Prepared in cooperation with the Federal Emergency Management Agency

Characterization of Peak Streamflows and Flood Inundation of Selected Areas in Louisiana from the August 2016 Flood

Scientific Investigations Report 2017–5005

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

Front cover. Neighborhood west of the Amite River at the Denham Springs streamflow-gaging station, Louisiana, August 13, 2016. Photograph by James Fountain, U.S. Geological Survey.

Back cover. Flooded home near Amite River, Port Vincent, Louisiana, August 16, 2016. Photograph by James Fountain, U.S. Geological Survey.
Map showing study area and location of flood-inundation mapping extents in Louisiana for the August 2016 flood.

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

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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 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
NOAA	National Oceanic and Atmospheric Administration
USGS	U.S. Geological Survey

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Abstract

Heavy rainfall occurred across Louisiana and southwestern Mississippi in August 2016 as a result of a slow-moving area of low pressure and a high amount of atmospheric moisture. The storm caused major flooding in the southern portions of Louisiana including areas surrounding Baton Rouge and Lafayette. Flooding occurred along the rivers such as the Amite, Comite, Tangipahoa, Tickfaw, Vermilion, and Mermentau Rivers. Over 31 inches of rain was reported in the city of Watson, 20 miles northeast of Baton Rouge, La., over the duration of the event. Streamflow-gaging stations operated by the U.S. Geological Survey (USGS) recorded peak streamflows of record at 10 locations, and 7 other locations experienced peak streamflows ranking in the top five for the duration of the period of record. In August 2016, USGS hydrographers made 50 discharge measurements at 21 locations on streams in Louisiana. Many of those discharge measurements were made for the purpose of verifying the accuracy of stage-streamflow relations at gaging stations operated by the USGS. Following the storm event, USGS hydrographers recovered and documented 590 high-water marks, noting location and height of the water above land surface. Many of these high-water marks were used to create 12 flood-inundation maps for selected communities of Louisiana that experienced flooding in August 2016. Digital datasets of the inundation area, modeling boundary, water depth rasters, and final map products are available online.

Introduction

A slow-moving sheared inland tropical depression gained energy and moisture as it moved from the Southeast across the gulf coast to Louisiana and southwestern Mississippi during the period of August 9–14, 2016. The majority of the rain fell in Louisiana from August 11 to 14 and caused major flooding across southern Louisiana, with rainfall amounts exceeding 31 inches (in.) in some areas (National Oceanic and Atmospheric Administration, 2016; fig.1). Historic flooding occurred in areas of Louisiana as a result of the prolonged, heavy rainfall. Damages resulting from flooding were estimated to be $10 billion (National Oceanic and Atmospheric Administration, 2016a) and resulted in at least 13 fatalities (National Oceanic and Atmospheric Administration, 2016b). In the immediate aftermath of the August 2016 flood, the U.S. Geological Survey (USGS) and the Federal Emergency Management Agency (FEMA) initiated a cooperative study to evaluate the flood's magnitude, extent, and probability of occurrence. Flood-peak streamflow data were recorded for 16 streamflow-gaging stations operated by the USGS in Louisiana (table 1, fig. 1).

Purpose and Scope

The purpose of this report is to document the data collection, flood-peak magnitudes, and flood-inundation products generated by the USGS in support of the FEMA response and recovery operations following the August 2016 flood event in Louisiana. The technical scope of the report includes (1) description of the atmospheric conditions and 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 probabilities at selected locations, and (3) the identification and surveying of high-water marks (HWM) and the geographic information system (GIS) analysis of HWM locations and elevations to produce flood-inundation maps (areal extent and depth of flooding) for six heavily flooded areas in Louisiana.

Study Area

The geographic scope of the report encompasses most of southern Louisiana. Areas affected by flooding described within this report lie within the West Gulf Coastal Plain, Mississippi Alluvial Plain, and East Gulf Coastal Plain physiographic sections (Fenneman, 1946; fig. 1). In general, the area consists of rolling hills in the northern parts of the study area and flat lands with swamps and marshes in the

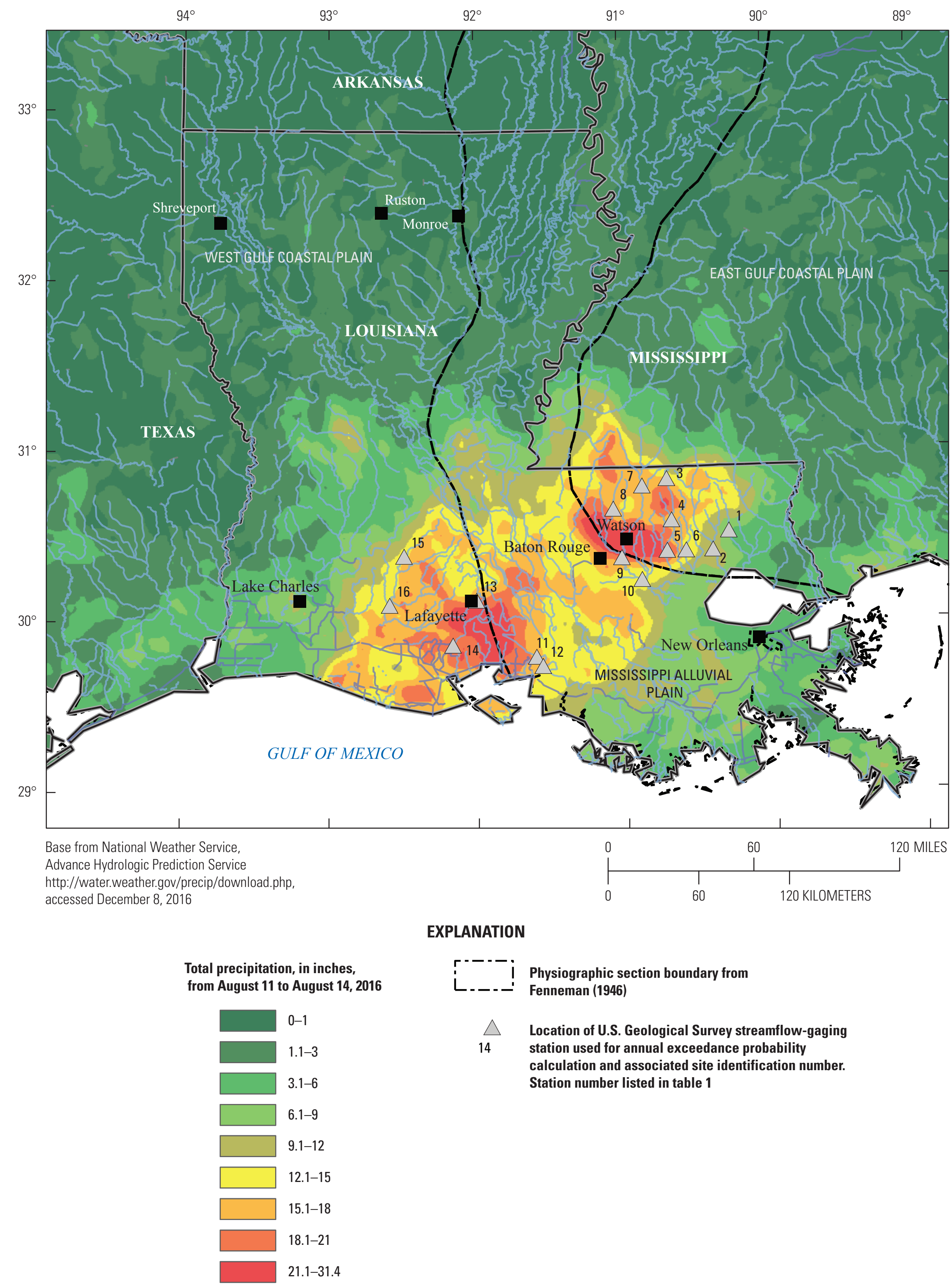


Figure 1. Cumulative rainfall from August 11 to August 14, 2016, and location of U.S. Geological Survey streamflow-gaging stations used to calculate annual exceedance probabilities.

Table 1. Site identification number, station information, peak information, location, and drainage area of U.S. Geological Survey streamflow-gaging stations.

[mi², square miles; LA, Louisiana; --, no data]

Site identification number (fig. 1)	Station number	Station name	Drainage area (mi²)	Latitude (decimal degrees)	Longitude (decimal degrees)
1	07375000	Tchefuncta River near Folsom, LA	103	30.61602	-90.24870
2	07375500	Tangipahoa River at Robert, LA	646	30.50658	-90.36175
3	07375800	Tickfaw River at Liverpool, LA	89.7	30.93074	-90.67343
4	07375960	Tickfaw River at Montpelier, LA	220	30.68630	-90.64315
5	07376000	Tickfaw River at Holden, LA	247	30.50380	-90.67732
6	07376500	Natalbany River at Baptist, LA	79.5	30.50436	-90.54592
7	07377000	Amite River near Darlington, LA	580	30.88907	-90.84455
8	07377500	Comite River near Olive Branch, LA	145	30.75657	-91.04399
9	07378500	Amite River near Denham Springs, LA	1,280	30.46408	-90.99038
10	07380120	Amite River at Port Vincent, LA	1,596	30.33269	-90.85204
11	07385765	Bayou Teche at Adeline Bridge near Jeanerette, LA	--	29.87937	-91.58622
12	07385790	Charenton Drainage and Navigation Canal at Baldwin, LA	--	29.82306	-91.54167
13	07386880	Vermilion River at Surrey Street at Lafayette, LA	--	30.21742	-91.99290
14	07386980	Vermilion River at Perry, LA	--	29.95111	-92.15636
15	08010000	Bayou Des Cannes near Eunice, LA	131	30.48289	-92.49069
16	08012150	Mermentau River At Mermentau, LA	1,381	30.19000	-92.59056

southern parts of the study area. Land-surface elevations within the affected areas range in elevation from about -1 to about 400 feet (ft) relative to the North American Vertical Datum of 1988 (NAVD 88). The 30-year normal rainfall from 1981 to 2010 in Louisiana varies from 49 in. in northwestern Louisiana to 68 in. in southern Louisiana (Durre and others, 2012).

Weather Conditions Prior to and During the Flood

Heavy rainfall occurred across Louisiana and southwestern Mississippi during August 11–14, 2016, as a result of a slow-moving sheared inland tropical depression, which gained energy and moisture as it moved as a low pressure system across the gulf coast into Louisiana and southern Mississippi. The system tapped into deep tropical moisture resulting in intense rainfall and thunderstorms across a large part of the area causing major flooding across southern Louisiana.

The NOAA rainfall data showed the heaviest rainfall occurred across a swath of East Baton Rouge, Livingston, and St. Helena Parishes, where 20 to more than 31 in. fell over a 48-hour period, topping the 0.2-percent annual exceedance probability (AEP) (National Oceanic and Atmospheric Administration, 2016c). The city of Watson, La., received 31.39 in. of rain during August 11–14, and the town of Livingston recorded 17 in. of rain in a single day (National Oceanic and Atmospheric Administration, 2016d). Two-day rainfall totals of 20 in. or more were common across areas around Baton Rouge and Lafayette. Table 2 lists rainfall totals for the flood event for selected NOAA precipitation stations across southern Louisiana.

The heavy rainfall led to widespread flash flooding and record river flooding. Many of the broken records had been previously set during the flooding of April 1983. In total, 13 people died in southern Louisiana as a result of the flooding. The event was also responsible for an estimated total of $10 billion in damages across southern Louisiana and southwestern Mississippi (National Oceanic and Atmospheric Administration, 2016a). This estimate includes impacts of the initial flash flooding and the resultant river flooding. August 2016 was the wettest month on record for Louisiana with a statewide average of 12.9 in., topping the previous record of 9.71 in. set in August 1940 (National Oceanic and Atmospheric Administration, 2016d).

Some of the same communities and rivers in Louisiana that flooded in August also flooded in March 2016 from heavy rainfall that occurred across Louisiana, Texas, Arkansas, and Mississippi (Breaker and others, 2016). The areas around

Table 2. Rainfall totals reported from National Oceanic and Atmospheric Administration meteorological stations during August 11–14, 2016, floods in Louisiana. (From National Oceanic and Atmospheric Administration Climatological Data, 2016e)

[NE, northeast; LSU, Louisiana State University; SW, southwest; FCWOS, FAA contract weather observing station; AP, Airport]

Location	Rainfall amounts (inches)
New Roads 5 NE, Pointe Coupee Parish, Louisiana	16.07
Opelousas, St. Landry Parish, Louisiana	15.83
Baton Rouge Metro Airport, East Baton Rouge, Louisiana	18.07
Livingston, Livingston Parish, Louisiana	26.33
LSU Ben-Hur Farm, Baton Rouge, East Baton Rouge Parish, Louisiana	13.07
Norwood, East Feliciana Parish, Louisiana	23.02
Pine Grove Fire Tower (7 miles west of Montpelier), St. Helena Parish, Louisiana	17.55
Ponchatoula, Tangipahoa Parish, Louisiana	8.61
St. Francisville, West Feliciana Parish, Louisiana	19.38
Abbeville, Vermilion Parish, Louisiana	19.05
Crowley 2 NE, Acadia Parish, Louisiana	16.96
Jennings, Jefferson Davis Parish, Louisiana	16.94
Kaplan, Vermilion Parish, Louisiana	15.23
Lake Arthur 7 SW, Jefferson Davis Parish, Louisiana	15.59
Donaldsonville 4 SW, Ascension Parish, Louisiana	15.59
Lafayette FCWOS, Lafayette Parish, Louisiana	21.35
New Iberia AP-Acadiana Regional, Iberia Parish, Louisiana	23.03
St. Martinsville, St. Martin Parish, Louisiana	25.1
Jeanerette 5 NW, Iberia Parish, Louisiana	17.88
Dutchtown #2, Ascension Parish, Louisiana	16.9
Gonzales, Ascension Parish, Louisiana	14.54

the Amite River, Tangipahoa River, and Tickfaw River, in particular, experienced high peak streamflow from both events. A comparison of the peak streamflow data from the August and March 2016 floods is shown in table 3.

Methods

The methods by which HWMs resulting from flooding were identified, documented, and referenced as well as the methods used to create flood-inundation maps using these HWMs are discussed in this section. The estimation of flood magnitude and frequency were developed through analysis of the annual peak streamflows at 16 streamflow-gaging stations (table 1) operated by the USGS, and these methods are also discussed in this section. All streamflow data used in support of this report can be accessed from the USGS National Water Information System (U.S. Geological Survey, 2017).

Collection of High-Water-Mark Data

High-water marks provide valuable data for understanding flood events (Koenig and others, 2016). The best HWMs are formed from small seeds or floating debris carried by floodwaters that adhere to smooth surfaces or lodge in tree bark to form a distinct line. Stain lines on buildings, fences, and other structures also provide excellent marks. The HWMs are best identified immediately following the peak stage because time and weather may alter evidence of the peak water line. The HWMs collected for this flood event were made available through the USGS Short-Term Network (STN; U.S. Geological Survey, 2016), which is an online interface created to facilitate the dissemination of field data.

The USGS field crews identified 590 HWMs in Louisiana with a depth above land-surface measurement made in feet and 465 of these HWMs were surveyed for elevation above land surface. Identification and marking of HWMs began on August 23 and continued through September 10, 2016. After an acceptable HWM was identified, a more permanent identification mark was established, such as a Parker-Kalon nail with a disk, a stake, a chiseled mark, or a paint line. 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, NAVD 88.

During the mapping process, the HWMs used to create flood-inundation maps (Heal and Watson, 2017) were checked for location and elevation accuracy through comparison of field note diagrams and descriptions to aerial photography and detailed street and parcel maps. The HWM was not used if the location could not be determined accurately or the elevation was substantially different from other HWMs in the area.

Flood-Inundation Mapping

Twelve flood-inundation maps were created along impacted rivers using GIS for several communities in southern Louisiana (fig. 2). Flood-inundation maps are intended to estimate the aerial extent and depth of flooding that correspond to the HWMs identified and surveyed by USGS hydrographers following the flood event. Table 4 lists the community, parish, waterbody, reach length, 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 and a GIS interpolation technique. A geographic limit was placed on the extent of the

Table 3. Flood-peak gage heights and peak streamflows for the March and August 2016 floods and previous peak streamflows at selected U.S. Geological Survey streamflow-gaging stations in Louisiana.

[Data shown are considered provisional as of the date of publication. Peak of record shown in bold. ft, feet; ft^3/s, cubic feet per second; <, less than; NA, annual exceedance probability not computed; --, no data]

Station number	Maximum streamflow for August 2016 flood				
	Date	Peak gage height (ft)	Peak streamflow (ft^3/s)	Estimated annual exceedance probability (percent)	Rank/number of annual peak streamflows in record
07375000	8/13/2016	24.28	32,700	1	2/73
07375500	**8/13/2016**	**27.33**	**120,000**	<0.2	1/78
07375800	**8/12/2016**	**13.87**	**43,000**	0.9	1/60
07375960	**8/12/2016**	**26.04**	**120,000**	<0.2	1/44
07376000	**8/13/2016**	**22.16**	**35,800**	<0.2	1/76
07376500	**8/12/2016**	**25.58**	**22,100**	<0.2	1/73
07377000	**8/12/2016**	**22.54**	**116,000**	1	1/68
07377500	**8/13/2016**	**27.28**	**78,000**	<0.2	1/74
07378500	**8/14/2016**	**46.2**	**205,000**	<0.2	1/78
07380120	**8/15/2016**	**17.9**	**199,000**	<0.2	1/32
07385765	**8/14/2016**	**5.91**	**5,450 (2016–08–13)**	NA	1/19
07385790	8/13/2016	3.9	19,500 (2016–08–19)	NA	2/48
07386880	8/15/2016	17.62	5,260 (2016–08–21)	5	3/48
07386980	8/14/2016	13.75	15,400	4.4	2/31
08010000	8/16/2016	22.37	11,500 (2016–08–14)	1–2	2/77
08012150	8/18/2016	10.82	40,500	NA	4/72

Station number	Maximum streamflow for March 2016 flood			Previous maximum streamflow		
	Date	Peak gage height (ft)	Peak streamflow (ft^3/s)	Date	Peak gage height (ft)	Peak streamflow (ft^3/s)
07375000	**3/11/2016**	**25.25**	**43,000**	4/6/1983	24.12	29,800
07375500	3/12/2016	25.52	85,300	4/7/1983	25.87	85,000
07375800	3/11/2016	12.47	16,800	4/6/1983	13.3	32,000
07375960	3/11/2016	18.72	21,500	5/23/1974	108.311	28,400
07376000	3/11/2016	20.23	16,700	4/7/1983	21.04	22,500
07376500	3/11/2016	19.76	8,190	4/7/1983	20.8	9,810
07377000	3/12/2016	16.82	36,400	1/25/1990	22.05	104,000
07377500	3/11/2016	14.00	11,100	6/8/2001	19.15	25,300
07378500	3/13/2016	36.09	65,200	4/8/1983	41.5	112,000
07380120	3/14/2016	11.20	41,700	1/28/1990	--	69,500
07385765	3/10/2016	--	1,400	7/6/2010	4.69	4,750
07385790	3/11/2016	3.54	13,600 (3/19/2016)	1/16/2013	2.04	20,600
07386880	3/12/2016	11.58	2790 (3/20/2016)	7/17/1989	--	6,280
07386980	3/12/2016	8.83	7,520	10/28/1985	--	15,800
08010000	3/13/2016	16.73	2,710	5/20/1953	22.36	11,900
08012150	3/15/2016	3.89	12,100	11/2/1985	--	58,000

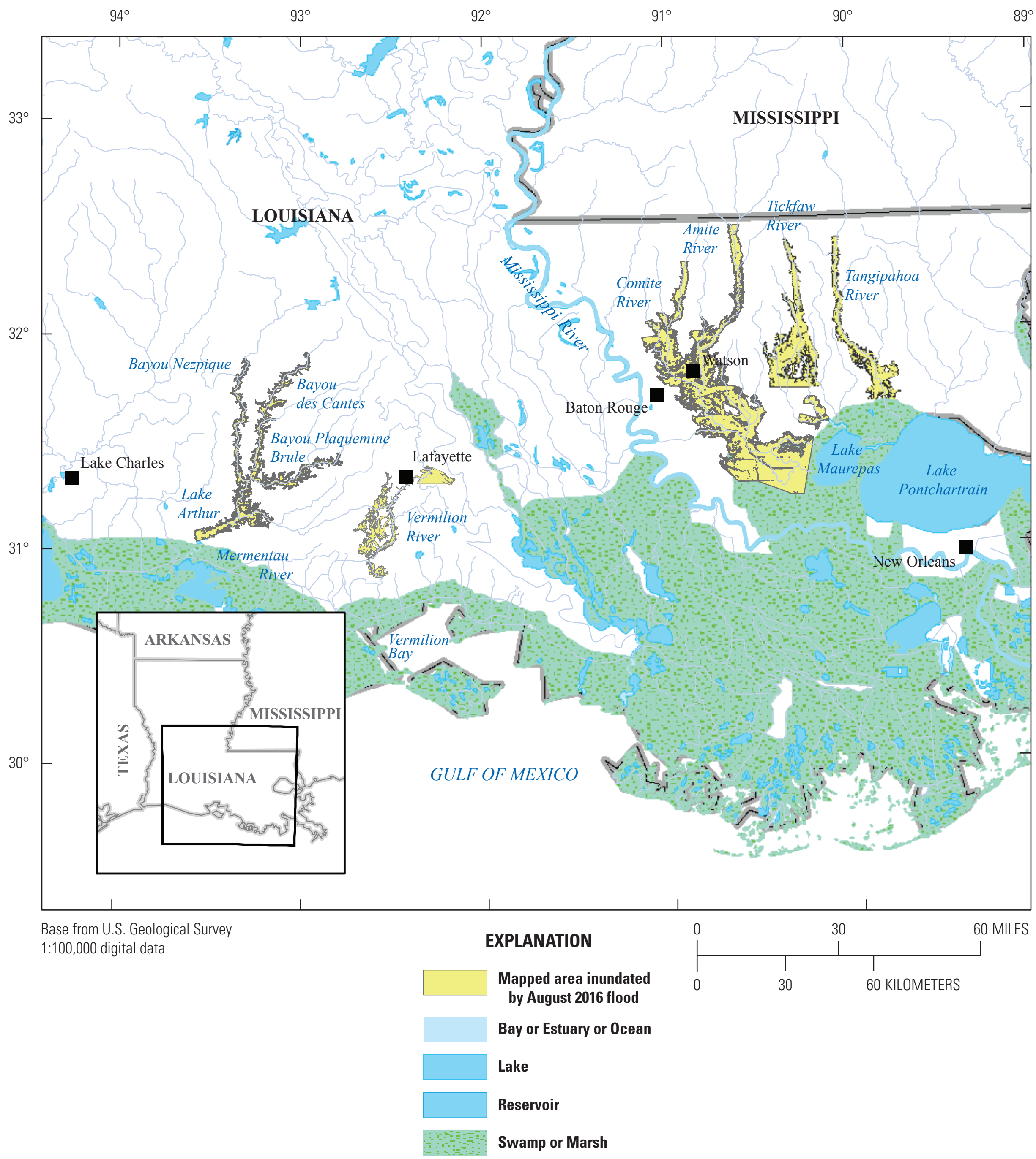


Figure 2. Study area and location of flood-inundation mapping extents in Louisiana for the August 2016 flood.

Table 4. Communities, waterbodies, reach lengths, and number of high-water marks used to generate flood-inundation maps.

Community	Parish	Waterbody	Reach length (miles)	Number of high-water marks
Denham Springs, Port Vincent, French Settlement, Maurepas	East Feliciana, St. Helena, East Baton Rouge, Livingston, Ascension, St. James, St. John the Baptist	Amite River	68	167
Baton Rouge, North Baton Rouge	East Baton Rouge, East Feliciana	Comite River	33	35
Mermentau	Jefferson Davis, Acadia, Cameron, Vermilion	Mermentau River	16.3	12
Eunice, Mermentau	Jefferson Davis, Acadia, Evangeline, St. Landry	Bayou des Cantes	38	9
Basile, Mermentau	Jefferson Davis, Acadia, Allen, Evangeline	Bayou Nezpique	33	11
Crowley, Estherwood	Jefferson Davis, Acadia	Bayou Plaquemine Brule	26	6
Kentwood, East Ponchatoula, Hammond	Tangipahoa	Tangipahoa River	40	20
Liverpool, Montpelier, Holden	St. Helena, Livingston	Tickfaw River- upper/middle	33	58
Killian	Livingston	Tickfaw River- near mouth	7	9
Lafayette, Abbeville, Perry	St. Martin, Lafayette, Vermilion	Vermilion River	34	36

generated surface based on the distribution of HWMs and an understanding of the natural hydrologic flow in the area of each community. The GIS interpolation method used to create the flood-inundation maps follows those described for the “Topo to Raster” tool in Musser and others (2016).

The flood-elevation surface that was created by using GIS interpolation was then combined with a 5-meter cell size digital elevation model (DEM). The DEM was derived from light detection and ranging (lidar) data having a 15–30-centimeter vertical root-mean-square error and will support contours of 1–2 ft vertical map accuracy standards (Louisiana State University, 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 involved in the flood-inundation mapping, the inundation surfaces were not clipped to show 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. Hydraulic models were not used to determine the extent or depth of flood inundation. The flood-elevation surfaces were all created using interpolation between HWM elevations rather than hydraulic models. Changes in land-surface features in flood plains, timing of the flooding that may occur from some of the smaller inflow tributaries versus the larger main stem tributaries, and the intermingling flows from adjacent streams are not accounted for without 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 Probabilities of Peak Streamflows

The probability that a peak streamflow will occur at a given location in a given year is known as the annual exceedance probability (AEP) and is determined from the existing annual peak streamflow data at a streamflow-gaging station. An annual peak streamflow is the maximum instantaneous streamflow experienced at a streamflow-gaging station during a given water year (defined as October 1 through September 30 of a given year). Streamflow-gaging stations with the longest annual peak streamflow record are the most reliable for estimating an AEP. An AEP of 0.01 means there is a 1-percent chance that a specific peak streamflow may occur at a given location in a given year. The recurrence interval for a given AEP is determined by dividing 1 by the AEP; therefore, an AEP of 0.01 is equivalent to a 100-year flood.

During the month of August 2016, USGS hydrographers made over 50 streamflow measurements by using direct methods (Rantz and others, 1982a; Turnipseed and Sauer, 2010) and 8 measurements by indirect methods (Benson and Dalrymple, 1967; Rantz and others, 1982b) at 21 continuous-record streamflow-gaging station locations. Streamflow measurements were made to verify accuracies of stage-streamflow rating curves or to extend the stage-streamflow rating curve for a given streamflow-gaging station (Rantz and others, 1982a). The stage-streamflow rating curve for a given streamflow-gaging station is used to calculate instantaneous streamflow values for a given streamflow-gaging station, which in turn are used to populate USGS annual peak streamflow files.

For selected streamflow-gaging stations (table 1), AEPs corresponding to peak streamflows that occurred during the August 2016 flood and streamflows associated with selected AEPs (0.01, 0.005, and 0.002) were estimated using the Expected Moments Algorithm (Cohn and others, 1997, 2001) in the USGS PeakFQ program (Veilleux and others, 2014). Outputs from the USGS PeakFQ program provide estimates for 15 specific AEPs ranging from 0.995 to 0.002. In order to estimate AEPs for specific peak streamflows that occurred during the August 2016 floods, the 15 specific AEPs and associated streamflows produced by PeakFQ were used to create generalized additive models (GAM) with integrated smoothness estimation (Wood, 2004, 2011) in R statistical software (R Core Team, 2016). The GAMs were then used to estimate the AEP associated with the peak streamflow from the August 2016 flood. For these streamflow-gaging stations in Louisiana, AEP estimates were not weighted with regional regression equations owing to the availability of recent equations. Peak gage-height data and peak streamflow data from the August 2016 flood and the corresponding AEPs (in percentage) were determined for nine streamflow-gaging stations (fig. 1; table 5).

Table 5. Site identification number, station number, peak information, and estimated annual exceedance probabilities for selected U.S. Geological Survey streamflow-gaging stations in Louisiana.

[ft^3/s, cubic feet per second; AEP, annual exceedance probability; <, less than]

Site identification number (fig. 1)	Station number	Flood data			AEP for observed August 2016 flood			
						66.7 percent confidence interval		
		Peak streamflow (ft^3/s)	Rank/number of annual peak streamflows in record	Number of years in annual peak analysis	Estimate (percent)	Lower (percent)	Upper (percent)	Upper
1	07375000	32,700	2/73	73	1.0	0.8	4.4	139,000
2	07375500	120,000	1/78	78	<0.2	<0.2	2.3	204,000
3	07375800	43,000	1/60	60	0.8	0.2	3.0	200,000
4	07375960	120,000	1/44	44	<0.2	<0.2	4.1	272,000
5	07376000	35,800	1/76	76	<0.2	<0.2	2.4	57,900
6	07376500	22,100	1/73	73	<0.2	<0.2	2.5	33,800
7	07377000	116,000	1/68	68	1.0	0.2	2.6	341,000
8	07377500	78,000	1/74	74	<0.2	<0.2	2.4	153,000
9	07378500	205,000	1/78	78	<0.2	<0.2	2.3	307,000

Site identification number (fig. 1)	Station number	Expected peak streamflows for selected AEP with 95 percent confidence intervals								
		1 percent AEP (100-year recurrence)			0.5 percent AEP (200-year recurrence)			0.2 percent AEP (500-year recurrence)		
		Estimate (ft^3/s)	95 percent confidence interval		Estimate (ft^3/s)	95 percent confidence interval		Estimate (ft^3/s)	95 percent confidence interval	
			Lower	Upper		Lower	Upper		Lower	Upper
1	07375000	34,400	23,200	66,100	43,000	27,500	92,000	56,400	33,500	139,000
2	07375500	76,200	56,200	121,000	89,500	63,400	153,000	108,000	72,400	204,000
3	07375800	41,100	25,900	88,900	52,200	31,000	128,000	69,400	38,000	200,000
4	07375960	52,800	33,500	122,000	65,800	39,600	174,000	86,000	47,900	272,000
5	07376000	25,200	19,300	37,500	28,600	21,300	45,500	33,300	23,500	57,900
6	07376500	12,500	9,600	19,800	14,700	10,800	25,100	17,800	12,500	33,800
7	07377000	118,000	84,600	199,000	139,000	95,100	253,000	169,000	108,000	341,000
8	07377500	47,600	34,100	82,100	57,400	39,300	108,000	71,900	46,300	153,000
9	07378500	136,000	104,000	200,000	154,000	114,000	243,000	180,000	126,000	307,000

Estimated Magnitudes and Flood Probabilities of Peak Streamflows

New peaks of record streamflow were experienced at 10 of the 16 USGS streamflow-gaging stations listed in table 3. The remaining six streamflow-gaging stations experienced peak streamflows that ranked in the top five for the period of record. Streamflow from the August 2016 flood event exceeded streamflow from the March 2016 flood event for 15 of the 16 USGS streamflow-gaging stations selected in this study. The flood-frequency statistics computed for this study are presented in table 5. The AEP estimates for the analyzed streamflow-gaging stations ranged from less than 0.2 to 1 percent. The number of years of peak streamflow record for analyzed streamflow-gaging stations ranged from 44 to 78, with the mean number of 69 years.

Flood-Inundation Maps

Twelve flood-inundation maps were created for communities in Louisiana (fig. 2). Each map presents the areal extent of the flood waters. The HWMs used to create the inundation maps and associated information can be accessed at the USGS STN website (USGS, 2016) and are provided in Heal and Watson (2017). Digital datasets of the inundation area, modeling boundary, water depth rasters, and final map products are available for download at Heal and Watson (2017). The locations of specific flood-inundation maps are described in the following sections.

Amite River

The Amite River has its headwaters in southwestern Mississippi and flows for approximately 117 miles (mi) to Lake Maurepas in southeastern Louisiana. Multiple communities in East Feliciana, St. Helena, East Baton Rouge, Livingston, Ascension, St. James, and St. John the Baptist Parishes are located along a 68-mi reach of the Amite River, including Denham Springs, Port Vincent, French Settlement, and Maurepas. A total of 194 HWMs were documented along this reach, and 167 were surveyed and used to develop the inundation map. The depths of water at the HWMs ranged from 0.6 to 9.6 ft aboveground, and the elevations ranged from 4.3 to 194.3 ft above NAVD 88.

The USGS operates 7 streamflow-gaging stations on the Amite River and 19 streamflow-gaging stations on smaller tributaries that were used in the analysis to create the inundation map. The Amite River streamflow-gaging stations used in the creation of the inundation maps include:

1. Amite River near Darlington, La. (USGS 07377000), recorded a peak stage of 22.54 ft gage datum and a water-surface elevation of 168.35 ft above NGVD 29 on August 12, 2016;
2. Amite River at Grangeville, La. (USGS 07377150), recorded a peak stage of 44.62 ft gage datum and a water-surface elevation of 116.46 ft above NGVD 29 on August 13, 2016;
3. Amite River at Magnolia, La. (USGS 07377300), recorded a peak stage of 58.56 ft gage datum and a water-surface elevation of 57.42 ft above NAVD 88 on August 13, 2016;
4. Amite River near Denham Springs, La. (USGS 07378500), recorded a peak stage of 46.2 ft gage datum and a water-surface elevation of 44.85 ft above NAVD 88 on August 14, 2016;
5. Amite River at Port Vincent, La. (USGS 07380120), recorded a peak stage of 17.45 ft gage datum and a water- surface elevation of 16.09 ft above NAVD 88 on August 15, 2016;
6. Amite River near French Settlement, La. (USGS 07380200), recorded a peak stage of 9.21 ft gage datum and a water-surface elevation of 8.30 ft above NAVD 88 on August 16, 2016; and
7. Amite River at Highway 22 near Maurepas, La. (USGS 07380215), recorded a peak stage of 5.73 ft gage datum and a water-surface elevation of 4.48 ft above NAVD 88 on August 17, 2016.

Precipitation ranged from about 5 to 26 in. within the Amite River Basin over the duration of the event. The aerial extent of flood inundation for the upper Amite River, which extends from near the Mississippi-Louisiana State border to the confluence with the Comite River, is shown in figure 3. The aerial extent of flood inundation for the lower Amite River, which extends from the confluence with the Comite River to Lake Maurepas, is shown in figure 4. The aerial extent of flood inundation for the combined upper and lower Amite River reaches is shown in figure 5.

Comite River

The Comite River flows south through the community of Baton Rouge (and surrounding communities) in East Baton Rouge and East Feliciana Parishes, in the northern part of Baton Rouge. The extent of the inundation map is a 33-mi reach of the Comite River from Clinton through Baton Rouge. A total of 74 HWMs were documented in the Comite River Basin, and 59 HWMs were surveyed along the Comite River; 35 of the HWMs were used in the creation of an inundation depth map for the city of Baton Rouge and surrounding areas. Seventeen HWMs were documented but were not surveyed. Some of the unsurveyed HWMs were used in the creation of the inundation depth map with height aboveground estimated from the lidar DEM. The measured depths of water at the HWMs ranged from 0.2 to 5.9 ft aboveground, and the elevations ranged from 63.5 to 79.3 ft above NAVD 88.

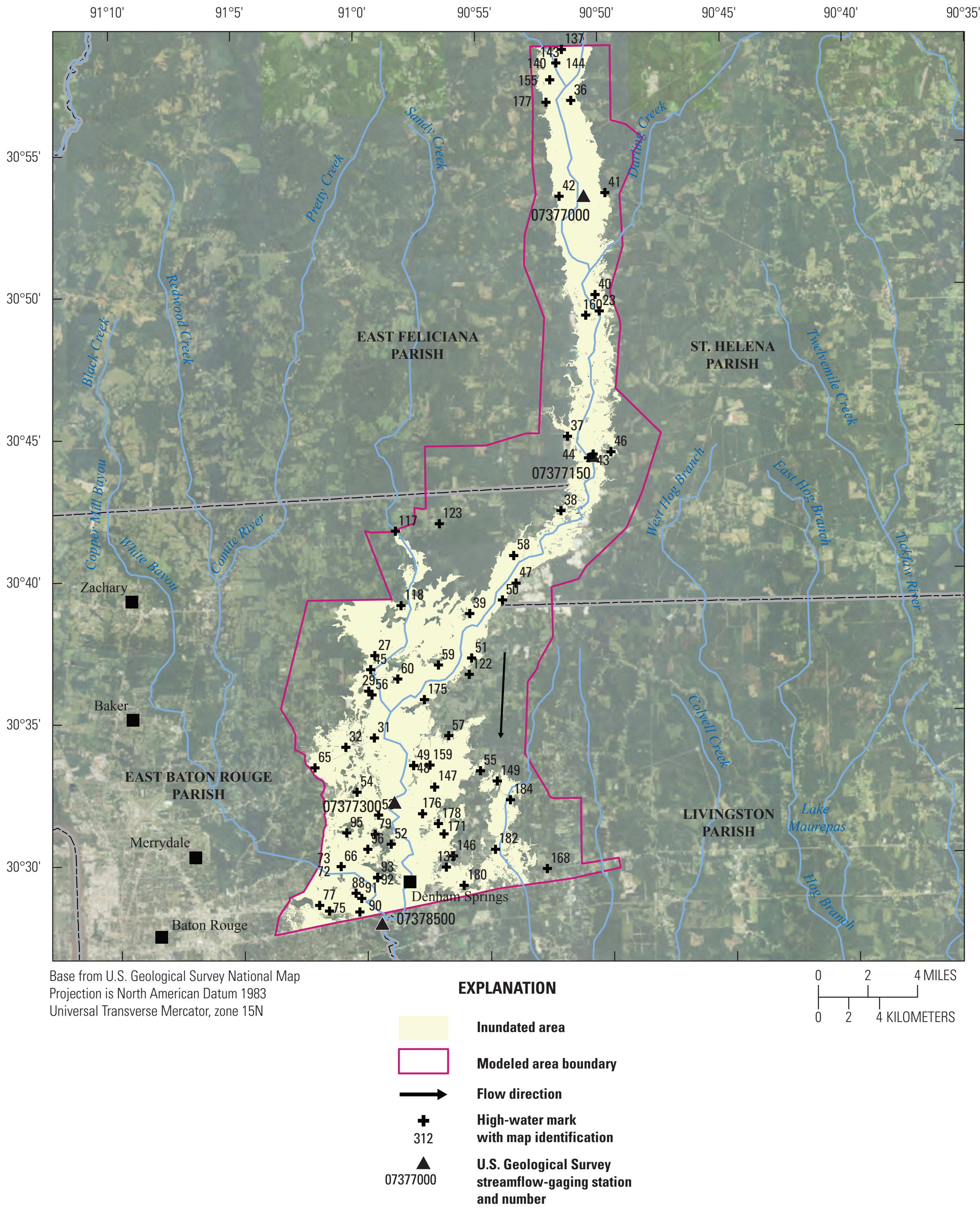


Figure 3. Flood-inundation map of the upper reach of the Amite River, Louisiana, August 2016.

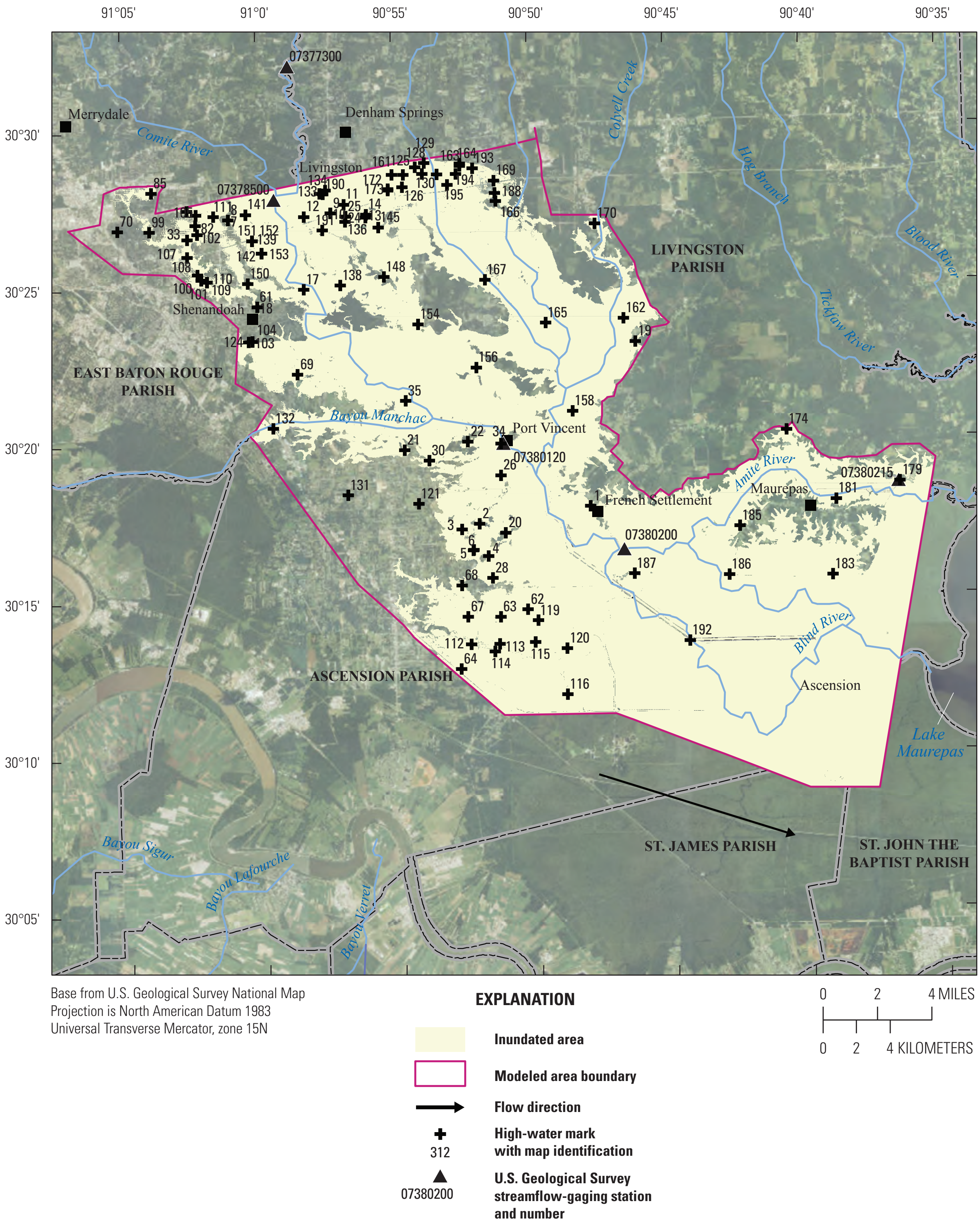


Figure 4. Flood-inundation map of the lower reach of the Amite River, Louisiana, August 2016.

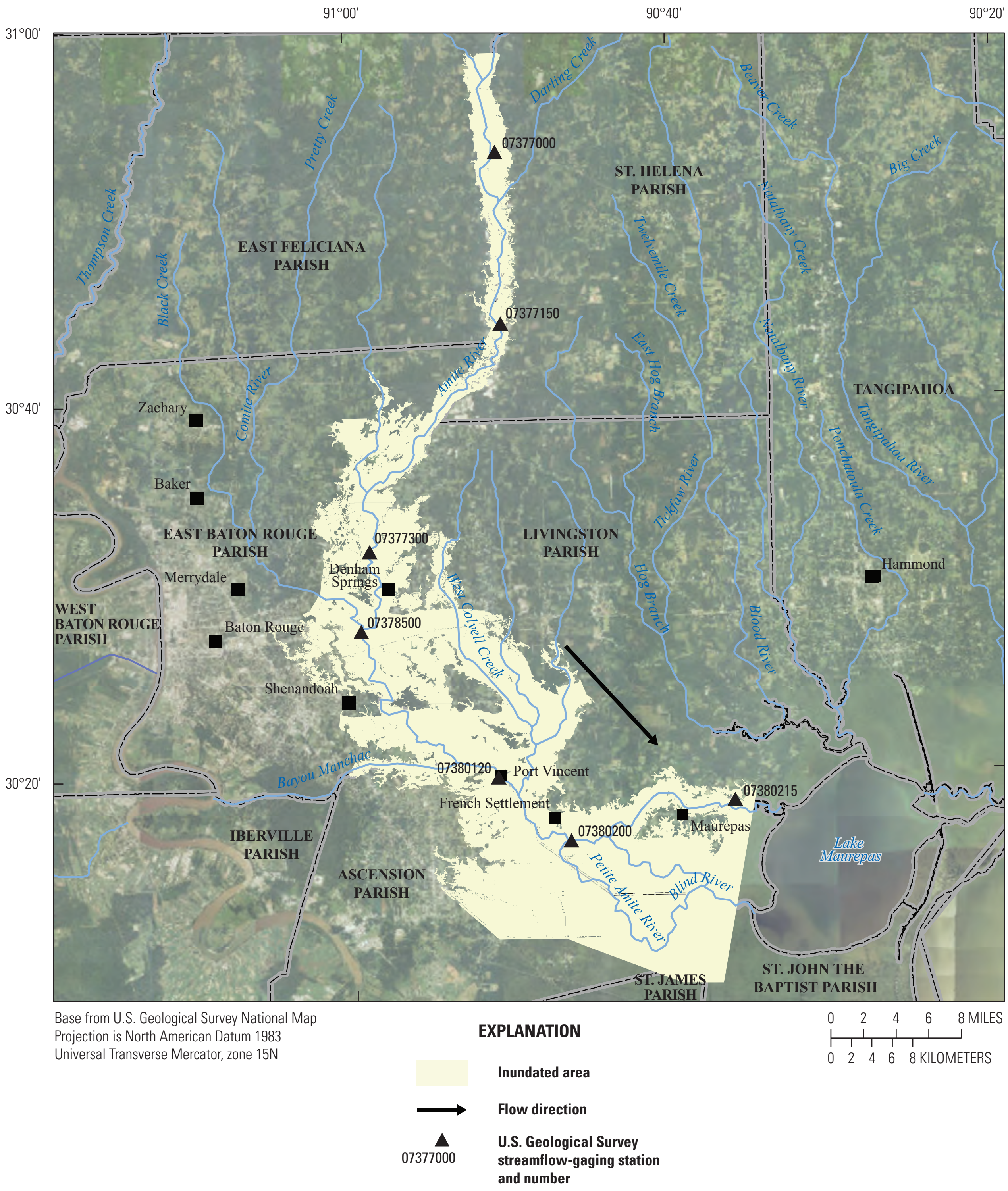


Figure 5. Flood-inundation map of the upper and lower reaches of the Amite River, Louisiana, August 2016.

The USGS streamflow-gaging station Comite River at Point Hudson-Pride Road near Milldale, La. (USGS 07377600), recorded a peak stage of 38.98 ft on August 13, 2016. The USGS streamflow-gaging station Comite River at Hooper Road near Baton Rouge, La. (USGS 07377870), recorded a peak stage of 31.56 ft on August 13, 2016. During the August flood event, 18 in. of rainfall was reported at the Baton Rouge Metro Airport for the period of August 11–14, 2016. By comparison, the average annual precipitation at the airport is 53.54 in. (National Oceanic and Atmospheric Administration, 2016e). Precipitation ranged from about 6 to 26 in. within the Comite River Basin over the duration of the event. The aerial extent of flood inundation for this location is shown in figure 6.

Mermentau River and Tributaries

The Mermentau River flows southwest through the community of Mermentau, La., 40 mi west of Lafayette (fig. 2) in Jefferson Davis, Acadia, Cameron, and Vermilion Parishes. The extent of the inundation map is a 16.3-mi reach of the Mermentau River from Mermentau through Lake Arthur.

A total of 15 HWMs was documented in the Mermentau River Basin; 14 HWMs were documented and surveyed along the Mermentau River, and 12 of the HWMs were used in the creation of the inundation depth map in the community of Mermentau and surrounding areas. One HWM was not surveyed. The unsurveyed HWM was used in the creation of the inundation depth map in which height aboveground was estimated from the lidar DEM. The measured depths of water at the HWM ranged from 0.75 to 5.9 ft aboveground, and the elevations ranged from 4.5 to 13.7 ft above NAVD 88.

The USGS operates three streamflow-gaging stations on the Mermentau River and surrounding tributaries that were used in the creation of the inundation maps. The Mermentau River streamflow-gaging stations used in the creation of the inundation maps include:

1. Mermentau River at Mermentau, La. (USGS 08012150), recorded a peak stage of 10.82 ft gage datum and water-surface elevation of 11.4 ft above NGVD 29 on August 18, 2016;

2. Bayou Des Cannes near Eunice, La. (USGS 08010000), recorded a peak stage of 22.37 ft and water-surface elevation of 37.21 ft above NGVD 29 on August 15, 2016; and

3. Bayou Nezpique near Basile, La. (USGS 08012000), recorded a peak stage of 25.81 ft and water-surface elevation of 29.39 ft above NAVD 88 on August 16, 2016.

During the August flood event, 16.94 in. of rainfall was reported at the Jennings Weather Station (5.6 mi northwest of Mermentau) for the period of August 11–14, 2016. By comparison, the departure from normal monthly precipitation is 18.83 in. (National Oceanic and Atmospheric Administration, 2016e). Precipitation ranged from about 5 to 22 in. within the Mermentau River Basin over the duration of the event. The aerial extent of flood inundation for this location is shown in figure 7. The locations of streamflow-gaging stations USGS 08010000 and USGS 08012000 are shown on figure 8.

Bayou des Cantes

Bayou des Cantes, a tributary to the Mermentau River, flows south toward Mermentau, La., through Eunice, La., 40 mi west of Lafayette (shown on fig. 2) in Jefferson Davis, Acadia, Evangeline, and St. Landry Parishes. The extent of the inundation map is a 38-mi reach of Bayou des Cantes from Eunice to the confluence with the Mermentau River.

A total of 14 HWMs were documented in the Bayou des Cantes Basin; 12 HWMs were surveyed along the Bayou des Cantes and 9 of the HWMs were used in the creation of the inundation depth map in the community of Mermentau and surrounding areas. Two HWMs were not surveyed. Both of the unsurveyed HWMs were used in the creation of the inundation depth map in which height aboveground was estimated from the lidar DEM. The measured depths of water at the HWMs ranged from 2.09 to 5.1 ft aboveground, and the elevations ranged from 10.9 to 51.0 ft above NAVD 88.

Two USGS streamflow-gaging stations were used for the inundation analysis: (1) Bayou Des Cannes near Eunice, La. (USGS 08010000), recorded a peak stage of 37.09 ft on August 15, 2016, and (2) Mermentau River at Mermentau, La. (USGS 08012150), recorded a peak stage of 11.36 ft on August 18, 2016. The aerial extent of flood inundation for this location is shown in figure 8.

Bayou Nezpique

Bayou Nezpique, a tributary to the Mermentau River, flows south toward Mermentau, La., through Jennings, La., 40.9 mi. west of Lafayette (shown on fig. 2) in Jefferson Davis, Acadia, Allen, and Evangeline Parishes. The extent of the inundation map is a 33-mi reach of Bayou Nezpique from Basile to Mermentau near Lake Arthur.

A total of 13 HWMs were documented in the Bayou Nezpique Basin; 4 HWMs were surveyed along the Bayou Nezpique, and 11 of the HWMs were used in the creation of the inundation depth map in the community of Mermentau and surrounding areas. Nine HWMs were not surveyed. Some of those nine unsurveyed HWMs were used in the creation of the inundation depth map, in which height aboveground was estimated from the lidar DEM. The measured depths of water at the HWMs ranged from 1.3 to 6.7 ft aboveground, and the elevations ranged from 10.5 to 44.5 ft above NAVD 88.

Two USGS streamflow-gaging stations were used in the inundation analysis: (1) Bayou Nezpique near Basile, La. (USGS 08012000), recorded a peak stage of 25.81 ft on August

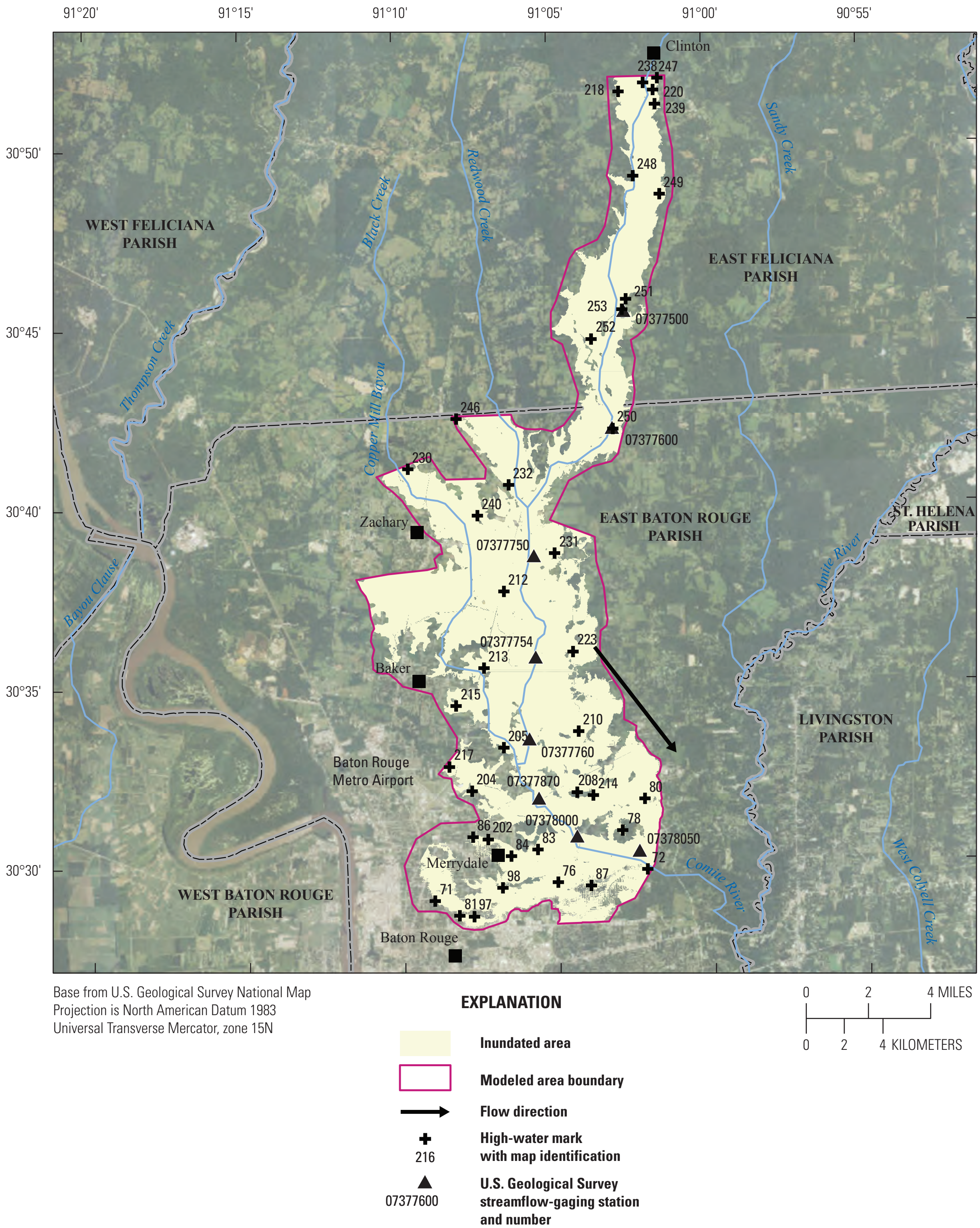


Figure 6. Flood-inundation map of Comite River, Louisiana, August 2016.

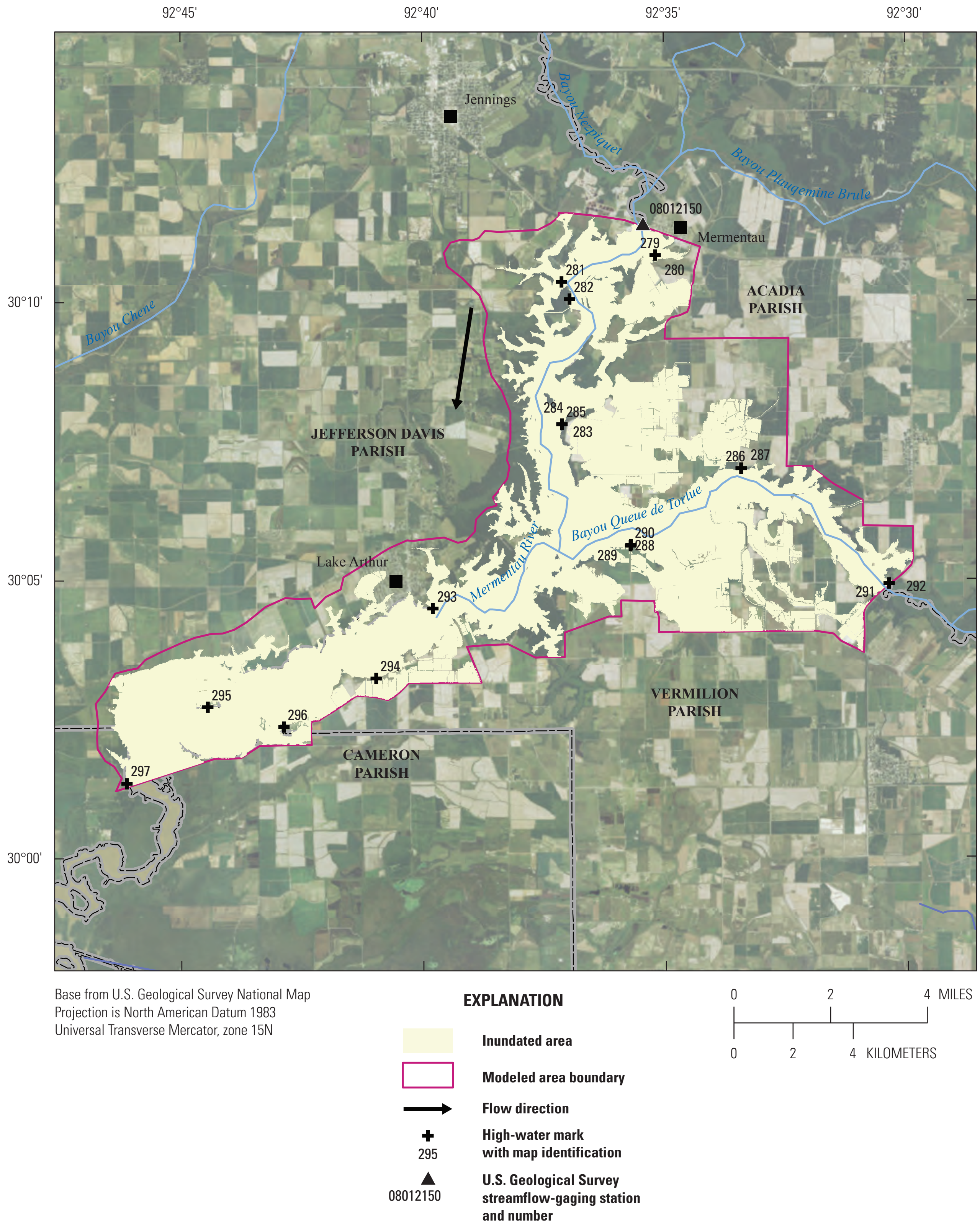


Figure 7. Flood-inundation map of Mermentau River, Louisiana, August 2016.

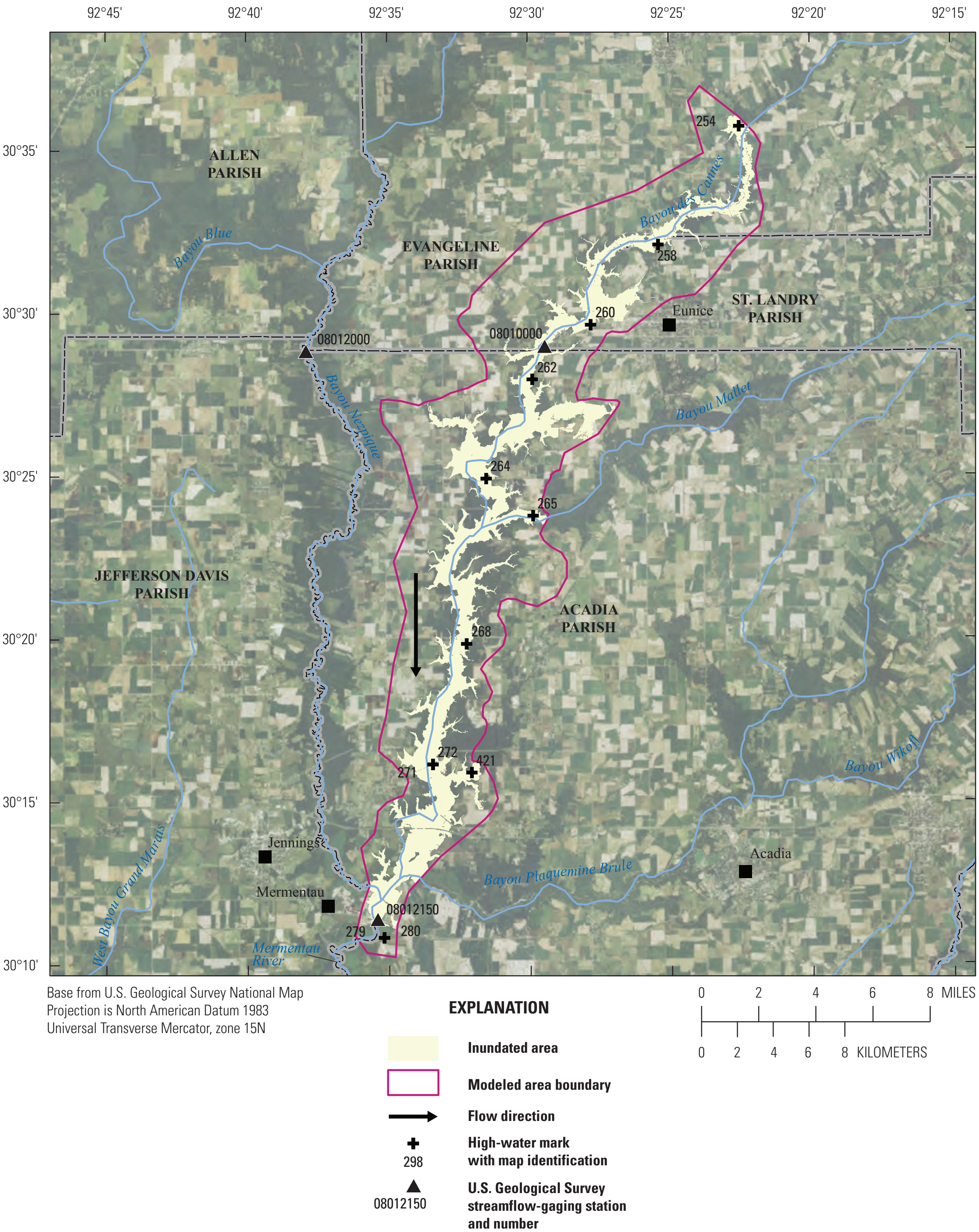


Figure 8. Flood-inundation map of Bayou des Cantes, tributary to Mermentau River, Louisiana, August 2016.

16, 2016, and (2) Mermentau River at Mermentau, La. (USGS 08012150), recorded a peak stage of 11.36 ft on August 18, 2016. The aerial extent of flood inundation for this location is shown in figure 9.

Bayou Plaquemine Brule

Bayou Plaquemine Brule, a tributary to the Mermentau River, flows west toward Mermentau, La., through Crowley and Estherwood, La., 32.2 mi west of Lafayette (shown on fig. 2) in Jefferson Davis and Acadia Parishes. The extent of the inundation map is a 26-mi reach of Bayou Plaquemine Brule from Rayne to Mermentau near Lake Arthur.

A total of nine HWMs were documented in the Bayou Plaquemine Brule Basin; 8 HWMs were surveyed along Bayou Plaquemine Brule, and 6 of the HWMs were used in the creation of the inundation depth map in the community of Mermentau and surrounding areas. One HWM was not surveyed. The measured depth of water at the HWMs ranged from 2.3 to 6.3 ft aboveground, and the elevations ranged from 8.9 to 26.6 ft above NAVD 88. The aerial extent of flood inundation for this location is shown in figure 10.

Tangipahoa River

The Tangipahoa River flows generally south to southeast through Tangipahoa Parish into Lake Pontchartrain. The extent of the inundation map is a 40-mi reach of the Tangipahoa River from Kentwood to Ponchatoula/Hammond in Tangipahoa Parish. A total of 29 HWMs was documented along the Tangipahoa River, and 20 of the HWMs were surveyed and used to create the inundation map. The depths of water at the HWMs ranged from 0.6 to 10.6 ft aboveground, and the elevations ranged from 17.22 to 128.13 ft above NAVD 88. The USGS operates four streamflow-gaging stations on the Tangipahoa River that were used in the creation of the inundation maps. The streamflow-gaging stations used in the creation of the inundation maps include:

1. Tangipahoa River near Kentwood, La. (USGS 07375300), recorded a peak stage of 16.30 ft gage datum and water-surface elevation of 196.37 ft above NGVD 29 on August 12, 2016;

2. Tangipahoa River near Amite, La. (USGS 07375430), recorded a peak stage of 29.28 ft gage datum and water-surface elevation of 109.28 ft above NAVD 88 on August 12, 2016;

3. Tangipahoa River at Robert, La. (USGS 07375500), recorded a peak stage of 27.33 ft gage datum and a water-surface elevation of 33.93 ft above NAVD 88 on August 13, 2016; and

4. Tangipahoa River near Ponchatoula, La. (USGS 07375650), recorded a peak stage of 21.87 ft gage datum and a water-surface elevation of 19.18 ft above NAVD 88 on August 14, 2016.

Precipitation ranged from about 6 to 17 in. within the Tangipahoa River Basin over the duration of the event. The aerial extent of flood inundation for this location is shown in figure 11.

Tickfaw River

The Tickfaw River flows south from southwestern Mississippi through St. Helena and Livingston Parish into Lake Maurepas. The extent of inundation mapping has been separated into two reaches because of the location of the HWMs that were surveyed. One map includes a 33-mi reach of the upper to middle Tickfaw River from Liverpool in St. Helena Parish to Holden in Livingston Parish. The second map is a 7-mi reach in Killian, located in Livingston Parish, flowing to the mouth of the river at Lake Maurepas. A total of 95 HWMs were documented along the Tickfaw River; 58 of the HWMs were surveyed and used to create the inundation map for the upper reach, and 9 were surveyed and used to create the inundation map for the area around the mouth of the river. The depths of water for the upper to middle reach at the HWMs ranged from 0.91 to 9.6 ft aboveground, and the elevations ranged from 35.2 to 218.6 ft above NAVD 88. The depths of water for the reach near the mouth of the river at the HWMs ranged from 0.73 to 5.97 ft aboveground, and the elevations ranged from 6.48 to 18.2 ft above NAVD 88.

The USGS operates three streamflow-gaging stations on the Tickfaw River that were used in the creation of the inundation maps. The streamflow-gaging stations used in the creation of the inundation maps include:

1. Tickfaw River at Liverpool, La. (USGS 07375800), recorded a peak stage of 13.87 ft gage datum and a water-surface elevation of 218.31 ft above NGVD 29 on August 12, 2016;

2. Tickfaw River at Montpelier, La. (USGS 07375960), recorded a peak stage of 26.04 ft gage datum and a water-surface elevation of 112.92 ft above NAVD 88 on August 12, 2016; and

3. Tickfaw River at Holden, La. (USGS 07376000), recorded a peak stage of 22.16 ft gage datum and a water-surface elevation of 40.81 ft above NAVD 88 on August 13, 2016.

The Tickfaw River watershed experienced a loss of flow to the neighboring Natalbany River watershed between the Tickfaw River streamflow-gaging stations in Montpelier and Holden. Precipitation ranged from about 6 to 24 in. within the Tickfaw River Basin over the duration of the event. The aerial extent of flood inundation for this location is shown in figures 12 and 13.

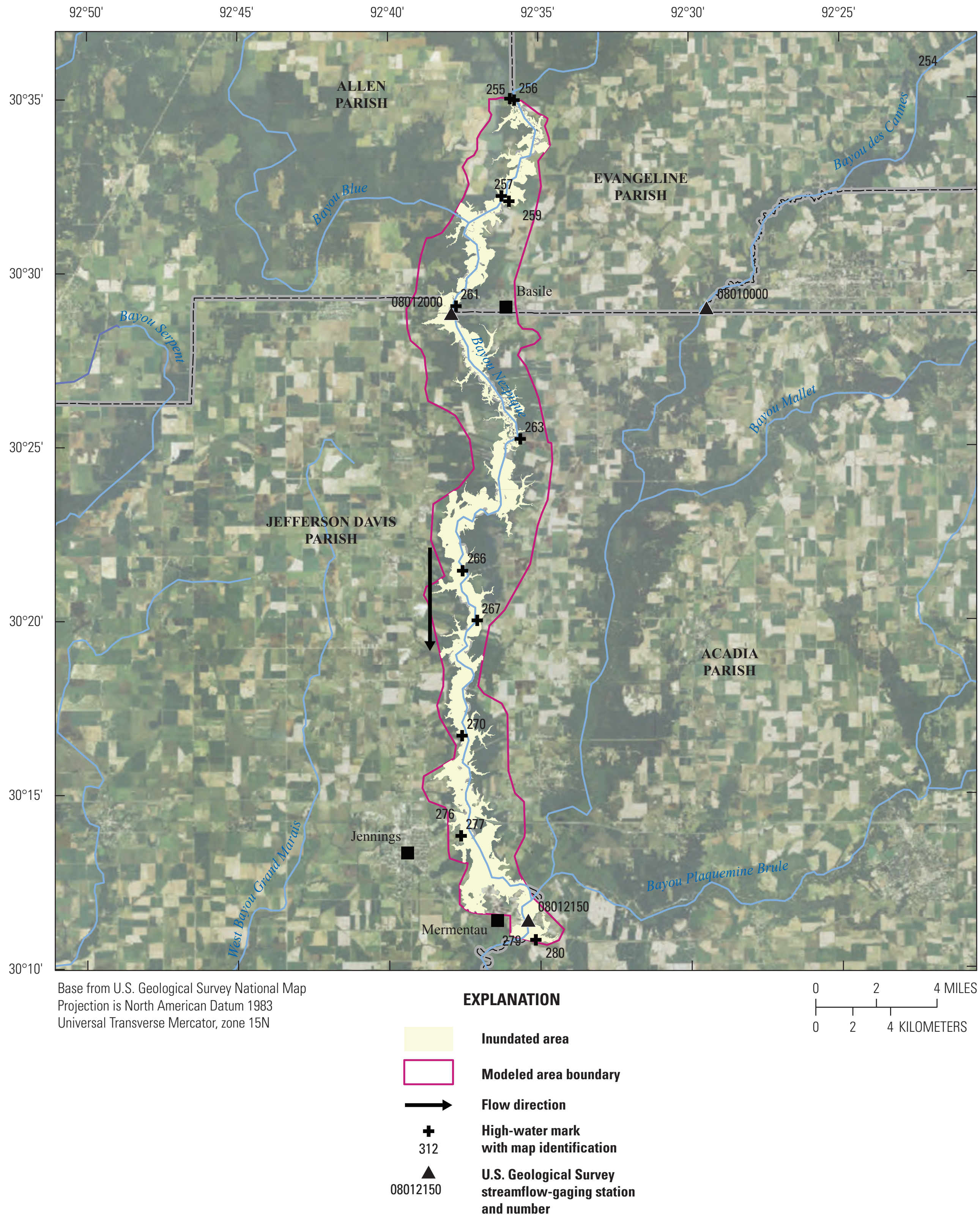


Figure 9. Flood-inundation map of Bayou Nezpique, tributary to Mermentau River, Louisiana, August 2016.

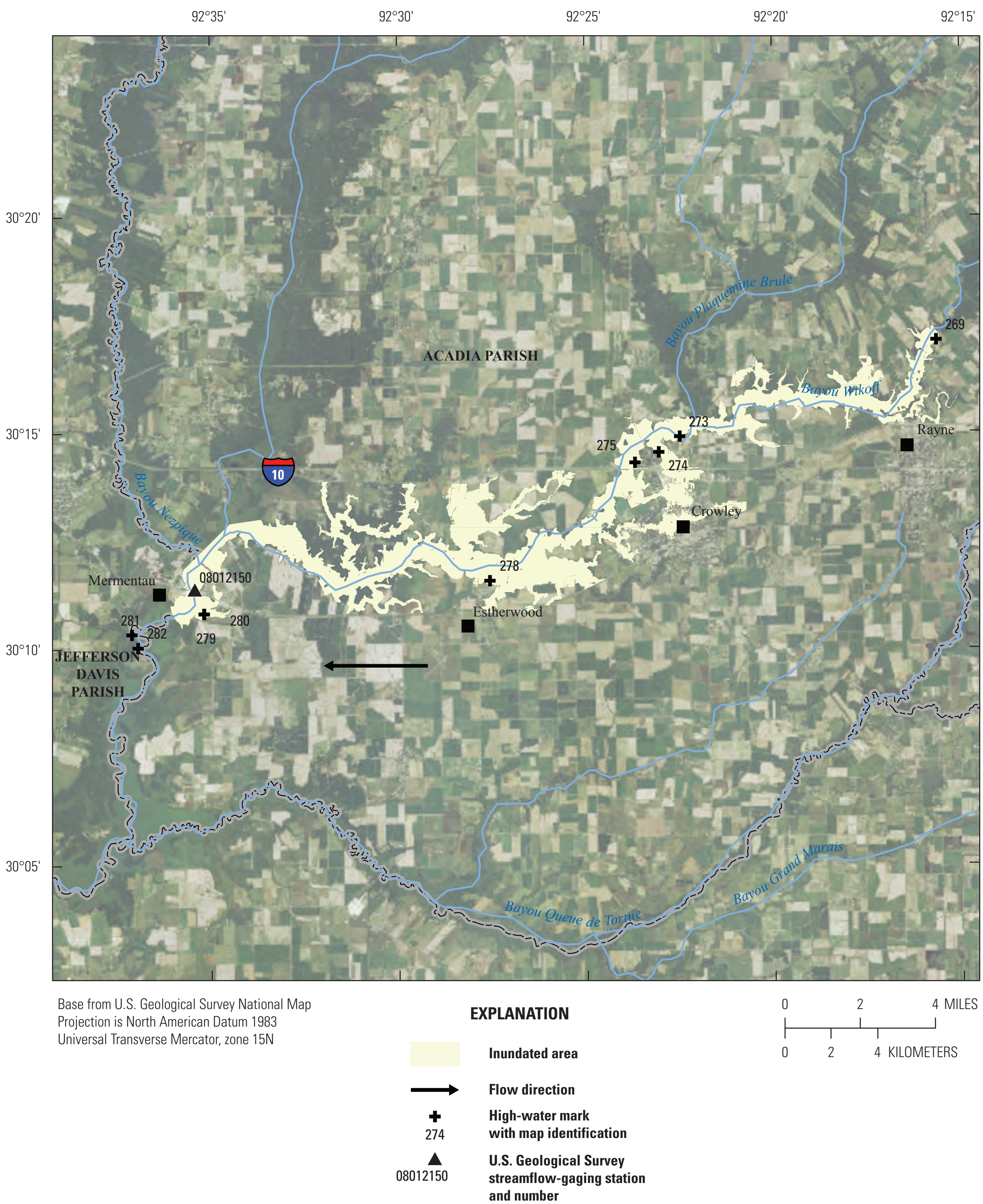
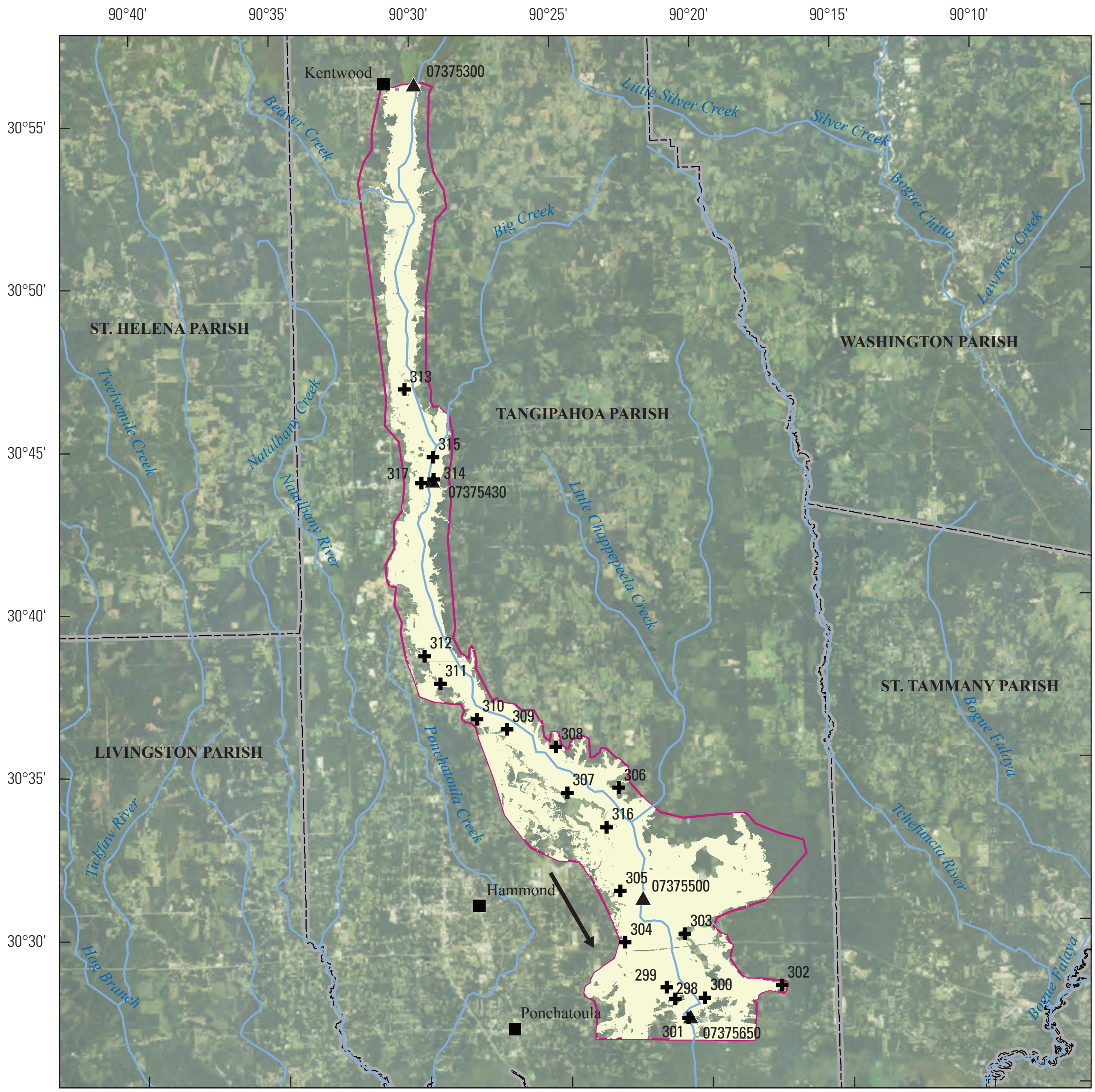


Figure 10. Flood-inundation map of Bayou Plaquemine Brule, tributary to Mermentau River, Louisiana, August 2016.



Base from U.S. Geological Survey National Map
Projection is North American Datum 1983
Universal Transverse Mercator, zone 15N

EXPLANATION

- Inundated area
- Modeled area boundary
- Flow direction
- High-water mark with map identification (312)
- U.S. Geological Survey streamflow-gaging station and number (07375300)

0 2 4 6 8 MILES

0 2 4 6 8 KILOMETERS

Figure 11. Flood-inundation map of Tangipahoa River, Louisiana, August 2016.

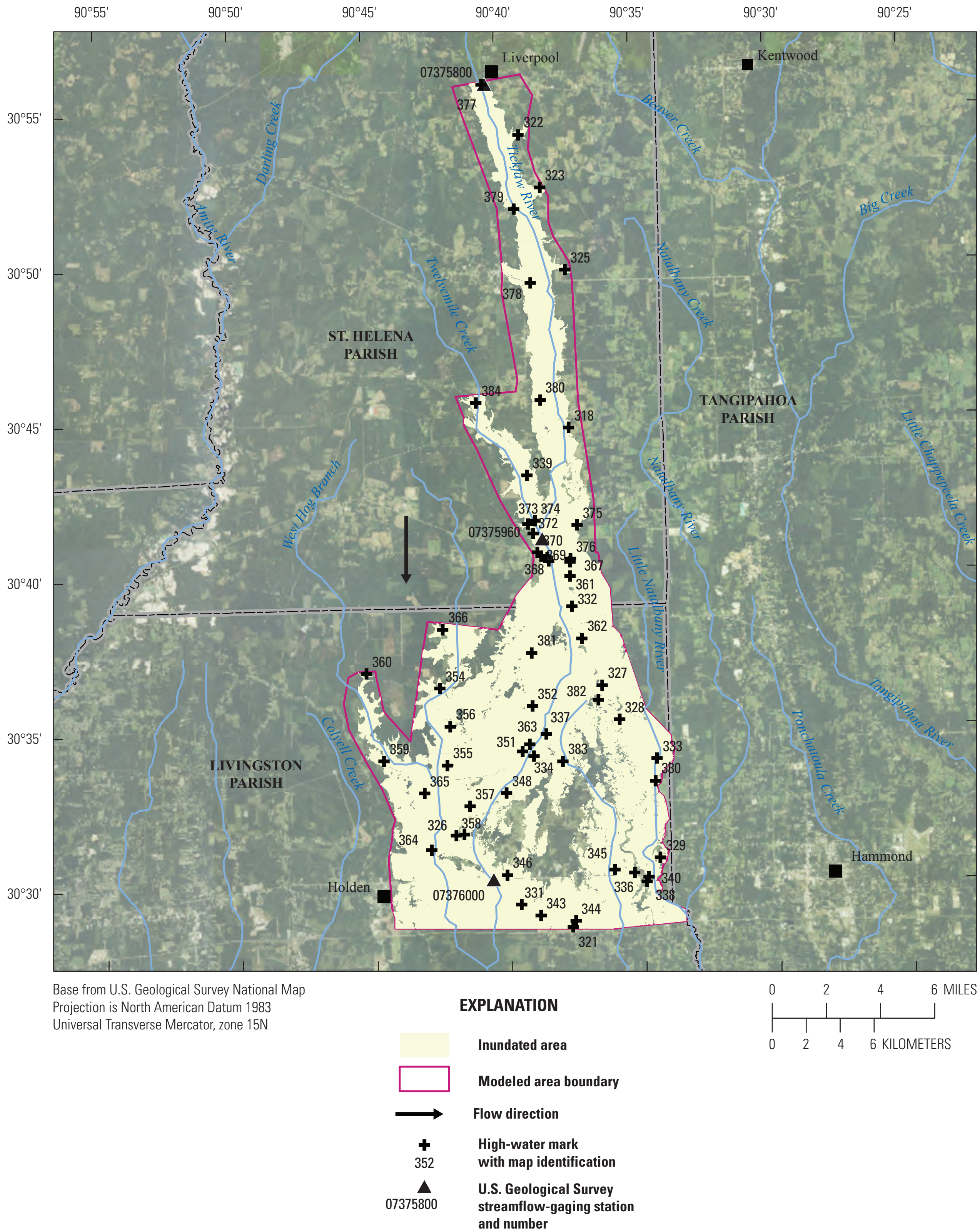


Figure 12. Flood-inundation map of the upper reach of Tickfaw River, Louisiana, August 2016.

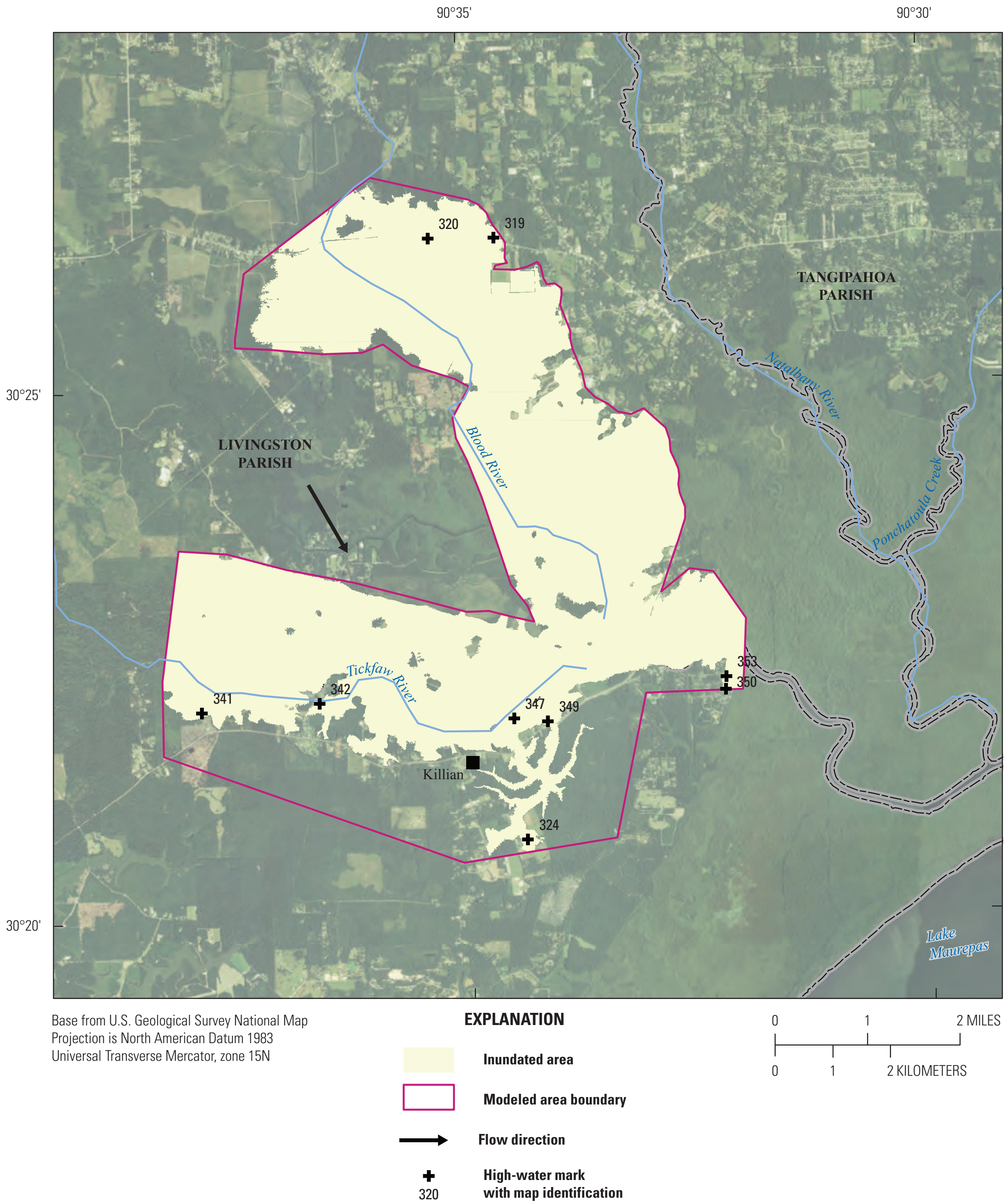


Figure 13. Flood-inundation map of area around the mouth of Tickfaw River, Louisiana, August 2016.

Vermilion River

The Vermilion River is formed by several small bayous in southern Louisiana and flows south for approximately 70 mi to Vermilion Bay at the Gulf of Mexico (shown on fig. 2). Several communities in St. Martin, Lafayette, and Vermilion Parishes are located along a 34-mi reach of the Vermilion River, including Lafayette, Abbeville, and Perry. During heavy rainfall events, flow direction of the Vermilion River in the Lafayette area can reverse because of the large area of urbanization. This was confirmed by flood profiles from the August flood event. A total of 64 HWMs were documented along this reach, and 36 were surveyed and used to develop the inundation map. The depths of water at the HWMs ranged from 0.7 to 6.8 ft aboveground, and the elevations ranged from 7.0 to 30.5 ft above NAVD 88. The USGS operates four streamflow-gaging stations on the Vermilion River that were used in the creation of the inundation maps. The streamflow-gaging stations used in the creation of the inundation maps include:

1. Vermilion River near Lafayette, La. (USGS 07386850), recorded a peak stage of 15.01 ft gage datum and a water-surface elevation of 15.01 ft above NAVD 88 on August 17, 2016;
2. Vermilion River at Surrey St. at Lafayette, La. (USGS 07386880), recorded a peak stage of 17.62 ft gage datum and a water-surface elevation of 14.88 ft above NAVD 88 on August 15, 2016;
3. Vermilion River at Highway 733 near Lafayette, La. (USGS 07386940), recorded a peak stage of 19.91 ft gage datum and a water-surface elevation of 19.91 ft above NAVD 88 on August 13, 2016; and
4. Vermilion River at Perry, La. (USGS 07386980), recorded a peak stage of 13.75 ft gage datum and a water-surface elevation of 10.29 ft above NGVD 29 on August 14, 2016.

Precipitation ranged from about 12 to 26 in. within the Vermilion River Basin over the duration of the event. The aerial extent of flood inundation for this reach of the Vermilion River is shown in figure 14.

Flood Damages

During August 2016, flooding on numerous streams and rivers in Louisiana resulted in at least 13 fatalities and damage to more than 140,000 homes (National Oceanic and Atmospheric Administration, 2016b). Monetary losses resulting from damages to numerous homes, businesses, and infrastructure were estimated to be $10 billion (National Oceanic and Atmospheric Administration, 2016a). This storm event has been regarded as the worst natural disaster in the United States since Hurricane Sandy on the east coast in 2012 (Yan and Flores, 2016).

Summary

During the period of August 11–14, 2016, a slow-moving area of low pressure and a high amount of atmospheric moisture over Louisiana and southwestern Mississippi resulted in heavy rainfall with amounts of 20 to more than 31 inches that caused historic flooding in numerous stream basins in Louisiana. New peaks of record streamflow were experienced at 10 U.S. Geological Survey (USGS) streamflow-gaging stations. Six streamflow-gaging stations included in this study experienced peak streamflows that ranked in the top five for the period of record. Streamflow from the August 2016 flood event exceeded streamflow from the March 2016 flood event for 15 of the 16 USGS streamflow-gaging stations selected in this study.

At least 13 fatalities were reported, and damages resulting from the flood were estimated to be $10 billion. In the immediate aftermath of the flood, the USGS and the Federal Emergency Management Agency (FEMA) initiated a cooperative study to evaluate the flood's magnitude, extent, and probability of occurrence. The USGS hydrographers identified and documented 590 high-water marks, some of which were used to create 12 flood-inundation maps that document the extent and depth of flooding. Peak gage-height data, peak streamflow data, and estimated annual exceedance probabilities are provided for 16 streamflow-gaging stations operated by the USGS in Louisiana.

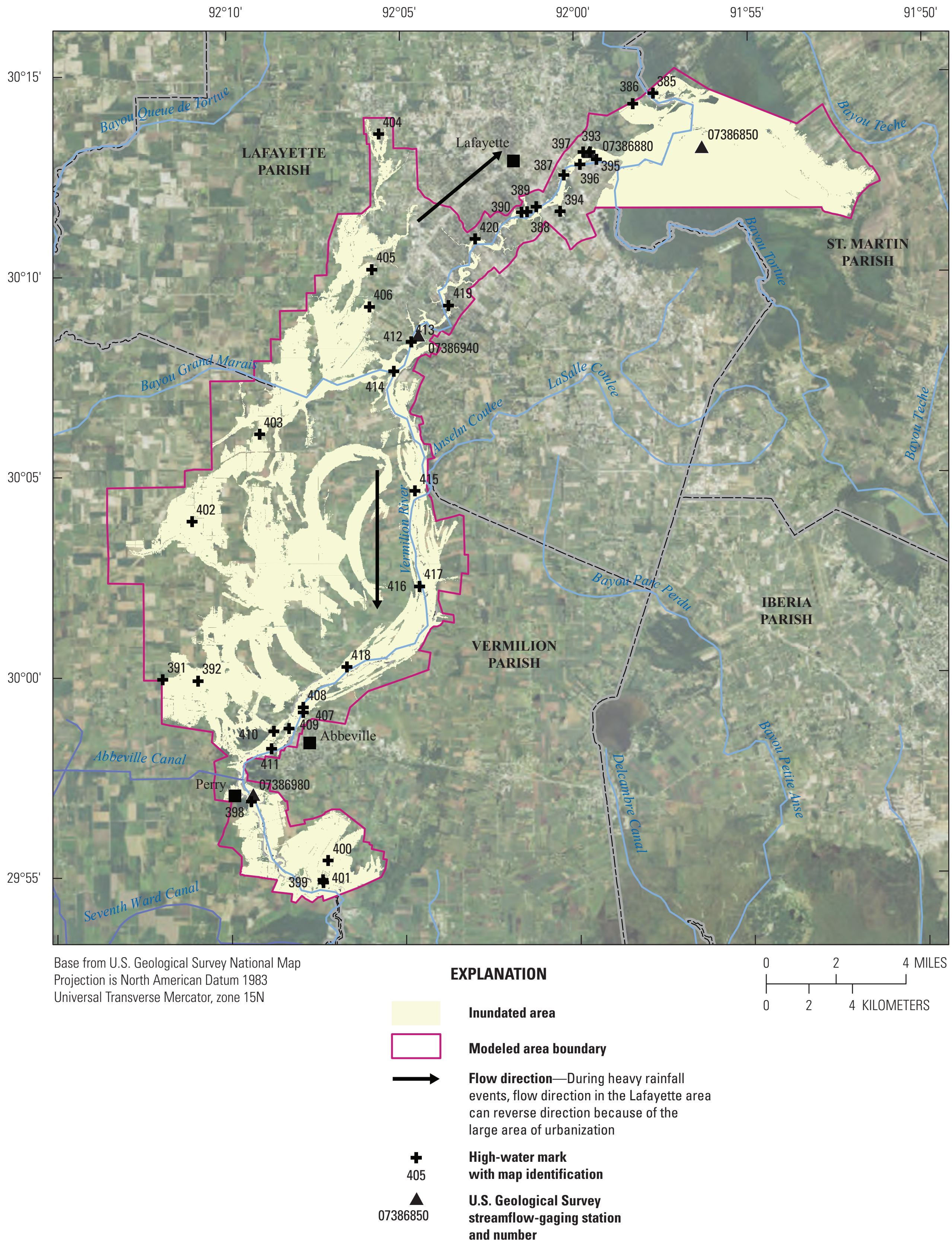


Figure 14. Flood-inundation map of Vermilion River, Louisiana, August 2016.

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For more information about this publication contact:
Director
USGS Lower Mississippi-Gulf Water Science Center
401 Hardin Road
Little Rock, AR 72211
http://ar.water.usgs.gov

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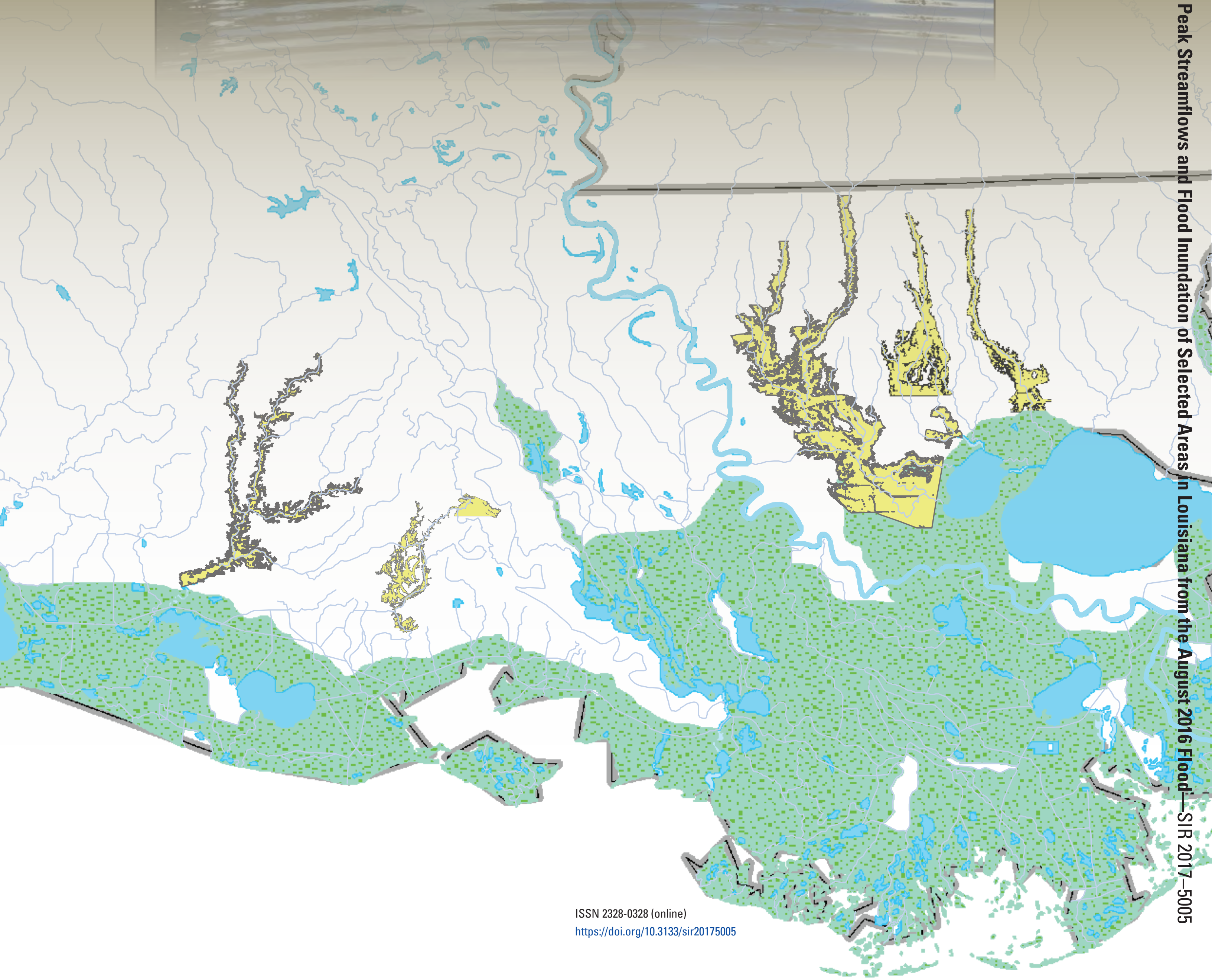

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