest observed blank concentration approximates the concentration range at which contamination markedly affected the environmental data. The percentage of results among the environmental samples that were lower than three times the highest blank concentration was calculated and characterized as follows: “negligible” (less than 5 percent), “some” (5 to 50 percent), and “many” (51 to 100 percent). Finally, the combination of the frequency and magnitude of constituent detections in blanks was interpreted as follows:

1. “No bias likely”—any blank concentration detection frequency coupled with a negligible percentage of environmental samples having concentrations that were less than three times the highest concentration in a blank (6 constituents).

2. “Low concentrations possibly biased high”—infrequent or occasional detections in blanks coupled with some environmental samples having concentrations that were less than three times the highest concentration in a blank (3 constituents).

Table 3. Potential bias of surface water samples based on the magnitude and frequency of constituent detections in field blanks collected in Currituck Sound, 2011–15.

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

Constituent	Concentration units	Blanks analyzed for constituent	Blanks with detections		Description of frequency of detections in blank samples	3 times the highest concentration detected in a blank	Environmental sample concentration results			Environmental samples with detections less than or equal to 3 times the highest concentration detected in a blank		Description of the percent of environmental samples with concentrations that exceed 3 times the highest concentration detected in a blank	Interpretation of potential positive bias in environmental samples considering frequency and magnitude of detections
		(Number)	(Number)	(Percent)		(Concentration units)	Minimum	Median	Maximum	(Number)	(Percent)		
Aluminum, total recoverable	µg/L	13	1	8	Infrequent	17.1	28.8	136	1,150	0	0	Negligible	No bias likely
Ammonia plus organic nitrogen, total recoverable	mg/L as N	13	1	8	Infrequent	0.21	0.5	1.2	1.9	0	0	Negligible	No bias likely
Arsenic, dissolved	µg/L	13	1	8	Infrequent	0.51	0.12	1.4	4.7	1	1	Negligible	No bias likely
Lead, total recoverable	µg/L	13	1	8	Infrequent	0.33	0.28	0.93	3.73	4	2	Negligible	No bias likely
Manganese, total recoverable	µg/L	13	2	15	Occasional	2.7	12.7	45.65	104	0	0	Negligible	No bias likely
Manganese, dissolved	µg/L	13	6	46	Frequent	1.14	0.96	3.13	45.1	3	2	Negligible	No bias likely
Lead, dissolved	µg/L	13	1	8	Infrequent	0.081	0.07	0.104	1.59	5	20	Some	Low concentrations possibly biased high
Nickel, total recoverable	µg/L	13	1	8	Infrequent	0.72	0.42	0.85	27.9	18	22	Some	Low concentrations possibly biased high
Selenium, total recoverable	µg/L	13	2	15	Occasional	0.327	0.119	0.366	3.97	71	47	Some	Low concentrations possibly biased high
Nitrate plus nitrite, dissolved	mg/L as N	13	1	8	Infrequent	0.03	0.01	0.02	0.11	25	60	Many	Positive bias possible
Iron, total recoverable	µg/L	13	1	8	Infrequent	278.1	86.1	220.5	1,620	116	62	Many	Positive bias possible
Suspended solids	mg/L	13	1	8	Infrequent	54	15	45	130	73	65	Many	Positive bias possible
Mercury, total recoverable	µg/L	13	1	8	Infrequent	0.087	0.005	0.013	0.251	7	88	Many	Positive bias possible
Chromium, dissolved	µg/L	13	1	8	Infrequent	1.44	0.21	0.37	0.67	15	100	Many	Positive bias possible
Mercury, dissolved	µg/L	13	1	8	Infrequent	0.033	0.009	0.009	0.009	1	100	Many	Positive bias possible
Silver, total recoverable	µg/L	13	1	8	Infrequent	0.063	0.034	0.036	0.037	2	100	Many	Positive bias possible
Benzo[*a*]anthracene, total recoverable	µg/L	12	1	8	Infrequent	0.015	0.006	0.007	0.007	2	100	Many	Positive bias possible
Chrysene, total recoverable	µg/L	12	1	8	Infrequent	0.03	0.001	0.001	0.001	1	100	Many	Positive bias possible
Silver, dissolved	µg/L	13	2	15	Occasional	0.045	0.023	0.025	0.026	2	100	Many	Positive bias possible
Bis(2-ethylhexyl) phthalate, total recoverable	µg/L	12	2	17	Occasional	7.17	0.031	0.494	2.6	26	100	Many	Positive bias possible
Zinc, dissolved	µg/L	13	3	23	Moderately frequent	16.2	4.3	5.7	9	3	100	Many	Positive bias likely
Zinc, total recoverable	µg/L	13	3	23	Moderately frequent	27.3	23.4	23.4	23.4	1	100	Many	Positive bias likely
Ammonia, water, dissolved	mg/L as N	13	5	38	Frequent	0.09	0.01	0.02	0.22	118	92	Many	Positive bias likely

3. “Positive bias possible”—infrequent or occasional detections in blanks coupled with many environmental samples having concentrations that were less than three times the highest concentration in a blank (11 constituents).

4. “Positive bias likely”—moderately frequent or frequent detections in blanks coupled with many environmental samples having concentrations that were less than three times the highest concentration in a blank (3 constituents). The three constituents for which positive bias was likely were dissolved zinc, total recoverable zinc, and dissolved ammonia. Discussion of environmental results for these three constituents should consider the positive bias.

Bias was also assessed for the 14 semi-volatile organic compounds (SVOCs) in surface water associated with a matrix spike (spiked replicate water sample) (table 4). As a percentage of added compound, the median recovery was 42 percent. The range was 30 percent for dibenzo[*a,h*]anthracene to 102 percent for *N*-nitrosodi-*n*-propylamine. Based on these recoveries, some compound concentrations measured in the surface-water samples may be underestimated.

The variability of constituent concentrations in surface-water samples was determined with 18 sets of field replicates for 49 constituents, excluding turbidity because most concentrations were estimated values and also excluding the field parameters. Note that the variability of TN was assessed, because it reflects the sum of other constituents (table 5). This yielded a total of 807 replicate sets as opposed to 882 (18×49) sets, because some constituents were not analyzed in some replicate sets. Of these replicate sets, there were 497 sets (62 percent) in which both concentrations were below the respective reporting levels for those constituents; these sets are not discussed further herein. Of the remaining replicate sets, there were 263 sets (33 percent) in which both concentrations were above the respective reporting levels for those constituents. Within this group, replicate concentrations that had a relative percent difference (RPD, absolute difference times 100 divided by the average) less than 25 percent were considered acceptable; these sets are not discussed further herein.

Table 4. Recovery (in percent) of semi-volatile organic compounds (SVOCs) in surface water collected in Currituck Sound.

Constituent	Recovery (percent)
N-Nitrosodi-*n*-propylamine	102
Bis(2-chloroethyl) ether	81
Pentachlorophenol	81
Phenanthrene	67
Bis(2-ethylhexyl) phthalate	52
N-Nitrosodimethylamine	52
Hexachlorobenzene	50
Benzo[*a*]anthracene	34
Benzo[*a*]pyrene	33
Chrysene	32
Benzo[*b*]fluoranthene	31
Indeno[1,2,3-*cd*]pyrene	31
Dibenzo[*a,h*]anthracene	30
Benzo[*k*]fluoranthene	30

Only 45 sets (6 percent of the 807 total sets) had RPDs that were equal to or greater than 25 percent and were further evaluated by calculating the absolute concentration difference between the two samples in the replicate set. Large RPDs associated with small concentration differences, as is often observed among concentrations near the reporting level, are expected and acceptable. In contrast, large RPDs associated with absolute concentration differences greater than or equal to three times the reporting level may warrant consideration of variability. Only 17 sets, 2 percent of the 807 total sets, had RPDs greater than or equal to 25 percent and had absolute concentration differences within each set greater than or equal to three times the respective reporting levels (table 5). Included in this group were 7 sets of dissolved constituents: manganese (5 pairs), and ammonia and arsenic (1 pair each). The remaining 10 sets were of total recoverable constituents: aluminum (3 pairs), and phosphorus, iron, lead, manganese, nickel, selenium, and *Enterococci* (1 pair each). The variability in total recoverable constituents is not unexpected and is probably due to the chance presence of isolated particles containing these constituents. The variability in dissolved manganese might reflect a sampling, handling, or analytical issue, given the number of pairs involved. Considering the frequency of constituent sets that had relatively high RPDs and absolute concentration differences, variability should be considered when making interpretations associated with dissolved manganese and total recoverable aluminum concentrations.

There were 42 replicate sets (5 percent) in which only one concentration was above the reporting level (table 5). These sets can be used to ascertain a minimum variability of these constituents. Of the 42 sets, 15 sets (2 percent of the 807 total replicate sets) had an RPD greater than or equal to 25 percent; however, the absolute concentration difference never exceeded three times the respective reporting levels in any of these sets. Constituents in these sets therefore had acceptable variability and are not discussed further herein.

Among the metals in water, there were several samples for which the reported dissolved concentration exceeded the reported total recoverable concentration. Because the total recoverable fraction includes the dissolved fraction, the former can never actually be smaller than the latter. Seven metals were affected, including copper, lead, manganese, nickel, zinc, arsenic, and selenium. Six of these (excluding copper) were previously mentioned as having relatively large variability in either the dissolved fraction (manganese and arsenic) or the total recoverable fraction (lead, manganese, nickel, and selenium).

To assess whether analytical variability could account for these results, the RPD for the difference between dissolved and total recoverable fractions was calculated for the aforementioned seven metals. Samples having RPDs less than 20 percent (filterable fraction at most 10 percent high and total recoverable fraction at most 10 percent low) were considered acceptable. The remaining samples having an RPD greater than 20 percent were further assessed. Using the minimum reporting levels (when there was a range) in the data-set, the following were done:

1. Dissolved fraction:
    - A. For concentrations within double the minimum reporting level, the minimum reporting level was subtracted from the concentration.
    - B. For concentrations higher than double the minimum reporting level, 10 percent was subtracted from the concentration.
2. Total recoverable fraction:
    - A. For censored concentrations or concentrations within double the minimum reporting level, the concentration was doubled.
    - B. For concentrations higher than double the minimum reporting level, 10 percent was added to the concentration.

After these adjustments were made, the adjusted dissolved and total recoverable concentrations were again compared with each other. Analytical variability could account for most instances in which the dissolved fraction exceeded the total recoverable fraction except for the following: copper and arsenic (1 sample each), nickel (5 samples), and selenium (37 samples). Those seven pairs (dissolved and total recoverable) of copper, arsenic, and nickel values were excluded from the dataset. For selenium, given the high number of samples for which analytical variability could not explain dissolved concentrations exceeding total recoverable concentrations, the entire selenium water dataset (both dissolved and total recoverable) was excluded.

Variability of the bacterial counts was further assessed by calculating the RPD and absolute cell-count differences in sets of analytical duplicates. All bacterial samples were routinely analyzed as analytical duplicates. There were 172 sets of analytical duplicates for the two bacterial groups, *Enterococci* and *E. coli*, resulting in 344 total duplicate sets (table 5). Of this total, both counts were below the reporting level in 182 duplicate sets (53 percent of 344 total sets) of either bacteria. Both samples were above the respective reporting levels in 69 duplicate sets (20 percent of 344 total sets). For these 69 sets, the median RPD was 40 percent and 32 percent for *Enterococci* and *E. coli,* respectively, although the median absolute difference for these pairs was only 10 MPN/100 mL (most probable number per 100 milliliters) for both bacterial groups. There were 93 duplicate sets (27 percent of the 344 total sets) in which only one concentration was above the reporting level. Because these sets were dominated by one concentration at the reporting level and one below the reporting level of 10 MPN/100 mL, the median RPD and absolute difference were indeterminate. Overall, the analytical variability of the bacterial analyses was considered acceptable.

Analytical bias in bed sediments was assessed using 11 reference materials for inorganic constituents and a matrix spike for SVOCs (appendix 2 and table 6). All quality-control results for physical properties and chemical and particle size analyses in bed sediment are shown in appendix 2. Median recovery for elements ranged from 116 percent for tin to 92 percent for total organic carbon. In contrast, recovery of trace organic compounds in a matrix spike was lower and ranged from 75 percent for 9,10-anthaquinone to 19 percent for acenaphthylene. Thus, the concentrations of some of these SVOCs may be underestimated.

Variability in concentrations of inorganics and the less than 63-micron fraction of bed sediment was assessed by analyzing 2 field replicates, 1 split replicate, and 2 analytical duplicates (fig. 2*A*, *B*). The analytical variability is isolated by analytical duplicates and is nested within the handling variability isolated by the split replicate. Field replicates reflect the overall variability associated with the sampling, handling, and analysis. Because of this nesting, the source of variability can potentially be isolated to a particular step in the overall concentration determination. In addition, the variability between analytical duplicates should be no greater than the variability of the split replicates, which in turn should be no greater than the variability of the field replicates. Indeed for most constituents, the highest variability was in one of the field replicates, which indicates much of the variability was due to small-scale heterogeneity in the bed sediment as opposed to handling or analysis (fig. 2*A*). For most constituents and samples, the RPDs were 25 percent or less, which was considered acceptable. RPDs were over 50 percent for manganese and phosphorus in one field replicate, cadmium and total organic carbon in the other field replicate, mercury in the split replicate, and tin in one analytical replicate. The RPDs for phosphorus and manganese in field replicates were associated with relatively large absolute concentration differences of 140 and 180 milligrams per kilogram (mg/kg) and 190 mg/kg, respectively (fig. 2*B*). These absolute concentration differences are relatively high compared to the concentration ranges in the environmental samples of 540 to 1,000 mg/kg for phosphorus and 240 to 420 mg/kg for manganese, and thus should be considered when interpreting the environmental concentrations. Vanadium, zinc, and, to a lesser extent, barium in one or both field replicates also had relatively large absolute concentration differences with respect to the constituent concentrations of the study samples. This variability should therefore be considered in comparisons of these three constituent concentrations between stations or over time.

Table 5. Summary of quality-control results for water-sample field replicates (all constituents) and bacterial analytical duplicates collected in Currituck Sound, 2011–15.

[RPD, relative percent difference; ≥, greater than or equal to; MPN/100 mL, most probable number per 100 milliliters; --, not calculated]

Descriptor	Number	Percent	Median RPD (percent)	Median absolute difference (MPN/100 mL)
Field replicates (all constituents)				
Replicate sets	18	--	--	--
Constituents determined in the replicate sets	49	--	--	--
Total replicate sets analyzed[1]	807	100	--	--
Replicate sets with both concentrations below the reporting level	497	62	--	--
Replicate sets with both concentrations above the reporting level:	263	33	--	--
RPD ≥25 percent	45	6	--	--
Absolute concentration difference ≥3 times the reporting level:	17	2	--	--
Manganese, dissolved	5	--	--	--
Ammonia, dissolved	1	--	--	--
Arsenic, dissolved	1	--	--	--
Aluminum, total recoverable	3	--	--	--
Phosphorus, total recoverable	1	--	--	--
Iron, total recoverable	1	--	--	--
Lead, total recoverable	1	--	--	--
Manganese, total recoverable	1	--	--	--
Nickel, total recoverable	1	--	--	--
Selenium, total recoverable	1	--	--	--
Enterococci	1	--	--	--
Replicate sets with only one concentration above the reporting level:	42	5	--	--
Minimum RPD ≥25 percent	15	2	--	--
Absolute concentration difference ≥3 times the reporting level	0	0	--	--
Bacterial analytical duplicates				
Duplicate sets	172	--	--	--
Constituents determined in the duplicate sets	2	--	--	--
Total duplicate sets analyzed	344	100	--	--
Duplicate sets with both concentrations below the reporting level	182	53	--	--
Duplicate sets with both concentrations above the reporting level:	69	20	--	--
Enterococci	--	--	40	32
Escherichia coli	--	--	32	10
Duplicate sets with only one concentration above the reporting level:	93	27	--	--
Enterococci	--	--	(Indeterminate)	(Indeterminate)
E. coli	--	--	(Indeterminate)	(Indeterminate)

[1] Not all constituents were determined in every replicate set.

Table 6. Recovery (in percent) of inorganic constituents in reference materials[1] and semi-volatile organic compounds (SVOCs) in a spiked sample of bed sediments collected in Currituck Sound.

[--, reporting level greater than reference value]

Constituent	Median recovery (percent)	Constituent	Recovery (percent)
Tin	116	9,10-Anthraquinone	75
Antimony	107	Dibenzothiophene	67
Beryllium	106	9*H*-Fluorene	66
Copper	106	1-Methyl-9*H*-fluorene	65
Molybdenum	106	4*H*-Cyclopenta[*def*]phenanthrene	65
Vanadium	105	Fluoranthene	65
Cadmium	104	Phenanthrene	64
Chromium	104	2,6-Dimethylnaphthalene	63
Nickel	104	1,6-Dimethylnaphthalene	63
Arsenic	103	Pyrene	63
Barium	103	Phenanthridine	63
Cobalt	103	1,2-Dimethylnaphthalene	62
Mercury	102	1-Methylphenanthrene	62
Iron	102	Acenaphthene	61
Strontium	102	2,3,6-Trimethylnaphthalene	61
Lithium	101	2-Ethylnaphthalene	61
Phosphorus	101	Diethyl phthalate	59
Titanium	101	Anthracene	58
Aluminum	100	Perylene	58
Calcium	100	1-Methylpyrene	57
Lead	100	Benzo[*a*]anthracene	56
Magnesium	100	Dibenzo[*a,h*]anthracene	55
Manganese	100	Pentachloroanisole	55
Potassium	100	Indeno[1,2,3-*cd*]pyrene	54
Sodium	100	Chrysene	54
Zinc	100	Carbazole	54
Carbon, total	99	2-Methylanthracene	53
Sulfur, total	99	Benzo[*ghi*]perylene	53
Uranium	98	Naphthalene	53
Selenium	97	Benzo[*e*]pyrene	51
Nitrogen, total	95	Pentachloronitrobenzene	51
Silver	93	Benzo[*k*]fluoranthene	50
Carbon, total organic	92	Benzo[*b*]fluoranthene	48
Thallium	--	Hexachlorobenzene	48
		Bis(2-ethylhexyl) phthalate	47
		Benzo[*a*]pyrene	47
		1,2,4-Trichlorobenzene	46
		Acenaphthylene	19

[1] See appendix 2.

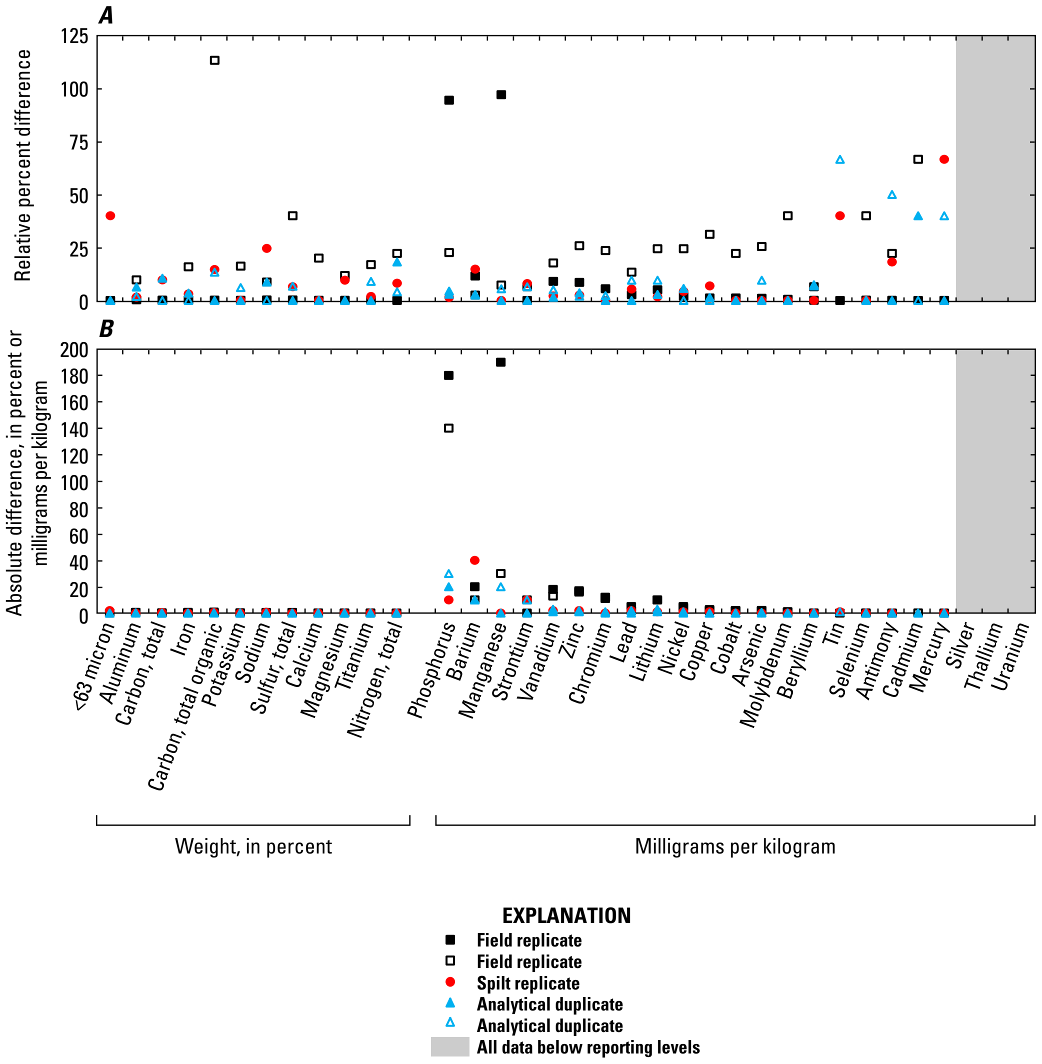

Figure 2. Variability of concentrations of grain sizes less than 63 microns, metals, nutrients, and carbons in bed sediments in Currituck Sound in, *A*, relative percent difference (RPD) and, *B*, absolute concentration difference.

Calculation of Summary Statistics

Summary statistics for all water and bed-sediment data collected as part of the study were computed using methods described in Bonn (2008). For water-quality constituents whose laboratory results contained censored values with one detection level, medians were computed using the rank method as described in Bonn (2008). For water-quality constituents whose laboratory results contained censored values with multiple detection levels, medians were computed using the Kaplan-Meier method, as described in Bonn (2008). Medians were not computed if greater than 75 percent of the data values in a dataset were censored. One exception was TN, which is presented as censored in appendix 1. The TN value obtained from NWIS is calculated as the sum of ammonia plus organic nitrogen, nitrate, and nitrite. These calculated values are reported as censored in the appendix if one of the measured values in the computation is censored. In this dataset, dissolved nitrate and nitrite concentrations were often less than the reporting limits, resulting in numerous censored values for TN. Therefore, the individual censored nitrogen constituent concentrations were assumed to be equal to their analytical reporting level in the computation of the reported TN values used for calculating the summary statistics.

The nonparametric Mann-Whitney test (Mann and Whitney, 1947) was used to determine whether the independent populations of samples collected monthly and following storms were statistically different at the 95-percent confidence level (p-value less than 0.05) for physical properties and constituents having less than 5 percent censored data (estimated to be less than the long-term method detection limit or LT–MDL). For physical properties and constituents having greater than 5 percent censored data, the nonparametric Gehan test (Gehan, 1965) was used to determine whether the independent populations were statistically different at the 95-percent confidence level (p-value less than 0.05). For concentrations of constituents that were not detected or were estimated to be less than the LT–MDL (censored data), concentrations were set equal to one-half of the respective LT–MDL. This approach is appropriate for rank-based nonparametric methods for singly censored data (Helsel, 2005). In addition, the nonparametric Mann-Whitney test (Mann and Whitney, 1947) was also used to determine whether the wind speed and direction data could be correlated with water-quality data collected in Currituck Sound.

For the seasonal analysis of water-quality data, the summer season consisted of July, August, and September; the fall season consisted of October, November, and December; the winter season consisted of January, February, and March; and the spring season consisted of April, May, and June. The spring and summer seasons are referred to herein as the “warmer” months and the fall and winter seasons are referred to as the “cooler” months.

Characterization of Water-Quality and Bed-Sediment Conditions in Currituck Sound

The following sections summarize the water-quality and bed-sediment chemistry data that were collected in Currituck Sound from August 2011 to January 2015. All results for field/physical properties and chemical data are shown in appendix 1 for water and in appendix 2 for bed sediment.

Summary of Water-Quality Sample Results

Sample results were compared to saltwater-quality standards and guidelines (hereafter referred to as “thresholds”) published by the North Carolina Department of Environmental Quality (North Carolina Department of Environment and Natural Resources, 2013), U.S. EPA (2002, 2015), and University of Tennessee (2013). These thresholds relate to actual or potential impairment for designated uses (saltwater–aquatic life propagation/protection and secondary recreation). Sample results were compared to the referenced thresholds (table 7) and were used to determine which constituents had concentrations above or below established thresholds in Currituck Sound prior to bridge construction. If more than one threshold existed, the State threshold for North Carolina was used for comparison to sample results.

For the samples collected from 2011 to 2015, concentrations were greater than water-quality thresholds for physical parameters/constituents on 52 occasions. It should be noted that 190 censored (“less-than”) results had reporting levels that were higher than their corresponding thresholds, and therefore could not be determined to be above or below those thresholds (table 7). Raised reporting levels among the metals generally reflected sample dilution required for these brackish-water samples prior to analysis. All 52 occurrences of concentrations greater than water-quality thresholds were limited to only seven physical properties or constituents, namely pH (25), turbidity (8), total recoverable chromium (6), total recoverable copper (6), dissolved copper (3), total recoverable mercury (2), and total recoverable nickel (2). Concentrations of 17 other constituents were never measured to be greater than their established water-quality thresholds during the study (table 7).

A summary of the measured baseline concentrations for physical properties and constituents that were identified as POCs in a collaborative USGS/NCDOT study that characterized bridge deck stormwater runoff across North Carolina (Wagner and others, 2011) and some additional pertinent physical properties (dissolved oxygen, specific conductance, and turbidity) are presented in figure 3. Monthly and storm samples are shown separately in figure 3 to illustrate differences between the hydrologic conditions associated with the samples. Statistical differences (p-values less than 0.05) were identified between monthly and storm samples for the following physical properties and constituents: pH, dissolved oxygen, specific conductance, turbidity, *E. coli* bacteria, total recoverable aluminum, and total recoverable iron.

In order to evaluate any seasonal variability in water-quality conditions, seasonal statistics (median, maximum, and minimum values) for the POCs identified in Wagner and others (2011), (including pH, nutrients, total recoverable and dissolved metals, and PAHs) and some additional pertinent physical properties (dissolved oxygen, specific conductance and turbidity) are summarized in table 8.

To further evaluate seasonality, time series of the 4 physical properties and 12 constituents with reported median concentrations in table 8 for the five stations are shown in figure 4. Initial graphical analysis of the data separated by station and top and bottom sample location revealed that the water sampled along the proposed bridge-alignment transect was well-mixed horizontally and vertically during storm and non-storm conditions. Monthly and storm sample concentrations for groupings of all stations were also initially plotted separately, and although statistical differences were identified for pH, dissolved oxygen, specific conductance, turbidity, *E. coli* bacteria, total recoverable aluminum, and total recoverable iron, the variability of the routine monthly samples bracketed that of samples collected following storms. Therefore, data from all stations, including top and bottom samples and monthly and storm sample data, were combined and displayed together in figure 4 to highlight the temporal variability in water quality, which is larger than the differences related to the other groupings of the data. For the purposes of this analysis, constituents that tended to have maximum values in summer or at least during the warmer months and minimum values in colder months, included pH, specific conductance, and total recoverable manganese and arsenic (fig. 4*A*, *C*, *M*, and *P*, respectively). Constituents having maximum values in colder months and minimum values in warmer months included turbidity, dissolved oxygen, total phosphorus, and total recoverable aluminum, iron, and lead (fig. 4*B*, *E*, *H*, *K*, *L*, and *N*, respectively). TN concentrations followed a unique pattern in that they tended to be lowest in late spring and highest in late summer-early fall (fig. 4*G*). Constituents that did not show a consistent seasonal signature from year to year during the study period include suspended solids, both bacterial groups, and total recoverable nickel (fig. 4*F*, *I*, *J*, and *O*, respectively). Many of the physical properties and constituents (pH, specific conductance, dissolved oxygen, turbidity, nitrogen, phosphorus, aluminum, arsenic, iron, lead, and manganese) exhibited obvious, persistent seasonality over the period of baseline data collection. Other constituents appeared to be affected by weather patterns and possibly changes in sources and sinks over similarly short times scales. The volume and residence time of water in Currituck Sound are such that water chemistry is relatively uniform spatially but variable temporally.

Finally, the water-velocity data in the Currituck Sound collected in conjunction with the sampling events were processed and spatially referenced to the water-quality data for the physical properties (DO, pH, specific conductance, and turbidity), phosphorus, nitrogen and the two metals (total recoverable chromium and copper) that had the largest number of concentrations that were greater than the thresholds at the five sampling stations. Spatial comparisons of water-quality and depth-averaged velocity data for individual sampling events are presented in appendix 3.

Table 7. Water-quality constituent standards and guidelines and concentrations of samples collected in Currituck Sound, 2011–15.

[N.C., North Carolina, EPA, Environmental Protection Agency; >, greater than; <, less than; --, no information; std. units, standard units; NTRU, nephelometric turbidity ratio units; NTU, nephelometric turbidity units; µg/L, micrograms per liter; mg/L as N, milligrams per liter as nitrogen; pct. sat., percent saturation; MPN/100 mL, most probably number per 100 milliliters; mg/L as P, milligrams per liter as phosphorus; m, meter]

Constituent	Unit	N.C. standard—saltwater, aquatic life	U.S. EPA standard—saltwater, aquatic life	Number greater than standard	Number of samples where the reporting level exceeded the standard	Reference
Threshold exists						
pH	Std. units	6.8–8.5	--	25 (all >8.5)	0	North Carolina Department of Environment and Natural Resources (2013)
Turbidity	NTRU	25 NTU	--	8	0	North Carolina Department of Environment and Natural Resources (2013)
Chromium, total recoverable	µg/L	20	--	6	0	North Carolina Department of Environment and Natural Resources (2013)
Copper, total recoverable	µg/L	3	--	6	27	North Carolina Department of Environment and Natural Resources (2013)
Copper, dissolved	µg/L	--	3.1	3	103	U.S. Environmental Protection Agency (2002)
Mercury, total recoverable	µg/L	0.025	--	2	0	North Carolina Department of Environment and Natural Resources (2013)
Nickel, total recoverable	µg/L	8.3	--	2	1	North Carolina Department of Environment and Natural Resources (2013)
Phenanthrene	µg/L	--	0.3	0	45	U.S. Environmental Protection Agency (2015); University of Tennessee (2013)
Silver, total recoverable	µg/L	0.1	--	0	6	North Carolina Department of Environment and Natural Resources (2013)
Nickel, dissolved	µg/L	--	8.2	0	4	U.S. Environmental Protection Agency (2002)
Zinc, dissolved	µg/L	--	81	0	4	U.S. Environmental Protection Agency (2002)
Arsenic, dissolved	µg/L	--	36	0	0	U.S. Environmental Protection Agency (2002)
Arsenic, total recoverable	µg/L	50	--	0	0	North Carolina Department of Environment and Natural Resources (2013)
Cadmium, dissolved	µg/L	--	8.8	0	0	U.S. Environmental Protection Agency (2002)
Cadmium, total recoverable	µg/L	5	--	0	0	North Carolina Department of Environment and Natural Resources (2013)
Dissolved oxygen	mg/L	<5.0	--	0	0	North Carolina Department of Environment and Natural Resources (2013)
Lead, dissolved	µg/L	--	8.1	0	0	U.S. Environmental Protection Agency (2002)
Lead, total recoverable	µg/L	25	--	0	0	North Carolina Department of Environment and Natural Resources (2013)
Mercury, dissolved	µg/L	--	0.94	0	0	U.S. Environmental Protection Agency (2002)
Pentachlorophenol	µg/L	--	7.9	0	0	U.S. Environmental Protection Agency (2002)
Silver, dissolved	µg/L	--	1.9	0	0	U.S. Environmental Protection Agency (2002)
Zinc, total recoverable	µg/L	86	--	0	0	North Carolina Department of Environment and Natural Resources (2013)
No threshold						
Aluminum, dissolved	µg/L	--	--	--	--	--
Aluminum, total recoverable	µg/L	--	--	--	--	--
Ammonia, dissolved	mg/L as N	--	--	--	--	--

Table 7. Water-quality constituent standards and guidelines and concentrations of samples collected in Currituck Sound, 2011–15.—Continued

[N.C., North Carolina, EPA, Environmental Protection Agency; >, greater than; <, less than; --, no information; std. units, standard units; NTRU, nephelometric turbidity ratio units; NTU, nephelometric turbidity units; µg/L, micrograms per liter; mg/L as N, milligrams per liter as nitrogen; pct. sat., percent saturation; MPN/100 mL, most probably number per 100 milliliters; mg/L as P, milligrams per liter as phosphorus; m, meter]

Constituent	Unit	N.C. standard—saltwater, aquatic life	U.S. EPA standard—saltwater, aquatic life	Number greater than standard	Number of samples where the reporting level exceeded the standard	Reference
Ammonia plus organic nitrogen, total recoverable	mg/L as N	--	--	--	--	--
Benzo[*a*]anthracene	µg/L	--	--	--	--	--
Benzo[*a*]pyrene	µg/L	--	--	--	--	--
Benzo[*b*]fluoranthene	µg/L	--	--	--	--	--
Benzo[*k*]fluoranthene	µg/L	--	--	--	--	--
Bis(2-chloroethyl) ether	µg/L	--	--	--	--	--
Bis(2-ethylhexyl) phthalate	µg/L	--	--	--	--	--
Chromium, dissolved	µg/L	--	--	--	--	--
Chrysene	µg/L	--	--	--	--	--
Dibenzo[*a*,*h*]anthracene	µg/L	--	--	--	--	--
Dissolved oxygen	Pct. sat.	--	--	--	--	--
Enterococci	MPN/100 mL	--	--	--	--	--
Escherichia coli	MPN/100 mL	--	--	--	--	--
Hexachlorobenzene	µg/L	--	--	--	--	--
Indeno[1,2,3-*cd*]pyrene	µg/L	--	--	--	--	--
Iron, dissolved	µg/L	--	--	--	--	--
Iron, total recoverable	µg/L	--	--	--	--	--
Manganese, dissolved	µg/L	--	--	--	--	--
Manganese, total recoverable	µg/L	--	--	--	--	--
Nitrate plus nitrite, dissolved	mg/L as N	--	--	--	--	--
Nitrogen, total	mg/L as N	--	--	--	--	--
N-Nitrosodimethylamine	µg/L	--	--	--	--	--
N-Nitrosodi-*n*-propylamine	µg/L	--	--	--	--	--
Orthophosphate, dissolved	mg/L as P	--	--	--	--	--
Phosphorus, total	mg/L as P	--	--	--	--	--
Suspended solids	mg/L	--	--	--	--	--
Transparency	m	--	--	--	--	--

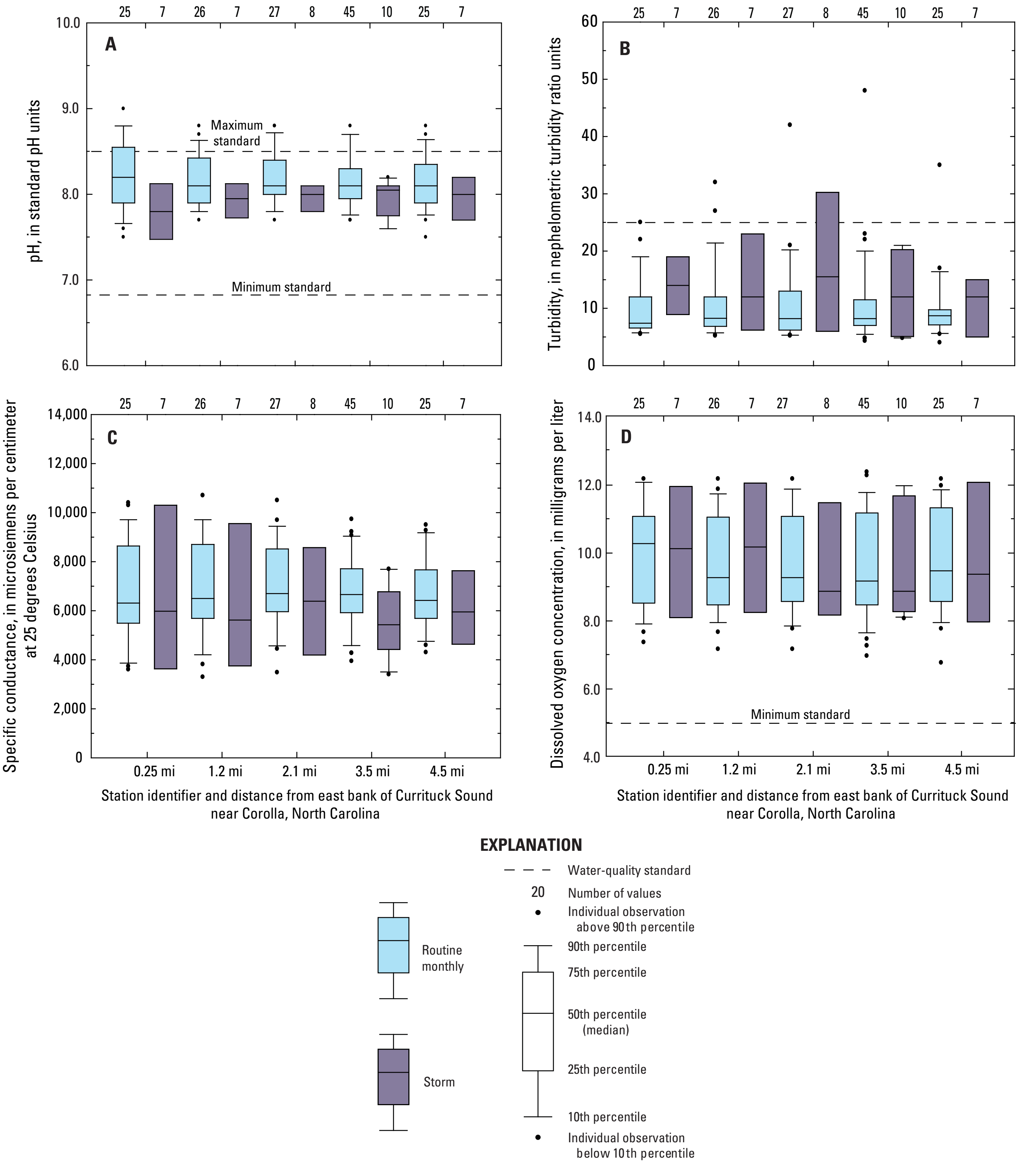

Figure 3. Boxplots showing physical properties and concentrations of selected constituents in monthly and storm water samples from Currituck Sound, North Carolina, 2011–15.

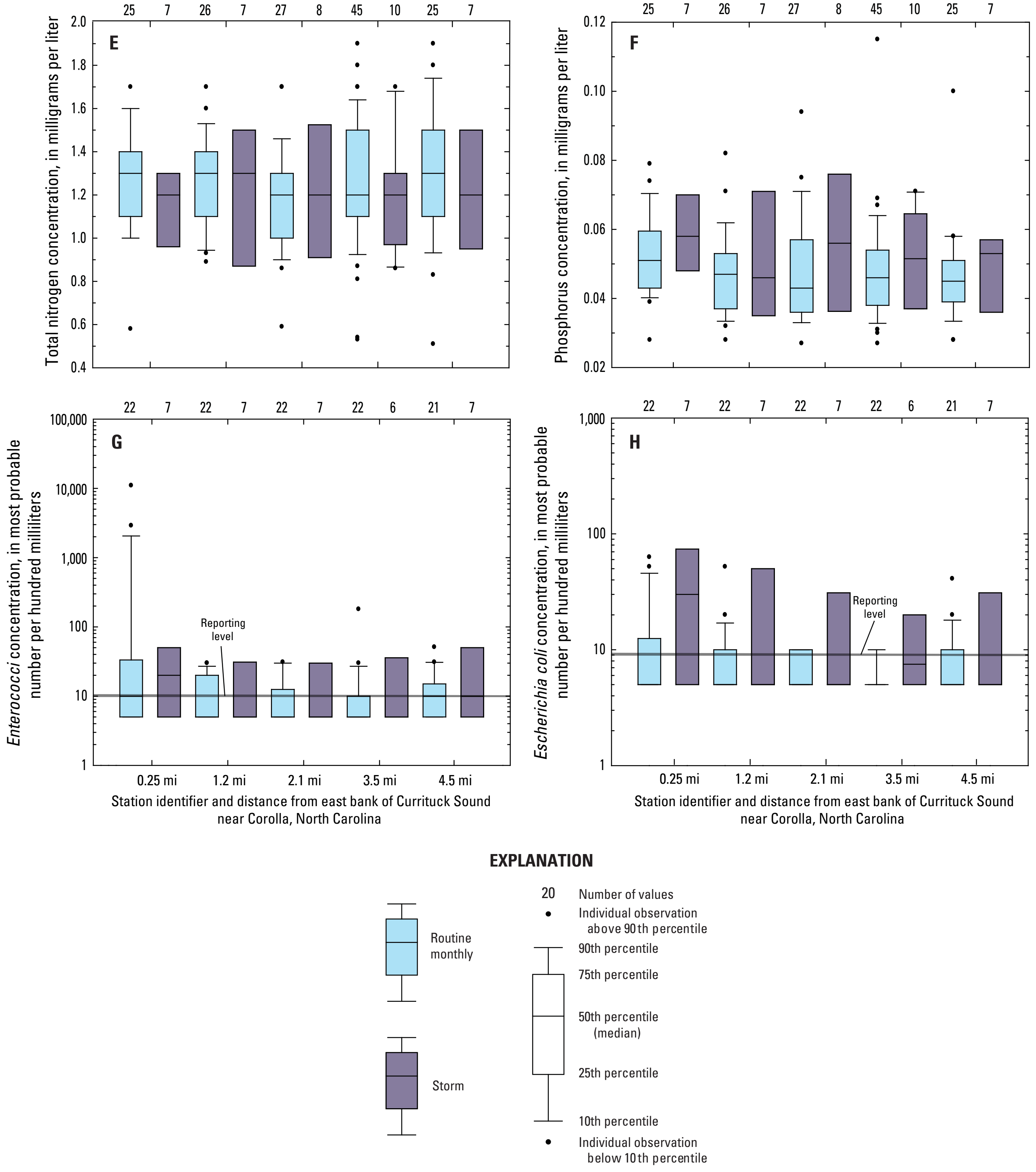

Figure 3. Boxplots showing physical properties and concentrations of selected constituents in monthly and storm water samples from Currituck Sound, North Carolina, 2011–15.—Continued

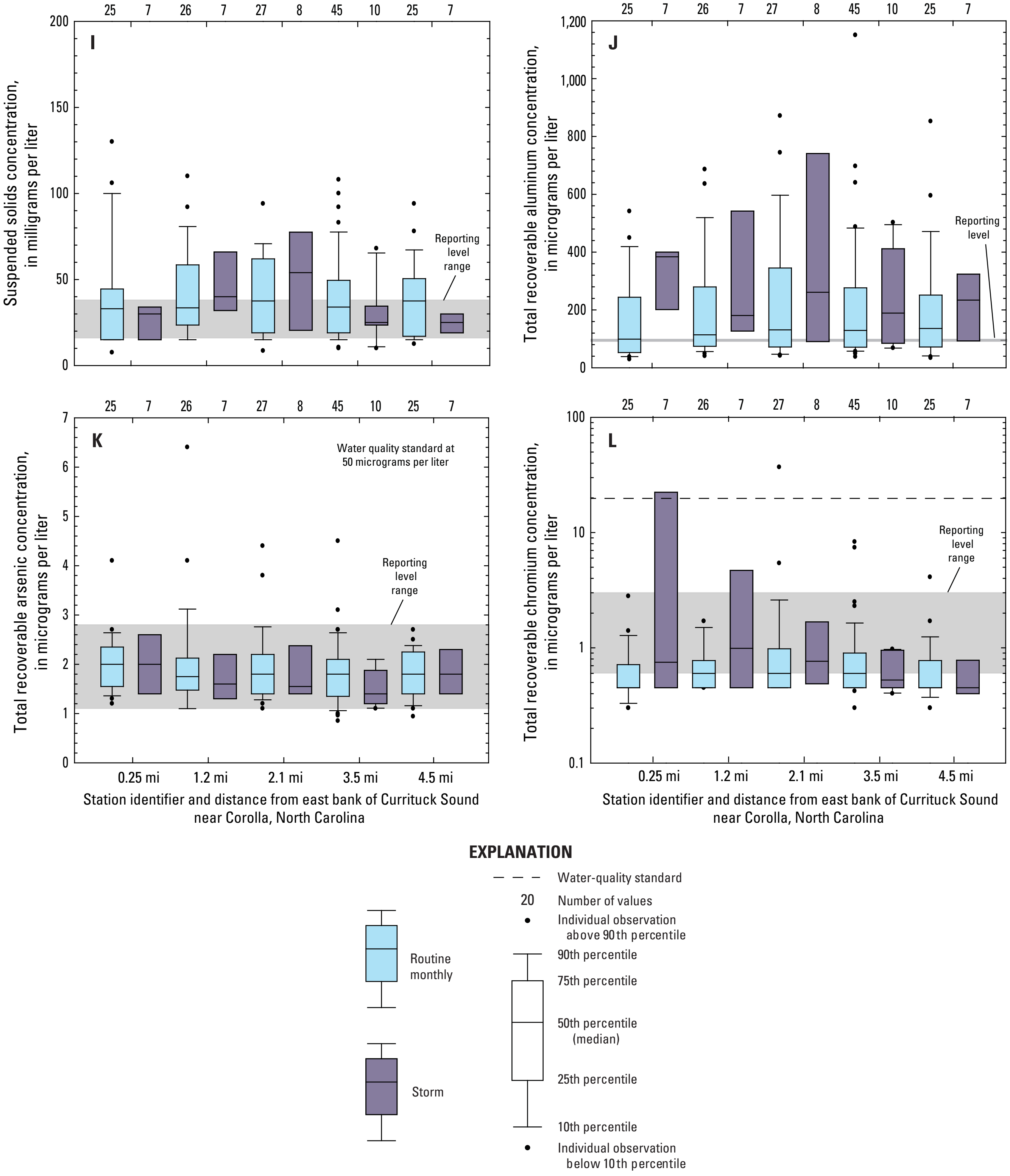

Figure 3. Boxplots showing physical properties and concentrations of selected constituents in monthly and storm water samples from Currituck Sound, North Carolina, 2011–15.—Continued

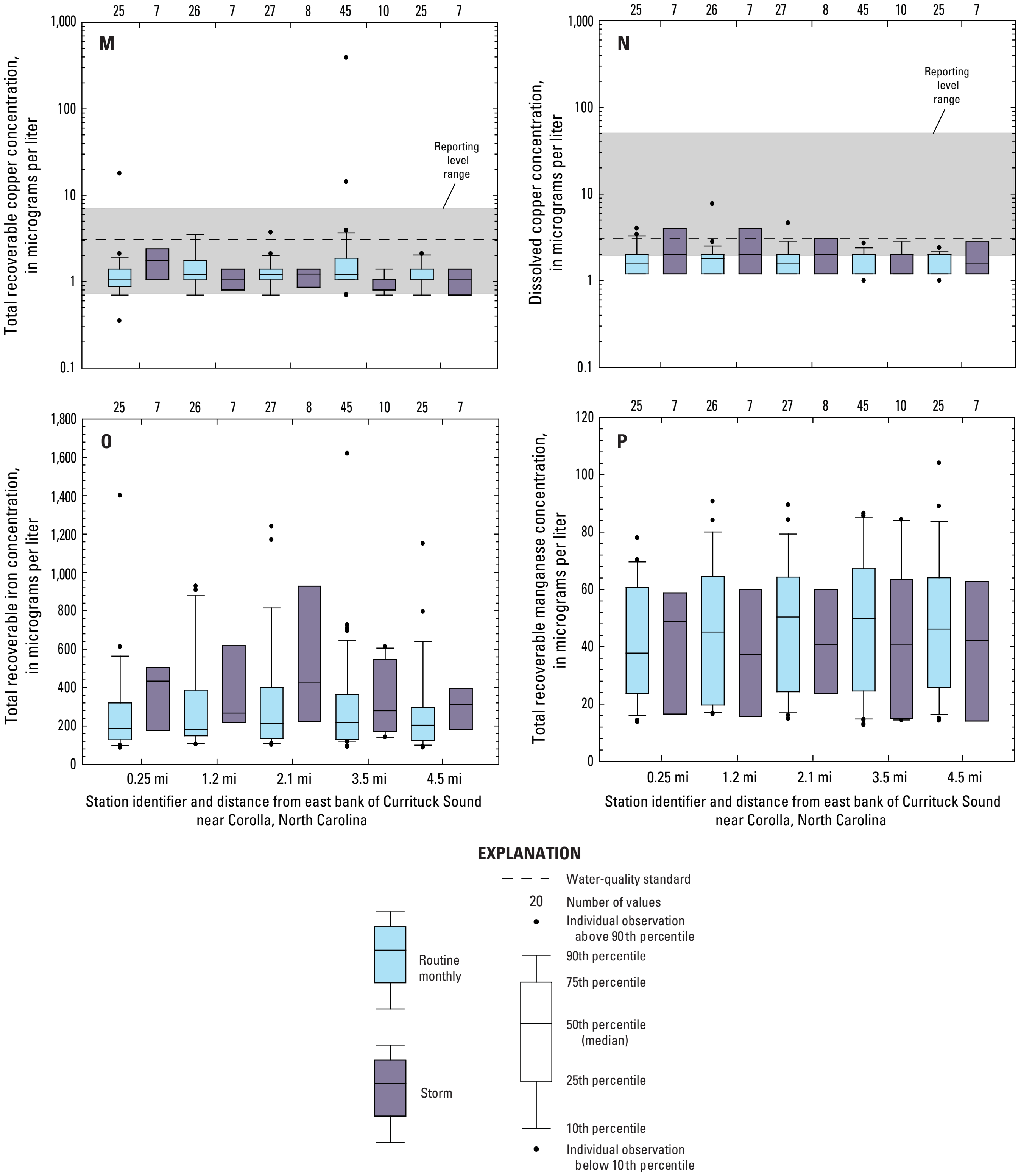

Figure 3. Boxplots showing physical properties and concentrations of selected constituents in monthly and storm water samples from Currituck Sound, North Carolina, 2011–15.—Continued

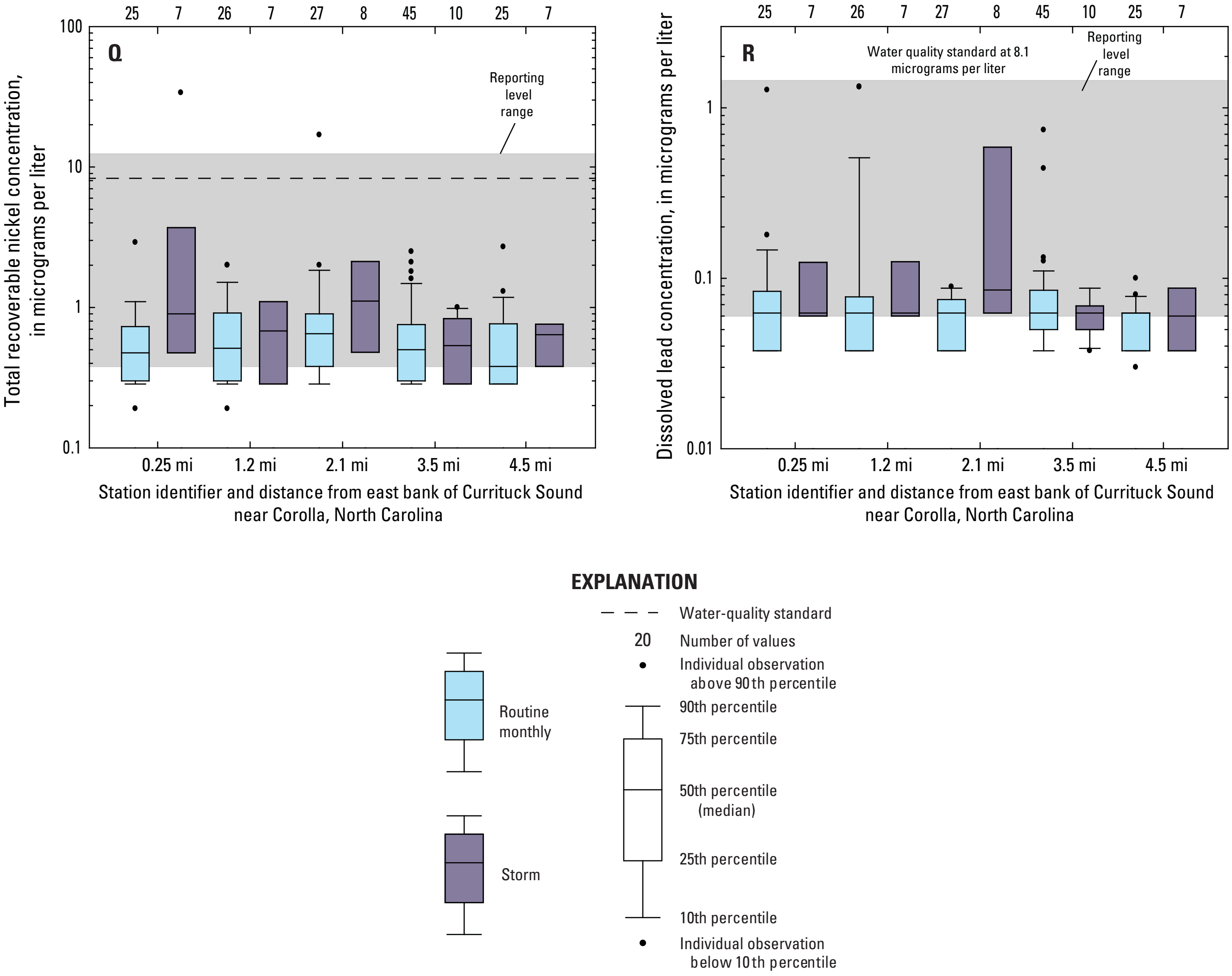

Figure 3. Boxplots showing physical properties and concentrations of selected constituents in monthly and storm water samples from Currituck Sound, North Carolina, 2011–15.—Continued

Table 8. Seasonal summary statistics for water-quality data collected in the Currituck Sound, 2011–15.

[Dates shown as month, day, year. mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; NTRU, nephelometric turbidity ratio units; µg/L, micrograms per liter; MPN/100 mL, most probable number per 100 milliliters; E, estimated; <, less than; --, value not calculated; Σ PAH, sum of polycyclic aromatic hydrocarbons]

Physical property	Unit	Median concentrations[1]			
		Fall	Winter	Spring	Summer
Dissolved oxygen	mg/L	10.8	11.5	8.5	8.35
pH	Standard units	8	7.8	8.1	8.6
Specific conductance	µS/cm	6,400	5,150	7,000	7,750
Turbidity, total recoverable	NTRU	9.7	17.5	5.65	7.5
Constituent	**Unit**	**Median concentrations[1]**			
		Fall	**Winter**	**Spring**	**Summer**
Phosphorus, total recoverable	mg/L	0.053	0.057	0.038	0.04
Total nitrogen, total recoverable	mg/L	1.3	1.2	0.96	1.5
Aluminum, total recoverable	µg/L	186	387	111.5	67.6
Iron, total recoverable	µg/L	269	472	185	124
Manganese, total recoverable	µg/L	51.8	16.7	40.7	68.6
Arsenic, total recoverable	µg/L	1.7	1.6	1.6	2.2
Lead, total recoverable	µg/L	1.15	1.44	0.59	0.52
Suspended solids, total recoverable	mg/L	<30	33	29	<15
Nickel, total recoverable	µg/L	<0.57	0.77	<0.57	<0.57
Enterococci	MPN/100 mL	<10	<10	<10	10
Escherichia coli	MPN/100 mL	<10	<10	<10	10
Mercury, total recoverable	µg/L	--	--	--	--
Chromium, total recoverable	µg/L	--	--	--	--
Copper, dissolved	µg/L	--	--	--	--
Copper, total recoverable	µg/L	--	--	--	--
Lead, dissolved	µg/L	--	--	--	--
Σ PAH, total recoverable	µg/L	--	--	--	--

[1] For parameters containing censored values with one detection level, medians were computed using the rank method as described by Bonn (2008). For parameters containing censored data with multiple detection levels, medians were calculated using the Kaplan-Meier method described by Bonn (2008).

[2] Number of miles from the east bank of Currituck Sound near Corolla, North Carolina (see text).

Table 8. Seasonal summary statistics for water-quality data collected in the Currituck Sound, 2011–15.—Continued

[Dates shown as month, day, year. mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; NTRU, nephelometric turbidity ratio units; µg/L, micrograms per liter; MPN/100 mL, most probable number per 100 milliliters; E, estimated; <, less than; --, value not calculated; Σ PAH, sum of polycyclic aromatic hydrocarbons]

Physical property	Unit	Minimum/maximum concentrations			
		Fall			
		Concentration	Dates	Stations[2]	Event
Dissolved oxygen	mg/L	7.0/12.4	10/10/2012;12/19/2013	0.25/3.5	Storm/monthly
pH	Standard units	7.5/8.4	10/10/2012; multiple	0.25/multiple	Storm/monthly
Specific conductance	µS/cm	3,290/9,710	11/15/2012; multiple	1.2/multiple	Monthly/multiple
Turbidity, total recoverable	NTRU	E5.5/48	11/21/2013; 11/15/2012	0.25/3.5	Monthly/monthly

Constituent	Unit	Maximum concentrations			
		Fall			
		Concentration	Date	Station[2]	Event
Phosphorus, total recoverable	mg/L	0.115	11/15/2012	3.5	Monthly
Total nitrogen, total recoverable	mg/L	1.9	10/18/2011	4.5	Monthly
Aluminum, total recoverable	µg/L	1,150	11/15/2012	3.5	Monthly
Iron, total recoverable	µg/L	1,620	11/15/2012	3.5	Monthly
Manganese, total recoverable	µg/L	90.7	10/18/2011	1.2	Monthly
Arsenic, total recoverable	µg/L	6.4	10/18/2011	1.2	Monthly
Lead, total recoverable	µg/L	3.73	11/15/2012	3.5	Monthly
Suspended solids, total recoverable	mg/L	110	10/18/2011	1.2	Monthly
Nickel, total recoverable	µg/L	3.7	10/10/2012	0.25	Storm
Enterococci	MPN/100 mL	180	11/15/2015	3.5	Monthly
Escherichia coli	MPN/100 mL	140	10/9/2012	0.25	Storm
Mercury, total recoverable	µg/L	0.063	10/18/2011	0.25	Monthly
Chromium, total recoverable	µg/L	8.3	10/18/2011	3.5	Monthly
Copper, dissolved	µg/L	4.6	11/21/2013	2.1	Monthly
Copper, total recoverable	µg/L	3.9	10/18/2011	3.5	Monthly
Lead, dissolved	µg/L	1.33	11/21/2013	1.2	Monthly
Σ PAH, total recoverable	µg/L	E 31.0	12/19/2013	3.5	Monthly

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[1] For parameters containing censored values with one detection level, medians were computed using the rank method as described by Bonn (2008). For parameters containing censored data with multiple detection levels, medians were calculated using the Kaplan-Meier method described by Bonn (2008).

[2] Number of miles from the east bank of Currituck Sound near Corolla, North Carolina (see text).

Table 8. Seasonal summary statistics for water-quality data collected in the Currituck Sound, 2011–15.—Continued

[Dates shown as month, day, year. mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; NTRU, nephelometric turbidity ratio units; µg/L, micrograms per liter; MPN/100 mL, most probable number per 100 milliliters; E, estimated; <, less than; --, value not calculated; Σ PAH, sum of polycyclic aromatic hydrocarbons]

Physical property	Unit	Minimum/maximum concentrations			
		Winter			
		Concentration	Dates	Stations[2]	Event
Dissolved oxygen	mg/L	8.7/13.1	3/21/2012; 3/6/2012	0.25/0.25	Monthly/storm
pH	Standard units	7.4/8.5	2/27/2013; 3/21/2012	0.25/1.2	Storm/monthly
Specific conductance	µS/cm	2,870/6,920	1/25/2015; multiple	2.1/multiple	Storm/monthly
Turbidity, total recoverable	NTRU	E6.7/37	3/21/2012; 2/27/2013	0.25/2.1	Monthly/storm

Constituent	Unit	Maximum concentrations			
		Winter			
		Concentration	Date	Station[2]	Event
Phosphorus, total recoverable	mg/L	0.092	2/27/2013	2.1	Storm
Total nitrogen, total recoverable	mg/L	1.5	3/6/2012	1.2	Storm
Aluminum, total recoverable	µg/L	887	2/27/2013	2.1	Storm
Iron, total recoverable	µg/L	1,070	2/27/2013	2.1	Storm
Manganese, total recoverable	µg/L	29.9	3/21/2012	4.5	Monthly
Arsenic, total recoverable	µg/L	2.7	2/22/2012	3.5/4.5	Monthly/monthly
Lead, total recoverable	µg/L	2.31	2/27/2013	2.1	Storm
Suspended solids, total recoverable	mg/L	520	1/24/2012	2.1	Monthly
Nickel, total recoverable	µg/L	27.9	2/27/2013	0.25	Storm
Enterococci	MPN/100 mL	20	March 2012 and 2013	1.2/0.25	Monthly/storm
Escherichia coli	MPN/100 mL	41	3/21/2012	4.5	Monthly
Mercury, total recoverable	µg/L	0.005	3/6/2012	2.1	Storm
Chromium, total recoverable	µg/L	62.1	2/27/2013	0.25	Storm
Copper, dissolved	µg/L	7.7	2/22/2012	2.1	Monthly
Copper, total recoverable	µg/L	17.8	2/22/2012	0.25	Monthly
Lead, dissolved	µg/L	1.59	1/25/2015	2.1	Storm
Σ PAH, total recoverable	µg/L	2.60	3/6/2012	3.50	Storm

[1] For parameters containing censored values with one detection level, medians were computed using the rank method as described by Bonn (2008). For parameters containing censored data with multiple detection levels, medians were calculated using the Kaplan-Meier method described by Bonn (2008).

[2] Number of miles from the east bank of Currituck Sound near Corolla, North Carolina (see text).

Table 8. Seasonal summary statistics for water-quality data collected in the Currituck Sound, 2011–15.—Continued

[Dates shown as month, day, year. mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; NTRU, nephelometric turbidity ratio units; µg/L, micrograms per liter; MPN/100 mL, most probable number per 100 milliliters; E, estimated; <, less than; --, value not calculated; Σ PAH, sum of polycyclic aromatic hydrocarbons]

Physical property	Unit	Minimum/maximum concentrations			
		Spring			
		Concentration	Dates	Stations[2]	Event
Dissolved oxygen	mg/L	7.7/11.3	6/26/2013; 6/20/2012	Multiple/0.25	Monthly/monthly
pH	Standard units	7.9/9	Multiple; 6/20/2012	Multiple/0.25	Monthly/monthly
Specific conductance	µS/cm	3,950/10,300	4/9/2013; multiple	0.25/multiple	Monthly/multiple
Turbidity, total recoverable	NTRU	E3.9/22	5/31/2012; 4/9/2013	0.25/0.25	Storm/monthly

Constituent	Unit	Maximum concentrations			
		Spring			
		Concentration	Date	Station[2]	Event
Phosphorus, total recoverable	mg/L	0.079	4/9/2013	0.25	Monthly
Total nitrogen, total recoverable	mg/L	1.4	4/9/2013	0.25	Monthly
Aluminum, total recoverable	µg/L	449	4/9/2013	0.25	Monthly
Iron, total recoverable	µg/L	612	4/9/2013	0.25	Monthly
Manganese, total recoverable	µg/L	60	5/31/2012	1.2	Storm
Arsenic, total recoverable	µg/L	3.8	5/30/2013	2.1	Monthly
Lead, total recoverable	µg/L	1.75	6/26/2013	3.5	Monthly
Suspended solids, total recoverable	mg/L	92	4/17/2012	1.2	Monthly
Nickel, total recoverable	µg/L	16.9	6/26/2013	2.1	Monthly
Enterococci	MPN/100 mL	11,000	6/20/2012	0	Monthly
Escherichia coli	MPN/100 mL	30	5/31/2012	0.25	Storm
Mercury, total recoverable	µg/L	<0.005	All	All	All
Chromium, total recoverable	µg/L	36.9	6/26/2013	2.1	Monthly
Copper, dissolved	µg/L	<8.0	All	All	All
Copper, total recoverable	µg/L	390	6/26/2013	3.5	Monthly
Lead, dissolved	µg/L	0.74	4/9/2013	3.5	Monthly
Σ PAH, total recoverable	µg/L	2.24	5/30/2013	1.20	Monthly

[1] For parameters containing censored values with one detection level, medians were computed using the rank method as described by Bonn (2008). For parameters containing censored data with multiple detection levels, medians were calculated using the Kaplan-Meier method described by Bonn (2008).

[2] Number of miles from the east bank of Currituck Sound near Corolla, North Carolina (see text).

Table 8. Seasonal summary statistics for water-quality data collected in the Currituck Sound, 2011–15.—Continued

[Dates shown as month, day, year. mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; NTRU, nephelometric turbidity ratio units; µg/L, micrograms per liter; MPN/100 mL, most probable number per 100 milliliters; E, estimated; <, less than; --, value not calculated; Σ PAH, sum of polycyclic aromatic hydrocarbons]

Physical property	Unit	Minimum/maximum concentrations			
		Summer			
		Concentration	Dates	Stations[2]	Event
Dissolved oxygen	mg/L	6.8/10.6	7/24/2013; 9/12/2012	4.5/0.25	Monthly/monthly
pH	Standard units	7.9/8.8	8/30/2011; multiple	4.5/multiple	Storm/monthly
Specific conductance	µS/cm	5,000/E16,300	9/12/2012; 8/30/2011	3.5/0.25	Monthly/storm
Turbidity, total recoverable	NTRU	E5.5/25	7/24/2013; 8/30/2011	2.1/4.5	Monthly/storm
Constituent	**Unit**	**Maximum concentrations**			
		Summer			
		Concentration	**Date**	**Station[2]**	**Event**
Phosphorus, total recoverable	mg/L	0.089	8/30/2011	0.25	Storm
Total nitrogen, total recoverable	mg/L	1.9	9/12/2012	3.5	Monthly
Aluminum, total recoverable	µg/L	453	8/30/2011	4.5	Storm
Iron, total recoverable	µg/L	578	8/30/2011	4.5	Storm
Manganese, total recoverable	µg/L	104	8/15/2012	4.5	Monthly
Arsenic, total recoverable	µg/L	3.5	8/30/2011	0.25	Storm
Lead, total recoverable	µg/L	1.67	8/30/2011	4.5	Storm
Suspended solids, total recoverable	mg/L	130	9/12/2012	0.25	Monthly
Nickel, total recoverable	µg/L	1.8	9/28/2011	2.1	Monthly
Enterococci	MPN/100 mL	2,900	7/24/2013	0.25	Monthly
Escherichia coli	MPN/100 mL	74	8/30/2011	0.25	Storm
Mercury, total recoverable	µg/L	0.251	9/28/2011	0.25	Monthly
Chromium, total recoverable	µg/L	60.8	8/30/2011	2.1	Storm
Copper, dissolved	µg/L	<50	All	All	All
Copper, total recoverable	µg/L	3.9	8/15/2012	3.5	Monthly
Lead, dissolved	µg/L	0.179	9/28/2011	0.25	Monthly
Σ PAH, total recoverable	µg/L	2.60	8/15/2013	3.5	Monthly

[1] For parameters containing censored values with one detection level, medians were computed using the rank method as described by Bonn (2008). For parameters containing censored data with multiple detection levels, medians were calculated using the Kaplan-Meier method described by Bonn (2008).

[2] Number of miles from the east bank of Currituck Sound near Corolla, North Carolina (see text).

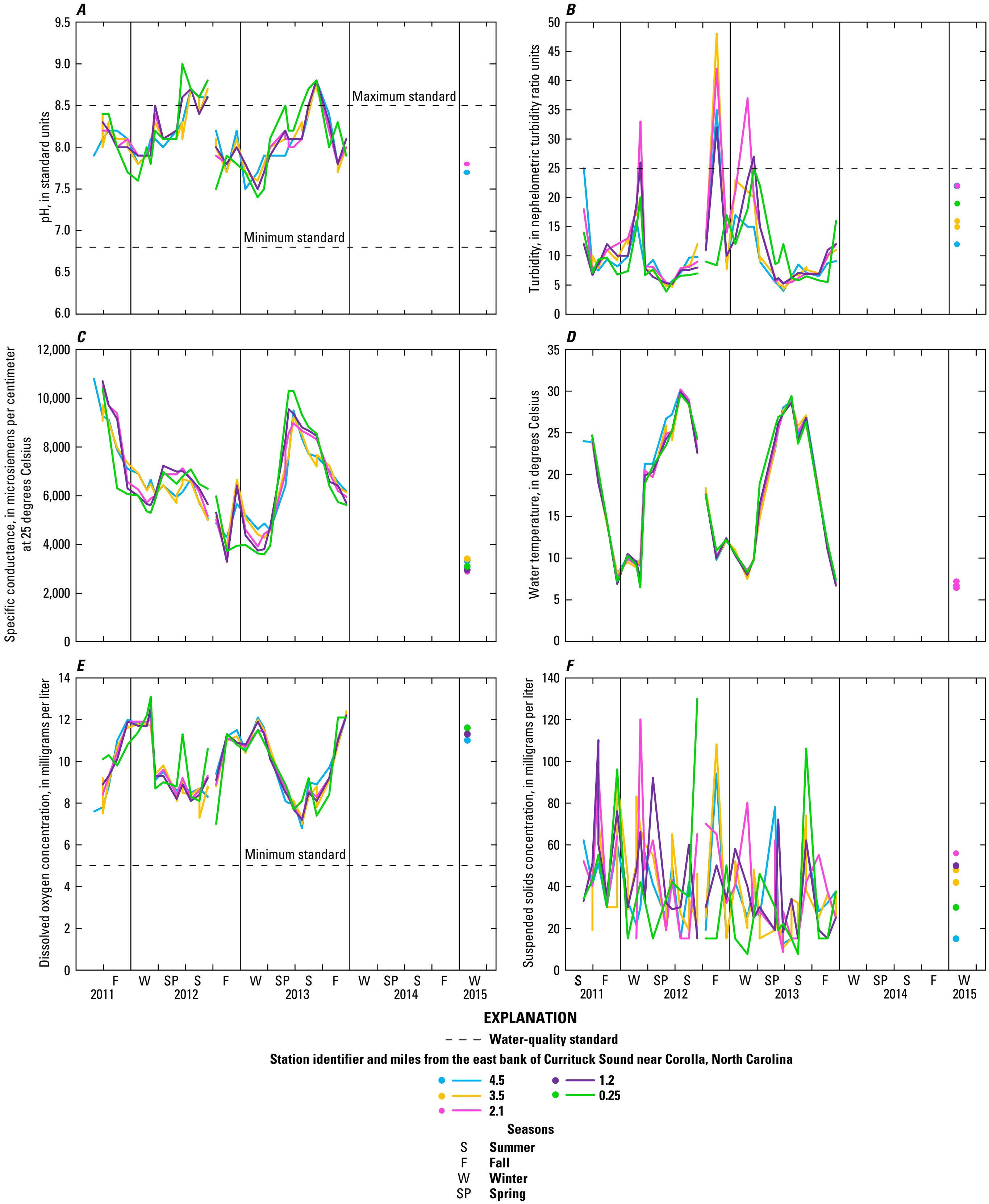

Figure 4. Time series plots showing physical properties and concentrations of selected constituents in monthly and storm water samples from Currituck Sound, North Carolina, 2011–15.

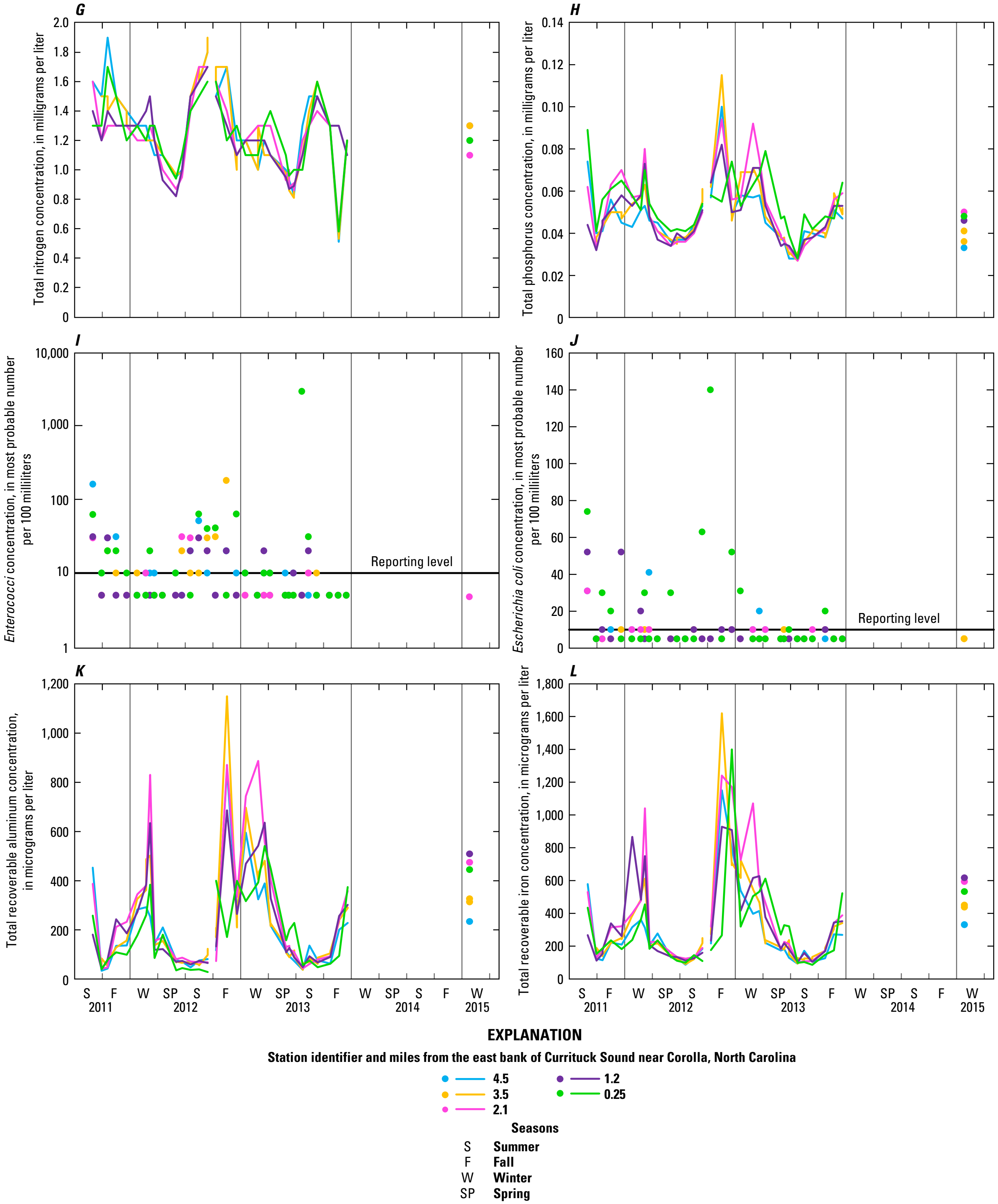

Figure 4. Time series plots showing physical properties and concentrations of selected constituents in monthly and storm water samples from Currituck Sound, North Carolina, 2011–15.—Continued

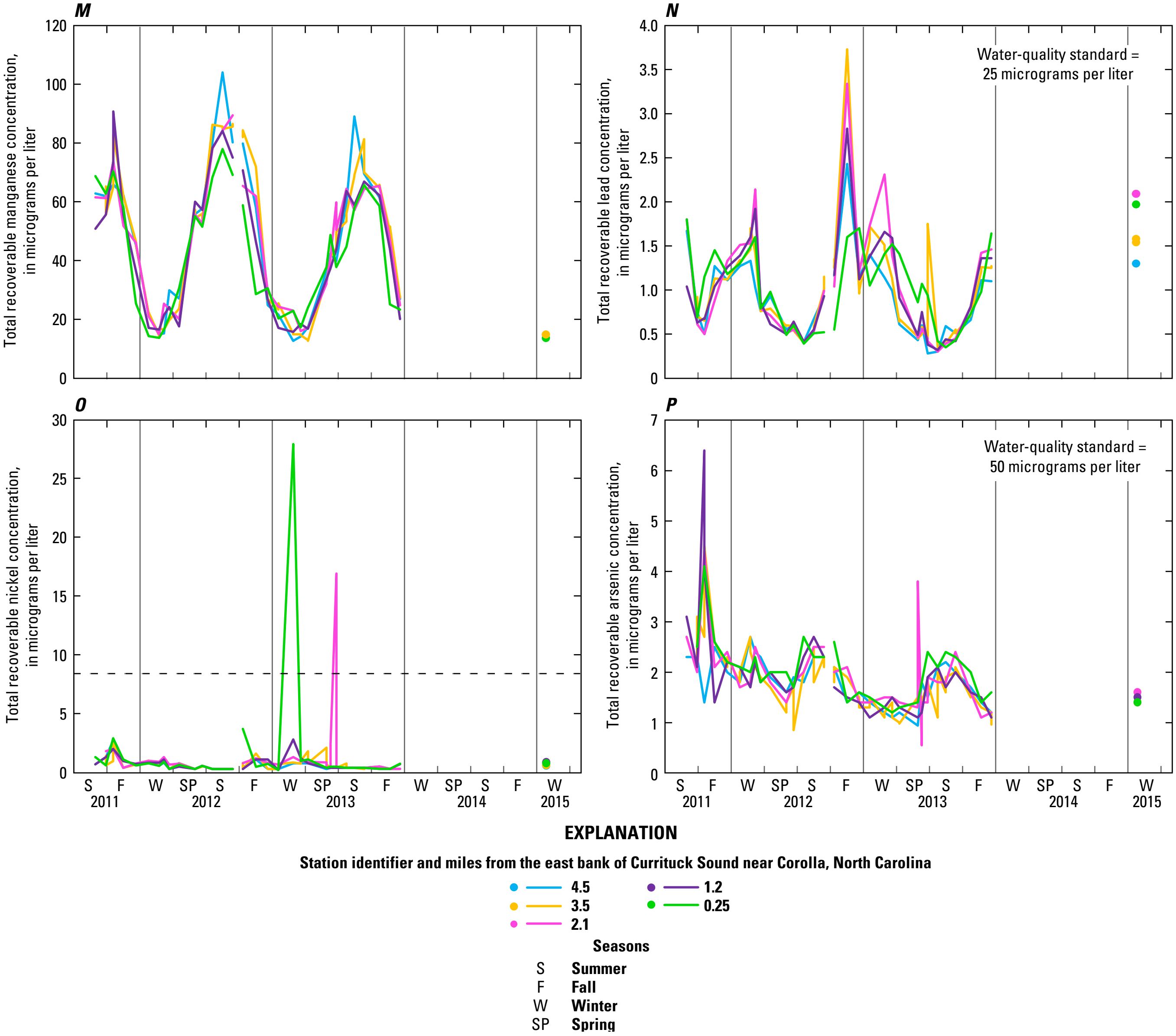

Figure 4. Time series plots showing physical properties and concentrations of selected constituents in monthly and storm water samples from Currituck Sound, North Carolina, 2011–15.—Continued

Correlation of Wind Speed and Direction to Water-Quality

Given that the most appreciable changes in water quality were hypothesized to probably occur during wind events (Caldwell, 2001, and Fine, 2008), summary statistics (median, mean, and standard deviation) of wind speed and direction data were compiled for the 24- and 72-hour periods prior to water-quality sampling (table 9), which can be used for correlation with water-quality conditions. The wind speed and direction data in table 9 were compiled from three meteorological stations in the vicinity of the proposed bridge crossing of Currituck Sound (fig. 1):

1. USGS gaging station, Currituck Sound on east bank near Corolla, N.C. (362228075500401) (http://nwis.waterdata.usgs.gov/nc/nwis/uv/?site_no=362228075500401)
2. Federal Aviation Administration meteorological station at Currituck County, N.C. airport (KONX) (http://www.wunderground.com/history/airport/KONX/2015/3/29/DailyHistory.html),
3. National Weather Service meteorological station at Elizabeth City, N.C. Coast Guard Air Stations (KECG) (http://www.wunderground.com/history/airport/KECG/2015/3/29/DailyHistory.html).

In addition, 72-hour total precipitation measured at the Currituck County airport (KONX) and Elizabeth City airport (KECG) are also summarized in table 9 to indicate the level of freshwater inputs prior to each water-quality sampling event.

The wind speed and direction data (table 9) corresponding to the sampling events for which the seasonal maximum (and minimum for physical properties) occurred were reviewed using statistical methods for possible correlation. The mean and median 24-hour and 72-hour antecedent wind directions were examined, and the 72-hour data were more variable, having larger standard deviations than the 24-hour data. The analysis focused on those sampling events for which there were four or more occurrences of the maximum and (or) minimum (for pH and dissolved oxygen) seasonal concentrations (shaded rows, table 9). During the 24 hours before such sampling events, the median wind direction was most often from the southwest, occurring 4 of 10 times. The most common wind direction leading up to all other sampling events, however, was also from the southwest, occurring 12 of 26 times. Statistical testing also indicated no differences between the 24-hour and 72-hour medians of the antecedent wind directions for the sampling events having four or more occurrences of the maximum and (or) minimum seasonal concentrations and all other sampling events. The wind speeds were also examined in the same manner as just described, and there were no statistical differences between the 24-hour and 72-hour medians of the antecedent wind speeds for all the sampling events with four or more occurrences of the maximum and (or) minimum seasonal concentrations and all other sampling events.

Table 9. Summary statistics of wind speed and direction 24 and 72 hours prior to water-quality sampling events and total precipitation over the 72-hour period prior to water-quality sampling events in Currituck Sound, 2011–15.

[Shaded sample events are those with 4 or more of the maximum and(or) minimum seasonal constituent concentrations. Sampling dates are shown as month, day, year. mph; mile per hour; h, hour; std dev, standard deviation; deg, degrees; in., inch; KONX, Currituck County, NC airport meteorological station; KECG, Elizabeth City, NC airport meteorological station; --,no data available; S., south; N., north; E., east; W., west; SW., southwest; SE., southeast; NE., northeast; NW., northwest]

Sample date	Sample time	Gage height (feet)	24-h antecedent wind speed (mph)			72-h antecedent wind speed (mph)			24-h antecedent wind direction			72-h antecedent wind direction			Total 72-h antecedent precipitation (in.)	
			Mean	Median	Std dev	Mean	Median	Std dev	Mean	Median	Std dev (deg. from 0, N)	Mean	Median	Std dev (deg. from 0, N)	KONX	KECG
Monthly samples																
Sept. 28, 2011	1145	0.97	7.89	7.90	3.39	7.89	7.90	3.39	SSW.	S.	32.18	SSW.	S.	32.18	0.13	0.53
Oct. 18, 2011	1120	0.8	11.31	11.00	3.10	13.54	13.00	4.97	SW.	SW.	24.25	SW.	SW.	25.20	0.00	0.13
Nov. 15, 2011	1015	0.43	15.47	15.00	2.73	13.35	15.00	2.73	SW.	SE.	13.12	SW.	SW.	10.65	0.00	0.00
Dec. 20, 2011	0955	0.1	11.97	12.00	2.35	10.58	12.00	3.87	SW.	SW.	25.16	SSE.	SW.	129.01	0.13	0.08
Jan. 24, 2012	1200	-0.12	8.41	8.40	3.24	11.85	12.00	4.86	SSW.	SW.	47.17	ESE.	NE.	121.17	0.44	0.74
Feb. 22, 2012	1245	-0.12	10.45	11.00	3.18	13.47	12.00	7.54	SW.	SW.	38.90	ESE.	NE.	114.98	0.72	0.55
Mar 21, 2012	1115	0.02	8.38	8.30	2.72	6.88	6.50	3.39	SSE.	SE.	31.79	SSE.	E.	83.32	0.05	0.04
Apr. 17, 2012	1345	0.32	13.75	14.00	3.34	15.68	16.00	3.06	SW.	SW.	69.75	SW.	SW.	44.01	0.00	0.00
June 20, 2012	1215	0.79	8.87	8.70	3.10	7.14	7.10	3.11	SSW.	SW.	57.57	SE.	SE.	88.44	0.00	0.00
July 18, 2012	1345	0.95	5.99	5.20	3.10	10.71	11.00	4.49	ENE.	NE.	75.24	NE.	NE.	44.11	0.00	0.00
Aug. 15, 2012	1330	1.11	11.00	12.00	2.89	8.23	8.00	3.71	SSW.	SW.	44.56	S.	SW.	65.25	0.17	1.93
Sept. 12, 2012	1215	-0.19	6.74	5.80	3.15	9.45	9.30	3.80	NE.	NE.	24.02	NE.	N.	83.97	0.13	0.19
Nov. 15, 2012	1130	-0.94	12.86	12.00	2.86	13.19	13.00	4.06	NNE.	N.	22.59	ENE.	N.	78.78	0.07	0.09
Dec. 18, 2012	1200	0.75	10.95	11.00	4.83	7.18	6.50	4.53	SW.	SW.	40.58	S.	S.	74.16	0.81	1.08
Jan. 17, 2013	1115	-0.08	6.01	5.10	3.50	7.00	6.20	4.41	E.	NE.	89.26	E.	NE.	95.30	0.56	0.44
Mar 20, 2013	0915	-0.07	10.48	9.35	4.58	--	--	--	SSW.	S.	123.45	--	--	--	0.04	0.01
Apr. 9, 2013	1115	0.27	13.39	13.00	3.63	11.44	12.00	3.63	SW.	SW.	74.49	SSE.	S.	163.18	0.00	0.00
May 30, 2013	1030	0.46	14.91	15.00	3.81	13.94	14.00	3.37	SSW.	SW.	20.04	SSW.	S.	30.67	0.00	0.00
May 30, 2013	1045	0.44	14.86	15.00	3.86	13.98	14.00	3.81	SSW.	SW.	20.04	SSW.	S.	30.40	0.00	0.00
June 26, 2013	1130	0.78	14.79	15.00	2.18	14.83	15.00	2.55	SW.	SW.	13.19	SW.	SW.	20.04	0.00	0.00
June 26, 2013	1145	0.8	14.78	15.00	2.17	14.84	15.00	2.53	SW.	SW.	13.12	SW.	SW.	20.04	0.00	0.00
July 24, 2013	1015	0.82	12.50	12.00	4.23	12.79	13.00	4.04	SW.	SW.	21.48	SW.	SW.	30.42	1.07	2.29
Aug. 15, 2013	1300	-0.21	10.04	9.60	4.14	10.25	9.95	4.12	SSE.	SE.	79.28	SE.	SE.	86.76	0.18	0.45
Sept. 11, 2013	1145	0.27	8.65	8.50	2.15	6.41	7.00	3.16	S.	S.	42.27	SE.	SE.	63.35	0.00	0.00
Oct. 23, 2013	0900	0.77	10.20	10.00	2.42	7.05	6.50	3.20	SW.	SW.	17.75	SSE.	SW.	97.65	0.00	0.00

Table 9. Summary statistics of wind speed and direction 24 and 72 hours prior to water-quality sampling events and total precipitation over the 72-hour period prior to water-quality sampling events on the Currituck Sound, North Carolina, 2011–15.—Continued

[Shaded sample events are those with 4 or more of the maximum and(or) minimum seasonal constituent concentrations. Sampling dates are shown as month, day, year. mph; mile per hour; h, hour; std dev, standard deviation; deg, degrees; in., inch; KONX, Currituck County, NC airport meteorological station; KECG, Elizabeth City, NC airport meteorological station; --,no data available; S., south; N., north; E., east; W., west; SW., southwest; SE., southeast; NE., northeast; NW., northwest]

Sample date	Sample time	Gage height (feet)	24-h antecedent wind speed (mph)			72-h antecedent wind speed (mph)			24-h antecedent wind direction			72-h antecedent wind direction			Total 72-h antecedent precipitation (in.)	
			Mean	Median	Std dev	Mean	Median	Std dev	Mean	Median	Std dev (deg. from 0, N)	Mean	Median	Std dev (deg. from 0, N)	KONX	KECG
Nov. 21, 2013	1200	-1.06	11.78	12.00	3.35	12.21	13.00	3.73	NE.	NE.	9.23	SE.	NE.	114.18	0.01	0.03
Dec. 19, 2013	1115	0.1	9.19	9.35	3.75	10.01	9.90	4.48	SW.	SW.	68.39	SSE.	S.	103.82	0.00	0.00
Storm samples																
Aug. 30, 2011[1]	1215	0.76	9.58	9.20	2.78	15.23	12.70	6.99	NE.	NE.	--	E.	NE.	--	5.92	4.93
Mar 6, 2012	1315	-0.59	16.50	16.00	5.55	14.06	14.00	5.73	E.	N.	140.18	SSE.	SW.	129.79	0.91	1.92
May 31, 2012	1230	0.76	11.06	12.00	3.99	13.46	14.00	4.03	SSE.	W.	127.41	SSW.	SW.	82.07	1.93	1.71
Oct. 10, 2012	0945	-0.31	10.03	10.00	2.26	11.75	12.00	3.31	SSE.	W.	150.11	E.	NE.	119.47	1.20	1.66
Oct. 9, 2012	1345		12.55	12.00	3.42	12.16	12.00	3.30	NNE.	NE.	38.36	ENE.	NE.	89.04	1.17	1.65
Feb. 27, 2013	0930	0.19	12.59	11.00	5.62	9.40	8.80	5.44	S.	S.	64.60	ESE.	E.	104.82	1.61	0.37
June 10, 2013	1045	0.62	12.35	12.00	3.19	14.21	12.00	8.07	S.	S.	56.00	SSE.	S.	70.55	0.88	1.27
June 10, 2013	1100	0.61	14.18	12.00	8.05	12.44	12.00	3.12	SSE.	S.	70.53	S.	S.	55.35	0.88	1.27
Jan. 25, 2015	1115	0.76	16.27	17.00	5.29	11.86	10.00	5.95	WNW.	W.	21.43	SSW.	S.	115.65	1.23	1.03

[1] Wind speed and direction data not available from U.S. Geological Survey station for this period, wind data are from the Currituck County airport meteorological station (KONX) for this event.

Summary of Bed-Sediment Sample Results

Concentrations of inorganics in the fines fraction of bed sediment are shown for the two sampling dates (20 months apart) and for each of the five stations (fig. 5). Concentrations for most elements did not vary appreciably between sampling dates or among sampling sites (fig. 6). The most abundant elements were those thought to be associated with the clay mineral lattice or oxyhydroxide coating (aluminum, iron, potassium, sodium, calcium, magnesium, and titanium) in addition to the elements in organic matter (carbon, sulfur, and nitrogen). Comparing total carbon and total organic carbon, all of the carbon in most of the samples was associated with organic matter (appendix 2). The constituents measured in milligrams per kilogram were dominated by phosphorus, which is probably organically and inorganically bound to sediment, in addition to elements likely present in oxyhydroxide or authigenic phases (barium, manganese, strontium, and vanadium). Next in abundance were elements that often have water-quality thresholds, including zinc, chromium, lead, nickel, copper, and cobalt. Constituents having concentrations of about 1 mg/kg or less included tin, selenium, antimony, cadmium, and mercury. Silver, thallium, and uranium concentrations were below the reporting levels in all samples.

Organic constituents were sampled a year apart at all five sampling sites in July of 2012 and 2013 for a total of 10 samples (table 10). Reporting levels were raised in samples when the minimum sample mass was not available to be analyzed. Most of the constituents were present below their respective reporting levels. The most frequently detected compounds in both 2012 and 2013 included 2,6-dimethylnaphthalene (all 10 samples), perylene (9 samples), fluoranthene (9 samples), and pyrene (9 samples). Other compounds detected in at least half the 10 samples included phenanthrene (6 samples), 9,10–anthraquinone (5 samples), bis(2-ethylhexyl) phthalate (5 samples), and 1-methylphenanthrene (5 samples). Bis(2-ethylhexyl)phthalate was not detected in any 2012 sample but was detected in all 2013 samples. Samples collected in 2013 from stations located 0.25, 1.2, and 4.5 mi from the east bank of Currituck Sound near Corolla, N.C., had measured concentrations of bis(2-ethylhexyl) phthalate that were well above some reporting levels for this compound among the 2012 samples. Thus, despite the relatively high reporting levels for several samples collected in 2012, bis(2-ethylhexyl)phthalate should have been detected if present at concentrations similar to those in 2013. Because precision data are lacking for bis(2-ethylhexyl)phthalate and other organics in bed sediments, it is difficult to conclude that the concentration of this phthalate actually increased in the 2013 samples.

One of the most spatially and temporally variable constituents in bed sediments was the fraction of fines (fig. 7). This is important because trace element concentrations in bulk sediments have been shown to be well-correlated with the concentration of fines and the total surface area of sediments (Horowitz and Elrick, 1987). Therefore, bulk-sediment total concentrations of elements that are not associated with the mineral lattice are largely controlled by the proportion of fines. The amount of fines ranged from less than 1 percent (stations 0.25 and 4.5 mi from the east bank of Currituck Sound near Corolla, N.C., on July 24, 2013) to 68 percent (station 3.5 mi from the east bank on July 18, 2012). In general, fines within the sound were more abundant at the three central stations (1.2, 2.1, and 3.5 mi from the east bank) than at the stations near the coastlines (0.25 and 4.5 mi from the east bank). Beyond the supply of fines to the sound, the input and deposition of larger particles also adds to the variability in the fraction of fines. These larger particles are associated with lower surface area available for adsorption of inorganic and organic constituents and thus act as a diluent on the bulk-sediment concentration of sorbed constituents. Future construction of the Mid-Currituck Sound Bridge with the associated structures in the water and bed sediments might affect the transport, deposition, and resuspension pattern of both fines and larger particles along and near this transect. This physical trapping, along with potential sediment and debris inputs from the bridge surface, could potentially affect the bulk-sediment constituent concentrations near the transect through changes in predominant bed-sediment particle size alone.

Because the quality thresholds for bed sediment are based on bulk sediment, all concentrations were multiplied by the fraction of fines to get concentrations on a bulk-sediment basis. For constituents having quality thresholds in nanograms per gram dry weight of bulk sediment, concentrations in weight percent were multiplied by 10^7 (divided by 100 and multiplied by 10^9) and concentrations in milligrams per kilogram were multiplied by 1,000. Concentrations in micrograms per kilogram were already in nanograms per gram dry weight. Constituents having quality thresholds in weight percent (aluminum and iron) were left in those units.

Constituent concentrations on a bulk-sediment basis that are greater than bed-sediment quality thresholds are shown in table 11. The accuracy of these calculated constituent concentrations for bulk sediment is less than that for the direct determination of constituent concentrations on the fine fraction because the error in the determination of the fine fraction is now included. Only four constituents were greater than a threshold: tin (5 instances), barium (4 instances), aluminum (2 instances), and diethyl phthalate (1 instance). The number of occurrences of concentrations greater than the threshold could be underestimated for diethyl phthalate, as well as for 21 other SVOCs, because the reporting level exceeded the thresholds in some or all of the samples. Thirty-five constituents had sampled concentrations that were never greater than quality thresholds and 33 constituents had no quality thresholds. Values less than the reporting level for cadmium, silver, and tin, as well as for many SVOCs, were not corrected for particle size.

Previous studies of bed-sediment quality in Currituck Sound are scarce. A review of 25 studies within the Albemarle-Pamlico system (Albemarle Sound and Pamlico Sound combined) published in 1989 did not contain any results for Currituck Sound (Wells and Kim, 1989). Since 1989, the Albemarle-Pamlico National Estuary program administered by the U.S. Environmental Protection Agency (EPA) has published bed-sediment quality index data for two sites in Currituck Sound that were both classified as “good” (U.S. Environmental Protection Agency, 2007). One site is about 6 mi south of the proposed bridge alignment and the other is about 9 mi northwest of it. The index reflects three components: sediment toxicity, sediment contaminants, and total organic carbon. A study by Corbett and others (2007) utilized naturally occurring radiochemical tracers (lead-210 [^{210}Pb] and cesium-137 [^{137}Cs]) in surficial bed sediments, included two sites in Currituck Sound, one about 3 mi southeast of the proposed transect and the other about 12.5 mi southwest of it. Measurable activities of excess ^{210}Pb (that portion not supported by *in situ* decay of radium-226 [^{226}Ra]) and ^{137}Cs were low and confined to the upper few centimeters of bed sediment at both sites, owing largely to the lack of fines available for sorption of these radionuclides at both sites. The amount of fines over the upper 1 ft or so ranged from about 10 to about 80 weight percent (Corbett and others, 2007). This large variability over perhaps decades is consistent with the variability observed in surficial sediments between 2011 and 2013 noted earlier. Overall, the sedimentation is characterized by low and transient input, frequent resuspension, and little long-term deposition of fines in that portion of Currituck Sound.

The fine-grained molar ratio of organic carbon to TN of the bed sediments was relatively constant at about 7:1 (fig. 8). Assuming most of the total nitrogen is organically bound, this ratio is very similar to the Redfield ratio of 6.6:1, which is the empirical ratio for non-nutrient-limited marine phytoplankton assemblages (Redfield, 1958; Redfield and others, 1963). Thus, the organic matter in the bed sediments appeared to be relatively fresh and not degraded, as would be indicated by a higher C:N molar ratio resulting from preferential nitrogen remineralization (Suess and Müller, 1980). The observed C:N molar ratio reflected the relatively shallow depths within the sound, allowing little time for decomposition prior to deposition.

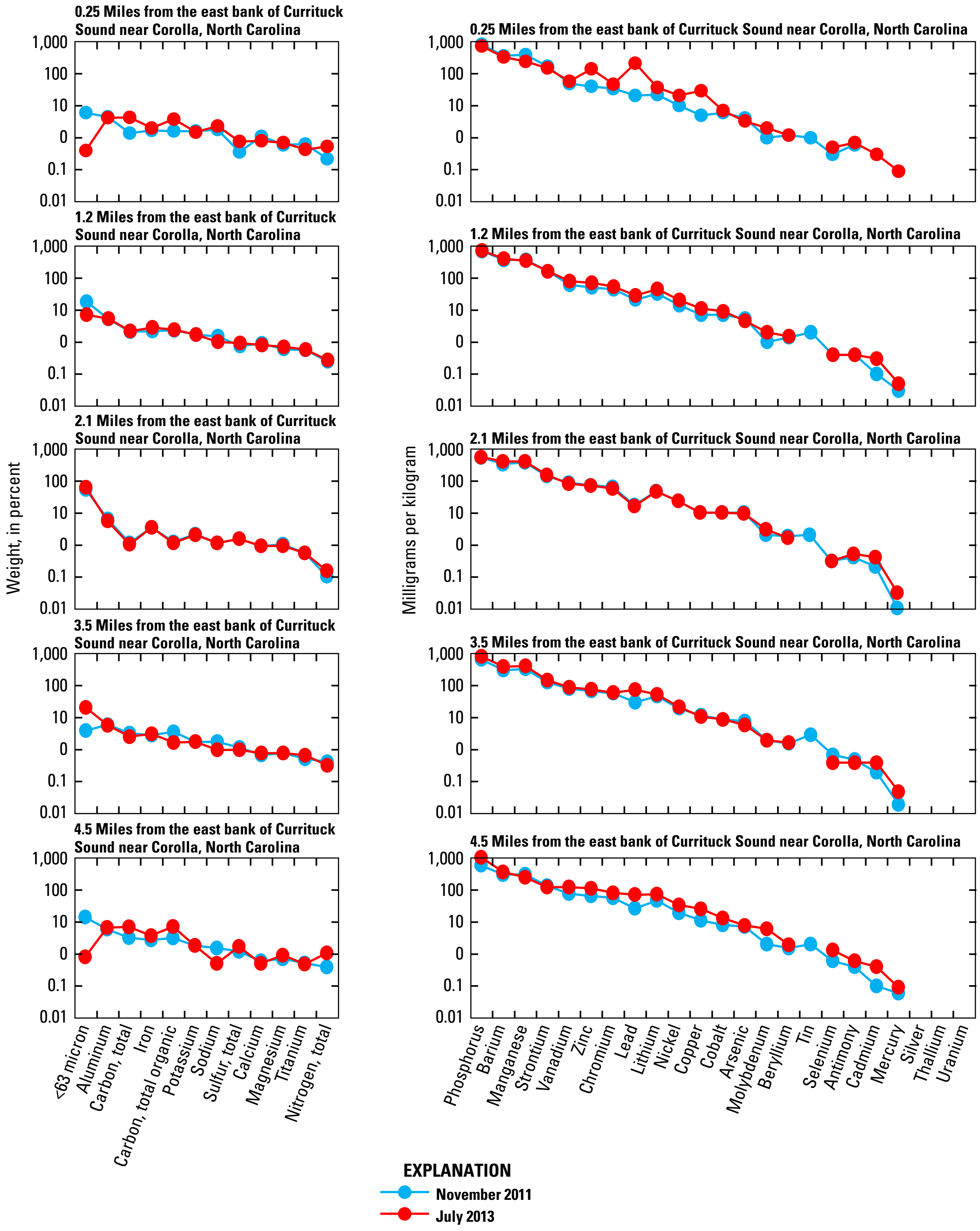

Figure 5. Inorganic constituent concentrations and percentage of grain size less than 63 microns in bed sediments collected from five sampling sites on two dates in Currituck Sound, North Carolina, 2011 and 2013, grouped by sampling site.

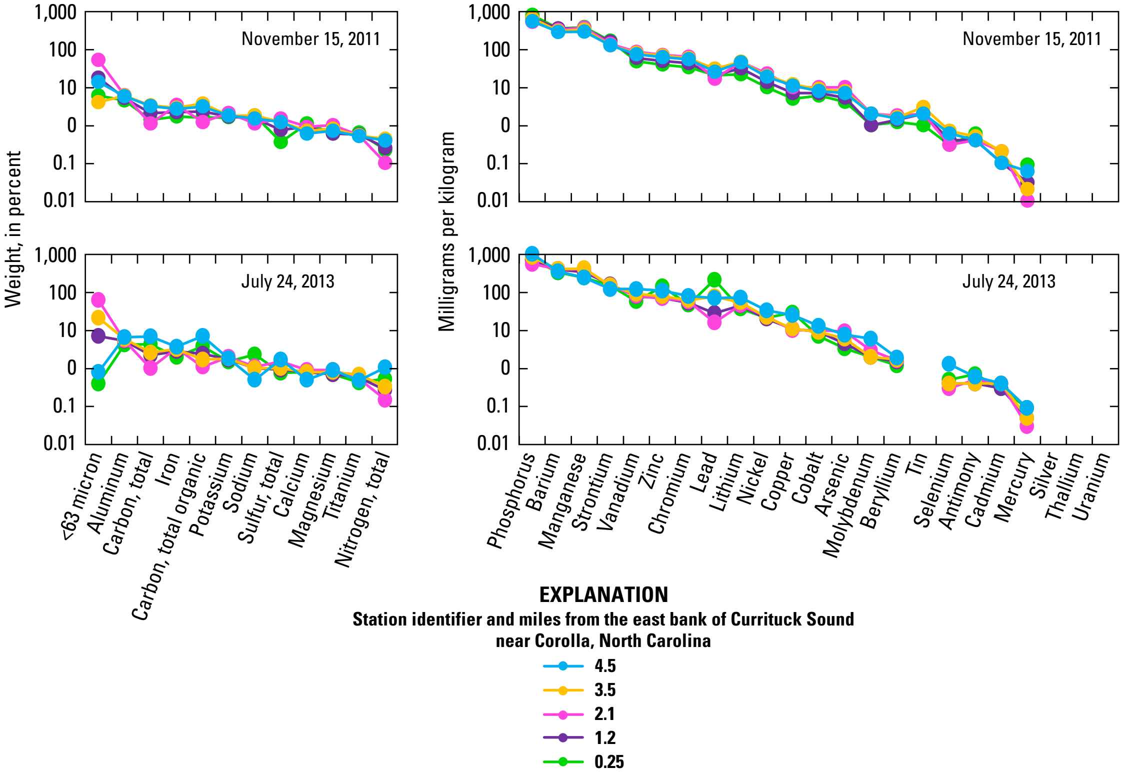

Figure 6. Inorganic constituent concentrations and percentage of grain size less than 63 microns in bed sediments collected from five sampling sites on two dates in Currituck Sound, North Carolina, 2011 and 2013, grouped by sampling date.

Table 10. Organic constituents in bed sediments collected in 2012 and 2013 in Currituck Sound.

[µg/kg, micrograms per kilogram; No., number; E, estimated; <, less than; NC, North Carolina]

Constituent	July 18, 2012						July 24, 2013					
	No. of detections	Concentration (µg/kg) at site					No. of detections	Concentration (µg/kg) at site				
		0.25 miles from the east bank of Currituck Sound near Corolla, NC	1.2 miles from the east bank of Currituck Sound near Corolla, NC	2.1 miles from the east bank of Currituck Sound near Corolla, NC	3.5 miles from the east bank of Currituck Sound near Corolla, NC	4.5 miles from the east bank of Currituck Sound near Corolla, NC		0.25 miles from the east bank of Currituck Sound near Corolla, NC	1.2 miles from the east bank of Currituck Sound near Corolla, NC	2.1 miles from the east bank of Currituck Sound near Corolla, NC	3.5 miles from the east bank of Currituck Sound near Corolla, NC	4.5 miles from the east bank of Currituck Sound near Corolla, NC
2,6-Dimethylnaphthalene	5	11	24.9	28.9	15.7	41.6	5	50.2	38	12.5	14.5	74.4
Perylene	5	13.8	43.3	59.1	32.8	79.8	4	<100	61.1	37.8	51.8	65.3
9,10-Anthraquinone	4	7.7	23.2	14.3	14.3	<330	1	<100	<176	10.8	<43.8	<159
Fluoranthene	4	13.1	21.8	11.4	21.2	<330	5	26.5	42.1	6.4	30.5	55.7
Phenanthrene	4	6.5	13	9.5	9.7	<330	2	<100	<176	<25.5	19.2	58
Pyrene	4	7.8	13.9	7.1	12.3	<330	5	17.2	23.2	3.3	17.6	31.6
Naphthalene	3	<40.0	16.3	9.8	11.6	<330	0	<100	<176	<25.5	<43.8	<159
1-Methylphenanthrene	2	<40.0	<75.0	6.3	3.6	<330	3	<100	<176	2.5	3.8	10.1
Benzo[*a*]anthracene	2	E2.9	<75.0	4.5	4.3	<330	1	<100	<176	<25.5	6.7	<159
1,6-Dimethylnaphthalene	1	<40.0	<75.0	7.4	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
1-Methylpyrene	1	<40.0	<75.0	3.4	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
4*H*-Cyclopenta[*def*]phenanthrene	1	<40.0	<75.0	3.4	<42.5	<330	1	<100	<176	<25.5	2.5	<159
Anthracene	1	<40.0	<75.0	6	<42.5	<330	3	<100	<176	3.4	6.2	10.3
Diethyl phthalate	1	1,680	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
Bis(2-ethylhexyl) phthalate	0	<130	<257	<125	<230	<1,100	5	2,320	891	128	298	1,770
Chrysene	0	<40.0	<75.0	E5.7	<42.5	<330	2	<100	<176	<25.5	8.9	13.8
1,2,4-Trichlorobenzene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
1,2-Dimethylnaphthalene	0	<40.0	<75.0	E2.8	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
1-Methyl-9*H*-fluorene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
2,3,6-Trimethylnaphthalene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
2-Ethylnaphthalene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
2-Methylanthracene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
9*H*-Fluorene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
Acenaphthene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
Acenaphthylene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
Benzo[*a*]pyrene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
Benzo[*b*]fluoranthene	0	E6.2	E9.9	E6.4	E7.6	<330	0	<100	<176	<25.5	<43.8	<159
Benzo[*e*]pyrene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159

Table 10. Organic constituents in bed sediments collected in 2012 and 2013 in Currituck Sound.—Continued

[µg/kg, micrograms per kilogram; No., number; E, estimated; <, less than; NC, North Carolina]

Constituent	July 18, 2012						July 24, 2013					
	No. of detections	Concentration (µg/kg) at site					No. of detections	Concentration (µg/kg) at site				
		0.25 miles from the east bank of Currituck Sound near Corolla, NC	1.2 miles from the east bank of Currituck Sound near Corolla, NC	2.1 miles from the east bank of Currituck Sound near Corolla, NC	3.5 miles from the east bank of Currituck Sound near Corolla, NC	4.5 miles from the east bank of Currituck Sound near Corolla, NC		0.25 miles from the east bank of Currituck Sound near Corolla, NC	1.2 miles from the east bank of Currituck Sound near Corolla, NC	2.1 miles from the east bank of Currituck Sound near Corolla, NC	3.5 miles from the east bank of Currituck Sound near Corolla, NC	4.5 miles from the east bank of Currituck Sound near Corolla, NC
Benzo[*ghi*]perylene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
Benzo[*k*]fluoranthene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
Carbazole	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
Dibenzo[*a*,*h*]anthracene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
Dibenzothiophene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
Hexachlorobenzene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
Indeno[1,2,3-*cd*]pyrene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
Pentachloroanisole	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
Pentachloronitrobenzene	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159
Phenanthridine	0	<40.0	<75.0	<35.0	<42.5	<330	0	<100	<176	<25.5	<43.8	<159

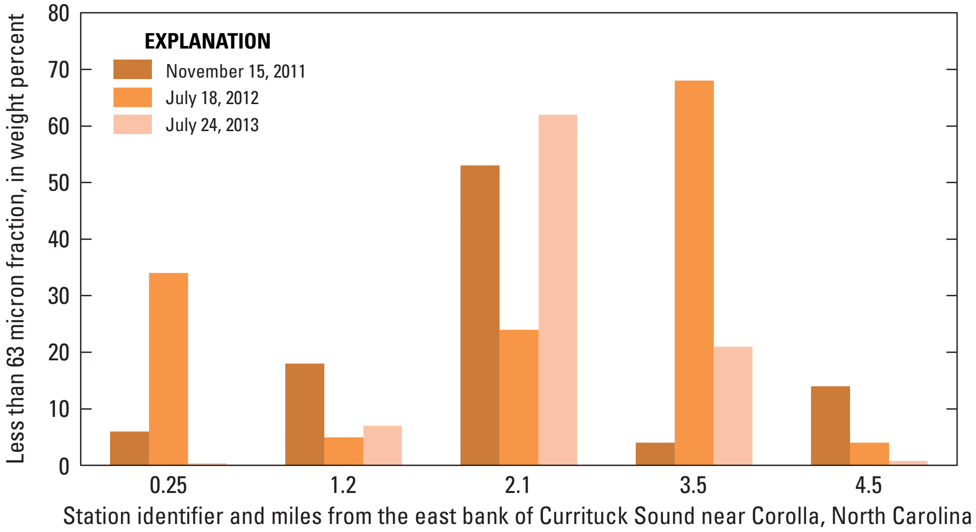

Figure 7. Summary of the less than 63-micron fraction of bed sediments measured at 5 sampling sites on three dates in Currituck Sound, North Carolina, 2011, 2012, and 2013.

Table 11. Bed-sediment standards and guidelines and bulk-sediment concentrations of samples collected in Currituck Sound, 2011–13.

[NC, North Carolina; ng/gdw, nanograms per gram dry weight of bulk sediment (equals parts per billion); wt%, weight percent; ND, not determined; E, estimated; <, less than reporting level; >, greater than; --, no information]

Constituent	Standard[1]	Unit	Number greater than the standard	Number of samples where the reporting level exceeded the standard	0.25 miles from the east bank of Currituck Sound near Corolla, NC			1.2 miles from the east bank of Currituck Sound near Corolla, NC		
					Nov. 15, 2011	July 18, 2012	July 24, 2013	Nov. 15, 2011	July 18, 2012	July 24, 2013
Threshold exists										
Tin	48	ng/gdw	5	0	60	ND	<0.1	360	ND	<0.1
Barium	48,000	ng/gdw	4	0	21,600	ND	2,800	64,800	ND	84,000
Aluminum	1.8	wt%	2	0	0.27	ND	0.053	0.936	ND	1.239
Diethyl phthalate	6	ng/gdw	1	9	ND	67.2	<100	ND	<75.0	<176
1,2,4-Trichlorobenzene	>4.8	ng/gdw	0	10	ND	<40.0	<100	ND	<75.0	<176
9*H*-Fluorene	19	ng/gdw	0	10	ND	<40.0	<100	ND	<75.0	<176
Acenaphthene	6.71	ng/gdw	0	10	ND	<40.0	<100	ND	<75.0	<176
Acenaphthylene	5.87	ng/gdw	0	10	ND	<40.0	<100	ND	<75.0	<176
Dibenzo[*a*,*h*]anthracene	6.22	ng/gdw	0	10	ND	<40.0	<100	ND	<75.0	<176
Hexachlorobenzene	6	ng/gdw	0	10	ND	<40.0	<100	ND	<75.0	<176
Anthracene	34	ng/gdw	0	6	ND	<40.0	<100	ND	<75.0	<176
Naphthalene	30	ng/gdw	0	6	ND	<40.0	<100	ND	11.1	<176
1-Methylphenanthrene	18	ng/gdw	0	5	ND	<40.0	<100	ND	<75.0	<176
Benzo[*a*]anthracene	61	ng/gdw	0	5	ND	E2.9	<100	ND	<75.0	<176
Benzo[*a*]pyrene	69	ng/gdw	0	5	ND	<40.0	<100	ND	<75.0	<176
Benzo[*ghi*]perylene	67	ng/gdw	0	5	ND	<40.0	<100	ND	<75.0	<176
Benzo[*k*]fluoranthene	70	ng/gdw	0	5	ND	<40.0	<100	ND	<75.0	<176
Indeno[1,2,3-*cd*]pyrene	68	ng/gdw	0	5	ND	<40.0	<100	ND	<75.0	<176
Benzo[*b*]fluoranthene	130	ng/gdw	0	3	ND	E6.2	<100	ND	E9.9	<176
Bis(2-ethylhexyl) phthalate	182	ng/gdw	0	3	ND	<130	9.3	ND	<257	62.4
Chrysene	82	ng/gdw	0	3	ND	<40.0	<100	ND	<75.0	<176
Phenanthrene	68	ng/gdw	0	3	ND	0.3	<100	ND	8.8	<176
Fluoranthene	113	ng/gdw	0	1	ND	0.5	0.1	ND	14.8	2.9
Perylene	74	ng/gdw	0	1	ND	0.6	<100	ND	29.4	4.3
Pyrene	125	ng/gdw	0	1	ND	0.3	0.1	ND	9.5	1.6
2,6-Dimethylnaphthalene	25	ng/gdw	0	0	ND	0.4	0.2	ND	16.9	2.7
Cadmium	380	ng/gdw	0	0	<0.1	ND	3.2	18	ND	84
Chromium	49,000	ng/gdw	0	0	2,040	ND	632	7,920	ND	13,020
Cobalt	10,000	ng/gdw	0	0	360	ND	104	1,260	ND	1,890
Copper	18,700	ng/gdw	0	0	300	ND	200	1,260	ND	2,310
Iron	22	wt%	0	0	0.102	ND	0.030	0.396	ND	0.672
Lead	30,000	ng/gdw	0	0	1,260	ND	552	3,780	ND	15,960
Manganese	260,000	ng/gdw	0	0	23,400	ND	1,920	64,800	ND	88,200
Mercury	130	ng/gdw	0	0	5.4	ND	0.72	5.4	ND	10.5
Nickel	15,000	ng/gdw	0	0	600	ND	264	2,520	ND	4,620
Selenium	1,000	ng/gdw	0	0	18	ND	10.4	72	ND	84
Silver	230	ng/gdw	0	0	<0.5	ND	<0.5	<0.5	ND	<0.5
Vanadium	57,000	ng/gdw	0	0	2,940	ND	960	10,800	ND	18,900
Zinc	94,000	ng/gdw	0	0	2,400	ND	880	9,000	ND	16,380

Table 11. Bed-sediment standards and guidelines and bulk-sediment concentrations of samples collected in Currituck Sound, 2011–13.—Continued

[NC, North Carolina; ng/gdw, nanograms per gram dry weight of bulk sediment (equals parts per billion); wt%, weight percent; ND, not determined; E, estimated; <, less than reporting level; >, greater than; --, no information]

Constituent	2.1 miles from the east bank of Currituck Sound near Corolla, NC			3.5 miles from the east bank of Currituck Sound near Corolla, NC			4.5 miles from the east bank of Currituck Sound near Corolla, NC		
	Nov. 15, 2011	July 18, 2012	July 24, 2013	Nov. 15, 2011	July 18, 2012	July 24, 2013	Nov. 15, 2011	July 18, 2012	July 24, 2013
Threshold exists									
Tin	1,060	ND	<0.1	120	ND	<0.1	280	ND	<0.1
Barium	174,900	ND	248,000	12,400	ND	27,300	40,600	ND	1,320
Aluminum	3.286	ND	3.348	0.244	ND	0.371	0.812	ND	0.017
Diethyl phthalate	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
1,2,4-Trichlorobenzene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
9*H*-Fluorene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
Acenaphthene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
Acenaphthylene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
Dibenzo[*a*,*h*]anthracene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
Hexachlorobenzene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
Anthracene	ND	1.4	2.1	ND	<42.5	1.3	ND	<330	0.1
Naphthalene	ND	2.4	<25.5	ND	0.6	<43.8	ND	<330	<159
1-Methylphenanthrene	ND	1.5	1.6	ND	0.2	0.8	ND	<330	0.1
Benzo[*a*]anthracene	ND	1.1	<25.5	ND	0.2	1.4	ND	<330	<159
Benzo[*a*]pyrene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
Benzo[*ghi*]perylene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
Benzo[*k*]fluoranthene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
Indeno[1,2,3-*cd*]pyrene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
Benzo[*b*]fluoranthene	ND	E6.4	<25.5	ND	E7.6	<43.8	ND	<330	<159
Bis(2-ethylhexyl) phthalate	ND	<125	79.4	ND	<230	62.6	ND	<1,100	14.2
Chrysene	ND	E5.7	<25.5	ND	<42.5	1.9	ND	<330	0.1
Phenanthrene	ND	2.3	<25.5	ND	0.5	4.0	ND	<330	0.5
Fluoranthene	ND	2.7	4.0	ND	1.1	6.4	ND	<330	0.4
Perylene	ND	14.2	23.4	ND	1.6	10.9	ND	27.1	0.5
Pyrene	ND	1.7	2.0	ND	0.6	3.7	ND	<330	0.3
2,6-Dimethylnaphthalene	ND	6.9	7.8	ND	0.8	3.0	ND	14.1	0.6
Cadmium	106	ND	248	8	ND	21	14	ND	1.2
Chromium	33,920	ND	35,340	2,360	ND	3,710	7,700	ND	188
Cobalt	5,300	ND	6,200	360	ND	630	1,120	ND	28
Copper	5,300	ND	6,200	480	ND	770	1,540	ND	116
Iron	1.802	ND	2.108	0.116	ND	0.196	0.378	ND	0.008
Lead	9,010	ND	9,920	1,240	ND	1,960	3,640	ND	840
Manganese	201,400	ND	248,000	13,600	ND	23,800	42,000	ND	960
Mercury	5.3	ND	18.6	0.8	ND	3.5	8.4	ND	0.36
Nickel	12,190	ND	14,260	800	ND	1,400	2,660	ND	84
Selenium	159	ND	186	28	ND	28	84	ND	2
Silver	<0.5	ND	<0.5	<0.5	ND	<0.5	<0.5	ND	<0.5
Vanadium	46,110	ND	49,600	3,280	ND	5,460	10,500	ND	232
Zinc	38,160	ND	43,400	2,760	ND	4,900	8,820	ND	560

Table 11. Bed-sediment standards and guidelines and bulk-sediment concentrations of samples collected in Currituck Sound, 2011–13.—Continued

[NC, North Carolina; ng/gdw, nanograms per gram dry weight of bulk sediment (equals parts per billion); wt%, weight percent; ND, not determined; E, estimated; <, less than reporting level; >, greater than; --, no information]

Constituent	Standard[1]	Unit	Number greater than the standard	Number of samples where the reporting level exceeded the standard	0.25 miles from the east bank of Currituck Sound near Corolla, NC			1.2 miles from the east bank of Currituck Sound near Corolla, NC		
					Nov. 15, 2011	July 18, 2012	July 24, 2013	Nov. 15, 2011	July 18, 2012	July 24, 2013
No threshold										
1,2-Dimethylnaphthalene	--	ng/gdw	--	--	ND	<40.0	<100	ND	<75.0	<176
1,6-Dimethylnaphthalene	--	ng/gdw	--	--	ND	<40.0	<100	ND	<75.0	<176
1-Methyl-9*H*-fluorene	--	ng/gdw	--	--	ND	<40.0	<100	ND	<75.0	<176
1-Methylpyrene	--	ng/gdw	--	--	ND	<40.0	<100	ND	<75.0	<176
2,3,6-Trimethylnaphthalene	--	ng/gdw	--	--	ND	<40.0	<100	ND	<75.0	<176
2-Ethylnaphthalene	--	ng/gdw	--	--	ND	<40.0	<100	ND	<75.0	<176
2-Methylanthracene	--	ng/gdw	--	--	ND	<40.0	<100	ND	<75.0	<176
4*H*-Cyclopenta[*def*] phenanthrene	--	ng/gdw	--	--	ND	<40.0	<100	ND	<75.0	<176
9,10-Anthraquinone	--	ng/gdw	--	--	ND	0.3	<100	ND	15.8	<176
Antimony	--	ng/gdw	--	--	36	ND	4.8	72	ND	84
Arsenic	--	ng/gdw	--	--	246	ND	60.8	954	ND	1,260
Benzo[*e*]pyrene	--	ng/gdw	--	--	ND	<40.0	<100	ND	<75.0	<176
Beryllium	--	ng/gdw	--	--	72	ND	15.2	252	ND	357
Calcium	--	ng/gdw	--	--	660,000	ND	40,000	1,620,000	ND	1,680,000
Carbazole	--	ng/gdw	--	--	<40.0	ND	<100	<75.0	ND	<176
Carbon, total	--	ng/gdw	--	--	960,000	ND	560,000	4,140,000	ND	3,570,000
Carbon, total organic	--	ng/gdw	--	--	840,000	ND	552,000	3,780,000	ND	5,460,000
Dibenzothiophene	--	ng/gdw	--	--	ND	<40.0	<100	ND	<75.0	<176
Lithium	--	ng/gdw	--	--	1,320	ND	576	5,760	ND	11,340
Magnesium	--	ng/gdw	--	--	360,000	ND	72,000	1,080,000	ND	1,680,000
Molybdenum	--	ng/gdw	--	--	60	ND	48	180	ND	420
Nitrogen, total	--	ng/gdw	--	--	132,000	ND	88,000	450,000	ND	693,000
Pentachloroanisole	--	ng/gdw	--	--	ND	<40.0	<100	ND	<75.0	<176
Pentachloronitrobenzene	--	ng/gdw	--	--	ND	<40.0	<100	ND	<75.0	<176
Phenanthridine	--	ng/gdw	--	--	ND	<40.0	<100	ND	<75.0	<176
Phosphorus	--	ng/gdw	--	--	49,200	ND	8,000	122,400	ND	174,300
Potassium	--	ng/gdw	--	--	960,000	ND	144,000	3,060,000	ND	3,780,000
Sodium	--	ng/gdw	--	--	1,080,000	ND	40,000	2,700,000	ND	2,100,000
Strontium	--	ng/gdw	--	--	10,200	ND	960	28,800	ND	31,500
Sulfur. Total	--	ng/gdw	--	--	216,000	ND	136,000	1,350,000	ND	2,100,000
Thallium	--	ng/gdw	--	--	<50	ND	<50	<50	ND	<50
Titanium	--	ng/gdw	--	--	378,000	ND	38,400	1,008,000	ND	1,428,000
Uranium	--	ng/gdw	--	--	<50	ND	<50	<50	ND	<50

[1] Standards from Buchman (2008).

Table 11. Bed-sediment standards and guidelines and bulk-sediment concentrations of samples collected in Currituck Sound, 2011–13.—Continued

[NC, North Carolina; ng/gdw, nanograms per gram dry weight of bulk sediment (equals parts per billion); wt%, weight percent; ND, not determined; E, estimated; <, less than reporting level; >, greater than; --, no information]

Constituent	2.1 miles from the east bank of Currituck Sound near Corolla, NC			3.5 miles from the east bank of Currituck Sound near Corolla, NC			4.5 miles from the east bank of Currituck Sound near Corolla, NC		
	Nov. 15, 2011	July 18, 2012	July 24, 2013	Nov. 15, 2011	July 18, 2012	July 24, 2013	Nov. 15, 2011	July 18, 2012	July 24, 2013
No threshold									
1,2-Dimethylnaphthalene	ND	E2.8	<25.5	ND	<42.5	<43.8	ND	<330	<159
1,6-Dimethylnaphthalene	ND	1.8	<25.5	ND	<42.5	<43.8	ND	<330	<159
1-Methyl-9*H*-fluorene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
1-Methylpyrene	ND	0.8	<25.5	ND	<42.5	<43.8	ND	<330	<159
2,3,6-Trimethylnaphthalene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
2-Ethylnaphthalene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
2-Methylanthracene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
4*H*-Cyclopenta[*def*]phenanthrene	ND	0.8	<25.5	ND	<42.5	0.5	ND	<330	<159
9,10-Anthraquinone	ND	3.4	6.7	ND	0.7	<43.8	ND	<330	<159
Antimony	212	ND	310	20	ND	28	56	ND	2.8
Arsenic	5,300	ND	5,766	316	ND	315	980	ND	13.2
Benzo[*e*]pyrene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
Beryllium	954	ND	992	64	ND	105	210	ND	4.8
Calcium	4,770,000	ND	5,580,000	280,000	ND	560,000	840,000	ND	32,000
Carbazole	<35.0	ND	<25.5	<42.5	ND	<43.8	<330	ND	<159
Carbon, total	6,360,000	ND	6,820,000	1,480,000	ND	1,680,000	4,340,000	ND	152,000
Carbon, total organic	5,830,000	ND	6,200,000	1,320,000	ND	1,540,000	4,480,000	ND	172,000
Dibenzothiophene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
Lithium	24,910	ND	28,520	1,920	ND	3,150	6,440	ND	148
Magnesium	5,300,000	ND	5,580,000	320,000	ND	490,000	980,000	ND	28,000
Molybdenum	1,060	ND	1,860	80	ND	140	280	ND	8
Nitrogen, total	530,000	ND	930,000	172,000	ND	189,000	546,000	ND	21,200
Pentachloroanisole	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
Pentachloronitrobenzene	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
Phenanthridine	ND	<35.0	<25.5	ND	<42.5	<43.8	ND	<330	<159
Phosphorus	286,200	ND	341,000	26,800	ND	49,000	79,800	ND	2,920
Potassium	11,130,000	ND	12,400,000	720,000	ND	1,190,000	2,520,000	ND	60,000
Sodium	5,830,000	ND	6,820,000	720,000	ND	700,000	2,100,000	ND	92,000
Strontium	74,200	ND	93,000	5,200	ND	11,200	18,200	ND	600
Sulfur. Total	7,950,000	ND	9,300,000	480,000	ND	644,000	1,680,000	ND	30,400
Thallium	<50	ND	<50	<50	ND	<50	<50	ND	<50
Titanium	2,862,000	ND	3,348,000	212,000	ND	406,000	714,000	ND	17,200
Uranium	<50	ND	<50	<50	ND	<50	<50	ND	<50

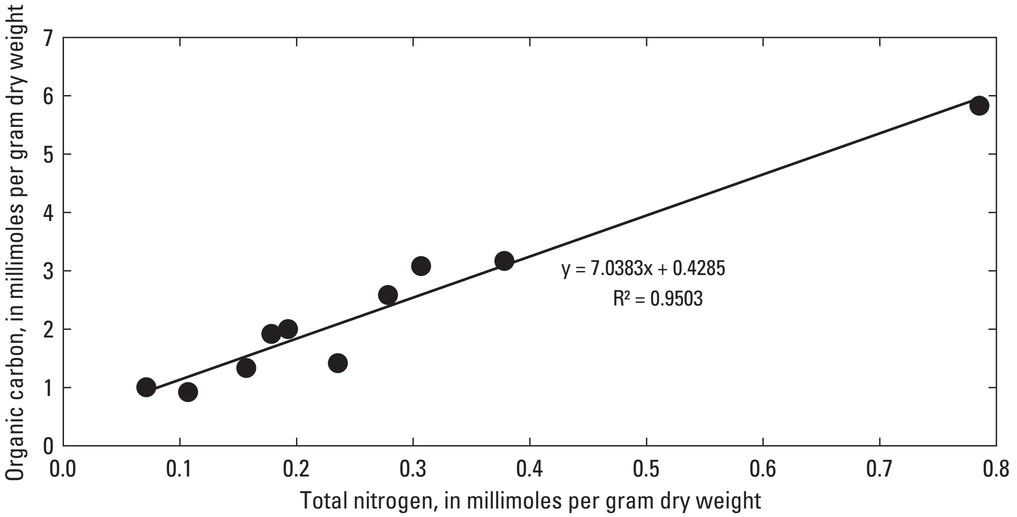

Figure 8. Molar ratio of organic carbon to total nitrogen in surficial bed sediments collected at five sampling sites in Currituck Sound, North Carolina, 2011-13.

Summary

The North Carolina Turnpike Authority, a division of the North Carolina Department of Transportation, is planning to make transportation improvements in the Currituck Sound area by constructing a two-lane bridge from U.S. Highway 158 just south of Coinjock, North Carolina, to State Highway 12 on the Outer Banks just south of Corolla, N.C. The results of the Final Environmental Impact Statement associated with the bridge and existing roadway improvements indicated potential water-quality and habitat impacts to Currituck Sound related to stormwater runoff, altered light levels, introduction of piles as hard substrate, and localized turbidity and siltation during construction.

There is evidence that bridge deck runoff has a relatively high loading of a variety of constituents, such as nutrients, solids, pesticides, metals, and polycyclic aromatic hydrocarbons. These substances have the potential to adversely affect aquatic life by directly or indirectly interfering with various biological processes and cycles; however, the actual impacts of stormwater runoff from bridges are highly site specific. Constituents in stormwater runoff or from a hazardous spill incident discharged into Currituck Sound could dissipate slowly because of limited water circulation and may result in bioaccumulation and higher sediment contamination levels than in receiving waters having better circulation and higher flow rates.

The primary objective of this initial study phase was to document water-quality conditions and bed-sediment chemistry of Currituck Sound in the vicinity of the planned alignment of the Mid-Currituck Bridge, which will be used to evaluate the impacts associated with the bridge construction and bridge deck stormwater runoff. Discrete water-quality samples were collected monthly and following selected storm events, during the period of 2011 to 2015, from five locations in Currituck Sound distributed along the proposed alignment of the Mid-Currituck Bridge. Samples were analyzed for water-quality physical properties and constituents associated with bridge deck stormwater runoff and important to waters designated as “SC” (saltwater–aquatic life propagation/protection and secondary recreation) under North Carolina’s water-quality classifications. Bed-sediment chemistry was also measured three times during the study at the five discrete water-quality sampling locations. Continuous water-level and wind speed and direction data in Currituck Sound were also collected by the U.S. Geological Survey during the water-quality sampling period. The circulation dynamics of the sound in the vicinity of the planned bridge were measured for each sampling event using an acoustic Doppler current profiler. The acoustic Doppler current profiler velocity data can be used to characterize and compare the circulation dynamics and how they relate to water quality in the vicinity of the bridge at the time of each sampling event before and after bridge construction.

Bias and precision of constituent concentrations were assessed through various quality-control samples. For water samples, quality-control samples included 18 field and equipment blanks, 1 semi-volatile organic compound (SVOC) spike sample, 18 sets of field replicates, and for the two bacteria species, 172 sets of analytical duplicates. Constituents in water were detected in only 6 percent of all 666 analyses of the 18 blanks and generally at low levels that probably did not compromise data analysis. Considering both the frequency of constituent detections in blanks and their magnitude relative to the concentrations determined in the environmental samples, only three constituents were deemed likely to have a positive bias, namely dissolved ammonia and both dissolved and total recoverable zinc. Recovery of 14 SVOCs in a water matrix spike were somewhat low, having a median of 42 percent and a range of 30 to 102 percent. The relative percent difference (RPD) of most constituents in replicate water sample sets was less than about 25 percent, which was considered acceptable. Of the 6 percent of replicate sets in which constituent concentrations had RPDs greater than 25 percent, only 17 sets (2 percent of 807 total replicate sets) had absolute concentration differences greater than three times the respective reporting levels. Included in these 17 constituent replicate sets with high relative and absolute variability were dissolved manganese (5 sets) and total recoverable aluminum (3 sets).

For bed-sediment samples, quality-control samples for SVOCs included a matrix spike. Median recovery of individual SVOCs was 58 percent, and the range of recoveries was 19 to 75 percent. For the inorganics, quality-control samples included concurrent analysis of materials with known constituent concentrations, 2 field replicates, 1 laboratory split replicate, and 2 analytical duplicates. The overall median recovery of the median recoveries of inorganic constituents in 11 materials having known constituent concentrations was 101 percent, and overall recoveries ranged from 92 to 116 percent. The RPDs for most inorganic constituents were less than 25 percent, and the overall variability was largely associated with the field sampling step as opposed to the handling and analytical steps. Only two constituents, phosphorus and manganese, had RPDs greater than 25 percent and relatively large absolute concentration differences, indicating a variability that should be considered when interpreting the data.

For the samples collected from 2011 to 2015, concentrations were greater than water-quality thresholds for physical parameters/constituents on 52 occasions and 190 additional censored results had a reporting level higher than specific thresholds. All 52 occurrences of concentrations greater than water-quality thresholds were limited to only seven physical properties or constituents, namely pH (25), turbidity (8), total recoverable chromium (6), total recoverable copper (6), dissolved copper (3), total recoverable mercury (2), and total recoverable nickel (2). Concentrations of 17 other constituents were never measured to be greater than their established water-quality thresholds during the study.

The focus of the water-quality characterization was on physical properties and concentrations of constituents that were identified as parameters of concern in a 2011 collaborative U.S. Geological Survey/North Carolina Department of Transportation study. That investigation characterized bridge deck stormwater runoff across North Carolina in terms of (1) selected physical properties and constituents, such as pH, nutrients, total recoverable and dissolved metals, and polycyclic aromatic hydrocarbons, and (2) some additional pertinent physical parameters, namely dissolved oxygen, specific conductance, and turbidity. Analysis of the data separated by station, top and bottom sample location (if water was stratified or depths were greater than 6.5 feet), and by hydrologic condition (monthly and storms) revealed that the water sampled along the proposed bridge alignment transect was well-mixed horizontally and vertically during storm and non-storm conditions. Statistical differences were identified between monthly and storm samples for pH, dissolved oxygen, specific conductance, turbidity, *Escherichia coli* bacteria, total recoverable aluminum, and total recoverable iron.

An analysis of seasonal variability in water-quality conditions was conducted. Physical properties and constituents that tended to have maximum values in summer, or at least during the warmer months, and minimum values in colder months included pH, specific conductance, and total recoverable manganese and arsenic. Constituents having maximum values in colder months and minimum values in warmer months included dissolved oxygen, turbidity, total phosphorus, and total recoverable aluminum, iron, and lead. Total nitrogen concentrations followed a unique pattern in that they tended to be the lowest in late spring and rapidly increased to maximum values in late summer-early fall. Constituents that did not show a consistent seasonal signature from year to year during the study period include suspended solids, both bacterial groups, and total recoverable nickel. Many of the physical properties and constituents (including pH, specific conductance, dissolved oxygen, turbidity, nitrogen, phosphorus, aluminum, arsenic, iron, lead, and manganese) exhibited persistent seasonality over the period of baseline data collection. The volume and residence time of the water in Currituck Sound are such that the water chemistry is relatively uniform spatially but variable temporally.

Given that the most appreciable changes in water quality were hypothesized to most likely occur during wind events, summary statistics (median, mean, and standard deviation) of wind speed and direction data were compiled for the 24- and 72-hour periods prior to water-quality sampling, which can be used to correlate with water-quality conditions. The wind speed and direction data were compiled from three meteorological stations in the vicinity of the proposed bridge crossing of Currituck Sound. The wind speed and direction data corresponding to the sampling events for which the seasonal maximum (and minimum for pH and dissolved oxygen) occurred were reviewed for possible correlation. The wind speed and direction data indicated that there was no statistical difference between the medians of the antecedent wind speed and direction for all the sampling events and those with four or more occurrences of the maximum and (or) minimum (for pH and dissolved oxygen) seasonal concentrations. This may indicate that although wind speed and direction have a nearly immediate and large impact on the circulation patterns and water levels in Currituck Sound, changes in water-quality occur over longer periods of time (that is, seasonally) and have a much less immediate response to wind speed and direction.

Concentrations of inorganic constituents in bed sediments did not vary appreciably either spatially among the five sites along the sampling transect or temporally between 2011 and 2013 at each site. Elements associated with clay mineral lattices or oxyhydroxide coating were most abundant and included aluminum, iron, potassium, sodium, calcium, magnesium, and titanium. Virtually all the total carbon was total organic carbon and therefore associated with organic matter in the bed sediment. Carbon, sulfur, and nitrogen were abundant and probably reflected the organic matter present in the bed sediments. Among the SVOCs analyzed in bed sediments in 2012 and 2013, four compounds were most commonly found, namely 2,6-dimethylnaphthalene, perylene, fluoranthene, and pyrene. Bis(2-ethylhexyl)phthalate was found at all five sites in 2013 but not at any site in 2012, although analytical constraints cannot be ruled out to explain this difference in occurrence between consecutive years. The fraction of fines was quite variable spatially and temporally. The fines are associated with the largest fraction of surface area available to sorb trace elements and organic compounds. Bridge construction, if it alters transport, deposition, and residence time of the fines, might be expected to alter bulk-sediment constituent concentrations in the vicinity of the bridge alignment.

Only four constituents had concentrations greater than their respective bed-sediment threshold: tin (5 instances), barium (4 instances), aluminum (2 instances), and diethyl phthalate (1 instance). Twenty-two SVOCs had reporting levels that were higher than the respective bed-sediment quality threshold. Thus, total exceedances might have been underestimated. Finally, the molar ratio of organic carbon to nitrogen was consistent with a relatively undegraded phytoplankton source. Overall, sedimentation in Currituck Sound near the proposed bridge site is characterized by variable and transient sediment input, frequent resuspension, and minimal long-term deposition of fines.

The characterization of baseline water-quality and bed-sediment chemistry in Currituck Sound along the proposed alignment of the Mid-Currituck Bridge summarized herein provides a baseline to which comparisons can be made to determine if and (or) to what extent the construction and bridge deck runoff from the competed bridge will affect environmental conditions in Currituck Sound.

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Appendix 3. Depth-Averaged Velocity and Water-Quality Conditions in the Vicinity of the Proposed Mid-Currituck Bridge in Currituck Sound for Selected Dates

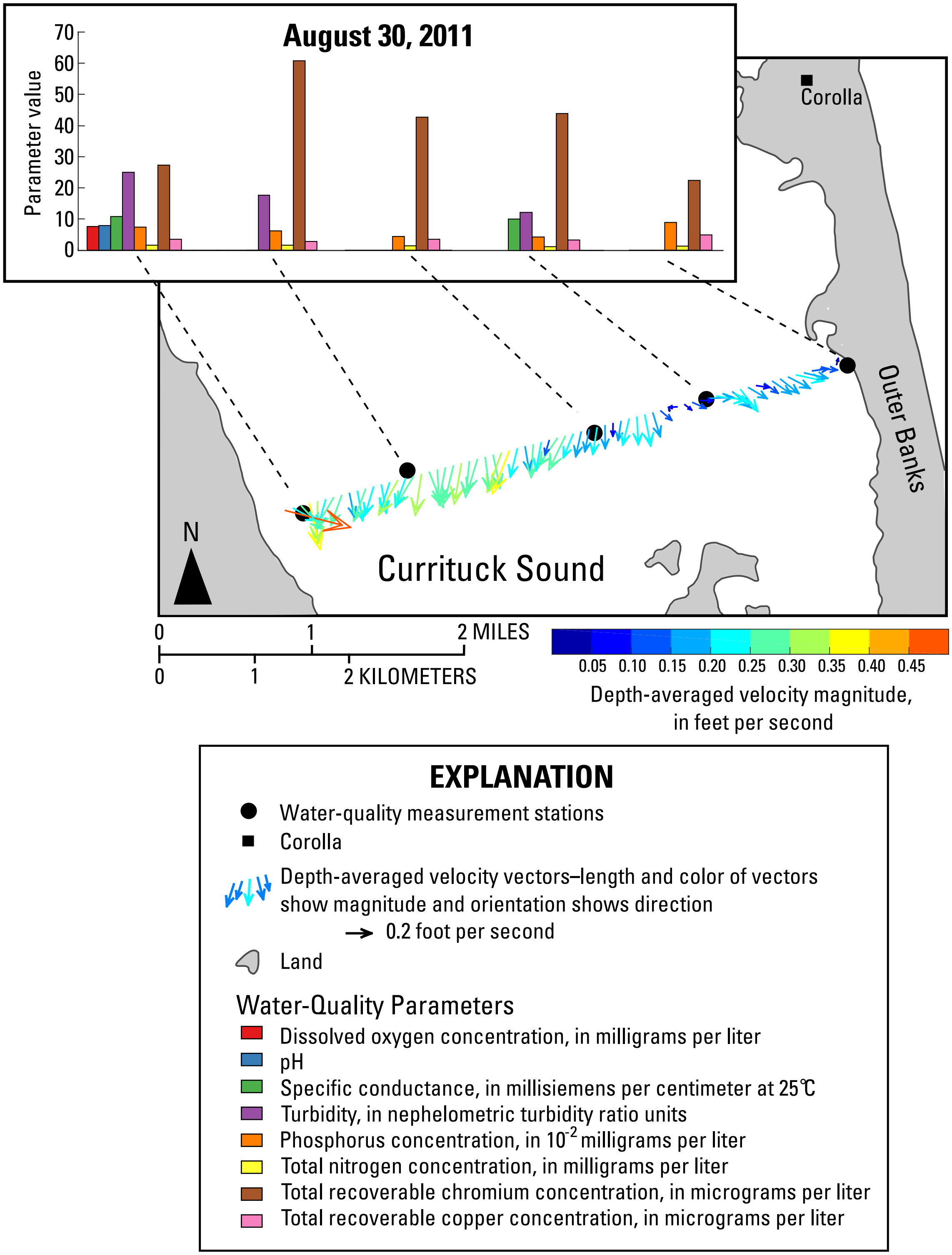

Figure 3-1. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, August 30, 2011.

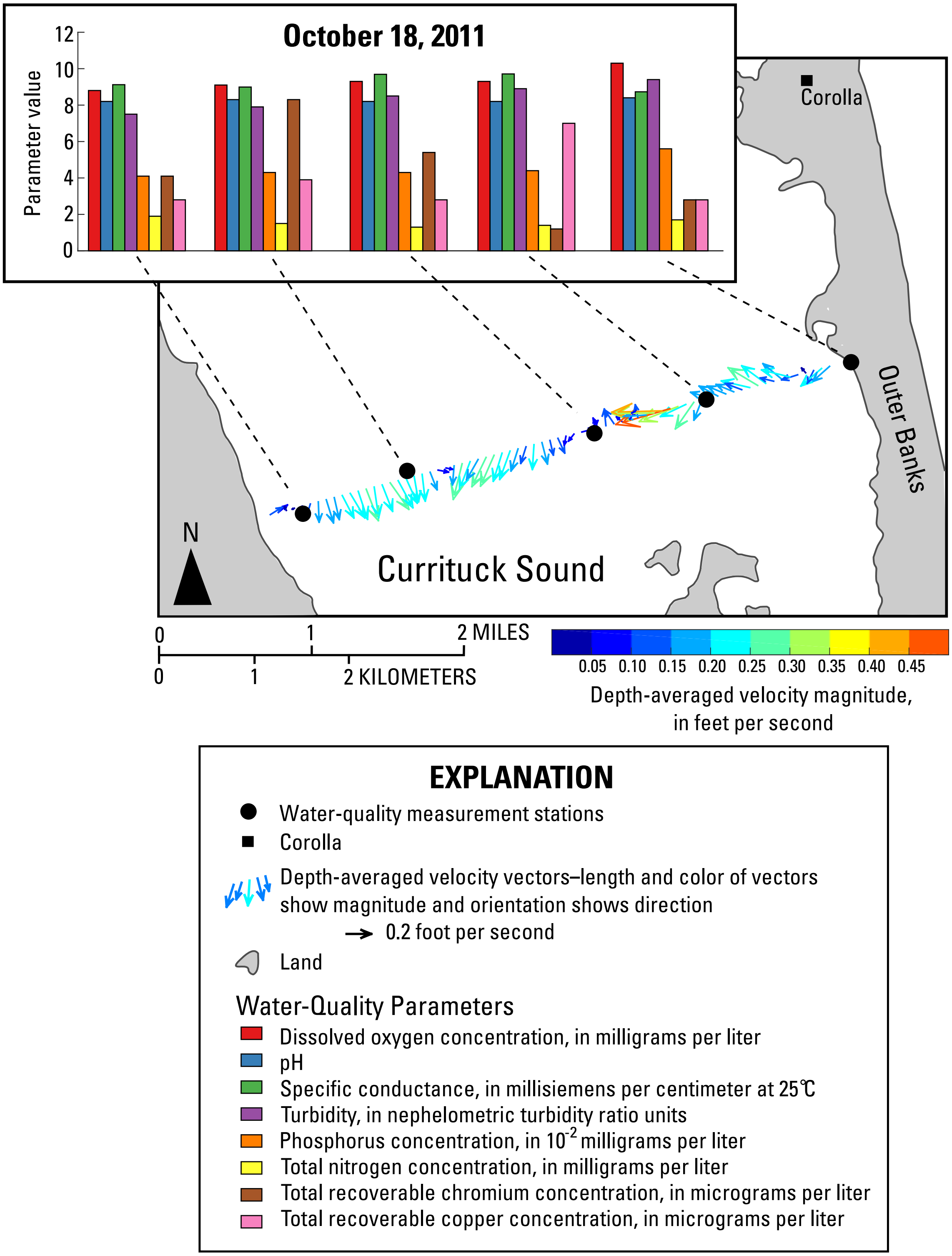

Figure 3-2. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, October 18, 2011.

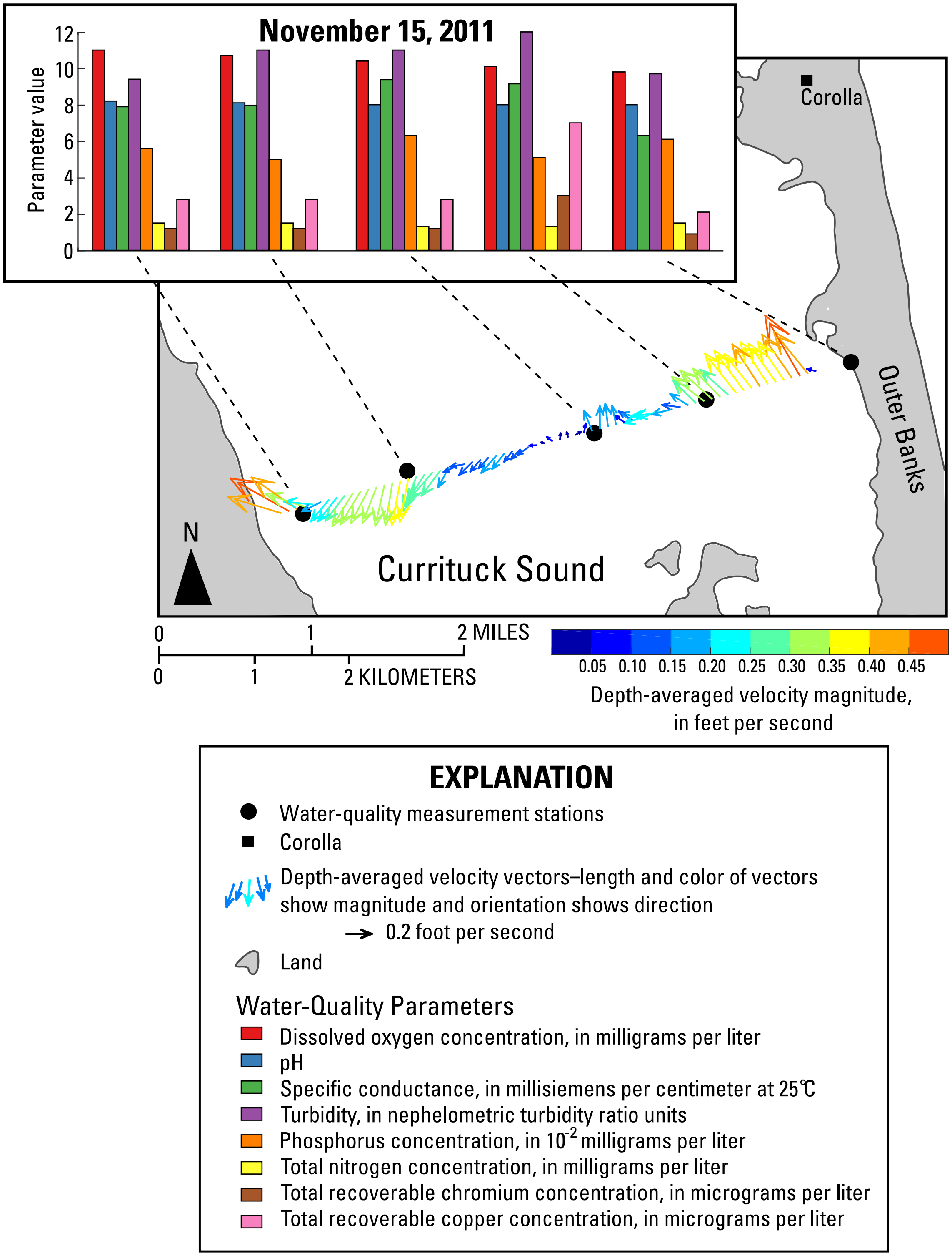

Figure 3-3. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, November 15, 2011.

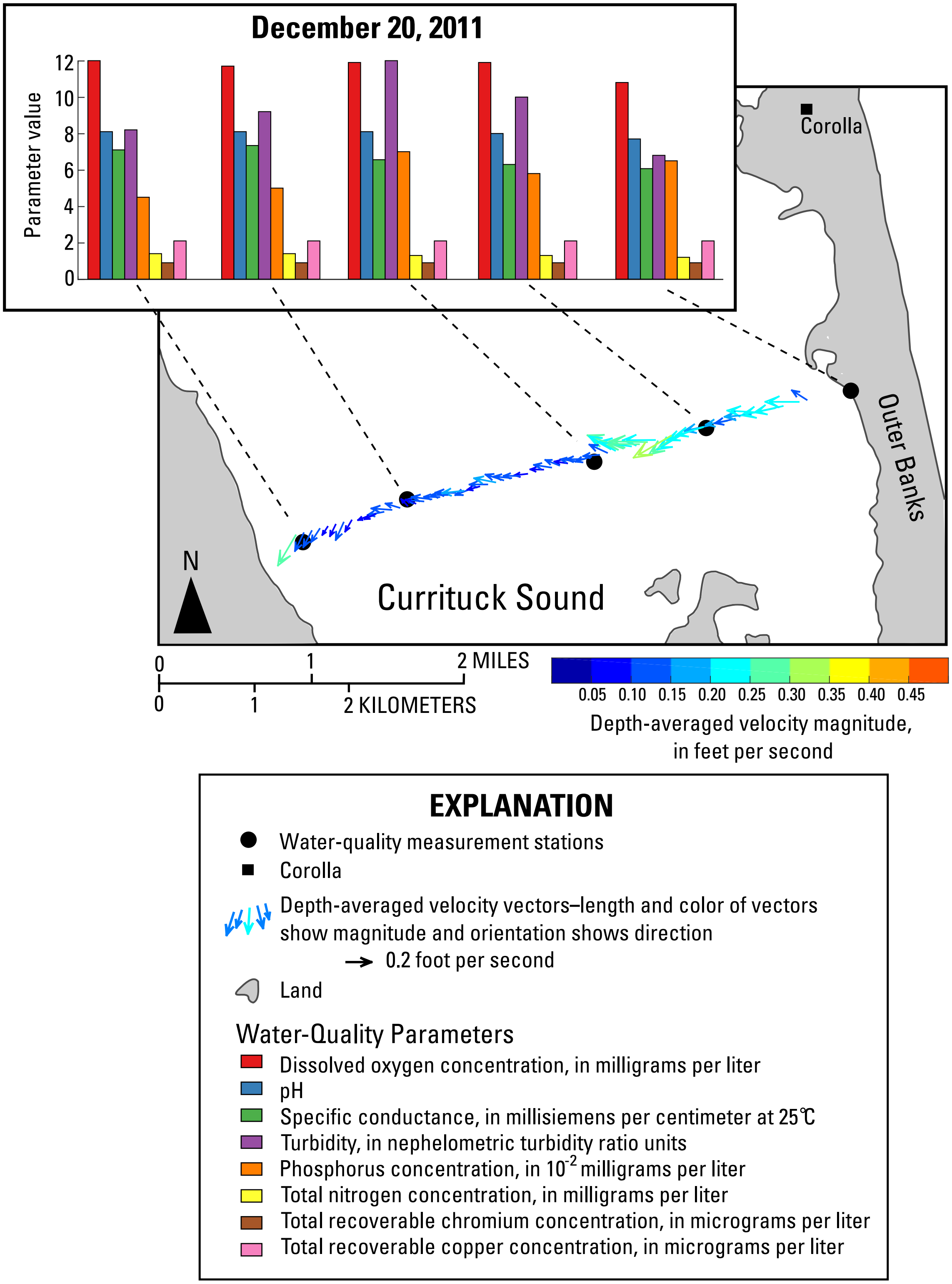

Figure 3-4. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, December 20, 2011.

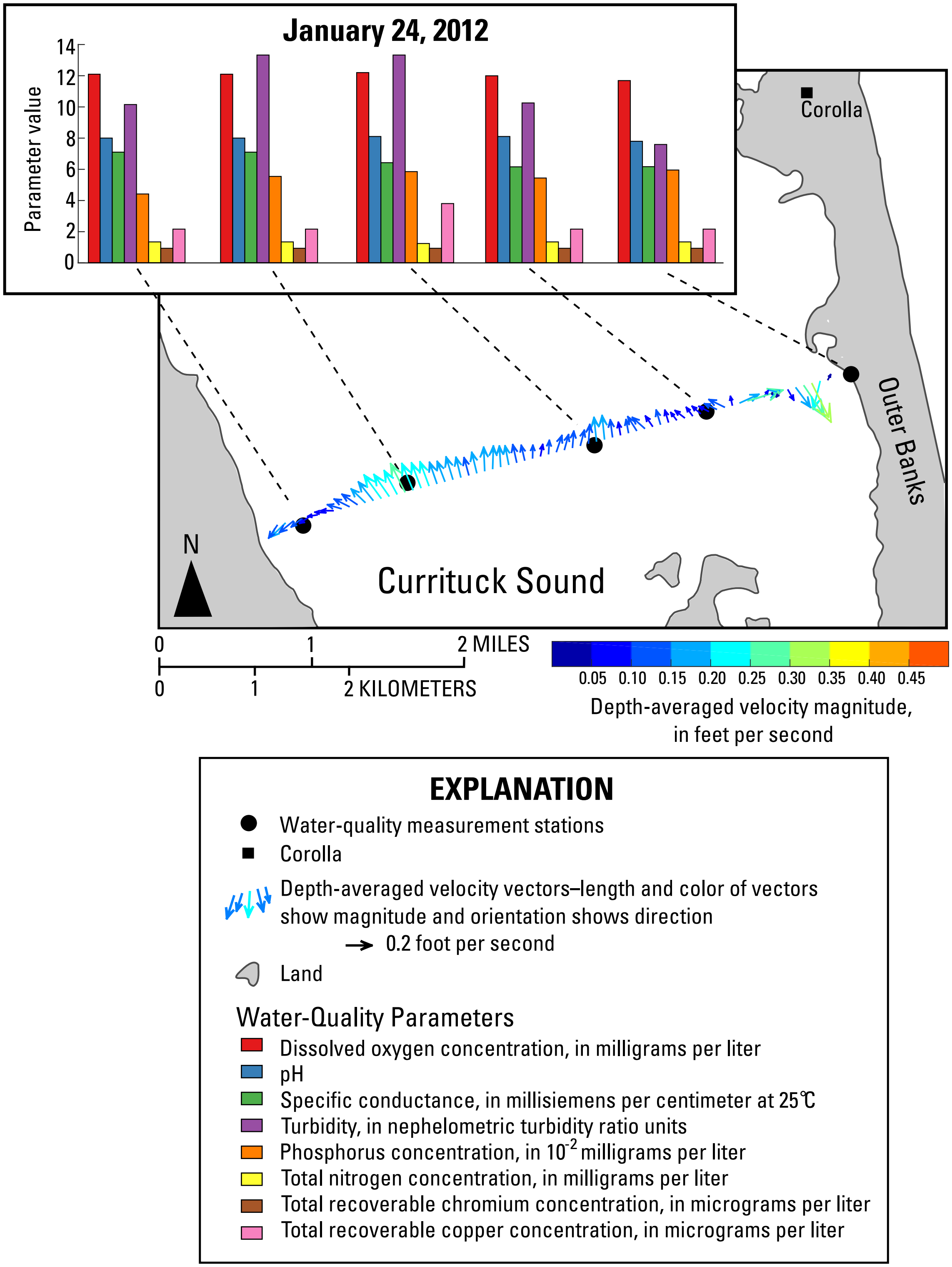

Figure 3-5. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, January 24, 2012.

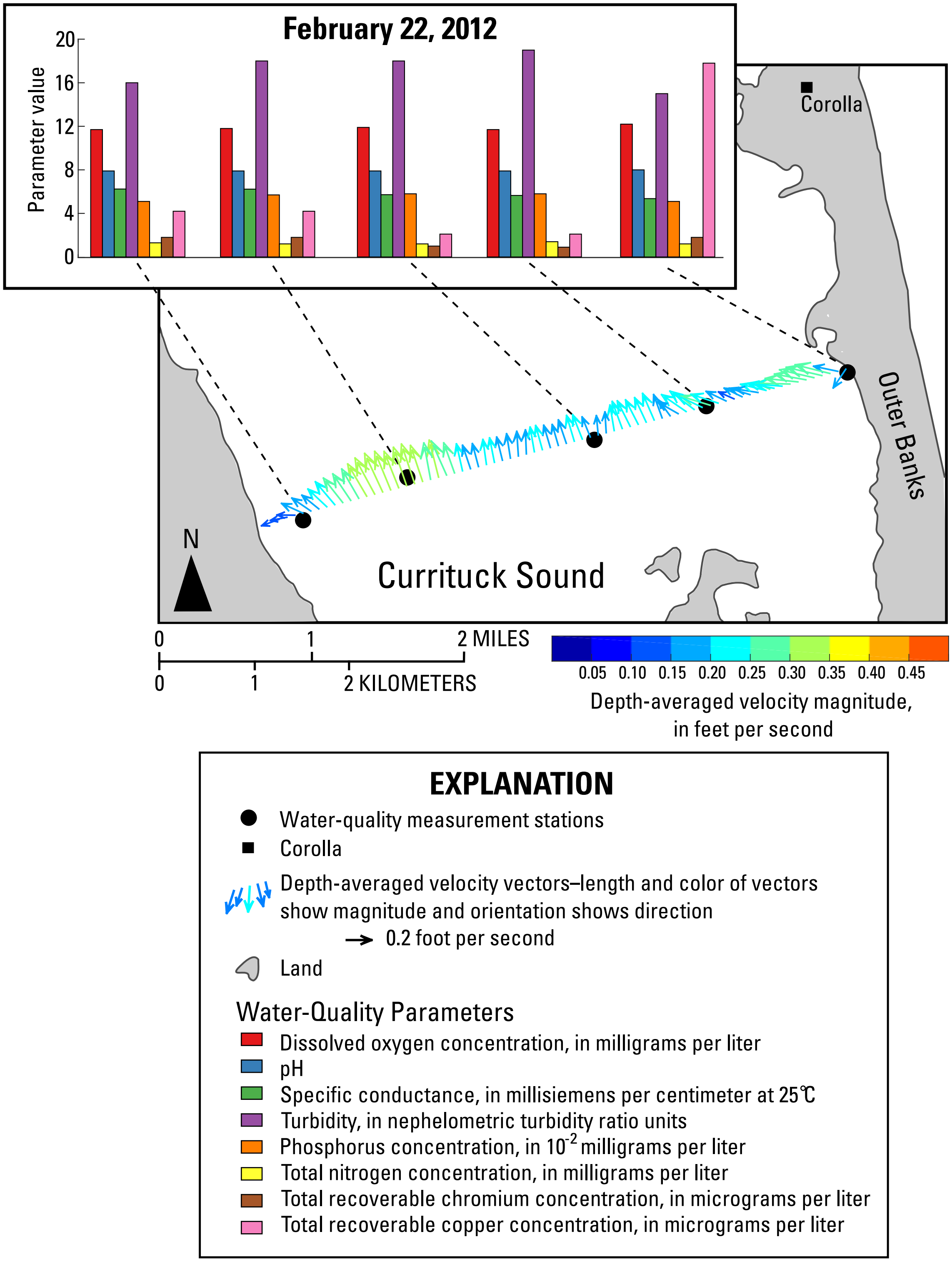

Figure 3-6. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, February 22, 2012.

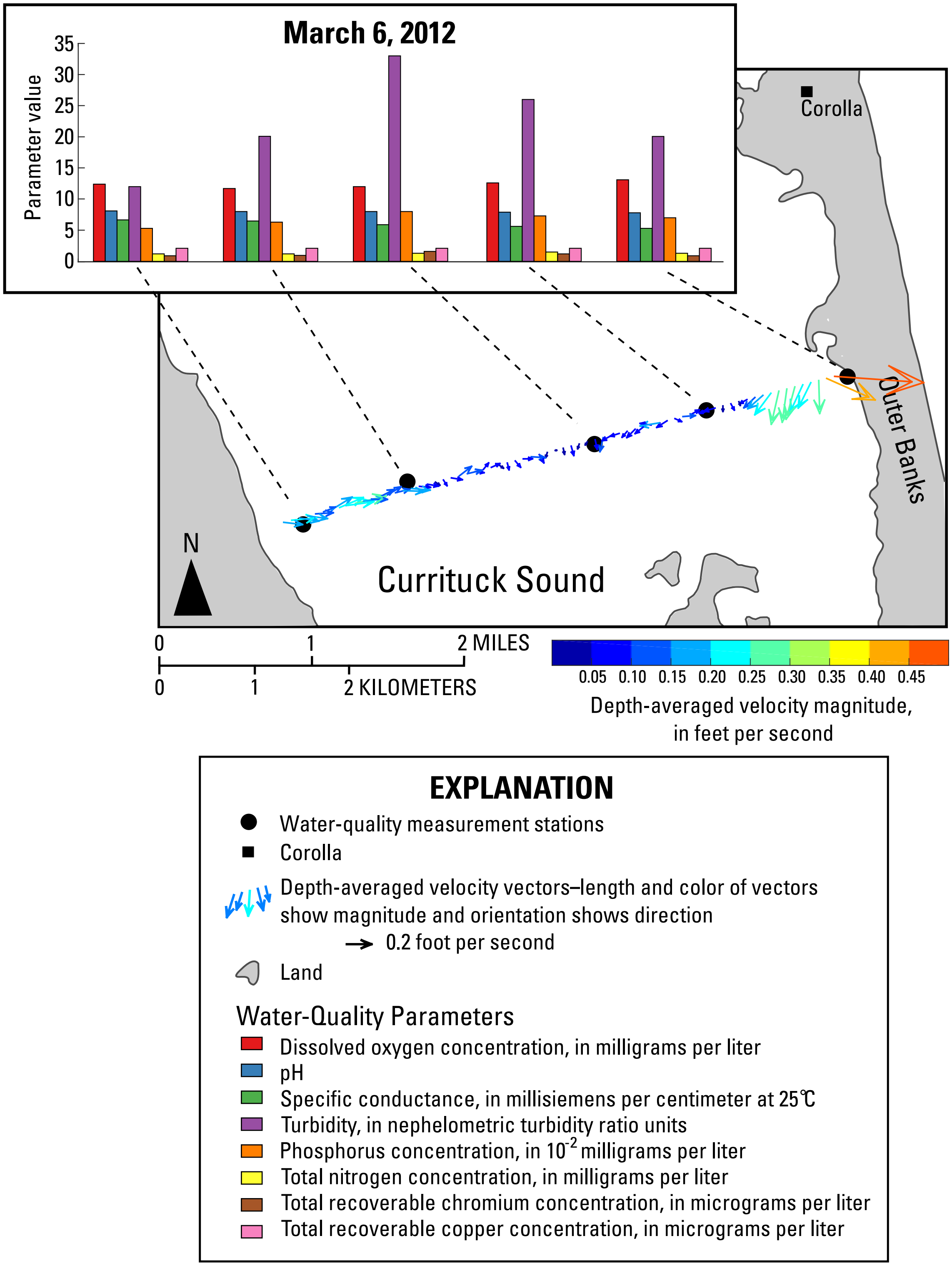

Figure 3-7. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, March 6, 2012.

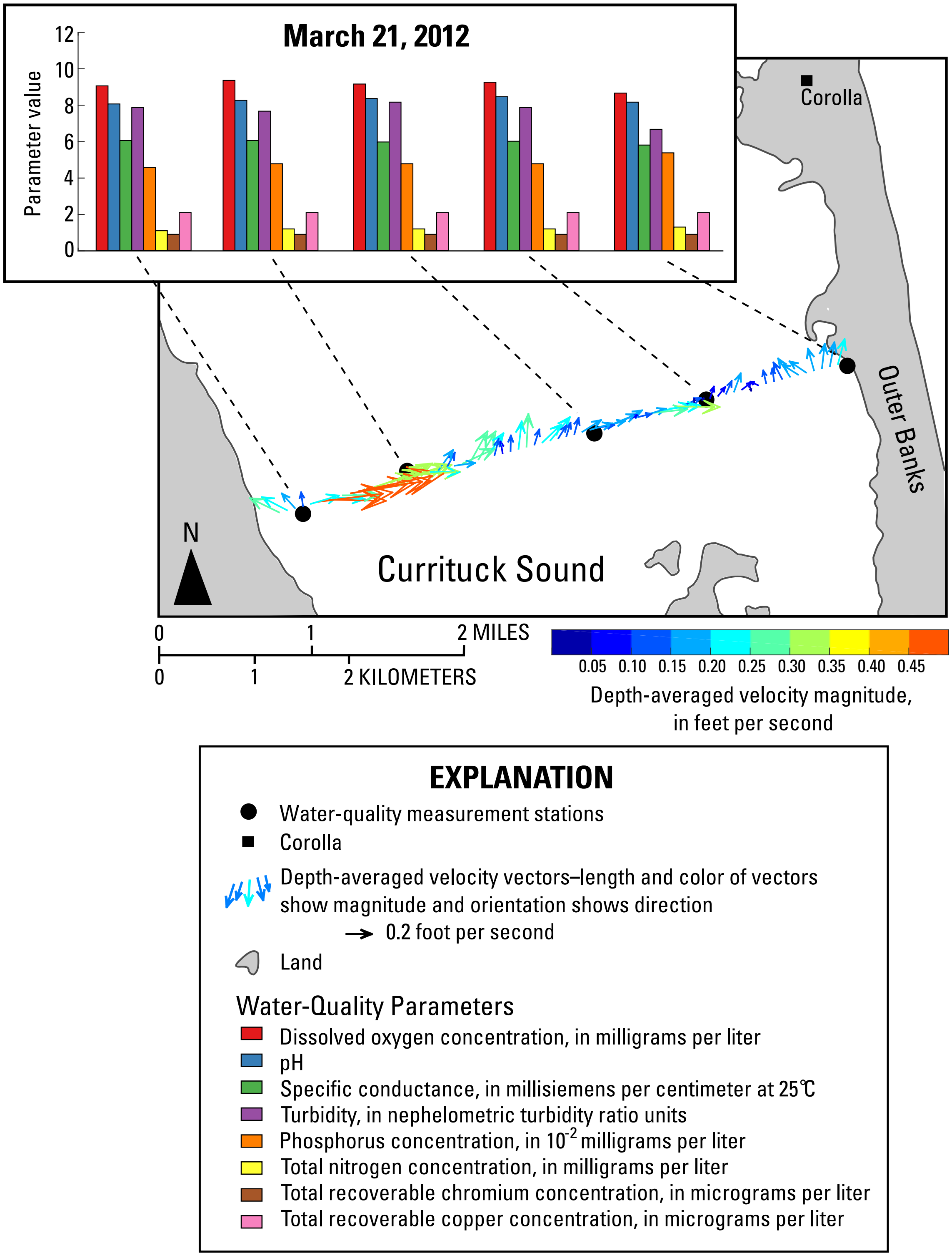

Figure 3-8. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, March 21, 2012.

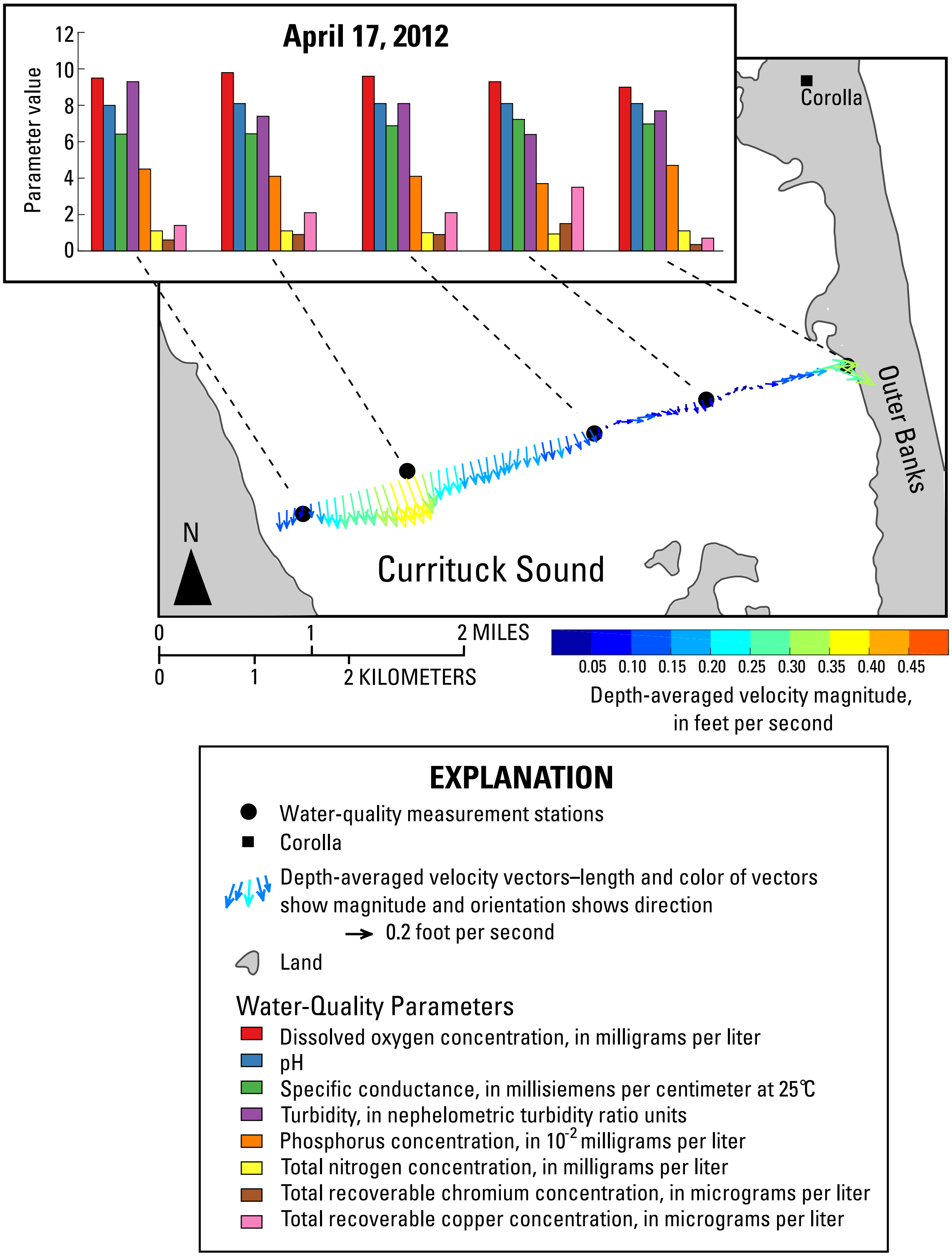

Figure 3-9. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, April 17, 2012.

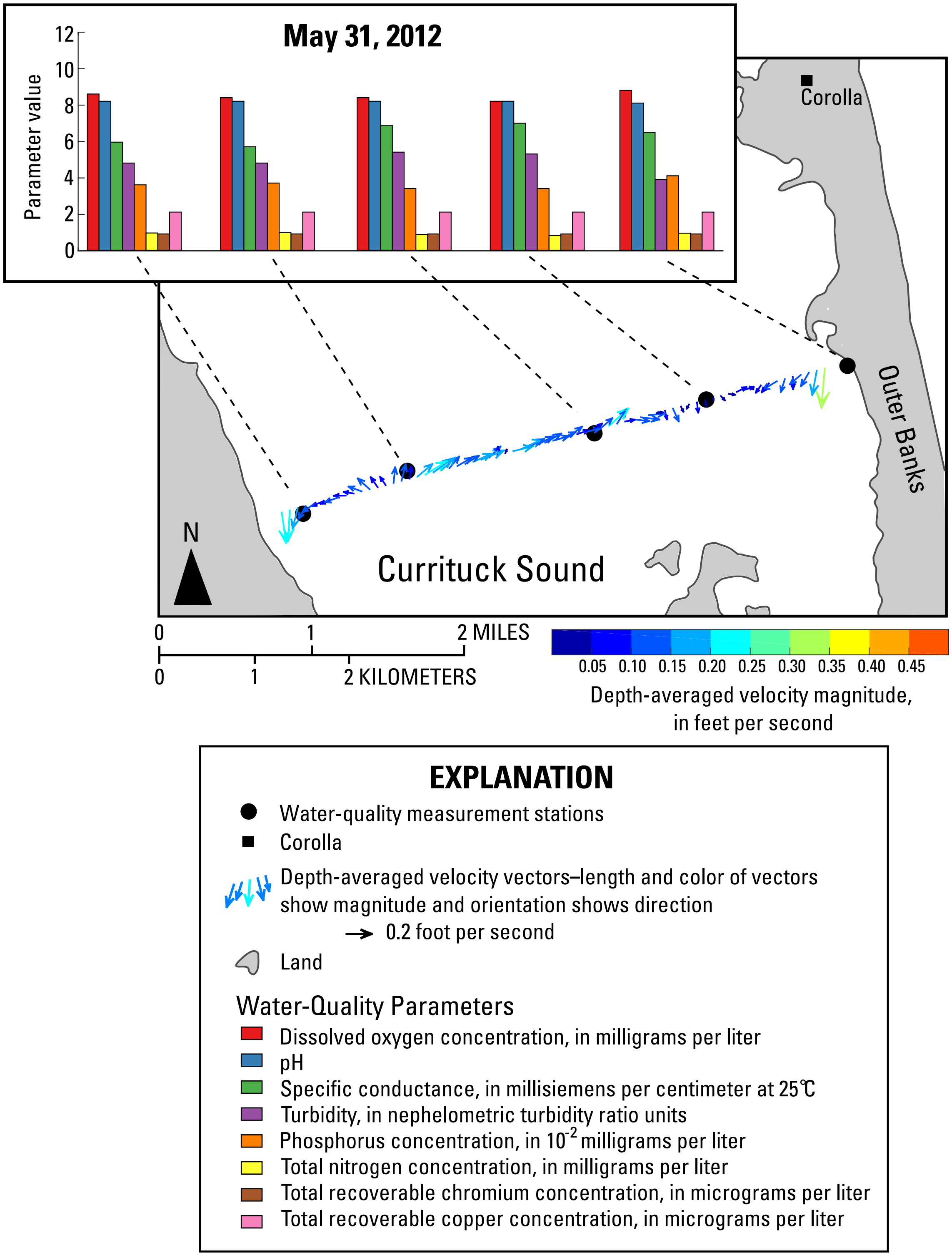

Figure 3-10. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, May 31, 2012.

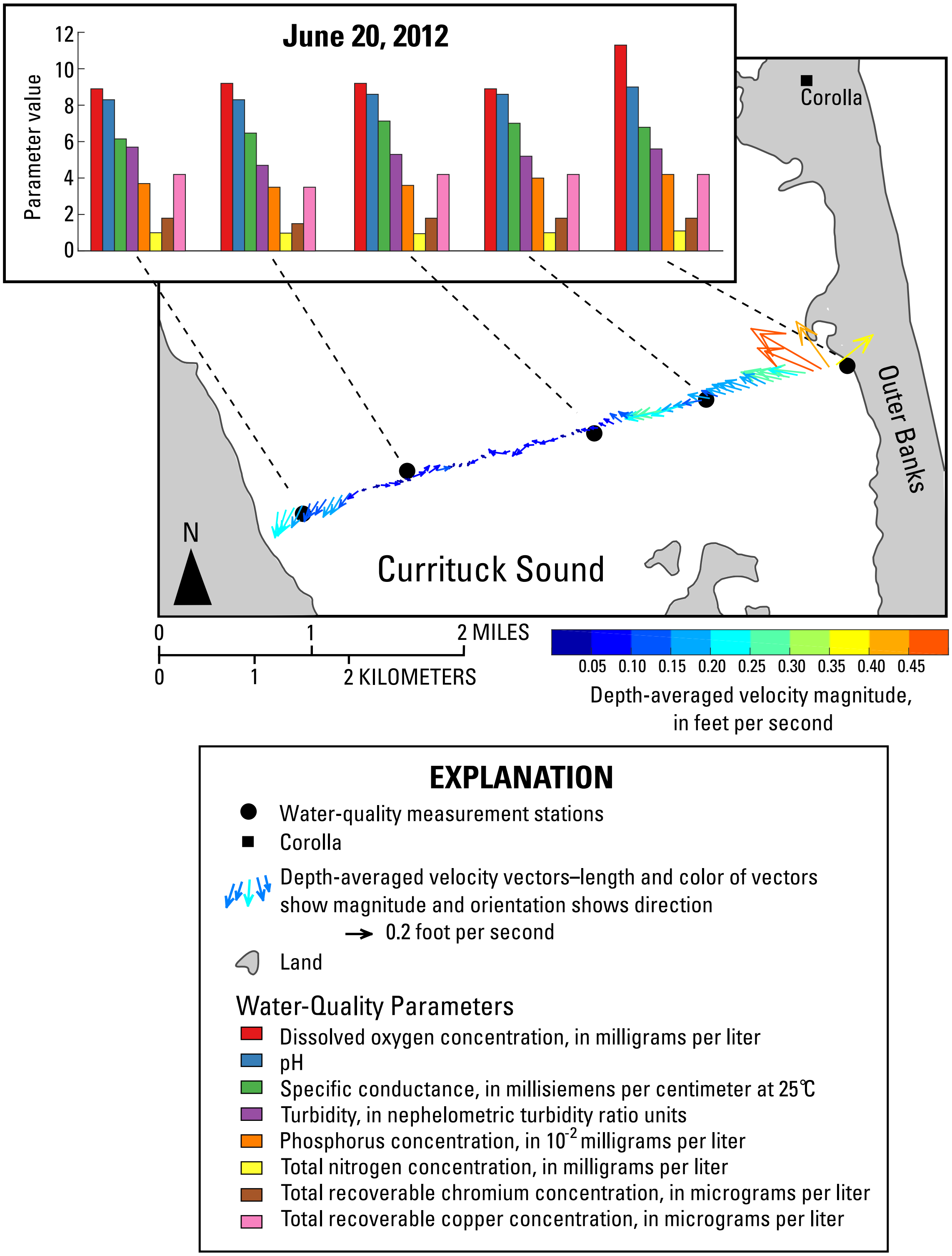

Figure 3-11. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, June 20, 2012.

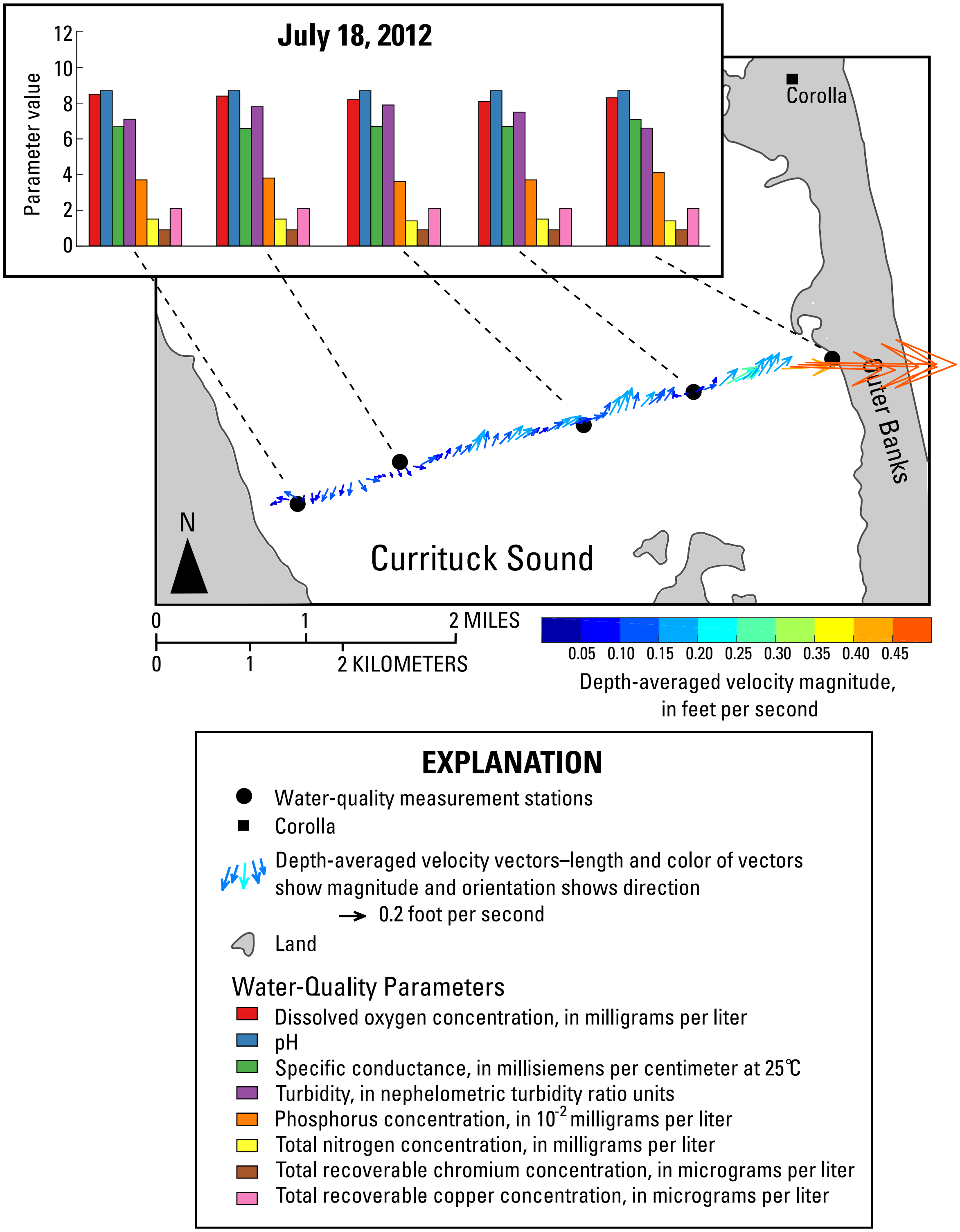

Figure 3-12. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, July 18, 2012.

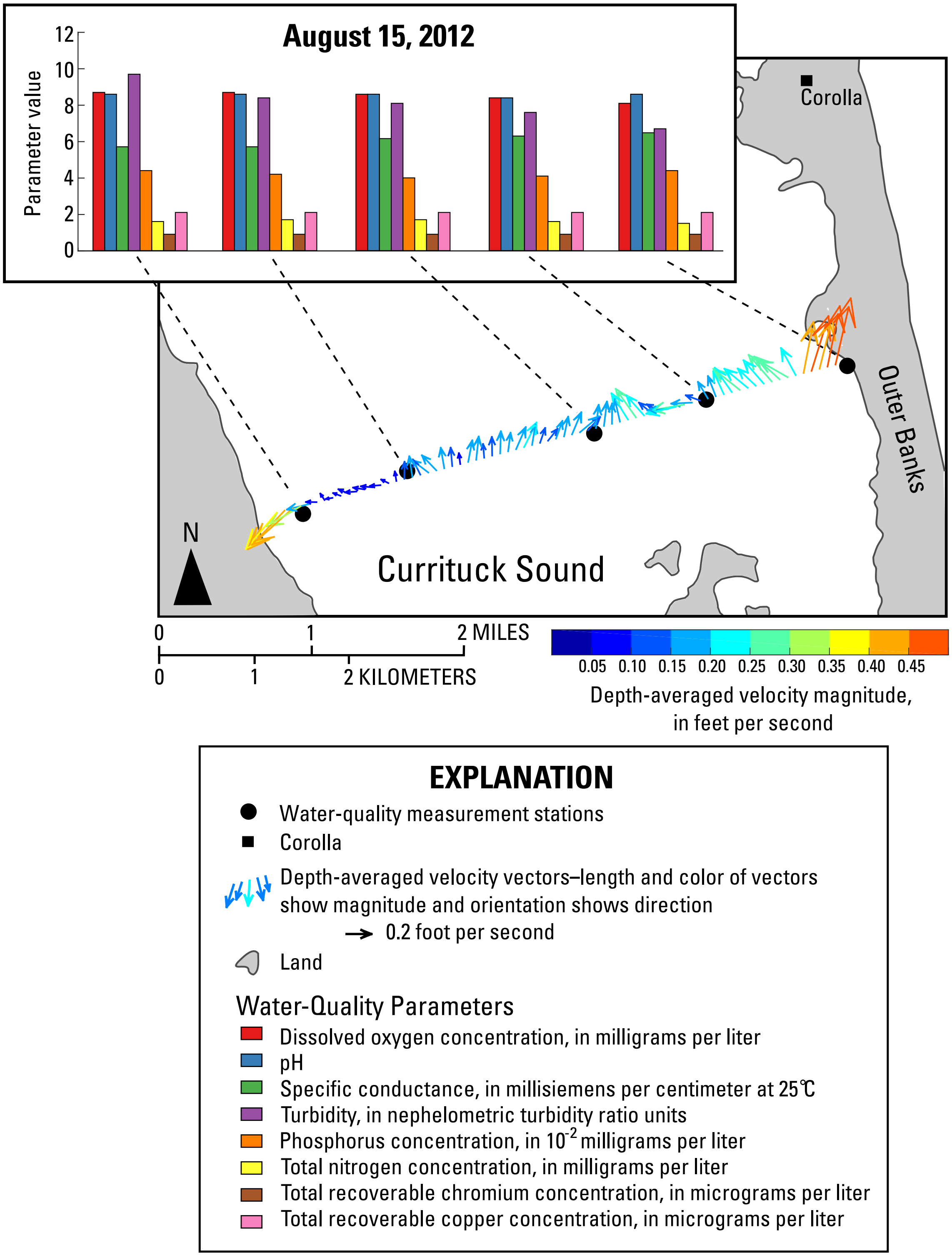

Figure 3-13. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, August 15, 2012.

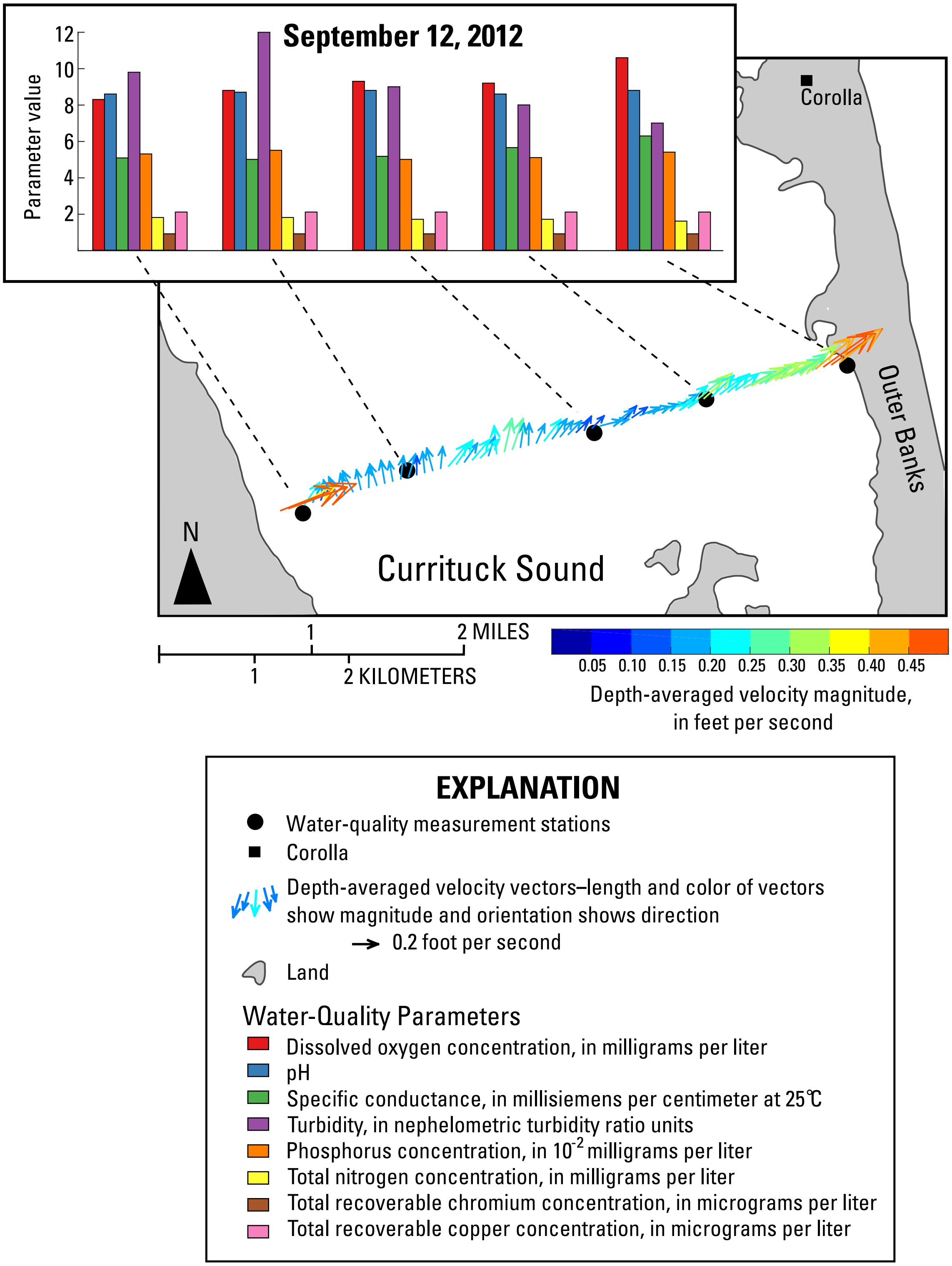

Figure 3-14. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, September 12, 2012.

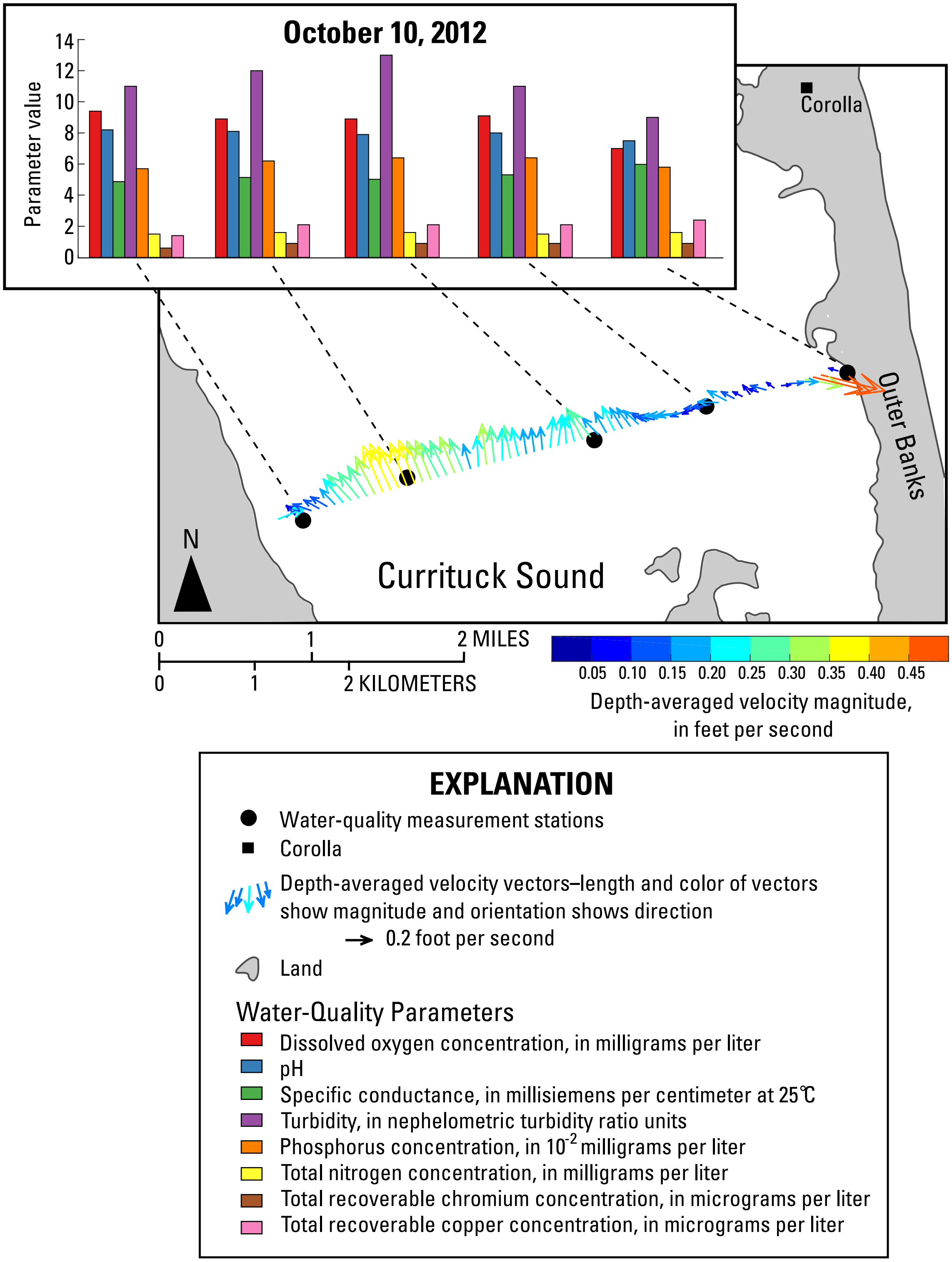

Figure 3-15. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, October 10, 2012.

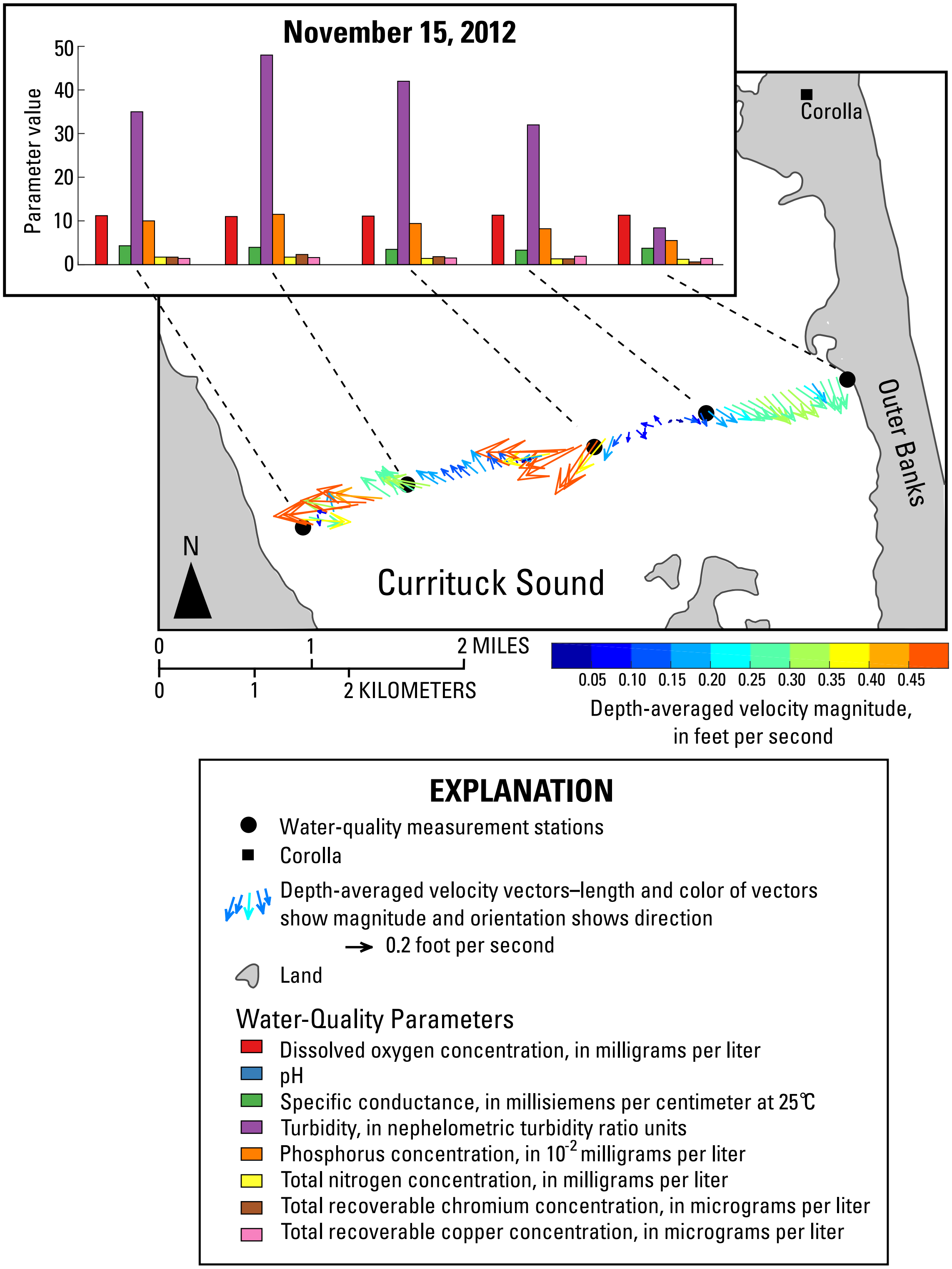

Figure 3-16. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, November 15, 2012.

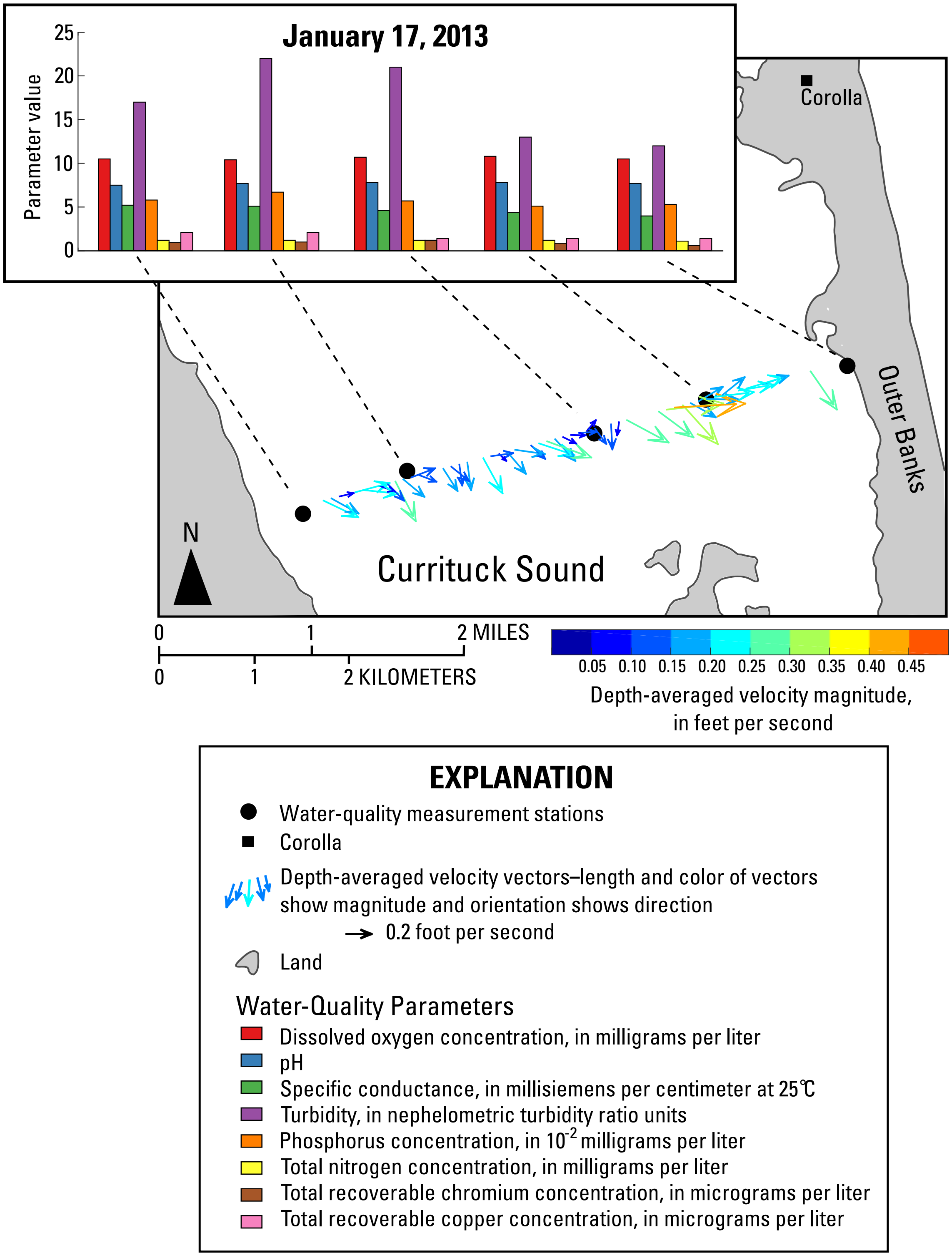

Figure 3-17. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, January 17, 2013.

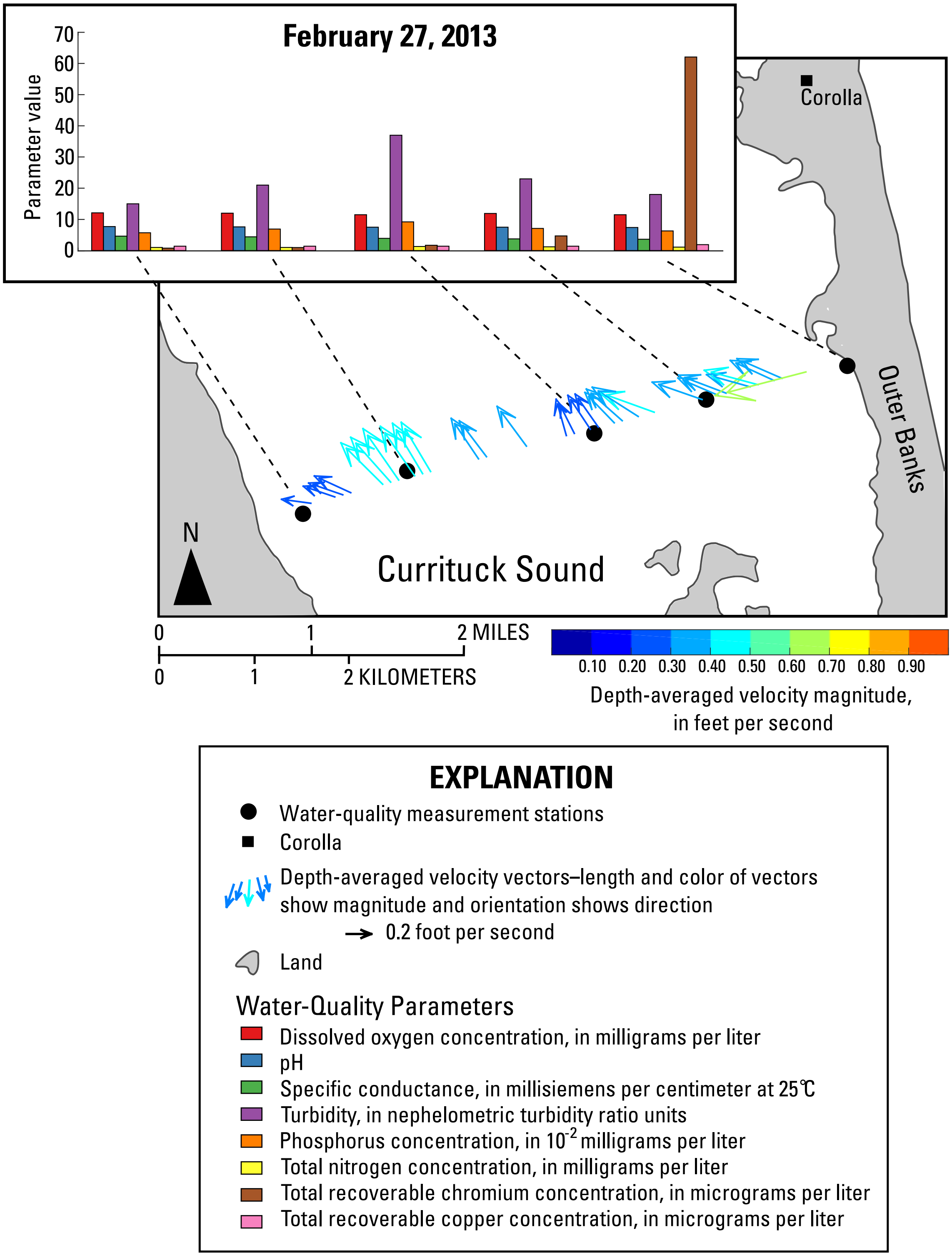

Figure 3-18. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, February 27, 2013.

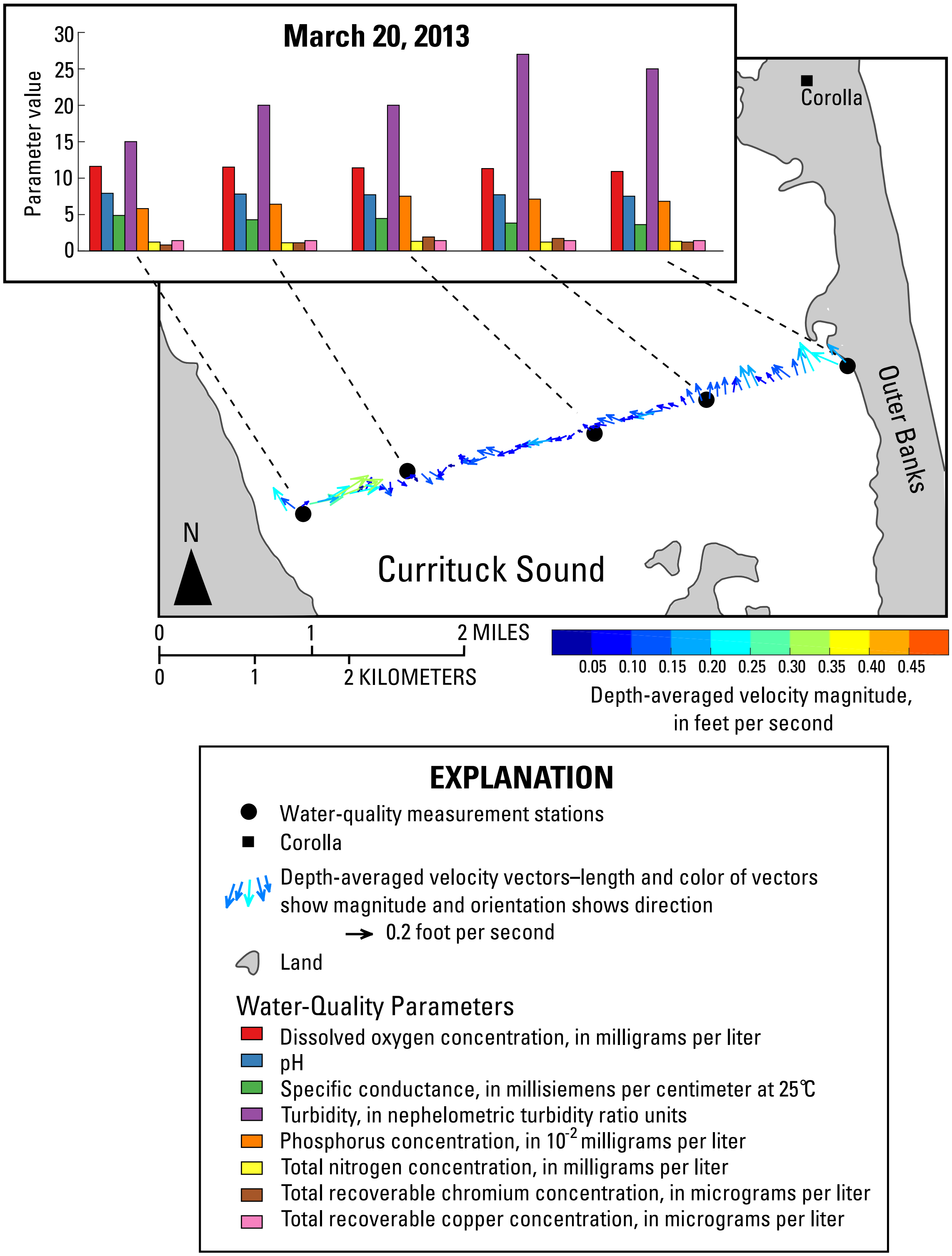

Figure 3-19. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, March 20, 2013.

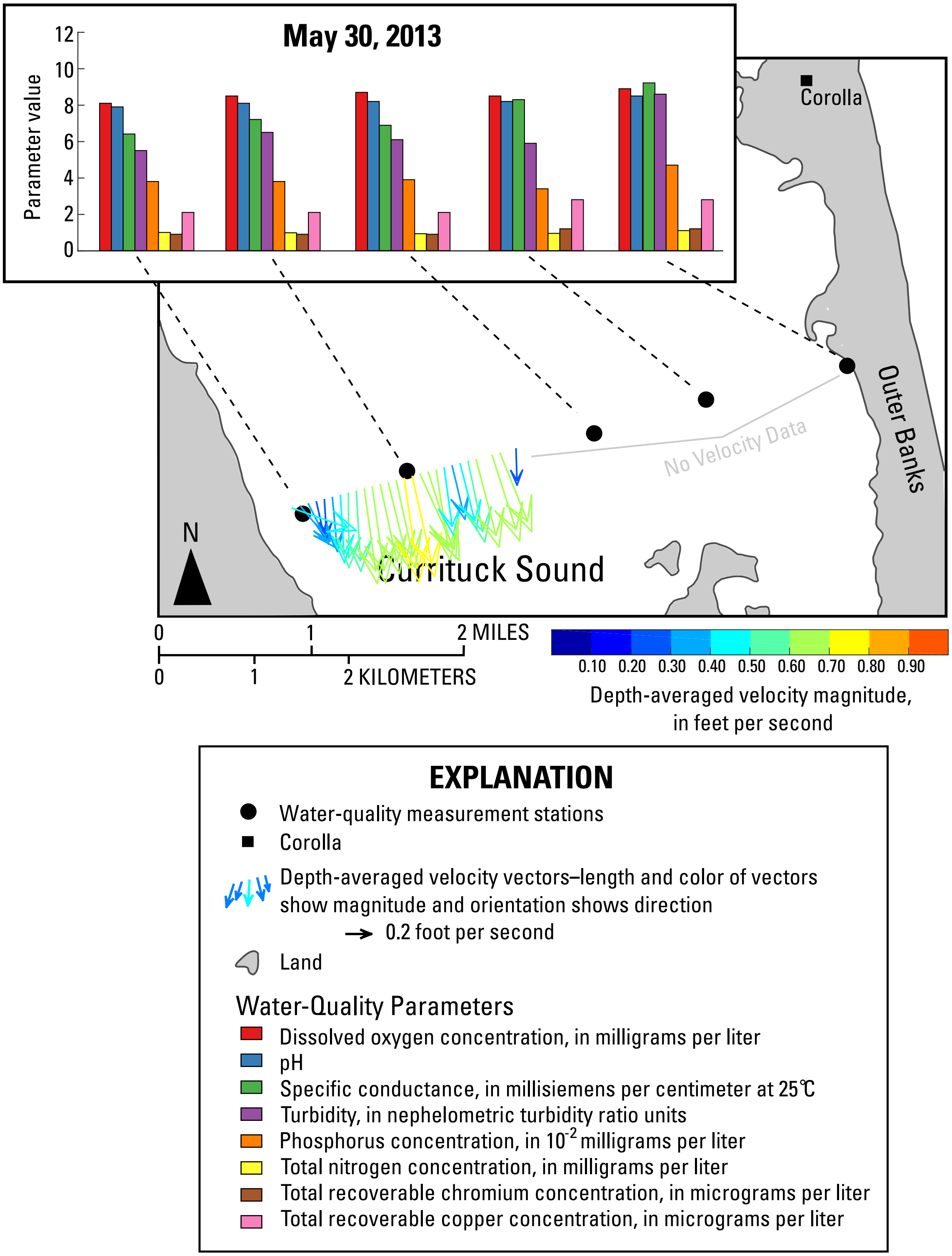

Figure 3-20. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, May 30, 2013.

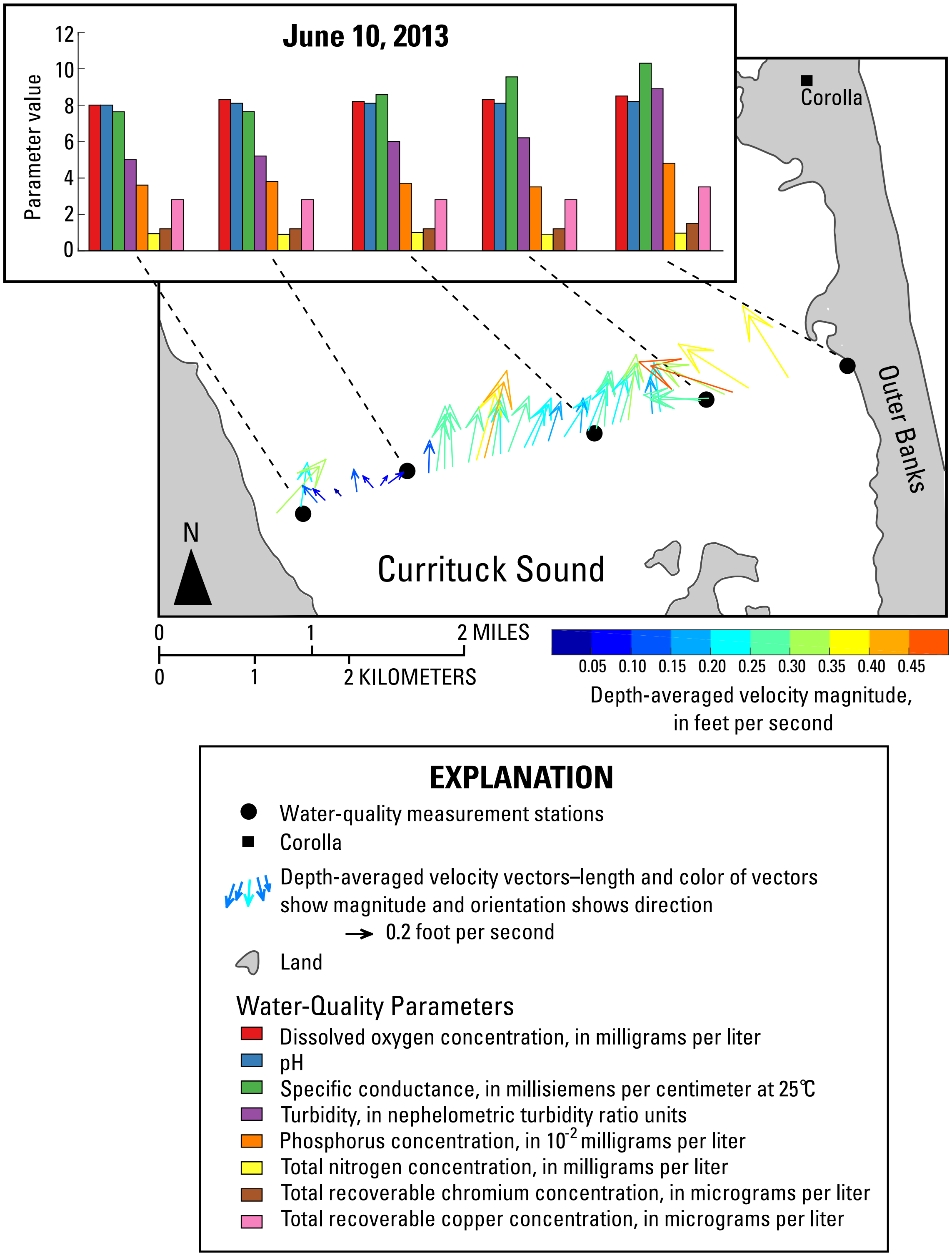

Figure 3-21. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, June 10, 2013.

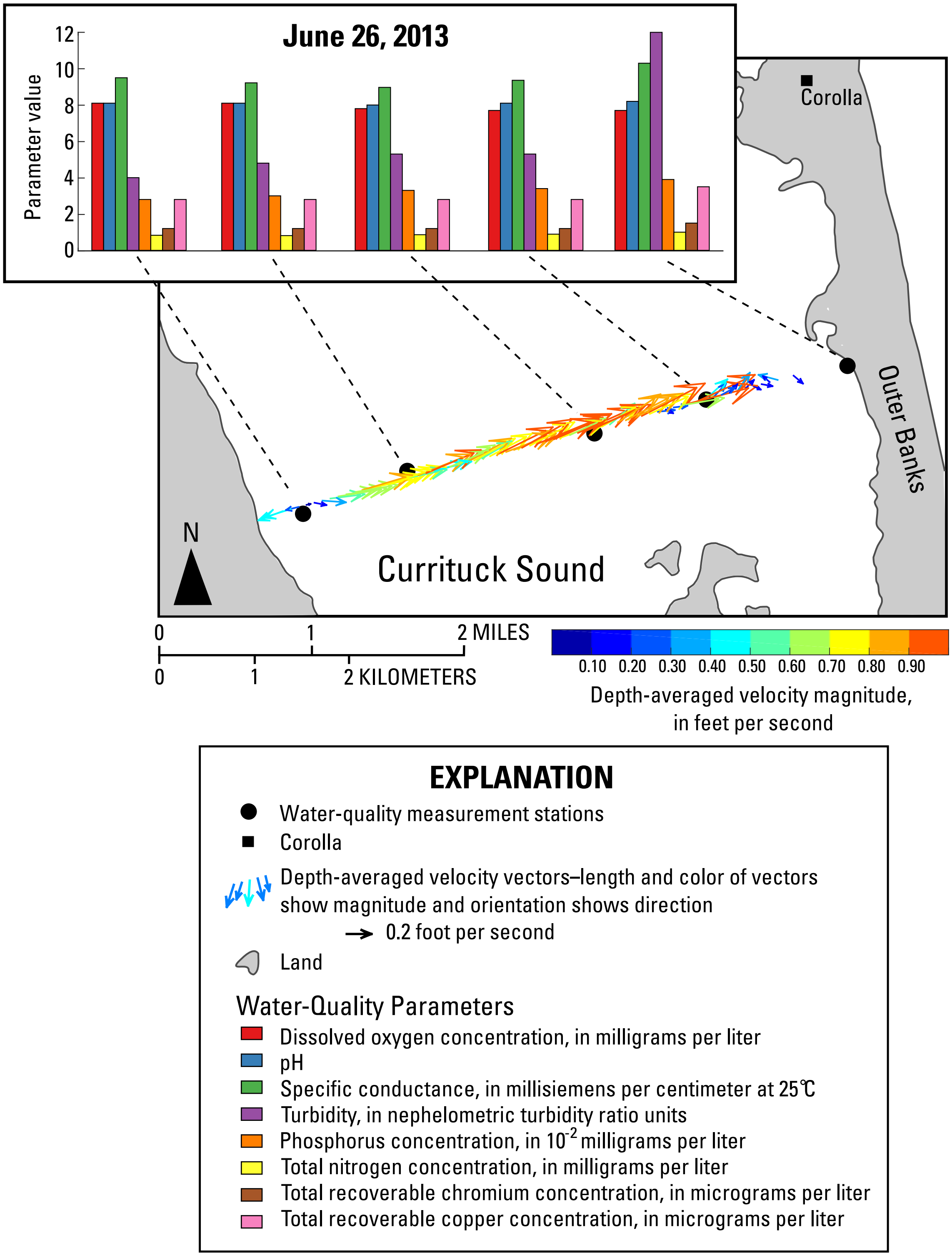

Figure 3-22. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, June 26, 2013.

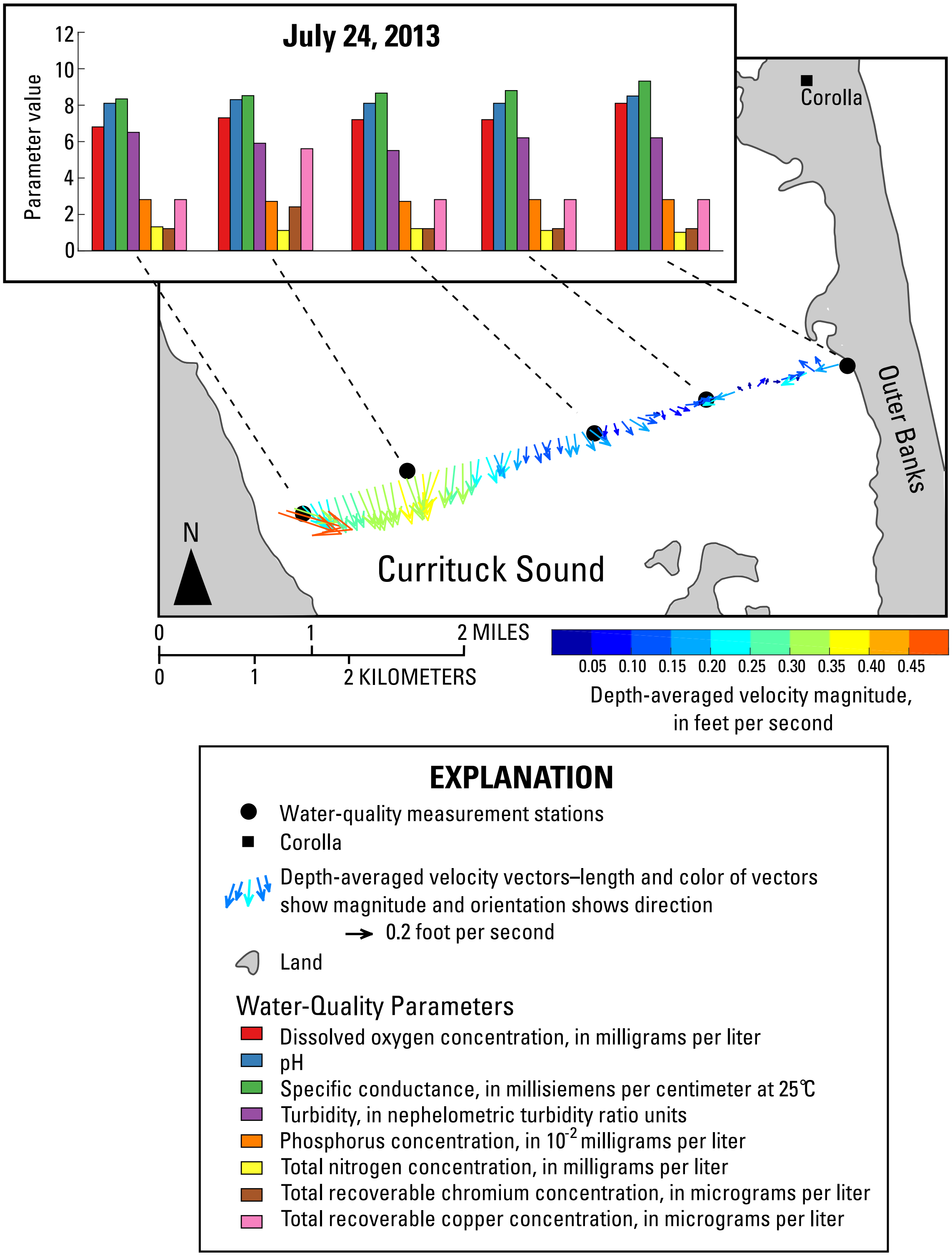

Figure 3-23. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, July 24, 2013.

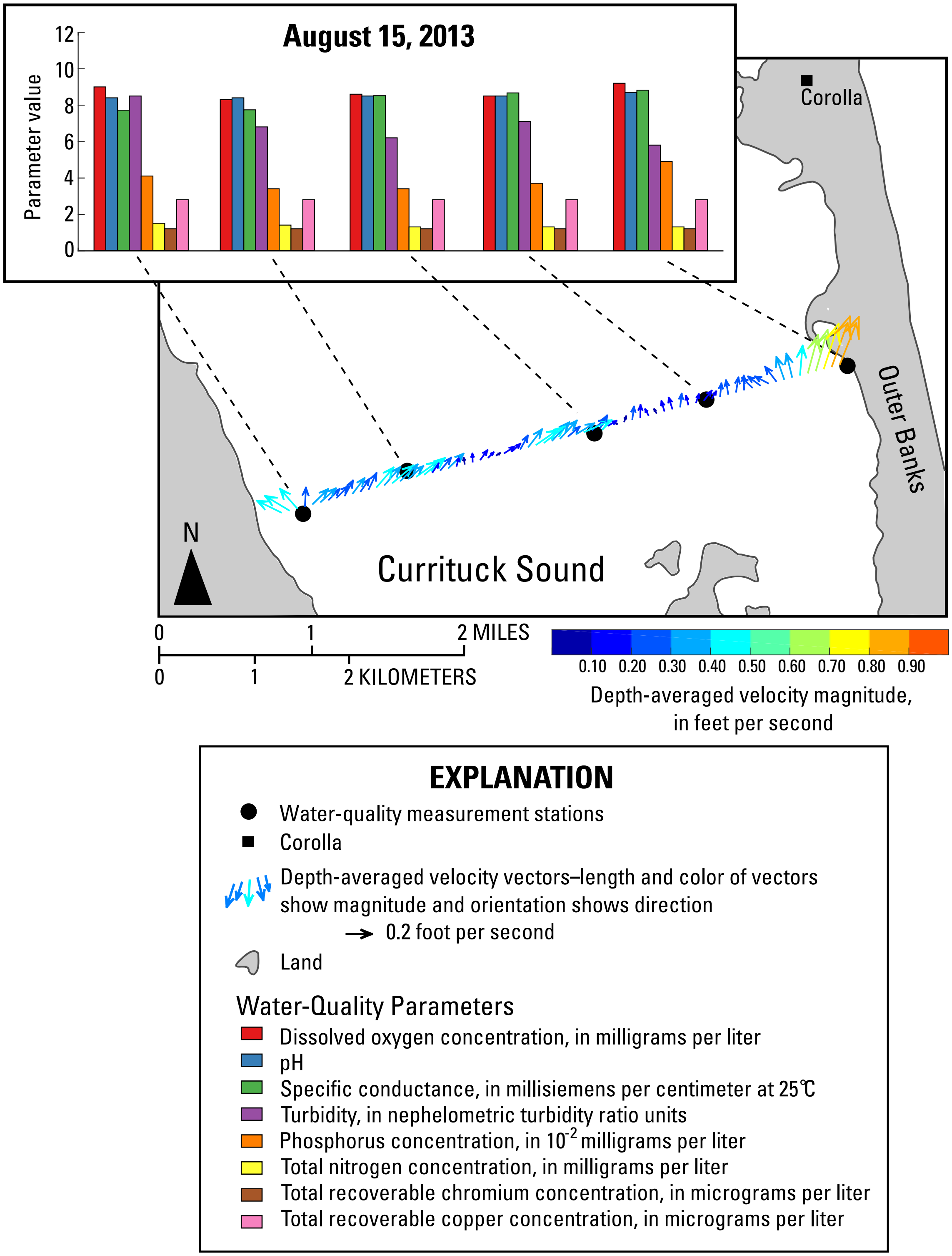

Figure 3-24. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, August 15, 2013.

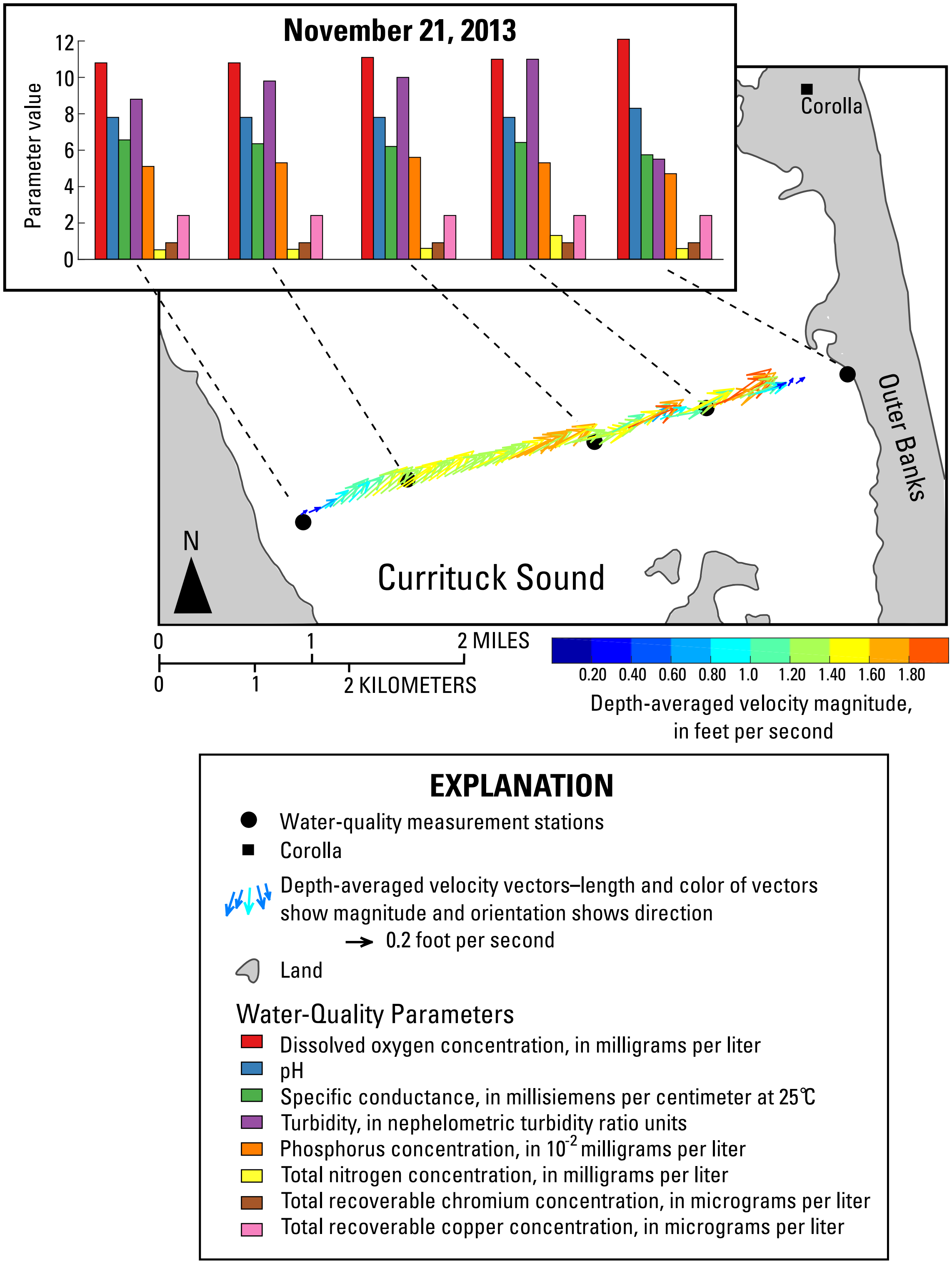

Figure 3-25. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, November 21, 2013.

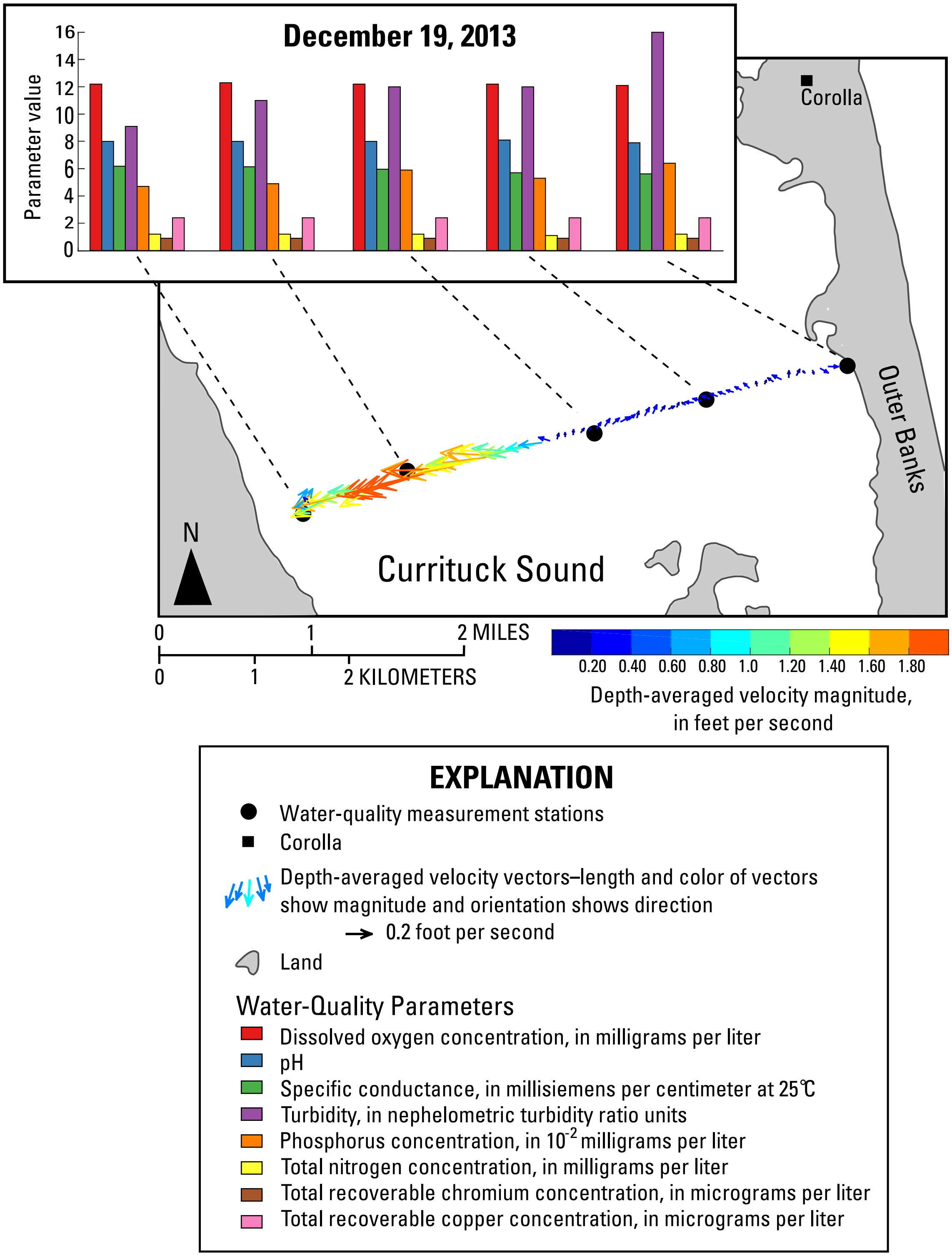

Figure 3-26. Depth-averaged velocity and water-quality conditions in the vicinity of the proposed Mid-Currituck Bridge in Currituck Sound, December 19, 2013.

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