Prepared in cooperation with the Federal Emergency Management Agency

Characterization of Peak Streamflows and Flood Inundation at Selected Areas in North Carolina Following Hurricane Matthew, October 2016

Open-File Report 2017–1047
Version 2.0, August 2017

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

Front cover. U.S. Geological Survey (USGS) streamgaging station Neuse River near Goldsboro (02089000), Wayne County, North Carolina. Photograph by Eric Rudisill, USGS.

Back cover. USGS hydrologist documenting a high-water mark in Lumberton, North Carolina. Photograph by Jonathan Musser, USGS.

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U.S. Geological Survey
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Conversion Factors

U.S. customary units 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)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88) and the National Geodetic Vertical Datum of 1929 (NGVD 29).

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

Elevation, as used in this report, refers to distance above the vertical datum.

Abbreviations

AEP	annual exceedance probability
DEM	digital elevation model
FEMA	Federal Emergency Management Agency
GIS	geographic information system
GPS	Global Positioning System
HWM	high-water mark
lidar	light detection and ranging
NCEM	North Carolina Emergency Management
NCGS	North Carolina Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
STN	Short-Term Network
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

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Abstract

The passage of Hurricane Matthew through central and eastern North Carolina during October 7–9, 2016, brought heavy rainfall, which resulted in major flooding. More than 15 inches of rain was recorded in some areas. More than 600 roads were closed, including Interstates 95 and 40, and nearly 99,000 structures were affected by floodwaters. Immediately following the flooding, the U.S. Geological Survey documented 267 high-water marks, of which 254 were surveyed. North Carolina Emergency Management documented and surveyed 353 high-water marks. Using a subset of these high-water marks, seven flood-inundation maps were created for hard-hit communities. Digital datasets of the inundation areas, study reach boundary, and water-depth rasters are available for download. In addition, peak gage-height data, peak streamflow data, and annual exceedance probabilities (in percent) were determined for 24 U.S. Geological Survey streamgages located near the heavily flooded communities.

Introduction

Hurricane Matthew brought heavy rainfall to parts of the Southeastern United States, including North Carolina, during October 7–9, 2016. The heavy rainfall resulted in major flooding in central and eastern North Carolina. Rainfall totals of 3 inches to more than 15 inches were widespread throughout the area (fig. 1; Southeast Regional Climate Center, 2016).

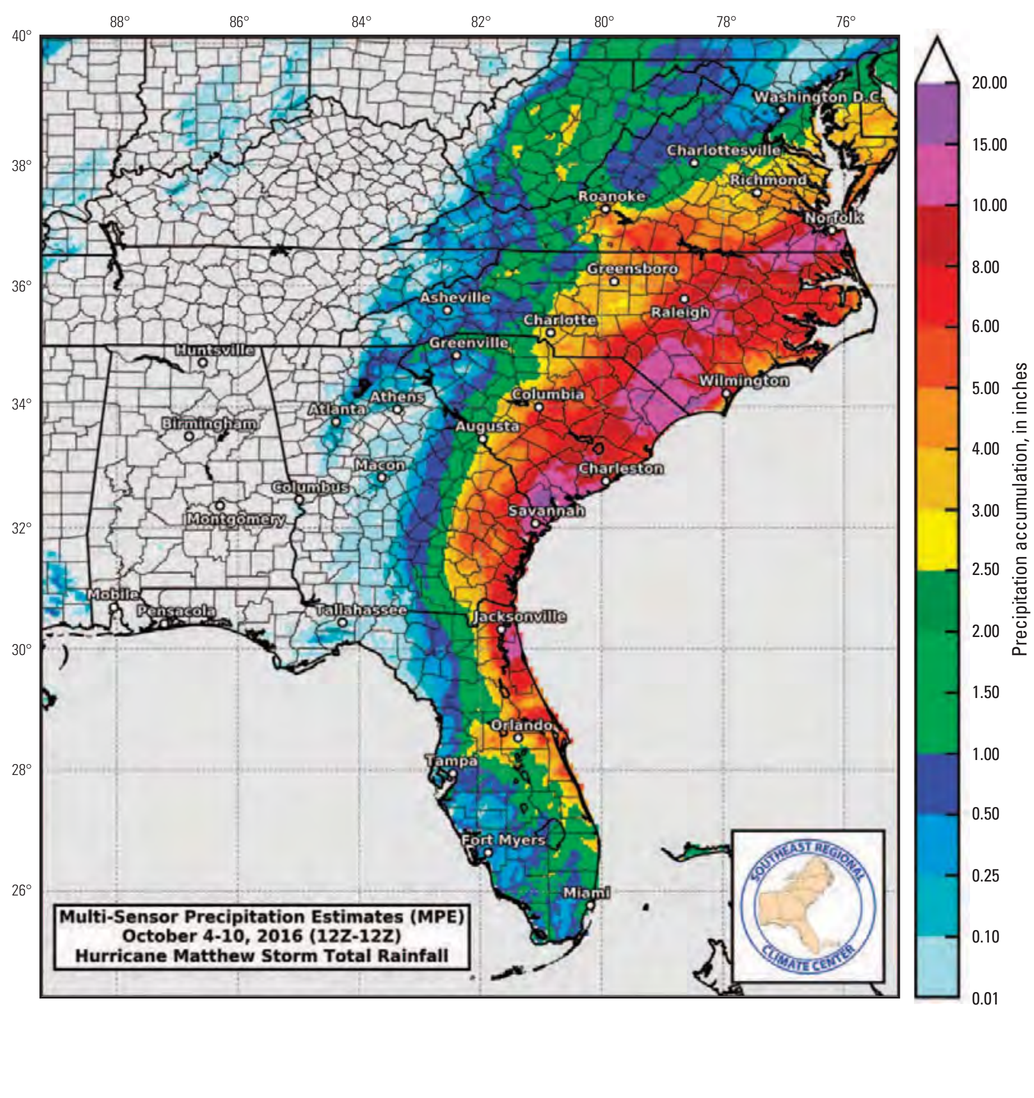


Figure 1. Hurricane Matthew storm total rainfall, October 4–10, 2016 (Southeast Regional Climate Center, 2016).

By the end of October, flooding from the passage of Hurricane Matthew had resulted in 28 fatalities in North Carolina, of which 17 were associated with vehicles that were swept off flooded roadways (Stradling, 2016). At the height of the event more than 600 roads had to be closed in North Carolina, including portions of Interstates 40 and 95. More than 2,100 road repairs were required to fix shoulder washouts and damages to drainage structures such as pipes, reinforced concrete box culverts, and bridges (Matthew Lauffer, N.C. Department of Transportation, written commun., November 30, 2016). The N.C. Department of Public Safety's Floodplain Mapping Program reported that nearly 99,000 structures across the State were affected by floodwaters. Emergency management officials have estimated damage in North Carolina from the storm at approximately $1.5 billion, not including damage to the State infrastructure or the agriculture industry (Nicholas Petro, National Oceanic and Atmospheric Administration, National Weather Service, written commun., November 9, 2016). On the basis of historical information compiled by the State Climate Office of North Carolina, Hurricane Matthew was the fourth costliest and fifth deadliest tropical cyclone on record in North Carolina (State Climate Office of North Carolina, 2015). In the aftermath of the October 2016 flooding, the U.S. Geological Survey (USGS) and the Federal Emergency Management Agency (FEMA) initiated a cooperative study to map the extent of flooding in seven communities in North Carolina, evaluate the magnitude of the flood, and determine the exceedance probability for 24 streamgages located in and around these communities.

Purpose and Scope

The purpose of this report is to document the collection, processing, and presentation of data by the USGS in support of FEMA response-and-recovery operations following the October 2016 flood event throughout central and eastern North Carolina from rainfall associated with Hurricane Matthew. The technical scope of the report includes (1) description of the atmospheric conditions, the temporal and spatial patterns of rainfall that triggered the flooding, and a narrative of the flood and its effects, (2) analysis of peak-flow magnitudes and the statistical exceedance probabilities at selected locations, (3) the identification and surveying of high-water marks (HWM), and (4) the geographic information system (GIS) analysis of HWM locations and elevations to produce flood-inundation maps (areal extent and depth of flooding) for seven heavily flooded communities in North Carolina.

Study Area

The study area description is extracted from a previously published companion report "Preliminary Peak Stage and Streamflow Data at Selected Streamgaging Stations in North Carolina and South Carolina for Flooding Following Hurricane Matthew, October 2016" (Weaver and others, 2016). North Carolina is located on the South Atlantic slope adjacent to the Atlantic Ocean and is generally divided into three major physiographic provinces: Blue Ridge, Piedmont, and Coastal Plain (Cooke, 1936; fig. 2). The communities and streamgages discussed in this report are all located in the Piedmont or Coastal Plain Provinces.

The Piedmont Province is characterized by rolling hills, elongated ridges, and moderately deep to shallow valleys. Piedmont land-surface elevations range from about 1,000 feet (ft) above sea level at the Blue Ridge foothills to about 300–400 ft above sea level at the Fall Line, which is the name given to the boundary between the Piedmont and Coastal Plain regions (fig. 2).

The Coastal Plain Province in North Carolina comprises about one-third of the State's total area and is overlain by a sedimentary wedge that thickens from a featheredge at the Fall Line to more than 10,000 ft at Cape Hatteras at the Outer Banks (Giese and Mason, 1993; Winner and Coble, 1996). At the Fall Line, a narrow, hilly subregion of the Coastal Plain, known as the Sand Hills, provides a transition zone between the Piedmont and Coastal Plain. The Sand Hills region is about 30 to 40 miles (mi) wide, with elevations ranging from about 200 to more than 500 ft. The lower part of the Coastal Plain consists of low-elevation, flat plains with many swamps, marshes, dunes, barrier islands, and beaches, which typically are lower, flatter, and more poorly drained than the upper part of the Coastal Plain (Omernik, 1987).

In North Carolina, precipitation is primarily delivered by storms that move inland from the Gulf of Mexico, the Caribbean Sea, and the Atlantic Ocean (U.S. Geological Survey, 1985). Additionally, local and upwind land surfaces, as well as lakes and reservoirs, provide moisture to the atmosphere by evaporation. In a normal year, monthly precipitation is highest in the winter, reaching a maximum in early March and then decreasing sharply in April and May. Fall is typically a dry season except in rare instances when tropical storms or hurricanes occur.

The average annual precipitation in the Piedmont ranges from about 40 inches in the west to about 50 inches in the east in the vicinity of the Fall Line (State Climate Office of North Carolina, 2016). Average annual precipitation in the Coastal Plain generally ranges from 50 to 55 inches, with higher values near 60 inches where tropical storms have affected parts of the southern coastal region of North Carolina.

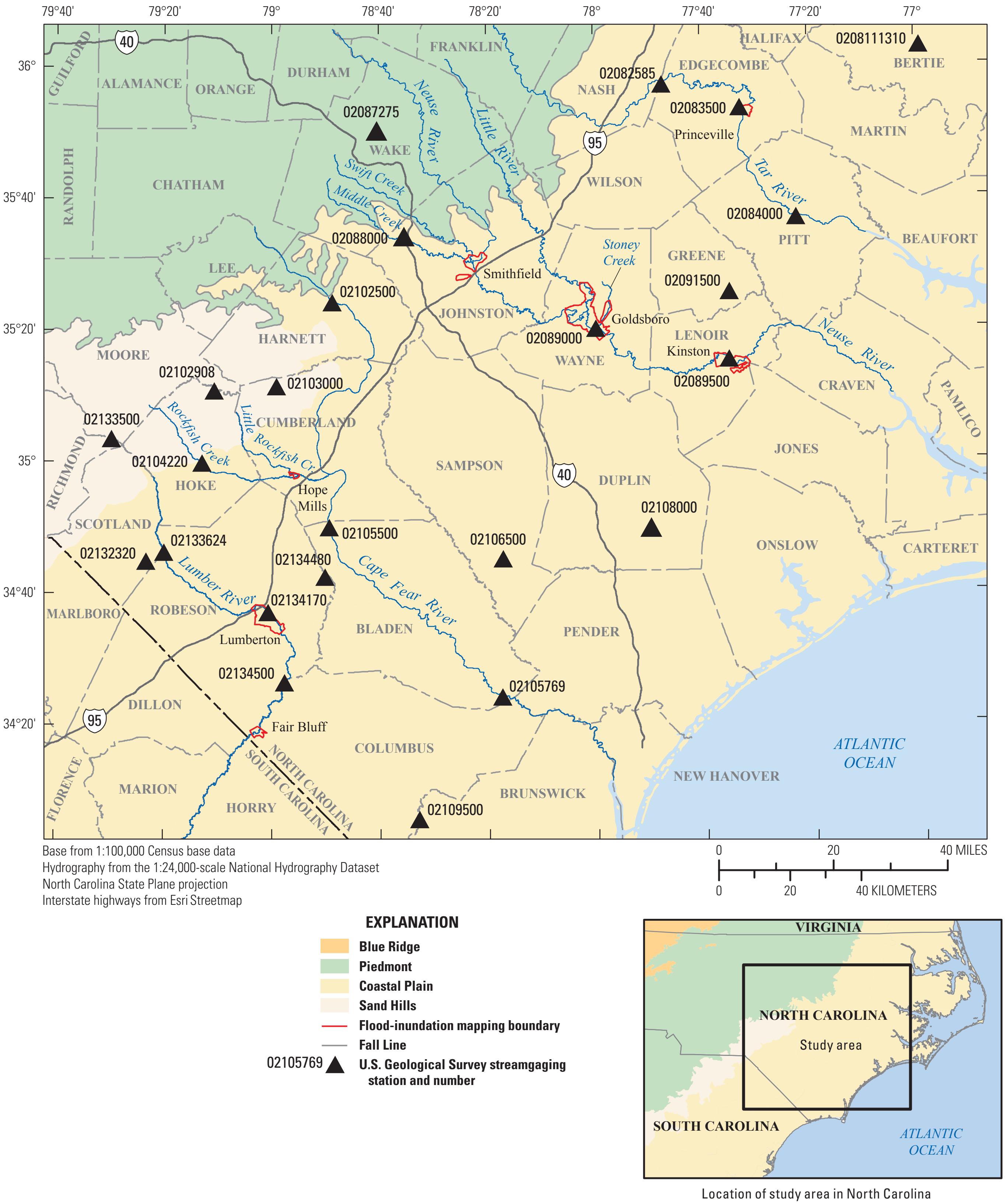


Figure 2. Study area showing location of flood-inundation mapping sites and streamgaging stations in eastern North Carolina.

General Weather Conditions and Precipitation That Contributed to the October 2016 Flooding

Rainfall from Hurricane Matthew in central and eastern North Carolina—the area most affected by flooding—occurred during October 7–9, 2016, and resulted in all-time record 1-day amounts for a number of locations across the region, with periods of climatic record ranging from 18 to 146 years (commonly 50+ years) (Nicholas Petro, National Oceanic and Atmospheric Administration, National Weather Service, written commun., November 9, 2016). One-day records were set at four locations in North Carolina: Tarboro (9.50 inches, tying previous record set on October 25, 1872; records back to 1870); Fayetteville (14.00 inches, surpassing 5.13 inches previously set just 10 days prior on September 29, 2016; Lumberton (12.53 inches, surpassing 7.62 inches set on September 15, 1999; records back to 1948); and Raleigh (6.45 inches; Weaver and others, 2016). At the USGS raingage at Cape Fear River at William O. Huske Lock near Tarheel in Bladen County, North Carolina (02105500), a total of 16.87 inches was recorded during October 7–9 (Weaver and others, 2016). The cumulative total rainfall estimate for the area ranged from 4.1 to 14.7 inches in the Neuse River Basin, from 4.6 to 16.1 inches in the Lumber River Basin, from 4.4 to 13.2 inches in the Tar River Basin, and from 6.9 to 13.8 inches in the Rockfish Creek Basin (fig. 3; National Weather Service, 2017). For a more detailed discussion about the weather conditions, see Weaver and others (2016).

Methods Used

The methods used to identify, document, and reference the HWMs resulting from flooding as well as the methods used to create flood-inundation maps using these HWMs are discussed in this section. Also discussed are the methods by which the estimation of flood magnitude and frequency were developed through analysis of the annual peak streamflows at 24 USGS streamgages, 3 of which are located within the areas of the flood-inundation maps. All streamflow data used in support of this report can be accessed from the USGS National Water Information System (U.S. Geological Survey, 2017b).

Collection of High-Water Mark Data

High-water marks are the evidence of the highest water levels during a flood and provide valuable data for understanding flood events. The USGS followed the guidance provided by Koenig and others (2016) for identification and documentation of HWMs. The best HWMs are formed from small seeds or floating debris that are carried by floodwaters and that adhere to smooth surfaces or are lodged in tree bark to form a distinct line. Stain lines on buildings, fences, and other structures also provide excellent marks. High-water marks are best identified immediately following the peak stage of a flood event, because time and weather (wind, rain, sun) may blow, wash, or fade away the evidence of the peak water line. Care was taken to identify HWMs as far from the main channel as feasible, where velocities generally are slow and where wave action and pileup or drawdown effects of fast-moving waters are best avoided. Information about the HWMs identified by the USGS for this flood event was made available to the public through the USGS Short-Term Network (STN; U.S. Geological Survey, 2016), which is an online interface created to facilitate the timely dissemination of field data. Additional information, including a download portal for HWM information, is available from the USGS Hurricane Matthew web page at https://water.usgs.gov/floods/events/2016/matthew/ (U.S. Geological Survey, 2017a).

Identification of HWMs, by the USGS, began on October 9 and continued through October 24, 2016. After an acceptable HWM was found, a more permanent identification mark was established, such as a Parker-Kalon (PK) nail, disk, stake, chiseled mark, or paint line; if possible, the identification marks were accompanied by orange flagging. Written descriptions, sketches, photographs, and Global Positioning System (GPS) horizontal measurements obtained with a hand-held GPS unit were made, so the marks could easily be found later, and surveyed to the standard vertical datum, North American Vertical Datum of 1988 (NAVD 88). The USGS field crews identified 267 HWMs in North Carolina with a depth above land-surface measurement made in feet, and 254 of these HWMs were surveyed for elevation above NAVD 88. North Carolina Emergency Management (NCEM) also identified and surveyed 353 HWMs. Information about these HWMs can be obtained by contacting NCEM directly.

During the mapping process, the HWMs used to create flood-inundation maps were checked for location and elevation accuracy by comparing field note diagrams and descriptions to aerial photography and detailed street and parcel maps. If the location could not be determined accurately or the elevation was substantially different from other HWMs in the area, the HWM was not used. Also, some HWMs were not used because they were the result of localized flooding of small areas and did not represent the water-surface elevation of the surrounding area.

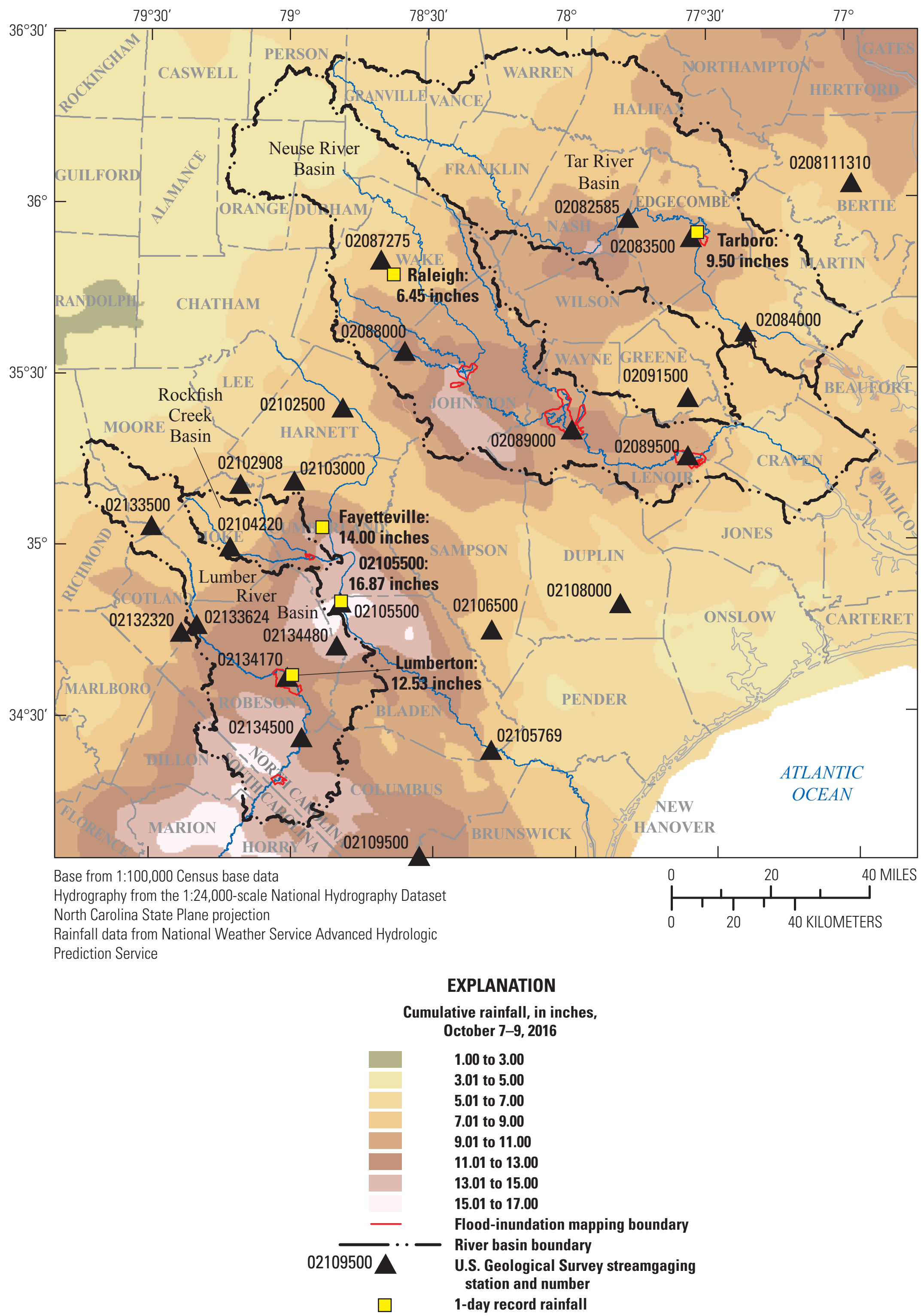


Figure 3. Cumulative rainfall October 7–9, 2016, for southeast North Carolina and northeast South Carolina.

Flood-Inundation Mapping

Flood-inundation maps were created using a GIS for seven communities near affected rivers in central and eastern North Carolina (fig. 2). The flood-inundation maps were used to estimate the aerial extent and depth of flooding that correspond to the HWMs identified and surveyed by USGS and NCEM hydrographers following the flood event. Table 1 lists the community, county, waterbodies, reach lengths, and number of HWMs used to generate the flood-inundation maps. The first step in the generation of the flood-inundation maps was the creation of a flood-elevation raster surface. Flood extent and depth surfaces were created independently for each community, using the HWM elevations, cross sections across the direction of flow at the HWMs and streamgages, and a GIS interpolation technique—the ArcGIS “Topo-to-Raster” tool (http://pro.arcgis.com/en/pro-app/tool-reference/3d-analyst/how-topo-to-raster-works.htm, accessed January 2015) as described by Musser and others (2016). In one case, a constant flood-elevation surface was used on a lake which only had one HWM. A geographic limit was placed on the extent of the generated surface on the basis of the distribution of HWMs and an understanding of the natural hydrologic flow in the area of each community.

The flood-elevation surface that was created by using GIS interpolation was then combined with a 3.125-ft cell size digital elevation model (DEM). The DEM was derived from light detection and ranging (lidar) data with an 18.2-centimeter vertical root-mean-square-error and a 0.07-meter or better nominal point spacing (North Carolina Floodplain Mapping Program, 2016). An inundated area was depicted where the flood-elevation surface was higher than the DEM land surface. The depth of flooding was determined as the difference between the flood-elevation surface and the DEM land surface. Because of the large number of bridges in the mapped reaches, the inundation surfaces were not clipped to show any bridges that were not inundated.

Uncertainties in the mapped extent and depth of flooding exist within the maps because of the mapping methods used and the number and spatial distribution of HWMs in a given mapped reach. Hydraulic models were not used to determine the extent or depth of flood inundation. The flood-elevation surfaces were all created using interpolation between cross sections drawn through the best available HWM elevations rather than hydraulic models. Changes in land-surface features in flood plains, timing of the flooding that may differ between the smaller inflow tributaries and the larger main stem tributaries, and the intermingling of flows from adjacent streams

Table 1. Communities, waterbodies, counties, reach lengths, and number of high-water marks used to generate flood-inundation maps.

Community	Waterbody or waterbodies	County or counties	Reach length (miles)	Number of high-water marks used to generate flood-inundation map for each community
Fair Bluff	Lumber River	Columbus, Robeson	3.5	5
Goldsboro	Neuse River	Wayne	20.8	20
	Little River		11.8	
	Stoney Creek		6.3	
Hope Mills	Rockfish Creek	Cumberland	1.5	7
	Little Rockfish Creek		3.2	
Kinston	Neuse River	Lenoir	9.3	10
	Southwest Creek		5.0	
Lumberton	Lumber River	Robeson	11.5	24
	Little Jacob Swamp		2.3	
	Jacob Branch		3.1	
Princeville	Tar River	Edgecombe	2.1	12
Smithfield	Neuse River	Johnston	4.8	10
	Swift Creek		2.6	
	Middle Creek		2.4	
	Holts Lake		2.6	

cannot be accounted for without the use of hydraulic models. In locations where HWMs are spaced farther apart, there is a greater possibility of decreased accuracy of spatial interpretation of the extent and depth of flood inundation. Within a given mapped area, some extrapolation was performed beyond the most upstream and downstream HWMs. In many cases, the boundary was extended to some anthropogenic structure, such as a road or bridge crossing.

Flood Exceedance Probabilities of Peak Streamflows

Information commonly needed by emergency managers and water resources engineers immediately after a major flood includes the expected frequency of peak discharges for the flow magnitudes observed during the event. Flood-frequency analyses for streamgages with sufficient record can provide insight into the occurrence or likelihood of peak discharges of varying magnitudes. The annual exceedance probability (AEP) for a particular streamflow is the probability of that streamflow being equaled or exceeded in any given year. For example, an AEP of 0.01 means there is a 1 percent (AEP×100) chance of that flow magnitude being equaled or exceeded in any given year. Stated another way, the odds are 1 in 100 that the indicated flow will be equaled or exceeded in any given year. The traditional concept of recurrence interval is directly related to the AEP. By definition, the recurrence interval (in years) is equal to one divided by the AEP. For example, the AEP of 0.01 (or 1 percent) corresponds to the 100-year flood. Table 2 lists the recurrence intervals for commonly used flood exceedance probabilities and the associated AEP, in percent.

Updated at-site flood-frequency discharges for selected AEPs (50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent) were computed for USGS streamgages in the areas where flood-inundation maps were created, using the computer program PEAKFQ, version 7.2 (Flynn and others, 2006; Veilleux and others, 2014). The PEAKFQ program is based on guidelines provided by the Interagency Advisory Committee on Water Data (1982) in Bulletin 17B. The October 2016 peak streamflows were included in the PEAKFQ analyses per guidance provided in USGS Office of Surface Water Technical Memorandum 2013.01 (Mason, 2012).

The updated at-site flood-frequency discharges, computed using PEAKFQ, were weighted with the regression equation estimates from Weaver and others (2009) for the streamgages with no regulation or urbanization. The at-site flood-frequency discharges for the streamgages with urbanization were weighted with the regression equations from Feaster and others (2014). The weighting method used is outlined in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982, appendix 8). The weighted discharge estimates were then used to determine the AEP associated with the October 2016 peak streamflow.

Table 2. Selected recurrence intervals and the associated annual exceedance probabilities.

Recurrence interval (years)	Annual exceedance probability (percent)
2	50
5	20
10	10
25	4
50	2
100	1
200	0.5
500	0.2

Estimated Magnitudes and Flood Exceedance Probabilities of Peak Streamflows

Peak gage-height data, peak streamflow data, and the corresponding AEPs (in percent) determined from the October 2016 flood for the 24 USGS streamgages that record annual peak streamflow in the areas in and near where flood-inundation maps were created are presented in table 3. If a streamgage is located within an area delineated by a flood-inundation map of a mapped community, then the map name and figure number associated with the streamgage is listed in table 3. Streamgage locations are shown in figure 2, and streamgages at mapped communities are also shown on respective flood-inundation maps. The estimated AEP for the October 2016 flood for each streamgage was determined using log-linear interpolation of the weighted discharge estimates following equation 1 in USGS Office of Surface Water Technical Memorandum 2013.01 (Mason, 2012). The estimated AEP provides a reasonably accurate estimate of the flood magnitude; however, uncertainty in this estimate can increase when a specific AEP is assigned to an observed flood. To show the uncertainty range, the AEP estimate is bracketed by a 90-percent confidence interval that is likely to include the true AEP. The data listed in table 3 currently (March 2017) are considered provisional until final approval of the data. New gage-height records were set at 14 of the 24 USGS streamgages listed in table 3. The flood-frequency statistics computed for this study are presented in table 4, which includes the length of the historical period for the streamgages that included historical flood information. The weighted flood-frequency statistics in table 4 were used to determine the AEP (in percent) associated with the October 2016 flood peaks in table 3.

Table 3. Flood-peak gage heights, peak streamflows, and estimated annual exceedance probabilities for the October 2016 flood at selected U.S. Geological Survey streamgages in North Carolina.

[Data shown are considered provisional as of the date of this publication. Peak of record is shown in bold. Abbreviations: USGS, U.S. Geological Survey; mi^2, square mile; ft^3/s, cubic foot per second; ft, foot; SR, Secondary Road; NC, North Carolina; AEP, annual exceedance probability. <, less than, —, station not shown on a flood-inundation map]

USGS station number (fig. 2)	Station name	Map ID	Drainage area (mi^2)	Gage period of record ([a]water year)	Type	Maximum prior to October 2016 flood			Maximum for October 2016 flood					
						Date	Gage height (ft)	Discharge (ft)	Date	Gage height (ft)	Discharge (ft)	Estimated annual exceedance probability (percent)	[b]90-percent confidence interval Lower	Upper
0208111310	Cashie River at SR1257 near Windsor, NC	—	108	1988–present	Unregulated	9/16/1999	18.52	15,700	10/9/2016	16.63	12,900	[b,e]0.53	1.2	14.9
02082585	Tar River at NC 97 at Rocky Mount, NC	—	925	1977–present	[c]Regulated	9/17/1999	31.66	34,100	10/10/2016	28.73	23,200	[b,e]2.46	0.9	11.1
02083500	Tar River at Tarboro, NC	Tar River at Princeville (fig. 10)	2,183	1897–1900, 1906–present	Unregulated	9/19/1999	41.51	70,600	10/12/2016	36.29	41,700	[b,e]1.74	0.7	5.3
02084000	Tar River at Greenville, NC	—	2,660	1919, 1940, 1997–present	Unregulated	9/21/1999	29.72	73,000	10/14/2016	24.46	46,200	[b,e]2.84	4.2	28.3
02087275	Crabree Creek at Highway 70 at Raleigh, NC	—	97.6	1996–present	Urbanized	6/29/1973	27.69	11,700	10/8/2016	22.70	6,350	[b,f]17.4	9.0	35.5
02088000	Middle Creek near Clayton, NC	—	83.5	1940–present	Unregulated	9/6/1996	14.88	11,900	**10/9/2016**	**16.18**	**20,600**	[b,e]<0.2	0.1	3.8
02089000	Neuse River near Goldsboro, NC	Neuse River near Goldsboro (fig. 7)	2,399	1984–2008, 2010–present	Regulated	9/20/1999	28.85	38,500	**10/12/2015**	**29.74**	**54,300**	[b]0.45	0.2	8.7
02089500	Neuse River at Kinston, NC	Neuse River at Kinston (fig. 8)	2,692	1984–present	Regulated	9/22/1999	27.71	36,300	**10/14/2016**	**28.31**	**38,200**	[b]0.80	0.2	8.4
02091500	Contentnea Creek at Hookerton, NC	—	733	1929–present	[c]Regulated	9/18/1999	28.28	31,900	10/11/2016	24.23	25,500	[b,e]0.37	0.4	5.2
02102500	Cape Fear River at Lillington, NC	—	3,464	1981–present	Regulated	2/3/1973	19.27	53,800	10/9/2016	19.41	53,400	[b]3.10	0.4	5.0
02102908	Flat Creek near Inverness, NC	—	7.63	1969–present	Unregulated	9/6/2008	8.2	668	**10/8/2016**	**8.63**	**733**	[b,e]0.60	0.1	5.9

Table 3. Flood-peak gage heights, peak streamflows, and estimated annual exceedance probabilities for the October 2016 flood at selected U.S. Geological Survey streamgages in North Carolina.—Continued

[Data shown are considered provisional as of the date of this publication. Peak of record is shown in bold. Abbreviations: USGS, U.S. Geological Survey; mi², square mile; ft³/s, cubic foot per second; ft, foot; SR, Secondary Road; NC, North Carolina; AEP, annual exceedance probability. <, less than, —, station not shown on a flood-inundation map]

USGS station number (fig. 2)	Station name	Map ID	Drainage area (mi²)	Gage period of record ([a]water year)	Type	Maximum prior to October 2016 flood			Maximum for October 2016 flood					
						Date	Gage height (ft)	Discharge (ft)	Date	Gage height (ft)	Discharge (ft)	Estimated annual exceedance probability (percent)	[b]90-percent confidence interval	
													Lower	Upper
02103000	Little River at Manchester, NC	—	348	1939–44, 1946–50, 2003–present	Unregulated	9/29/2016	31.18	9,720	**10/10/2016**	**32.19**	**10,600**	[b,e]0.93	0.2	10.9
02104220	Rockfish Creek at Raeford, NC	—	93.1	1989–present	Unregulated	9/7/2008	9.3	1,750	**10/9/2016**	**12.94**	**5,490**	[b,e]<0.2	0.2	9.8
02105500	Cape Fear River at William O Huske Lock near Tarheel, NC	—	4,852	1981–95, 1997–2004, 2006–12, 2014–present	Regulated	9/8/1996	26.75	[d]	**10/10/2016**	**36.37**	**77,300**	[b]0.47	0.2	8.4
02105769	Cape Fear River at Lock #1 near Kelly, NC	—	5,255	1981–present	Regulated	3/3/1979	24.92	57,700	**10/13/2016**	**28.62**	**66,600**	[b]1.37	0.1	6.1
02106500	Black River near Tomahawk, NC	—	676	1928, 1945, 1948, 1952–present	Unregulated	9/18/1999	27.14	28,500	**10/10/2016**	**27.92**	**39,100**	[b,e]<0.2	0.1	4.2
02108000	Northeast Cape Fear River near Chinquapin, NC	—	599	1941–present	Unregulated	9/18/1999	23.51	30,700	10/11/2016	19.98	18,200	[b,e]1.90	1.1	8.0
02109500	Wassamaw River at Freeland, NC	—	680	1940–2012, 2015–present	Unregulated	9/21/1999	19.3	31,200	10/12/2016	19.00	22,000	[b,e]0.72	0.5	6.1
02132320	Big Shoe Heel Creek near Laurinburg, NC	—	83.3	1988–91, 1994–present	Unregulated	9/10/2004	5.52	1,200	**10/10/2016**	**6.26**	**1,480**	[b,e]3.41	0.2	10.1
02133500	Drowning Creek near Hoffman, NC	—	183	1940–present	Unregulated	9/18/1945	10.29	10,900	10/9/2016	9.00	5,620	[b,e]2.05	2.6	11.4

Table 3. Flood-peak gage heights, peak streamflows, and estimated annual exceedance probabilities for the October 2016 flood at selected U.S. Geological Survey streamgages in North Carolina.—Continued

[Data shown are considered provisional as of the date of this publication. Peak of record is shown in bold. Abbreviations: USGS, U.S. Geological Survey; mi², square mile; ft³/s, cubic foot per second; ft, foot; SR, Secondary Road; NC, North Carolina; AEP, annual exceedance probability. <, less than, —, station not shown on a flood-inundation map]

USGS station number (fig. 2)	Station name	Map ID	Drainage area (mi²)	Gage period of record ([a]water year)	Type	Maximum prior to October 2016 flood			Maximum for October 2016 flood					
						Date	Gage height (ft)	Discharge (ft)	Date	Gage height (ft)	Discharge (ft)	Estimated annual exceedance probability (percent)	[b]90-percent confidence interval	
													Lower	Upper
02133624	Lumber River near Maxton, NC	—	365	1988–92, 1994–present	Unregulated	3/22/1998	13.52	3,380	**10/11/2016**	**15.49**	**6,790**	[b,e]0.57	0.2	9.8
02134170	Lumber River at Lumberton, NC	Lumber River at Lumberton (fig. 4)	708	2001–present	Unregulated	9/11/2004	18.29	7,420	**10/10/2016**	**21.87**	**14,600**	[b,e]0.57	0.3	16.2
02134480	Big Swamp near Tar Heel, NC	—	229	1986–present	Unregulated	9/17/1999	14.34	3,570	**10/9/2016**	**18.72**	**19,400**	[b,e]<0.2	0.6	5.4
02134500	Lumber River at Boardman, NC	—	1,228	1901, 1905–06, 1908–10, 1928, 1930–present	Unregulated	August 1928	11.80	25,000	**10/11/2016**	**14.41**	**38,200**	[b,e]<0.2	0.2	2.0

[a]Water year refers to the period October 1 to September 30 and is identified by the year in which the period ends. For example, October 1, 2001, to September 30, 2002, is water year 2002.

[b]Determined using methods in U.S. Geological Survey Office of Surface Water Technical Memorandum 2013.01 (Mason, 2012).

[c]Low-flow regulation only.

[d]Discharge unknown.

[e]Determined using AEP estimates that were computed using PEAKFQ and weighted with regional regression equation estimates from Weaver and others (2009).

[f]Determined using AEP estimates that were computed using PEAKFQ and weighted with regional regression equation estimates from Feaster and others (2014).

Table 4. Flood-frequency statistics for selected U.S. Geological Survey streamgages in North Carolina.

[USGS, U.S. Geological Survey, AEP, annual exceedance probability; G, estimated from Bulletin 17B (Interagency Advisory Committee on Water Data, 1982) analysis of the streamgaging station; R, estimated from the regression equation; W, weighted estimate; —, not applicable for regulated streamgages]

USGS station number	Number of annual peaks	Historical period of record (years)	Discharge, in cubic feet per second											
			50-percent chance AEP			20-percent chance AEP			10-percent chance AEP			4-percent chance AEP		
			G	R	W	G	R	W	G	R	W	G	R	W
0208111310	30	none	1,920	1,260	1,730	4,570	2,320	3,700	7,250	3,120	5,330	12,000	4,190	7,560
02082585	41	none	7,970	10,900	8,120	12,200	17,700	12,500	15,300	22,600	15,900	19,400	28,500	20,300
02083500	116	121	13,800	16,000	13,800	20,800	26,000	20,900	26,100	33,100	26,300	33,500	41,800	33,900
02084000	22	130	15,700	16,300	15,800	25,000	26,800	25,200	32,000	34,100	32,200	41,600	43,200	41,800
02087275	21	none	3,800	4,020	3,820	5,920	6,200	5,960	7,540	7,690	7,580	9,840	9,590	9,760
02088000	78	none	1,520	1,820	1,540	3,010	3,210	3,030	4,410	4,230	4,380	6,730	5,550	6,480
02089000	34	89	10,100	—	—	15,900	—	—	20,700	—	—	28,300	—	—
02089500	34	99	10,300	—	—	15,600	—	—	19,700	—	—	25,600	—	—
02091500	89	94	4,120	5,280	4,160	6,940	9,160	7,050	9,250	12,000	9,420	12,700	15,600	13,000
02102500	36	none	26,200	—	—	36,400	—	—	43,000	—	—	50,900	—	—
02102908	49	none	122	119	122	226	202	223	316	264	307	458	345	431
02103000	26	none	2,900	2,180	2,810	4,800	3,500	4,580	6,250	4,500	5,890	8,310	5,800	7,660
02104220	29	none	637	809	657	1,140	1,330	1,170	1,580	1,720	1,610	2,260	2,230	2,250
02105500	34	37	27,800	—	—	37,300	—	—	44,100	—	—	53,200	—	—
02105769	37	none	24,300	—	—	34,500	—	—	42,100	—	—	52,500	—	—
02106500	66	90	4,440	4,140	4,420	8,070	7,320	8,000	11,300	9,680	11,100	16,300	12,700	15,700
02108000	77	110	5,140	3,820	5,080	8,500	6,780	8,390	11,200	8,990	11,000	15,100	11,800	14,700
02109500	76	78	3,910	4,150	3,920	6,980	7,340	7,010	9,530	9,720	9,550	13,300	12,800	13,200
02132320	28	30	481	926	509	750	1,640	819	944	2,180	1,060	1,200	2,890	1,400
02133500	78	none	1,310	1,330	1,310	2,330	2,150	2,310	3,240	2,780	3,190	4,720	3,590	4,520
02133624	29	30	1,780	2,300	1,810	2,680	3,740	2,760	3,320	4,830	3,470	4,190	6,240	4,440
02134170	17	122	2,770	4,030	2,960	4,680	6,780	5,020	6,170	8,850	6,620	8,280	11,500	8,870
02134480	32	none	1,400	2,050	1,490	2,790	3,710	2,960	4,070	4,970	4,300	6,200	6,610	6,340
02134500	88	122	4,960	5,970	4,990	8,180	10,100	8,250	10,700	13,300	10,900	14,500	17,200	14,700

Table 4. Flood-frequency statistics for selected U.S. Geological Survey streamgages in North Carolina.—Continued

[USGS, U.S. Geological Survey, AEP, annual exceedance probability; G, estimated from Bulletin 17B (Interagency Advisory Committee on Water Data, 1982) analysis of the streamgaging station; R, estimated from the regression equation; W, weighted estimate; —, not applicable for regulated streamgages]

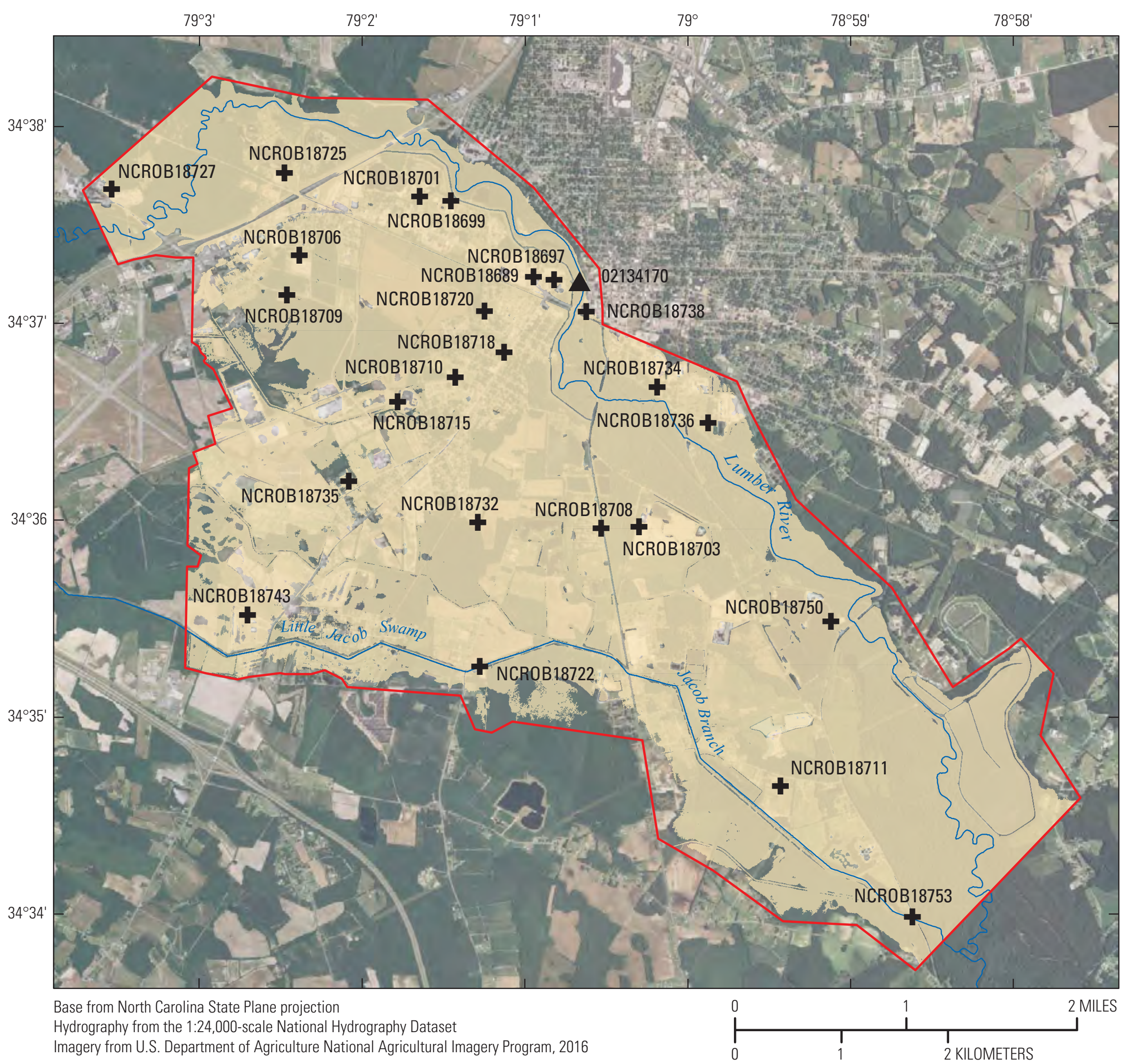
USGS station number	Number of annual peaks	Historical period of record (years)	Discharge, in cubic feet per second											
			2-percent chance AEP			1-percent chance AEP			0.5-percent chance AEP			0.2-percent chance AEP		
			G	R	W	G	R	W	G	R	W	G	R	W
0208111310	30	none	16,600	5,130	9,380	22,300	6,140	11,300	29,300	7,040	13,100	41,000	8,420	15,700
02082585	41	none	22,700	33,800	24,100	26,100	38,500	27,900	29,700	43,000	31,900	34,700	49,800	37,600
02083500	116	121	39,500	49,500	40,100	45,900	56,600	46,700	52,800	63,100	53,700	62,700	73,000	63,900
02084000	22	130	49,400	51,300	49,700	57,700	58,800	57,900	66,500	65,700	66,300	79,100	76,200	78,400
02087275	21	none	11,700	11,000	11,400	13,800	12,300	13,100	16,000	13,800	14,900	19,300	15,600	17,200
02088000	78	none	8,940	6,710	8,350	11,600	7,840	10,400	14,800	8,890	12,600	20,100	10,500	15,800
02089000	34	89	35,000	—	—	42,900	—	—	52,000	—	—	66,400	—	—
02089500	34	99	30,500	—	—	35,900	—	—	41,800	—	—	50,600	—	—
02091500	89	94	15,700	18,800	16,100	19,000	22,100	19,500	22,800	25,000	23,200	28,600	29,400	28,700
02102500	36	none	56,600	—	—	62,100	—	—	67,500	—	—	74,600	—	—
02102908	49	none	586	404	533	734	462	640	904	531	757	1,170	608	914
02103000	26	none	9,990	6,770	9,020	11,800	7,680	10,400	13,700	8,820	11,900	16,500	10,100	13,800
02104220	29	none	2,870	2,610	2,780	3,580	2,980	3,340	4,400	3,420	3,960	5,690	3,910	4,790
02105500	34	37	60,500	—	—	68,200	—	—	76,300	—	—	87,900	—	—
02105769	37	none	61,000	—	—	70,100	—	—	79,800	—	—	93,800	—	—
02106500	66	90	20,900	15,400	19,700	26,300	18,200	24,100	32,500	20,700	28,800	42,500	24,500	35,700
02108000	77	110	18,500	14,300	17,900	22,200	17,000	21,300	26,300	19,300	24,900	32,400	22,900	30,200
02109500	76	78	16,700	15,500	16,500	20,400	18,300	20,000	24,500	20,800	23,600	30,800	24,600	29,100
02132320	28	30	1,410	3,480	1,690	1,620	4,090	2,010	1,840	4,690	2,340	2,150	5,530	2,830
02133500	78	none	6,100	4,200	5,650	7,750	4,770	6,870	9,730	5,470	8,260	12,900	6,250	10,100
02133624	29	30	4,860	7,320	5,220	5,560	8,340	6,030	6,290	9,570	6,920	7,320	11,000	8,110
02134170	17	122	10,000	13,700	10,700	11,900	15,900	12,800	13,900	18,100	14,900	16,900	21,100	18,000
02134480	32	none	8,210	8,050	8,150	10,600	9,590	10,200	13,500	11,000	12,300	18,200	13,100	15,400
02134500	88	122	17,600	20,600	17,900	21,100	24,000	21,500	25,000	27,300	25,300	30,700	31,900	30,900

Flood-Inundation Maps

Seven flood-inundation maps were created for heavily flooded communities in North Carolina (figs. 4 to 10). Each map presents the areal extent of the flood waters. Information about the HWMs used to create the inundation maps, as well as digital datasets of the inundation area, modeling boundary, and water-depth rasters, are available for download at Watson and Musser, 2017. Details pertinent to the creation of specific flood-inundation maps are described in the following sections. All elevations are referenced to NAVD 88 unless otherwise noted.

Lumber River at Lumberton

The Lumber River generally flows southeast through south-central North Carolina and then into South Carolina. The extent of the inundation map around Lumberton in Robeson County is an 11.5-mi reach of the Lumber River and a 2.3-mi reach of Little Jacob Swamp, which flows into a 3.1-mi reach of Jacob Branch. A total of 27 USGS HWMs were documented and surveyed in the Lumberton area, and 24 were used to create the inundation map. Water-surface elevations at the HWMs ranged from 109.4 ft at NCROB18753 to 125.5 ft at NCROB18727. Elevation data from the USGS streamgaging station, Lumber River at Lumberton, NC (02134170), were also used in the creation of the inundation map. The streamgaging station recorded a peak flow of 14,600 ft^3/s, a peak stage of 21.87 ft gage datum, and a water-surface elevation of 119.26 ft on October 10, 2016. Eleven cross sections were created and used with the HWMs to generate a flood-elevation surface. Precipitation ranged from about 4.6 to 16.1 inches in the Lumber River Basin during October 7–9 (fig. 3). The aerial extent of flood inundation for this location is shown in figure 4.



EXPLANATION

Inundated area

Modeled area boundary

02134170 U.S. Geological Survey streamgaging station and number

NCROB18753 High-water mark with map identification

Figure 4. Flood-inundation map, Lumber River at Lumberton, North Carolina, October 2016.

Lumber River at Fair Bluff

The extent of the inundation map around Fair Bluff is a 3.5-mi reach of the Lumber River along the Robeson and Columbus County line. A total of six USGS HWMs were documented and surveyed along the Lumber River, and five were used to create the inundation map. Water-surface elevations at the HWMs ranged from 65.1 ft at NCCOL18749 to 67.8 ft at NCCOL18768. Five cross sections were created and used to generate a flood-elevation surface. Because the Lumber River flood plain is approximately 3.5 mi wide and all of the HWMs are located on one side of the river, the inundation map does not extend to the far edge of the flood plain. The aerial extent of flood inundation for this location is shown in figure 5.

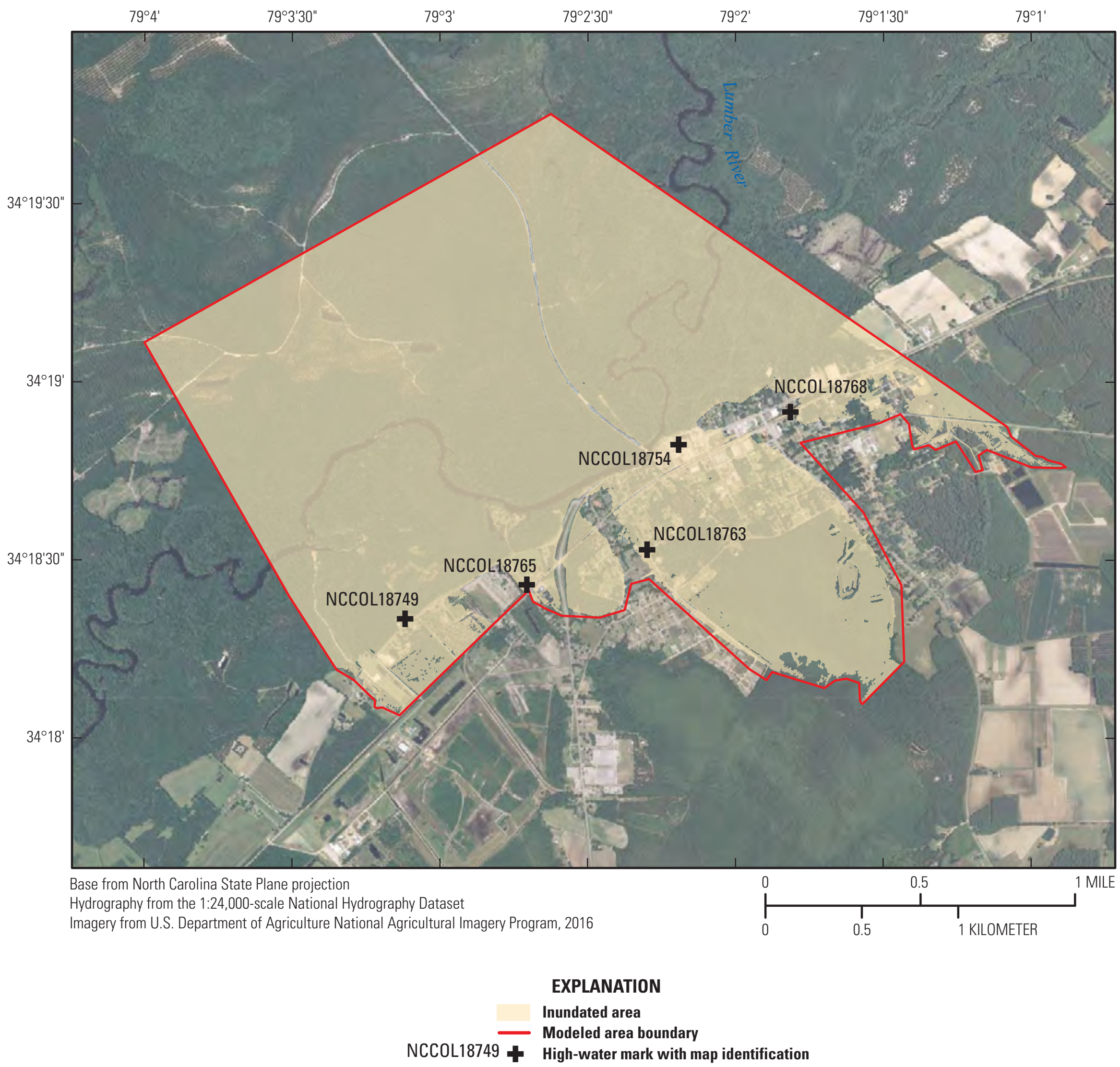


Figure 5. Flood-inundation map, Lumber River at Fair Bluff, North Carolina, October 2016.

Neuse River at Smithfield

The Neuse River generally flows southeast through central and eastern North Carolina. The extent of the inundation map around Smithfield in Johnston County is a 4.8-mi reach of the Neuse River, a 2.6-mi reach of Swift Creek, and a 2.4-mi reach of Middle Creek. Additionally, a 2.6-mi section of Holts Lake on Black Creek south of Smithfield was mapped. A total of 10 USGS HWMs were documented—seven on the Neuse River, one on Swift Creek, one on Middle Creek, and one on Holts Lake. Water-surface elevations at the HWMs ranged from 122.9 ft at NCJOH18782 to 128.5 ft on the Neuse River at NCJOH18797. The peak HWM on Swift Creek was 127.2 ft at NCJOH18798, and the peak HWM

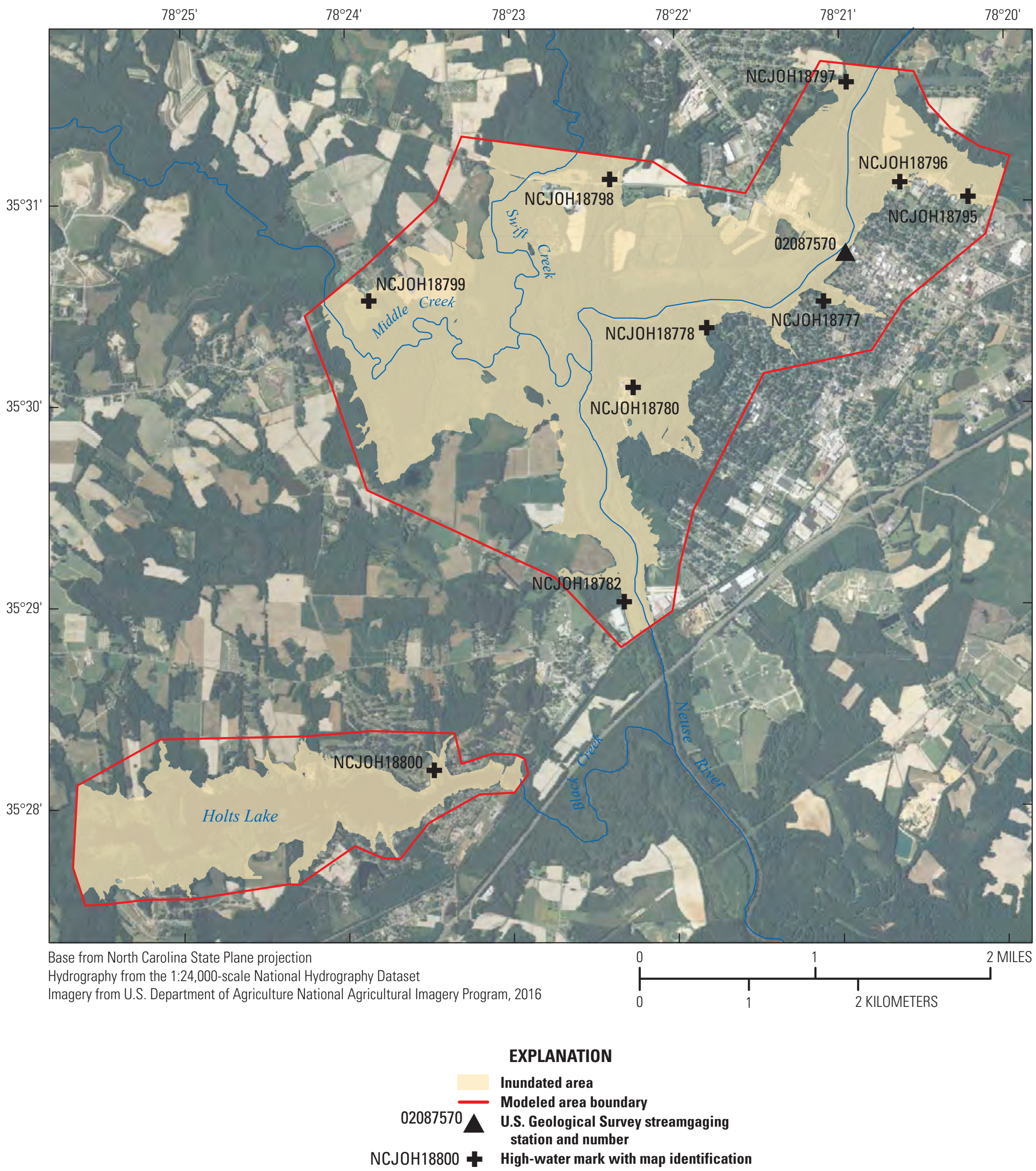
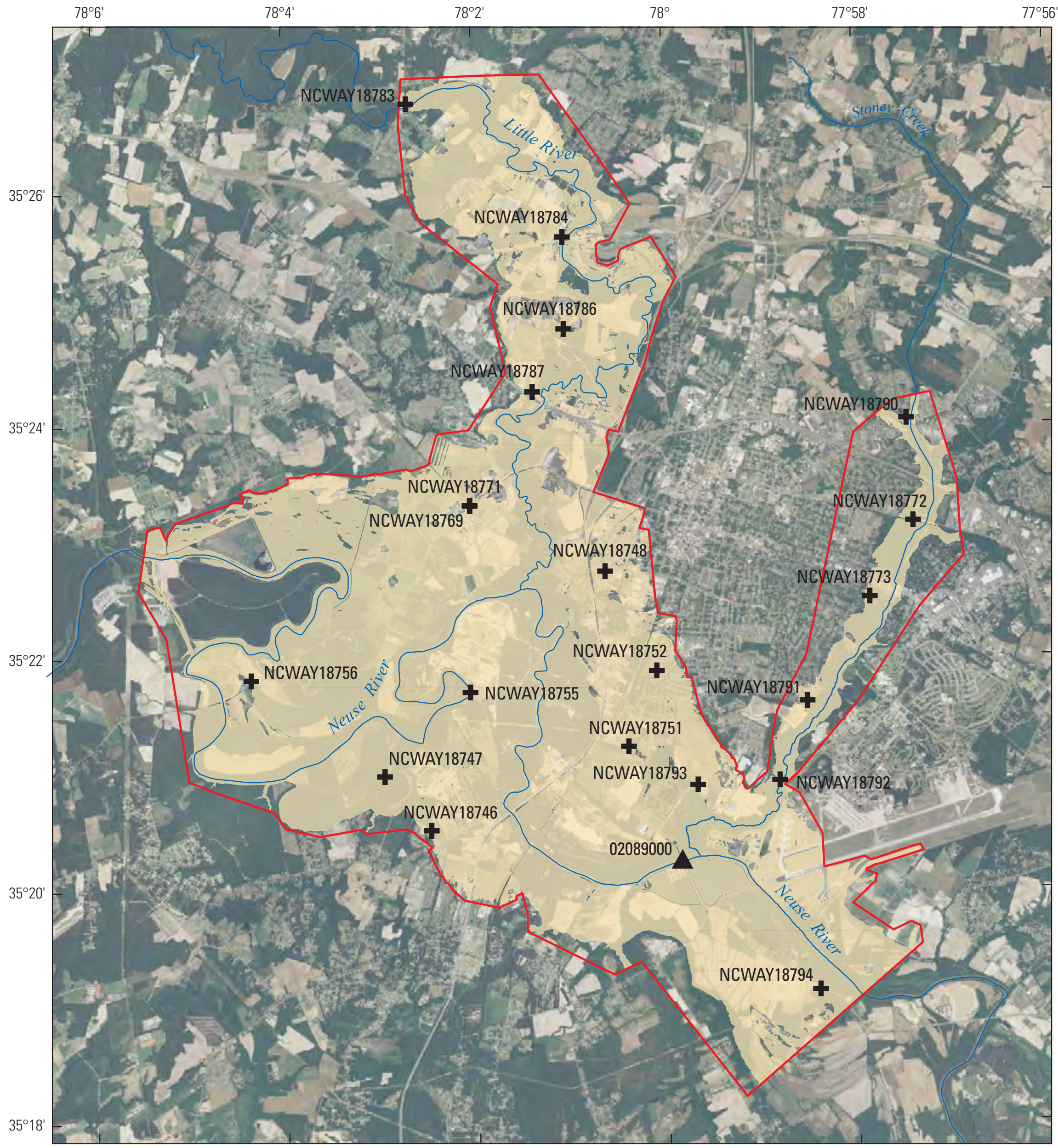


Figure 6. Flood-inundation map, Neuse River at Smithfield, North Carolina, October 2016.

on Middle Creek was 127.0 ft at NCJOH18799. The USGS stage only streamgaging station Neuse River at Smithfield, NC (02087570), recorded a peak stage of 29.09 ft gage datum and a water-surface elevation of 128.35 ft National Geodetic Vertical Datum of 1929 (NGVD 29) on October 9, 2016. The water-surface elevation was converted to 127.40 ft NAVD 88 using National Geodetic Survey VERTCON (National Geodetic Survey, 2017). This elevation was also used in the creation of the inundation map. Because the streamgage is stage only, flood-frequency computations could not be made at this location, and, therefore, the streamgage is not included in figures 2 and 3, and tables 3 and 4. Ten cross sections were used along the Neuse River, Swift Creek, and Middle Creek to generate the flood-elevation surface. In the area around Holts Lake, a constant surface of 122.3 ft, which was based on the HWM NCJOH18800, was used to determine the flood extent. Precipitation ranged from about 4.1 to 14.7 inches in the Neuse River Basin during October 7–9 (fig. 3). The aerial extent of flood inundation for this location is shown in figure 6.

Neuse River near Goldsboro

The Neuse River generally flows east through Goldsboro in Wayne County, and the Little River and Stoney Creek flow south into the Neuse River near Goldsboro. The extent of the inundation map around Goldsboro is a 20.8-mi reach of the Neuse River, an 11.8-mi reach of the Little River, and a 6.3-mi reach of Stoney Creek. A total of 22 USGS HWMs were documented and surveyed, and 20 were used to create the inundation map. Water-surface elevations at the HWMs on the Neuse River ranged from 69.2 ft at NCWAY18794 to 76.5 ft at NCWAY18756. The water-surface elevation on the Little River was 91.2 ft at NCWAY18783 and on Stoney Creek was 95.0 at NCWAY18790. Elevation data from the USGS streamgaging station Neuse River near Goldsboro, NC (02089000), were also used in the creation of the inundation map. The streamgaging station recorded a peak flow of 54,300 ft^3/s, a peak stage of 29.74 ft gage datum, and a water-surface elevation of 72.69 ft NGVD 29 on October 12, 2016. The water-surface elevation was converted to 71.67 ft NAVD 88 using VERTCON (National Geodetic Survey, 2017). Seventeen cross sections were create—eight on the Neuse River, four on the Little River, and five on Stoney Creek—to generate the flood-elevation surface. The aerial extent of flood inundation for this location is shown in figure 7.



Base from North Carolina State Plane projection
Hydrography from the 1:24,000-scale National Hydrography Dataset
Imagery from U.S. Department of Agriculture National Agricultural Imagery Program, 2016

0 1 2 MILES
0 1 2 KILOMETERS

EXPLANATION

- Inundated area
- Modeled area boundary
- 02089000 U.S. Geological Survey streamgaging station and number
- NCWAY18794 High-water mark with map identification

Figure 7. Flood-inundation map, Neuse River near Goldsboro, North Carolina, October 2016.

Neuse River at Kinston

The extent of the inundation map around Kinston in Lenoir County is a 9.3-mi reach of the Neuse River and a 5.0-mi reach of Southwest Creek. A total of 21 NCEM HWMs were documented and surveyed along the Neuse River and Southwest Creek, and 10 were used to create the inundation map. The elevation of water at the HWMs ranged from 32.9 ft at HWM 6 to 46.0 ft at HWM 8. Elevation data from the USGS streamgaging station Neuse River at Kinston, NC (02089500), were also used in the creation of the inundation map. The streamgaging station recorded a peak flow of 38,200 ft^3/s, a peak stage of 28.31 ft gage datum, and a water-surface elevation of 39.21 ft NGVD 29 on October 14, 2016. The water-surface elevation was converted to 38.05 ft NAVD 88 using VERTCON (National Geodetic Survey, 2017). Eight cross sections were created—six on the Neuse River and two on Southwest Creek—to generate the flood-elevation surface. The aerial extent of flood inundation for this location is shown in figure 8.

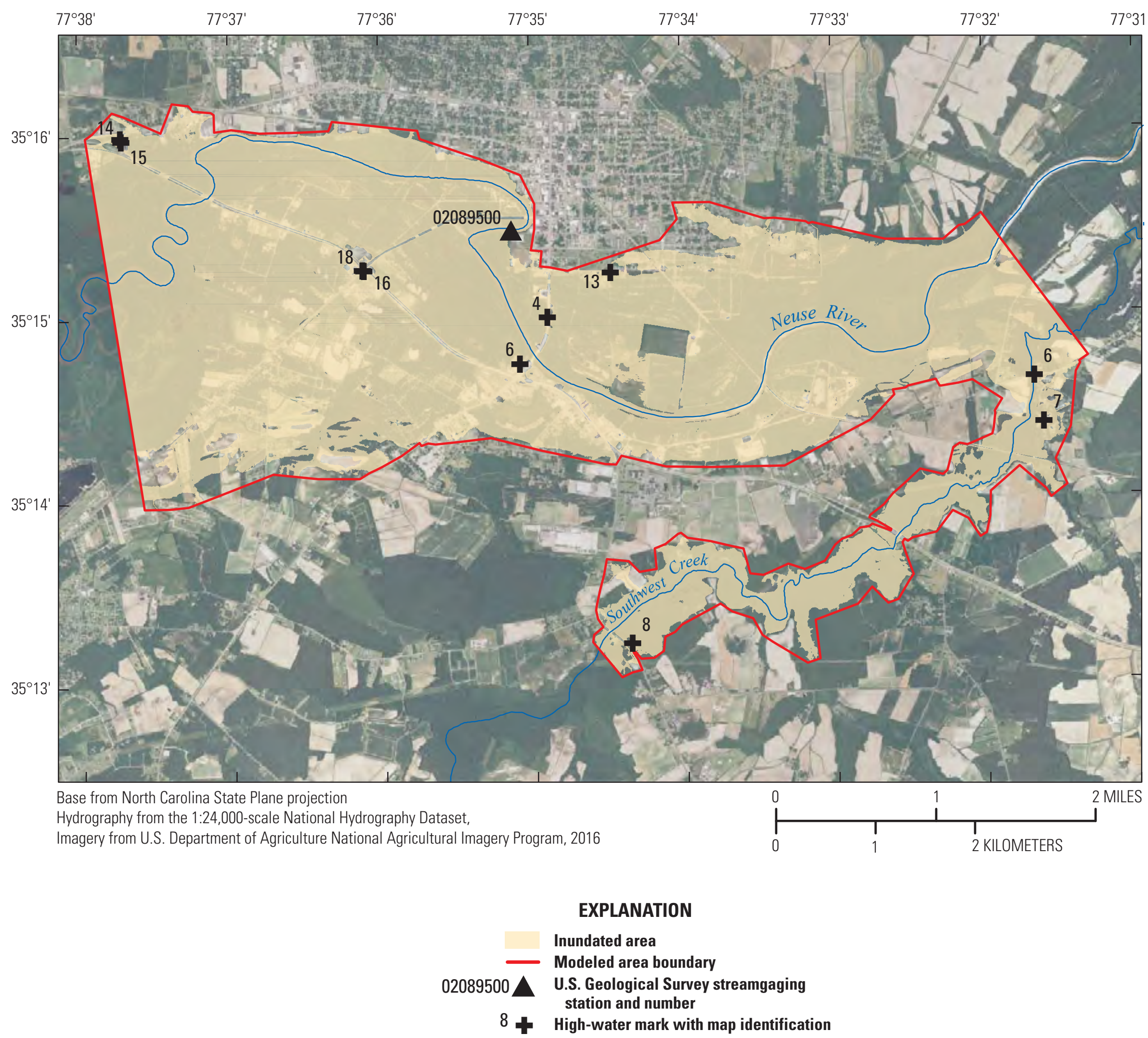


Figure 8. Flood-inundation map, Neuse River at Kinston, North Carolina, October 2016.

Rockfish Creek at Hope Mills

Little Rockfish Creek and Rockfish Creek flow east to the Cape Fear River in southeast North Carolina. The extent of the inundation map is a 3.2-mi reach of Little Rockfish Creek and a 1.5-mi reach of Rockfish Creek through Hope Mills in Cumberland County. A total of nine HWMs were documented and surveyed along the Little Rockfish Creek and Rockfish Creek, and seven were used to create the inundation map. Water-surface elevations at the HWMs ranged from 100.7 ft at NCCUM18714 on Rockfish Creek to 111.3 ft at NCCUM18726 on Little Rockfish Creek. Seven cross sections were created—three on Rockfish Creek and four on Little Rockfish Creek—to generate the flood-elevation surface. Precipitation ranged from about 6.9 to 13.8 inches in the Rockfish Creek Basin during October 7–9 (fig. 3). The aerial extent of flood inundation for this location is shown in figure 9.

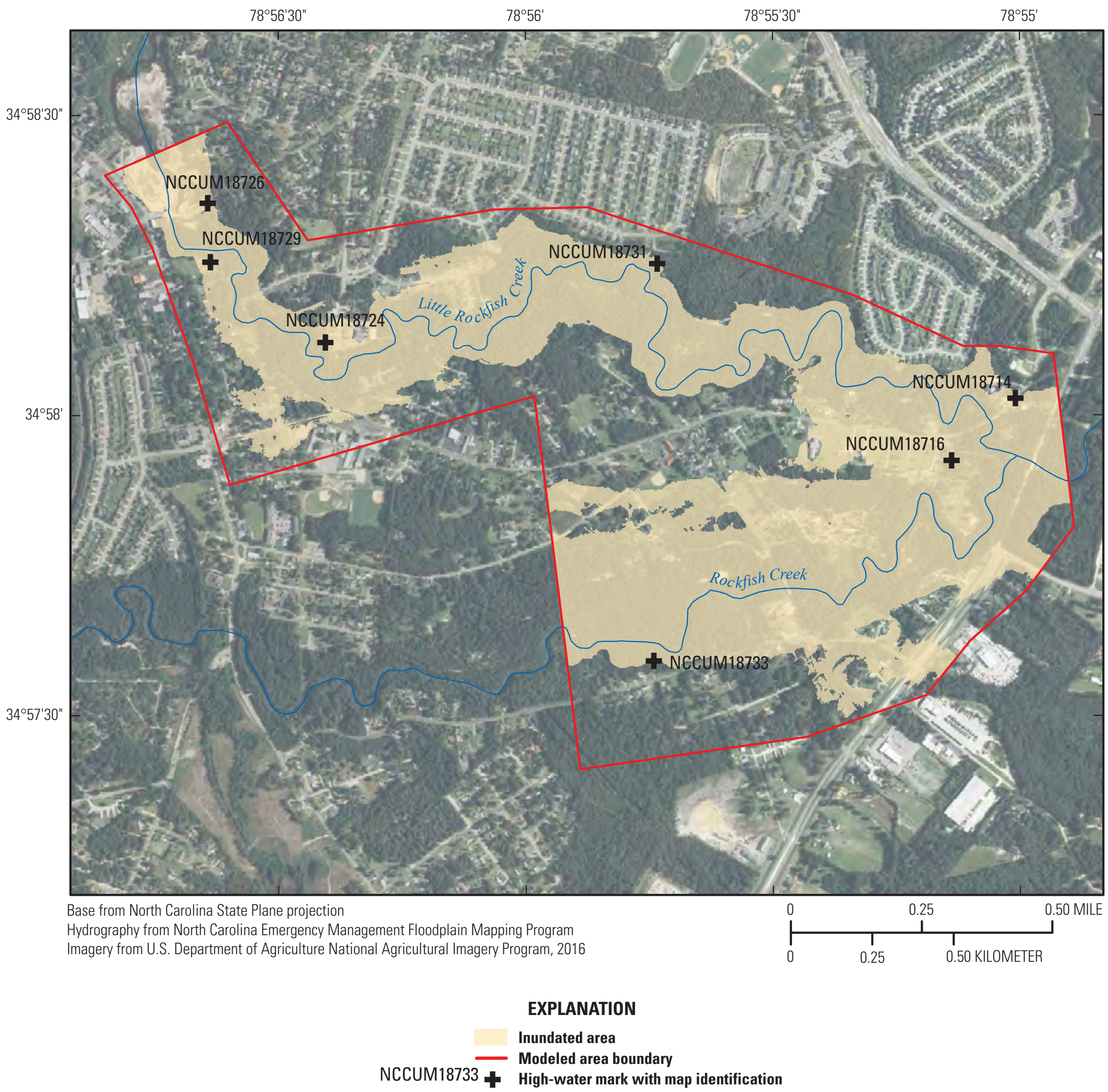


Figure 9. Flood-inundation map, Rockfish Creek at Hope Mills, North Carolina, October 2016.

Tar River at Princeville

The Tar River generally flows southeast through central and eastern North Carolina. The Tar River flows between the towns of Tarboro, to the northwest, and Princeville, to the southeast. A levee is located along the Princeville side of the Tar River. A total of 12 HWMs used to create the inundation map were documented and surveyed by the North Carolina Geodetic Survey (NCGS) in the vicinity of the Tar River on the town side of the levee within the town of Princeville during May 2017. The U.S. Army Corps of Engineers (USACE) had previously identified HWMs, which were surveyed by NCEM along the Tar River and around Prince-ville; however, it was subsequently determined that these marks did not represent peak water elevations. These water marks were used to monitor the differences in water elevation on either side of the levee during the flood (Wesley Brown, U.S. Army Corps of Engineers, written commun., April 4, 2017). Additional water marks were documented by the USACE but were not surveyed. Water-surface elevations at the NCGS-surveyed HWMs ranged from 44.27 ft at water marks FD 1 and RR 1 to 44.57 ft at water mark SS 1 over a reach of 2.1 miles. Elevation data from the USGS streamgaging station Tar River at Tarboro, NC (02083500), recorded a peak flow of 42,500 ft^3/s, a peak stage of 36.29 ft gage datum, and a water-surface elevation of 45.61 ft on October 12, 2016. Precipitation ranged from about 14.4 to 13.2 inches in the Tar River Basin during October 7–9 (fig. 3). The aerial extent of flood inundation within Princeville is shown in figure 10.

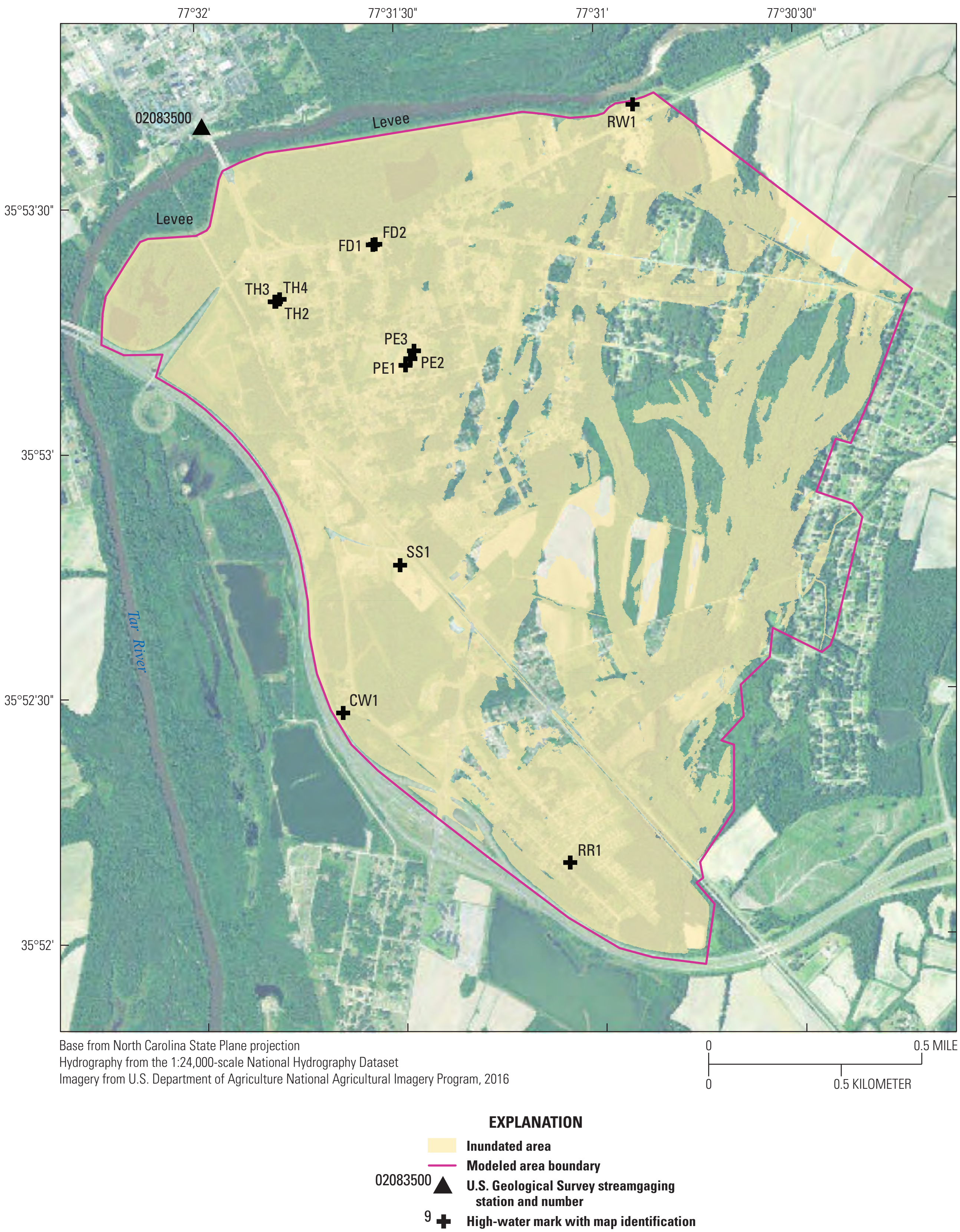


Figure 10. Flood-inundation map, Tar River at Princeville, North Carolina, October 2016.

Summary

In October 2016, rainfall from Hurricane Matthew caused flooding on numerous streams and rivers in central and eastern North Carolina. Rainfall totals of 3 inches to more than 15 inches were widespread throughout the area. More than 600 roads were closed, and nearly 99,000 structures were affected by floodwaters. The U.S. Geological Survey (USGS) documented 267 high-water marks (HWM) during the period October 9–24, 2016. Of these, 254 HWMs were surveyed to elevation above the North American Vertical Datum of 1988. In addition, North Carolina Emergency Management identified and surveyed 353 HWMs, and the North Carolina Geodetic Survey identified and surveyed 12 HWMs in Princeville. The HWMs were used to create seven maps showing the areas of inundation in seven heavily flooded communities. Additionally, the depth of the water in the mapped inundated areas was calculated, and a water-depth raster was created. The flood-inundation maps, water-depth rasters, and mapping boundaries are available for download. Flood-peak gage heights, peak streamflows, and estimated annual exceedance probabilities were calculated for 24 USGS streamgages located within or near the areas that were mapped. Additional information, including a download portal for HWM information, is available from the USGS Hurricane Matthew web page (https://water.usgs.gov/floods/events/2016/matthew/, accessed November 29, 2016).

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Glossary

The following definitions, except where noted, are from Langbein and Iseri (1960).

cubic feet per second A unit expressing rates of discharge. One cubic foot per second is equal to the discharge of a stream of rectangular cross section, 1 foot wide and 1 foot deep, flowing water an average velocity of 1 foot per second.

flood peak The highest value of the stage or discharge attained by a flood—thus, peak stage or peak discharge. Flood crest has nearly the same meaning, but because it connotes the top of the flood wave, it is properly used only in referring to stage—thus, crest stage, but not crest discharge.

flood exceedance probability The probability that a given event magnitude will be exceeded or equaled in any given year. Flood exceedance probability is directly related to recurrence interval. For example, there is a 1-percent chance that the 100-year peak flow will be exceeded or equaled in any given year. A flood exceedance probability of 0.01 has a recurrence interval of 100 years. The recurrence interval corresponding to a particular flood exceedance probability is equal to one divided by the flood exceedance probability (Interagency Advisory Committee on Water Data, 1982).

gage height The water-surface elevation referred to some arbitrary gage datum. Gage height is often used interchangeably with the more general term stage although gage height is more appropriate when used with a reading on a streamgage.

recurrence interval (return period) The average interval of time within which the given flood will be equaled or exceeded once. The recurrence interval is directly related to the flood exceedance probability. The recurrence interval corresponding to a particular flood exceedance probability is equal to one divided by the flood exceedance probability. For example, a 100-year recurrence interval has a flood exceedance probability of 0.01 (Interagency Advisory Committee on Water Data, 1982).

stream A general term for a body of flowing water. In hydrology the term is generally applied to the water flowing in a natural channel as distinct from a canal.

streamflow The discharge that occurs in a natural channel. Although the term discharge can be applied to the flow of a canal, the word streamflow uniquely describes the discharge in a surface stream course.

streamgage For the purposes of this report, the term is used to denote a gaging station where a continuous record of gage height (stage), velocity, or other properties are collected for the purpose of determining streamflow (Interagency Advisory Committee on Water Data, 1982).

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