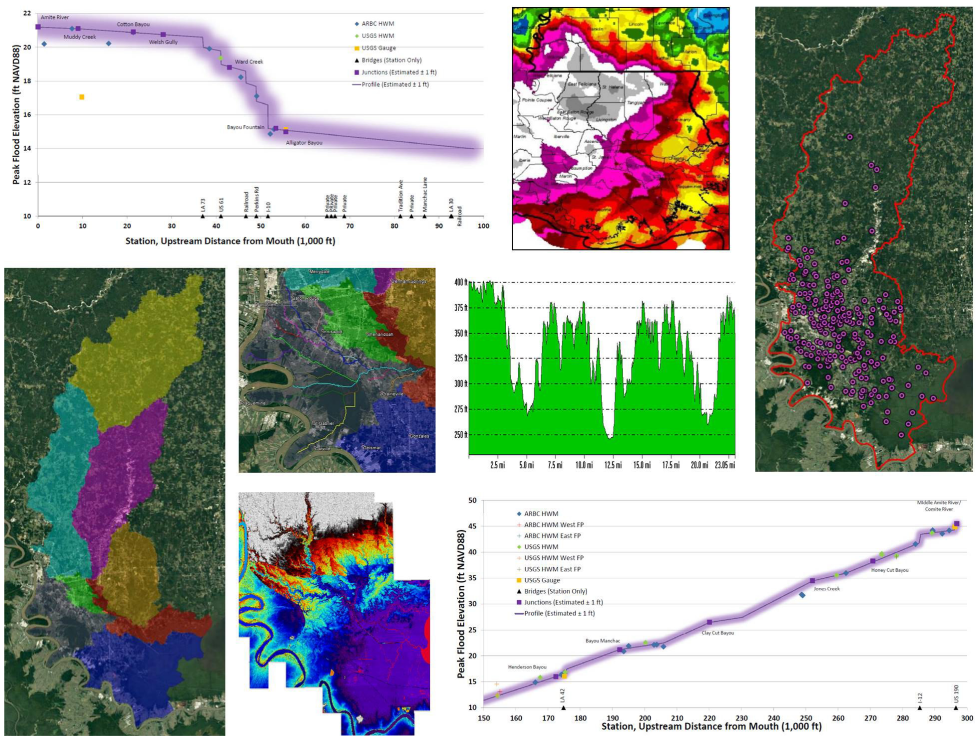
August 2016 Flood Preliminary Report
Amite River Basin



Prepared for

Amite River Basin
Drainage and Water Conservation District

AMITE RIVER BASIN
DRAINAGE AND WATER CONSERVATION DISTRICT

Prepared by

Bob Jacobsen PE, LLC

August 21, 2017

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August 21, 2017

Mr. Dietmar Rietschier
Executive Director
Amite River Basin Drainage and Water Conservation District
3535 S. Sherwood Forest Blvd.
Suite 135
Baton Rouge, Louisiana 70816

Subject: ***August 2016 Flood Preliminary Report, Amite River Basin***

Dear Mr. Rietschier:

Per the Contract for Professional Services (dated May 17, 2017) with the Amite River Basin Drainage and Water Conservation District (ARBD) Bob Jacobsen PE, LLC has completed an *August 2016 Flood Preliminary Report*. The attached Report includes four parts:

- Part I. Background—The Amite River Basin.
- Part II. Background—Flood Hazard and Risk in the Amite River Basin.
- Part III. The August 2016 Flood.
- Part IV. Conclusions and Recommendations.

Part III includes information on the ARBD High Water Mark (HWM) program (and USGS gauge and HWM programs), analysis of peak flood data quality, and Preliminary Peak Flood Profiles for 70 streams within the eight sub-basins of the Amite River Basin:

Upper Amite River	Honey Cut Bayou/Jones Creek/Clay Cut Bayou
Middle Amite River	Grays & Colyell Creeks
Lower Amite River	Bayou Manchac
Comite River	Blind River

Part IV includes key findings and conclusions based on the preliminary profiles, together with recommendations for finalizing the profiles and preparing a basin-wide inundation map using a high quality hindcast model. In addition, Part IV includes recommendations regarding *Full Spectrum* flood hazard and *Real Flood Risk* analyses.

Bob Jacobsen PE appreciates the opportunity to support the ARBD on this important project. Please do not hesitate to contact me if you have any questions.

Sincerely,

Robert W. Jacobsen, P.E.
President

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Robert W. Jacobsen, P.E.
Bob Jacobsen PE, LLC, President
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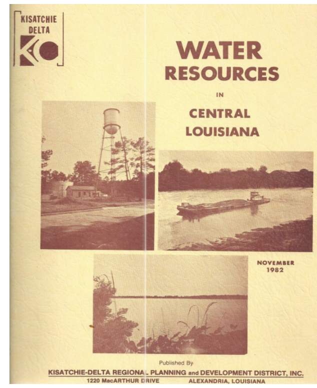
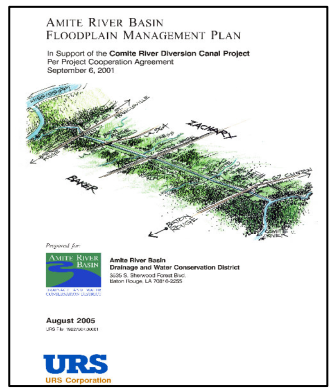
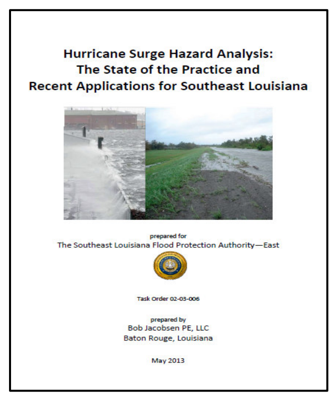
About the Author



Bob Jacobsen is a professional environmental engineer with over 35 years of experience addressing complex environmental, coastal, and flood water resource challenges. He received a MS in Civil Engineering from Louisiana State University in 1996 and has completed additional coursework towards a PhD. Since 2004 he has worked extensively in the burgeoning application of *High Performance Computing/High-Resolution* hydrodynamic modeling to flood risk management and hydrologic restoration.



Bob's experience in flood hydrologic studies dates to 1982. Since 2002, following Tropical Storm Allison he has served as a hydrologic consultant to the Amite River Basin Drainage and Water Conservation District (ARBD). He has authored/co-authored numerous studies for the Amite River Basin, including the 2005 *Draft Floodplain Management Plan*. He organized the post-August 2016 Flood *High Water Mark Survey* for the ARBD, as well as a *Workshop on Improving Amite River Basin Flood Forecasting and Hazard Analysis*.



Since 2011 Bob has worked for both the Southeast Louisiana Food Protection Authority—East and the Louisiana Coastal Protection and Restoration Authority on hurricane surge issues. In this capacity he authored *Hurricane Surge Hazard Analysis: The State of the Practice and Recent Applications for Southeast Louisiana* (May 2013), and *New Orleans East-Bank Hurricane Surge Residual Risk Reduction Report* (February 2016). For the Hurricane Katrina 10th Anniversary he authored several articles and presentations on New Orleans surge risk. He has also authored a *Hurricane Surge Hazard Primer* and a technical article on *Hurricane Surge Hazard Uncertainty in Coastal Flood Protection Design*.

Bob also has a professional background in environmental policy and recently authored the following on flood risk management: *Real Flood Risk* (a 3-minute video), *Real Flood Risk*: The Grassroots Revolution, and The Flood Risk Game.

Bob has given numerous presentations on HPC/High-Resolution hydrodynamic modeling and flood risk at professional and public meetings and has provided expertise to several news organizations, including the Advocate, the Times-Picayune, the Lens, the Baton Rouge Business Report, the Weather Channel, CNBC, WWL-TV, and WRKF. Bob recently served as President of the Louisiana Section of the American Society of Civil Engineers. He enjoys surf-fishing along Louisiana's coast and running marathons.

For more information see www.bobjacobsenpe.com or contact Bob Jacobsen at bobjacobsenpe@gmail.com .

Table of Contents

Executive Summary

Objectives of This Report

The Amite River Basin Drainage and Water Conservation District (ARBD) has overseen regional flood risk management for the Amite River Basin (ARB) since its inception in 1981, and for more than 35 years has been deeply committed to advancing scientific knowledge on ARB flood hazard and risk. The ARBD tasked Bob Jacobsen PE, LLC to prepare an *August 2016 Flood Preliminary Report*:

- Describing the ARBD sponsored post-flood High Water Mark (HWM) program;
- Evaluating the ARBD HWM data quality;
- Defining and analyzing peak flood profiles for major streams in the ARB using the ARBD and US Geological Survey (USGS) peak flood data; and
- Providing conclusions and recommendations for finalizing August 2016 Flood inundation maps, including a high quality, *State-of-the-Practice* model of the flood.

The peak flood profiles and analysis presented in this Report are *preliminary* and should not be used for flood related planning or engineering purposes until an analysis of the August 2016 Flood is finalized with the aid of a high quality "hindcast model" (computer simulation of the flood).

In addition to presenting the above data and preliminary analysis for the August 2016 Flood, this Report includes two pertinent background parts. *Part I, Background—The Amite River Basin* reviews the ARB sub-basins and major streams, regional terrain and river morphology, and types of flooding. These three sections provide a crucial basic understanding of the ARB flood setting.

Part II, Background—Flood Hazard and Risk in the Amite River Basin includes sections on *Full Spectrum* flood hazard, *Real Flood Risk*, the history of ARB flooding, and the history of ARB flood risk management. These sections are meant to give readers interested in flood risk management some important context for this Report and its recommendations. Information in these sections (e.g., the review of Annual Exceedance Probability) is useful for the first two sections in *Part III—The August 2016 Flood:* the first on the August 2016 rain event and second which addresses the USGS analysis of the flood data. The additional background information provides the basis for the further objectives and key recommendations discussed in *Part IV—Conclusions and Recommendations*.

Those readers familiar with the background material and only interested in the ARBD data, profiles, and associated findings and conclusions can easily limit their attention to the sections directly addressing these topics.

Preliminary Conclusions

The peak flood data and analysis of profiles yielded eight major preliminary conclusions regarding the August 2016 Flood:

1. Peak flood data for the August 2016 Flood exhibit good coverage, particularly of flooded areas. Due to limitations of survey time/funds and available/accessible evidence, the USGS and ARBD could not obtain HWMs for some major stream reaches (especially in the Hilly Uplands portion of the ARB). A total of 482 measurements (34 USGS gauges; 198 USGS HWMs; and 250 ARBD HWMs) were used to generate 1,060 miles of preliminary peak flood profiles for 70 major streams—on average 7 points per stream or one every half mile.

2. In terms of HWM repeatability (precision), the peak flood data are of very reasonable quality for use in flood analysis. A conservative estimate of uncertainty with respect to repeatability in the combined set of USGS/ARBD HWMs is ± 1.0 ft.
3. More than half the data were provided by the ARBD HWMs. In addition, the ARBD HWMs showed better repeatability than USGS HWMs. The ARBD HWMs will be a crucial resource for studying the August 2016 Flood and analyzing ARB flood hazards for decades to come.
4. Reasonable preliminary profiles were defined using engineering judgment for most reaches along the 70 selected major streams, manually fitting profiles to the peak flood data. Preliminary profiles were estimated using the regional terrain in reaches that lacked HWMs.
5. Many reach profiles in the ARB were influenced by backwater flooding. Those strongly affected by backwater flooding included Hurricane Creek; Robert Canal; lower portions of Honey Cut Bayou, Jones Creek; Grays Creek, and Colyell Creek; most of Clay Cut Bayou; Bayou Manchac and most of its tributaries; and the remaining lower Amite and Blind Rivers and their tributaries.
6. Bridges had a widespread impact on peak flood levels throughout the ARB—preliminary profiles indicate more than 80 bridges. Bridge impacts exceeded 1 foot at many locations. The most significant impact was the I-12 bridge/barrier at Grays Creek—about 4 ft. Bridge impacts were negligible in areas with more sluggish backwater flow. The widespread bridge impacts indicated by the August 2016 Flood preliminary profiles are consistent with the general limitation of bridges with respect to very extreme floods.
7. Two other structures markedly influenced the peak flood: Bayou Manchac Road (which restricted flow into Spanish Lake/Bluff Swamp) and the gate at the Marvin Braud Pump Station on New River (which restricted flow to the Petite Amite River).
8. Additional HWMs for many reaches would likely improve the quality of a hindcast model of the August 2016 Flood and finalizing stream peak flood profiles and basin-wide inundation maps.

<u>Further Objectives</u>

ARB leaders, planning officials, and the public need the results of a finalized analysis of the August 2016 Flood available online and accurate down to the parcel level, *as soon as possible*, in order to develop and implement a ***holistic strategy*** for ARB flood risk management. Such a strategy must seek to economically manage *Real Flood Risk* with minimal adverse impact, and must receive solid, basin-wide public support.

Finalizing the post-flood analysis includes:

1. Preparing high quality ARB-wide inundation maps for the August 2016 Flood (online, showing both peak flood elevation ft NAVD88 and depth above ground) and finishing a detailed study of flood characteristics and the impacts of terrain and man-made features (e.g., bridges).
2. Determining the *Full Spectrum* flood hazard and *Real Flood Risk* for current conditions throughout the ARB.
3. Evaluating changes to the *Full Spectrum* flood hazard and *Real Flood Risk* for “what if” scenarios.

Five Recommendations to Finalize Analysis

FIRST: Formalize coordination of the diverse technical programs and activities among the numerous entities with roles in ARB flood risk management.

SECOND: Develop and maintain an online ARB Geographic Information System (GIS) portal—to provide users and the public easy access to important reliable data and analysis.

THIRD: Develop a *State-of-the-Practice* hindcast model of the August 2016 Flood. Such a hindcast should incorporate the most modern approaches, including development of two interim models to assist in development.

FOURTH: Obtain additional HWMs where feasible to support final hindcast model development.

FIFTH: Develop additional tools to complete *Full Spectrum* flood hazard and *Real Flood Risk* analyses and scenario assessments, including: synthetic rainfall/coastal-wind events, risk assessment software, and "what if" inputs/conditions for climate change, sea level rise, river morphodynamics, land-use modifications, flood risk reduction projects and programs, and future development and infrastructure.

Acknowledgements

The ARBD Executive Director Dietmar Rietschier has been a leading advocate in the State of Louisiana for sound, science-based regional flood risk management for more than two decades. The ARBD high water mark survey and preliminary analysis for the August 2016 Flood were only able to be undertaken due to his understanding of the criticality of this work. He and the ARB Commission are to be greatly credited with diligently supporting many basin-wide flood risk management initiatives in the face of numerous obstacles.

Clint Willson, Ph.., P.E. graciously agreed to review this Report and his suggestions improved it immensely.

The author gladly shares any and all appreciation for this Report with them, and assumes sole responsibility for any and all flaws.

Part I.

Background—
The Amite River Basin

1. The Amite River Basin[1]

The Amite River is approximately 117 miles in length, originating in the steep hills of extreme southeastern Franklin and southwestern Lincoln Counties in Mississippi and terminating in Livingston Parish Louisiana at the tidal Lake Maurepas. Figure 1 presents the location of the Amite River Basin (ARB), which encompasses about 2,200 square miles within parts of six Louisiana parishes and four southwestern Mississippi counties, roughly 75/25 percent of the ARB, respectively.

Figures 2 and 3 show the eight principal sub-basins of the ARB and their major streams:

1. Upper Amite River (Figure 3a)—lies primarily in Amite County MS and includes 4 major streams. It extends southward to the confluence of the upper Amite River and Beaver Creek.
2. Middle Amite River (Figure 3b)—encompasses the portion of Amite River down to the confluence with the Comite River and ten major tributaries. Darling Creek on the east bank drains a small portion of western St. Helena Parish. Sandy Creek on the west bank drains some of eastern East Feliciana and northeastern East Baton Rouge Parishes (Brownsfield). The west bank of the middle Amite River below Sandy Creek drains portions of the City of Central lying east of Greenwell Springs Road. Spillers and Beaver Creek drain portions of northwestern Livingston Parish (e.g., Watson).

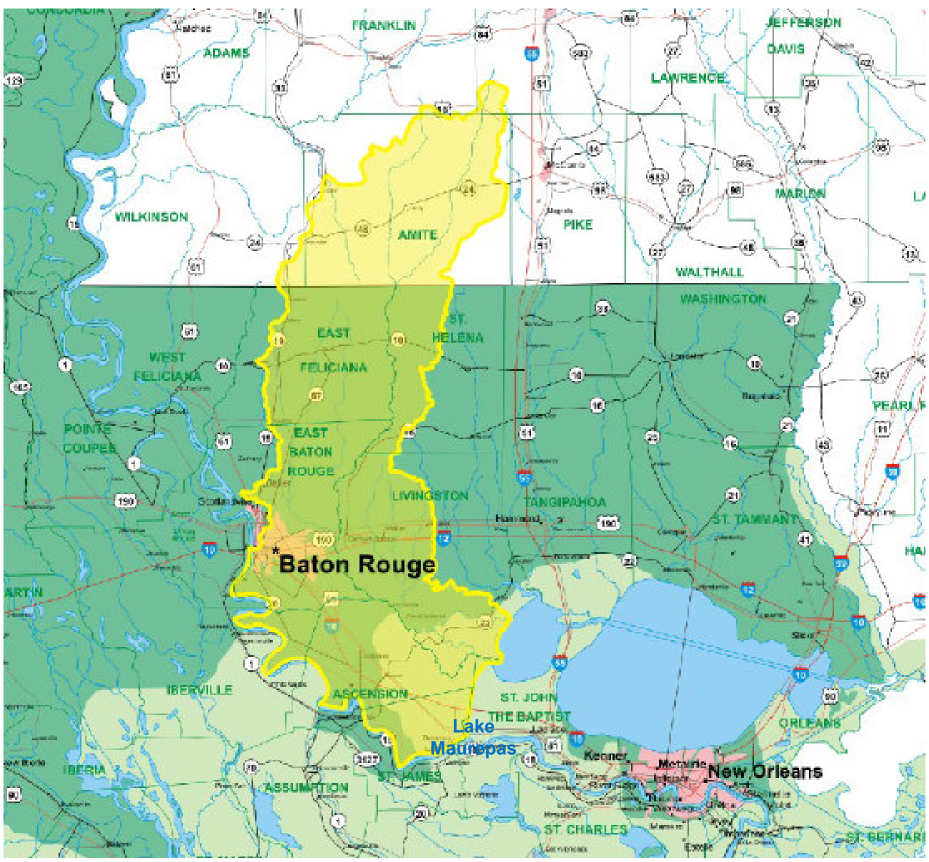
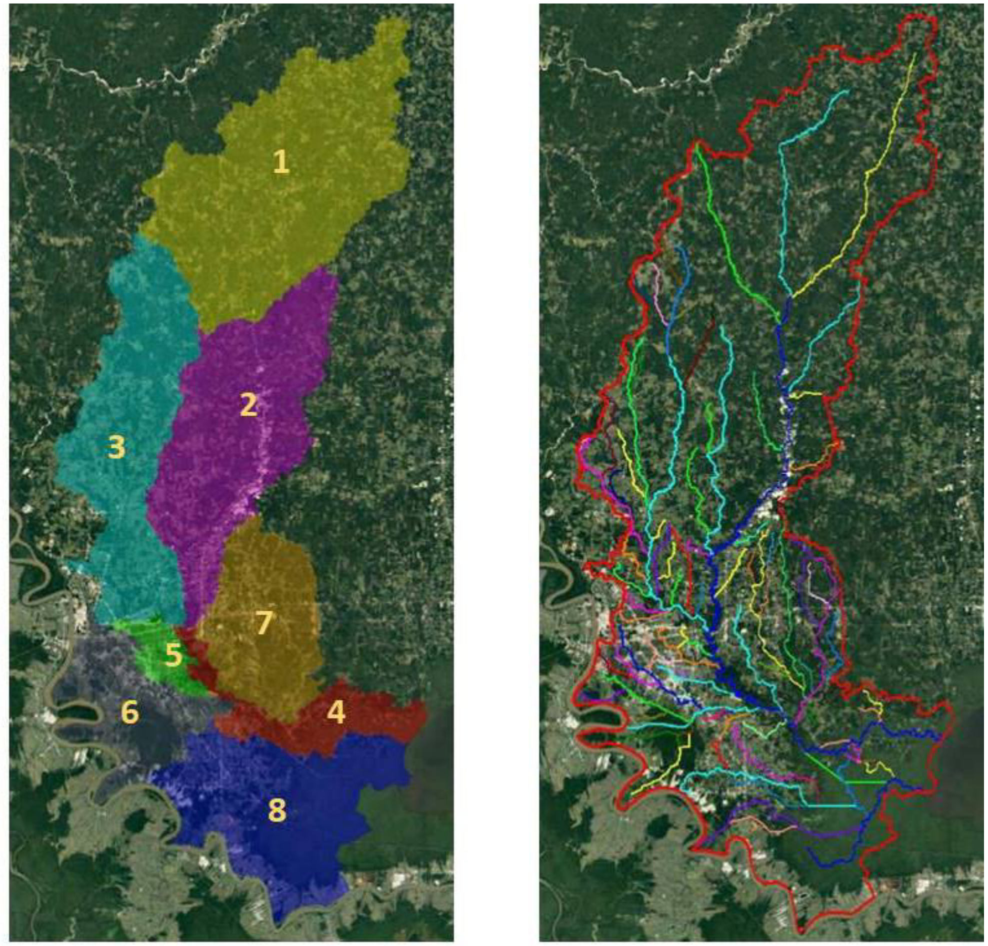


Figure 1. Amite River Basin
URS Corporation 2005

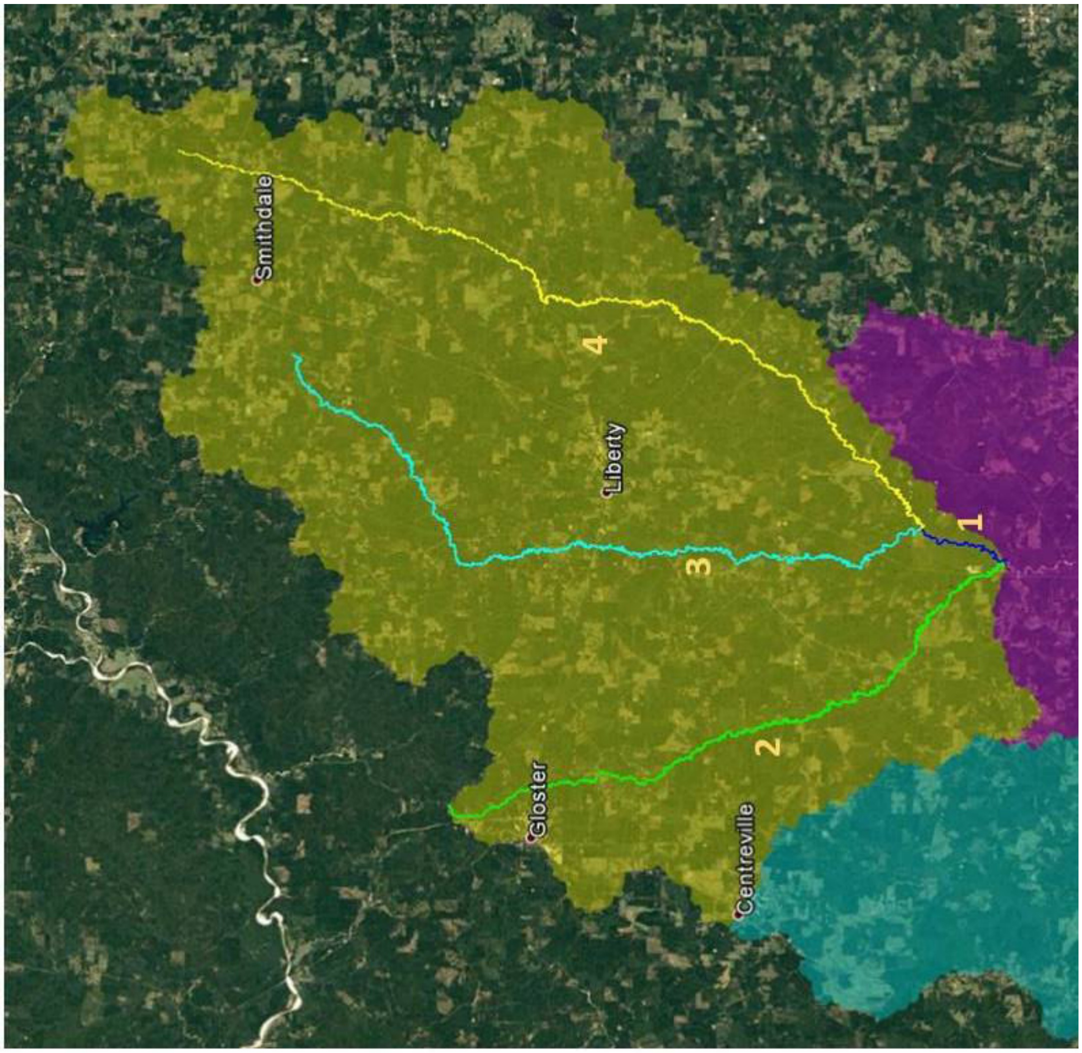
[1] Portions of this section are taken from the *ARB Floodplain Management Plan* (URS 2005 and GEC 2015).

1. Upper Amite River
2. Middle Amite River
3. Comite River
4. Lower Amite River
5. Honey Cut Bayou/Jones Creek/ Clay Cut Bayou
6. Bayou Manchac
7. Grays Creek/Colyell Creek
8. Blind River



8 Sub-Basins **Major Streams**

Figure 2. ARB Sub-Basins and Major Streams



1. Upper Amite River
2. Beaver Creek
3. West Fork Amite River
4. East Fork Amite River

Figure 3. Major Streams by Sub-Basin and Major Streams
a. Upper Amite River Sub-basin

1. Middle Amite River
2. Beaver Creek (Livingston Parish)
3. Hub Bayou
4. Spillers Creek
5. Darling Creek
6. Sandy Creek
7. Little Sandy Creek
8. Little Sandy Creek (2)
9. Mill Creek
10. Pigeon Creek
11. Bluff Creek

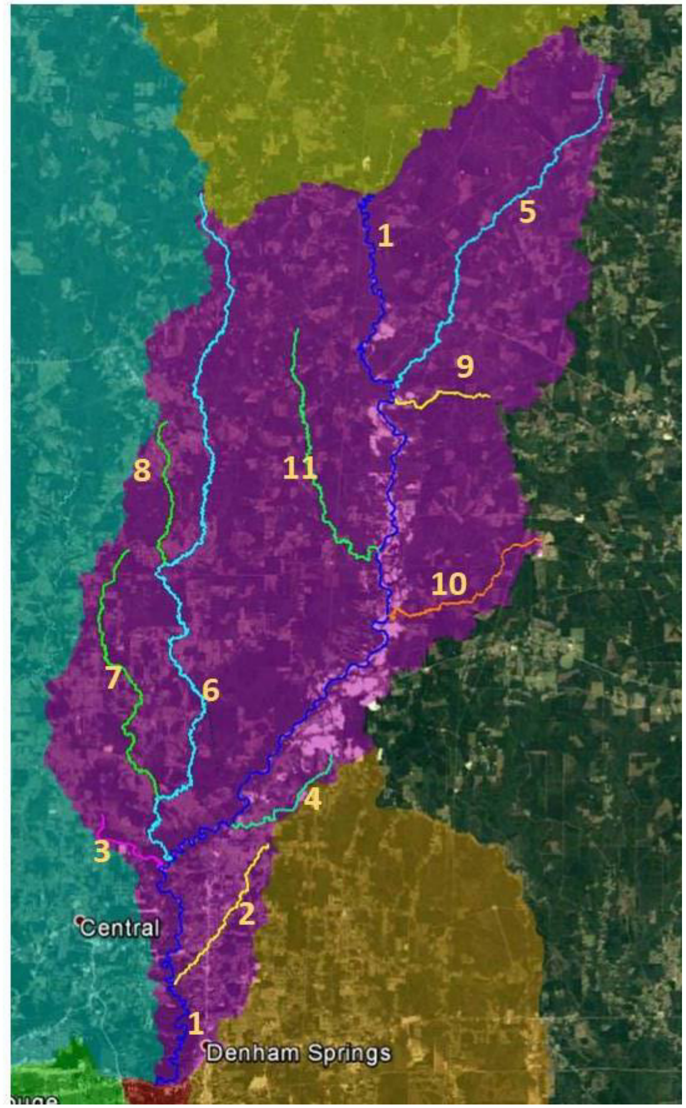


Figure 3. Major Streams by Sub-Basin and Major Streams
b. Middle Amite River Sub-basin

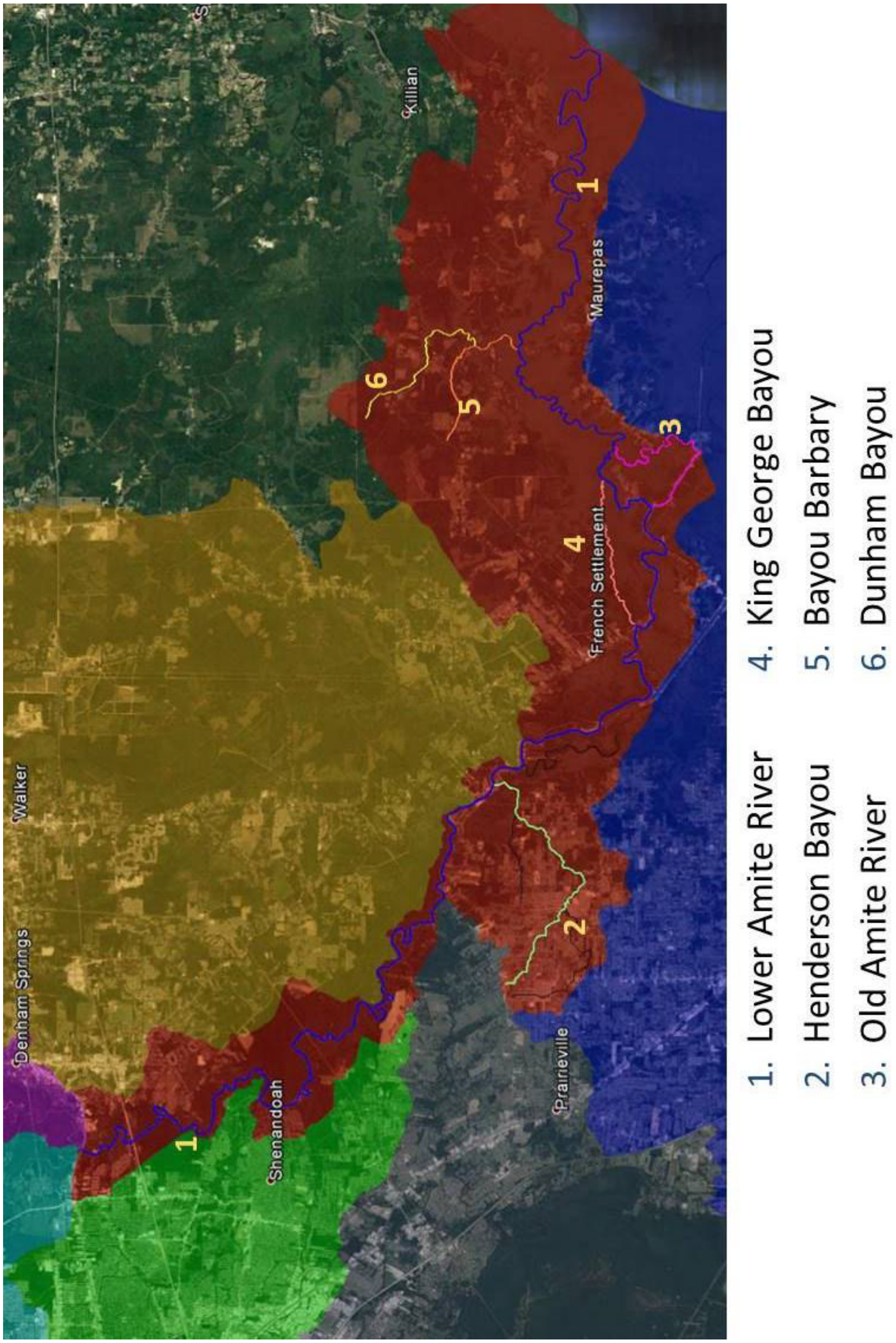


Figure 3. Major Streams by Sub-Basin and Major Streams
c. Lower Amite River Sub-basin

1. Comite River
2. Draughan Creek
3. Beaver Bayou
4. Comite River Drainage Tributary
5. Blackwater Bayou
6. Blackwater Bayou Drainage Tributary
7. Hurricane Creek
8. Robert Canal
9. Cypress Bayou
10. White Bayou
11. Old White Bayou
12. Old White Bayou Drainage Tributary
13. Brushy Bayou
14. Copper Mill Bayou
15. Black Creek
16. Saunders Bayou
17. Redwood Creek
18. Doyle Bayou
19. Pretty Creek
20. Comite Creek
21. Little Comite Creek

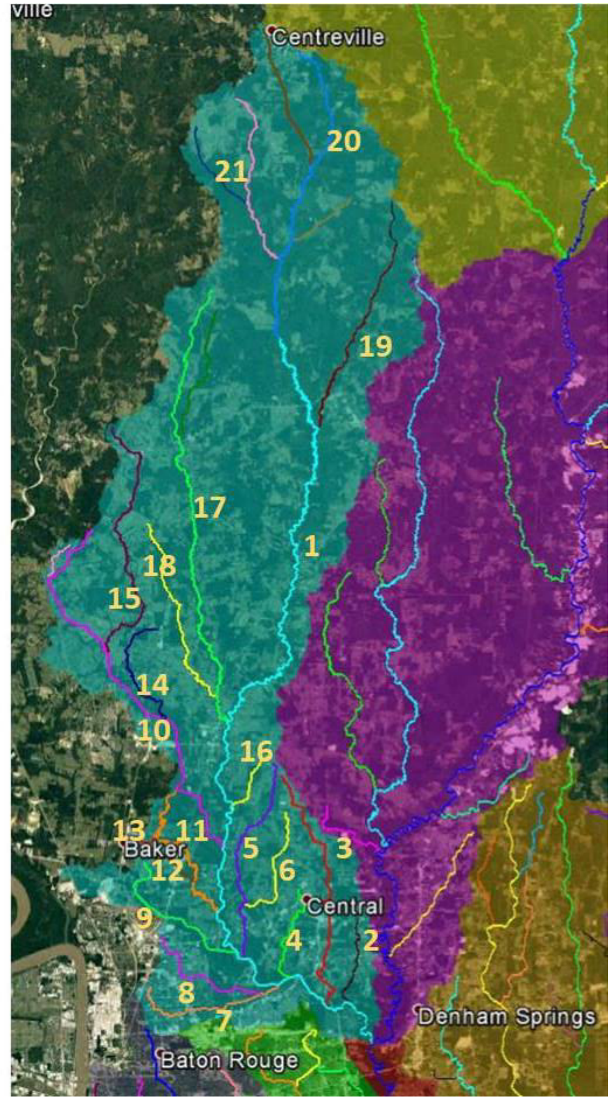


Figure 3. Major Streams by Sub-Basin and Major Streams
d. Comite River Sub-basin

1. Honey Cut Bayou
2. Jones Creek
3. Clay Cut Bayou
4. Lively Bayou
5. Jacks Bayou
6. Weiner Creek

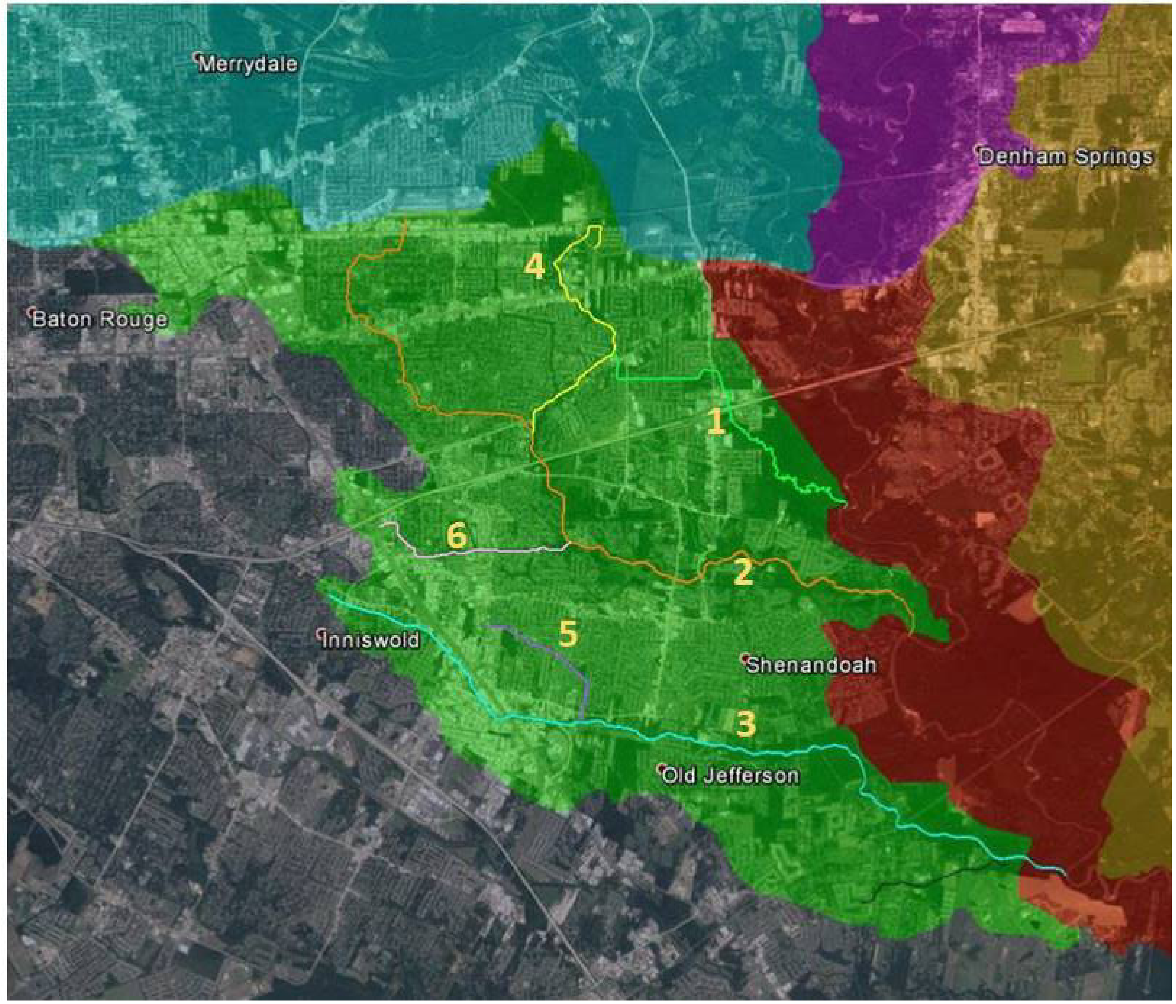


Figure 3. Major Streams by Sub-Basin and Major Streams
e. Honey Cut Bayou/Jones Creek/Clay Cut Bayou Sub-basin

1. Grays Creek
2. West Colyell Creek
3. Middle Colyell Creek
4. Colyell Creek
5. Little Colyell Creek
6. Hornsby Creek
7. Beaver Branch
8. Antioch Creek
9. Moler Bayou
10. Dumplin Creek
11. Felder Bayou
12. Prairie Bayou

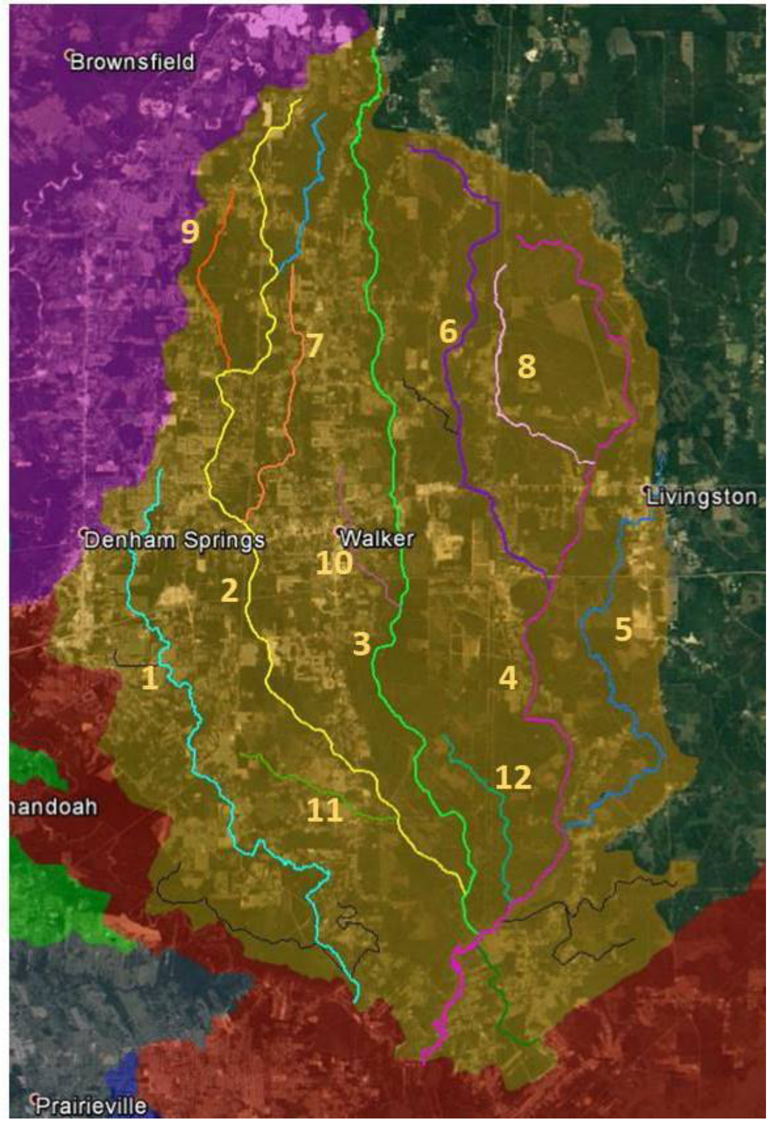


Figure 3. Major Streams by Sub-Basin and Major Streams
f. Grays Creek/Colyell Creek Sub-basin

1. Bayou Manchac
2. Muddy Creek
3. Welsh Gully
4. Alligator Bayou
5. Bayou Braud
6. Bayou Paul
7. Bayou Fountain
8. Ward Creek
9. Ward Creek Bypass
10. North Branch Ward Creek
11. Dawson Creek
12. Bayou Duplantier
13. Corporation Canal
14. Elbow Bayou
15. Selene Bayou

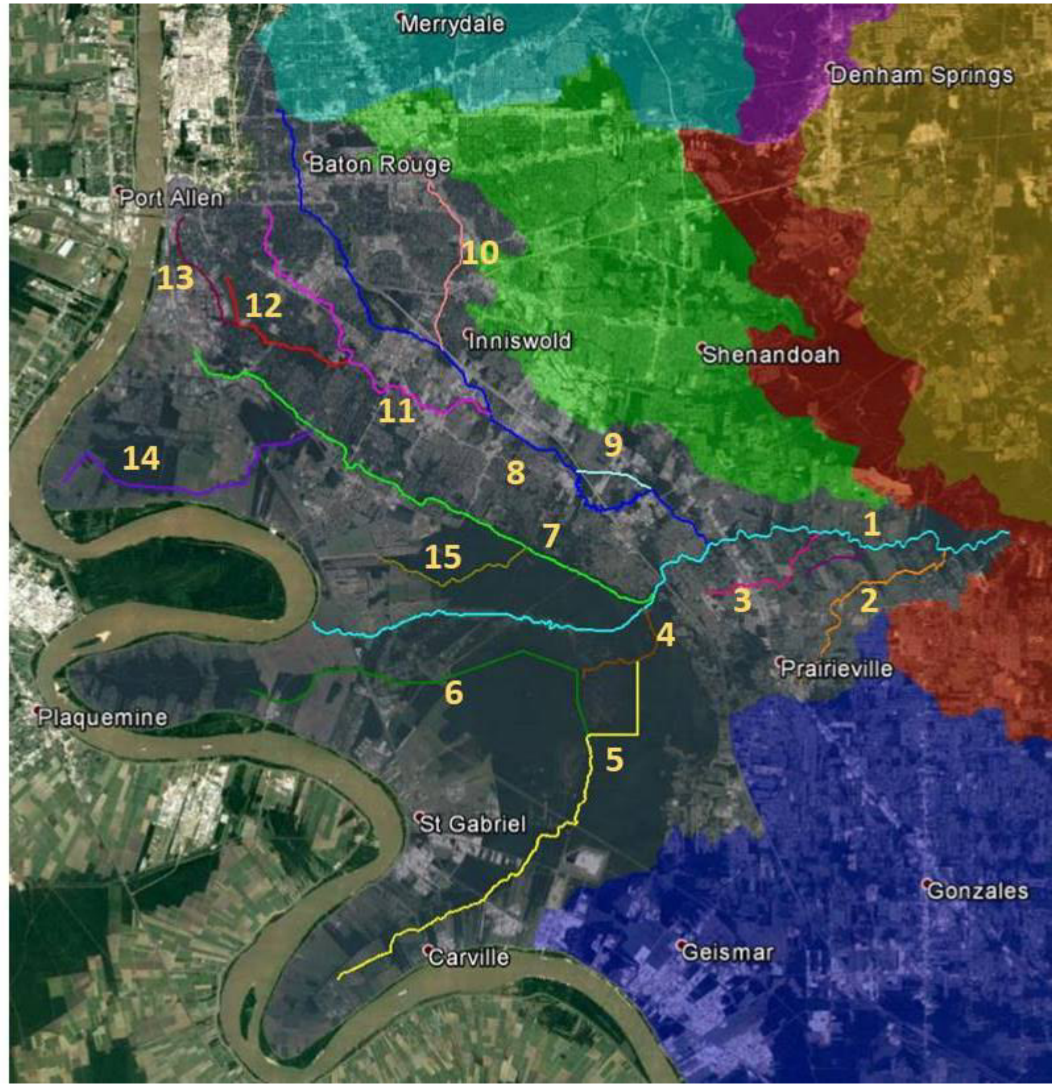
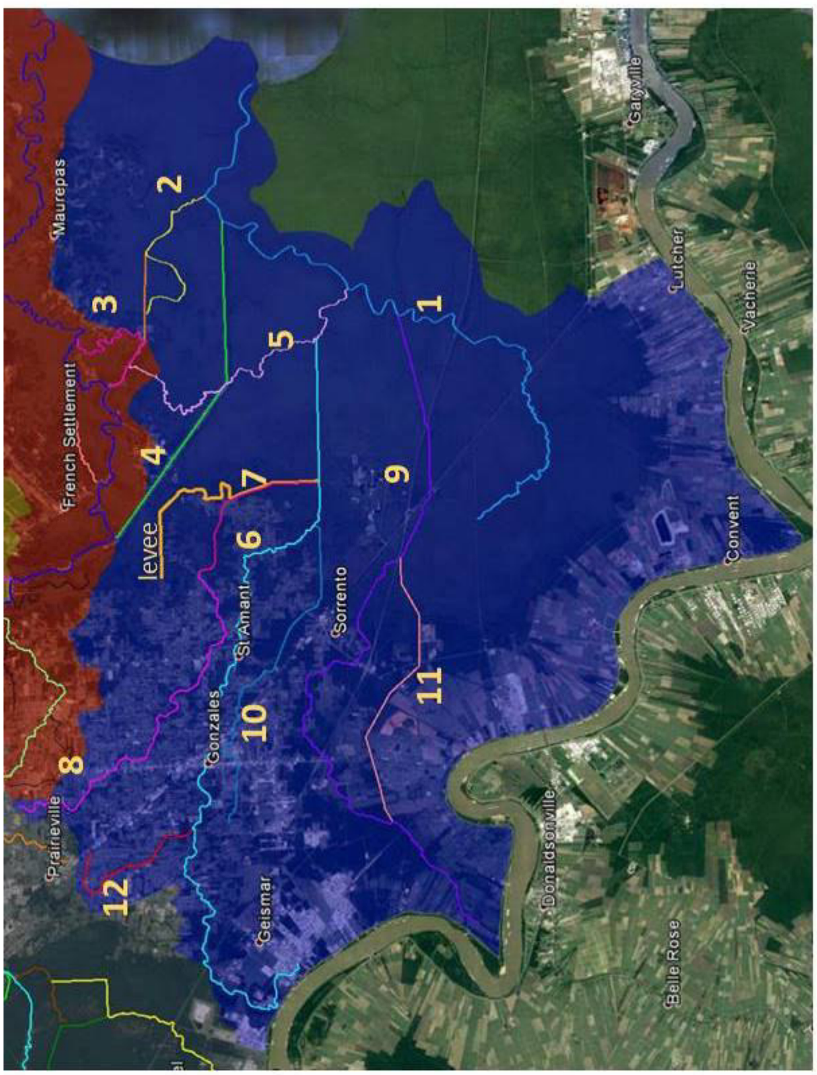


Figure 3. Major Streams by Sub-Basin and Major Streams
g. Bayou Manchac Sub-basin



1. Blind River
2. Bayou Chene Blanc
3. Chinquapin Canal
4. ARDC
5. Petite Amite River
6. New River
7. Saverio Canal
8. Black Bayou
9. Bayou Conway
10. Bayou Francois
11. Panama Canal
12. Grand Goudine Bayou

Figure 3. Major Streams by Sub-Basin and Major Streams
h. Blind River Sub-basin

3. Lower Amite River (Figure 3c)—runs 55 miles from the Comite River to Lake Maurepas. Two notable abandoned Amite River channels are present on the east bank (King George Bayou, and Old Amite River, in Livingston Parish). Henderson Bayou enters the Lower Amite River on the east bank in Ascension Parish, just below Port Vincent and above Colyell Creek. Ascension Parish has a levee system to partially control the Amite River floodplain. The intersection of Henderson Bayou with the levee, about 1.5 miles above the Amite River, includes a gate and pump station.
4. Comite River (Figure 3d)—extends 64 miles in length from southeastern Wilkinson and southwestern Amite Counties in Mississippi, through East Feliciana and East Baton Rouge Parishes, to the Amite River near Denham Springs. The Comite River is the largest tributary of the Amite River, with the Comite River sub-basin comprising about 348 square miles, or 27 percent of the 1,280 square miles in the ARB above the confluence with the Amite River. Figure 3 highlights 20 major streams in the Comite River sub-basin. The Comite River and its tributaries drain much of Norwood, Clinton, Ethel, and Slaughter in East Feliciana Parish, as well as eastern Zachary and Baker, western Central, and areas north of the Canadian-Northern Railroad (Choctaw Drive) in East Baton Rouge Parish.
5. Honey Cut Bayou/Jones Creek/Clay Cut Bayou (HCB/JC/CCB, Figure 3e))—are three west bank tributaries of the Lower Amite River just below Denham Springs. They drain portions of East Baton Rouge Parish south of Choctaw Drive, east of Airline Highway (US 61), and north of Hoo Shoo Too Road.
6. Grays Creek/Colyell Creek (Figure 3f)—drain western Livingston Parish below Beaver Creek, including Denham Springs, Walker, and Satsuma. They enter the Amite River just above and below Port Vincent, respectively.
7. Bayou Manchac (Figure 3g)— is an abandoned flood distributary of the Mississippi River and major west bank tributary to the lower Amite River. Bayou Manchac forms the boundary between East Baton Rouge Parish to the north and Iberville and Ascension Parishes to the south, entering the Amite River between Clay Cut Bayou and Grays Creek. The Bayou Manchac sub-basin includes about 169 square miles. Two major tributaries drain the southern portion of East Baton Rouge Parish: Wards Creek (and its tributaries Dawson Creek, Bayou Duplantier, etc.), which drains the area east of Highland Road and west of Airline Highway (extending into downtown Baton Rouge); and Bayou Fountain (and its tributaries) which drains the Mississippi River floodplain west of Highland Road. Alligator Bayou (and its tributaries Bayou Paul and Bayou Braud) and Frog Bayou (a minor stream about 1,000 feet east of Alligator Bayou) drain the Mississippi River floodplain portions of Iberville and Ascension Parishes south of Bayou Manchac, including Bluff Swamp and Spanish Lake. An old natural levee embankment, topped with the paved Alligator Bayou Road, runs along the south bank of Bayou Manchac west of I-10. Alligator and Frog Bayous connect to Bayou Manchac through Alligator Bayou Road via control gates which are normally open. During major floods the gates are closed to prevent backflow from Bayou Manchac. East of I-10, the extreme northern portion of Ascension Parish (e.g., Prairieville) drains to Bayou Manchac via several small tributaries, including Welsh Gully and Muddy Creek.
8. Blind River (Figure 3h)—lies in the coastal swamps southwest of Lake Maurepas, entering Lake Maurepas about 6 miles southwest of the mouth of the Amite River. The Petite Amite River is a distributary of the Amite River, joining the Blind River about 11 miles above its mouth and forming part of the boundary between Livingston and Ascension Parishes. In the

early 1960s the 10-mile Amite River Diversion Canal (ARDC) was dredged from near French Settlement to Blind River to enhance flood outflow to Lake Maurepas. The ARDC intersects the Petite Amite River near its halfway point. Thus, the upper western portion of the ARDC, including the old rock control weir at the head of the ARDC, is in Ascension Parish, while the lower eastern portion is in Livingston Parish. Several Blind River tributaries drain the bulk of east Ascension Parish (Dutchtown, Geismar, Gonzales, St. Amant, and Sorrento). The Sevario Canal joins the channelized portion of the New River just inside the Ascension levee system. The intersection of the New River with the levee, about 4 miles west of the Petite Amite River, includes a gate and the Marvin Braud Pump Station. The upper Blind River above Bayou Conway drains St. James Parish, including communities along the Mississippi River.

In this Report the delineation of major streams and their sub-basins is derived from the US Geological Survey (USGS) National Hydrography Dataset (NHD) with some minor modifications. The Upper Amite River sub-basin as defined in this Report extends to the confluence with Beaver Creek. The Amite River below this confluence, including Darling Creek, are part of the Middle Amite River sub-basin. Sub-basins for Honey Cut Bayou, Jones Creek, and Clay Cut Bayou have been combined as HCB/JC/CCB sub-basin.

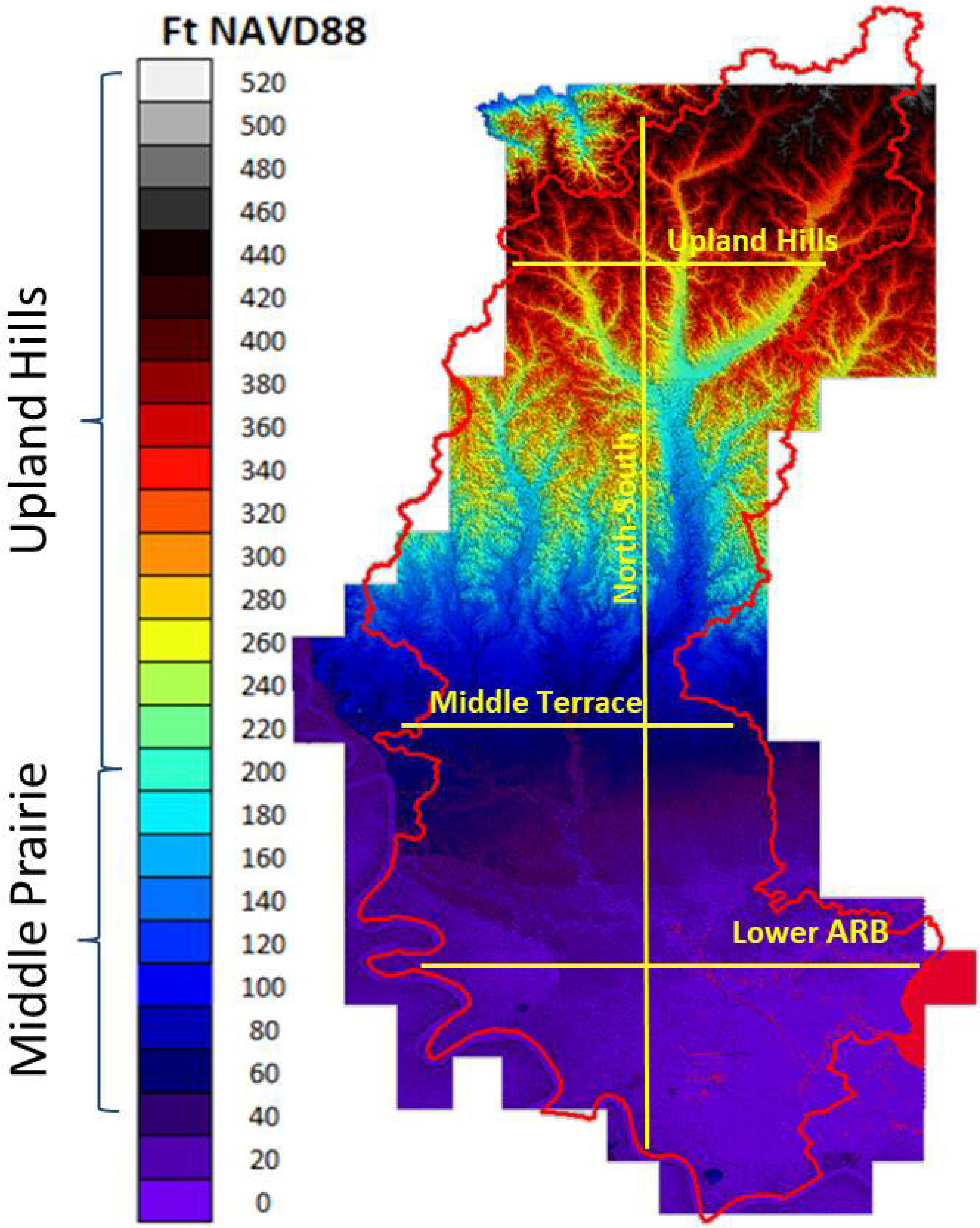
During floods, the floodplains for major streams can merge, particularly near their confluence and where such junctions are characterized by expansive wetlands. For such floods, the delineation between sub-basins in these areas is arbitrary.

Each sub-basin area can be subdivided into component watersheds for each major stream. Each watershed, in turn, can be further subdivided into numerous drainage catchments for each stream tributary.

2. Regional Terrain and Stream Morphology

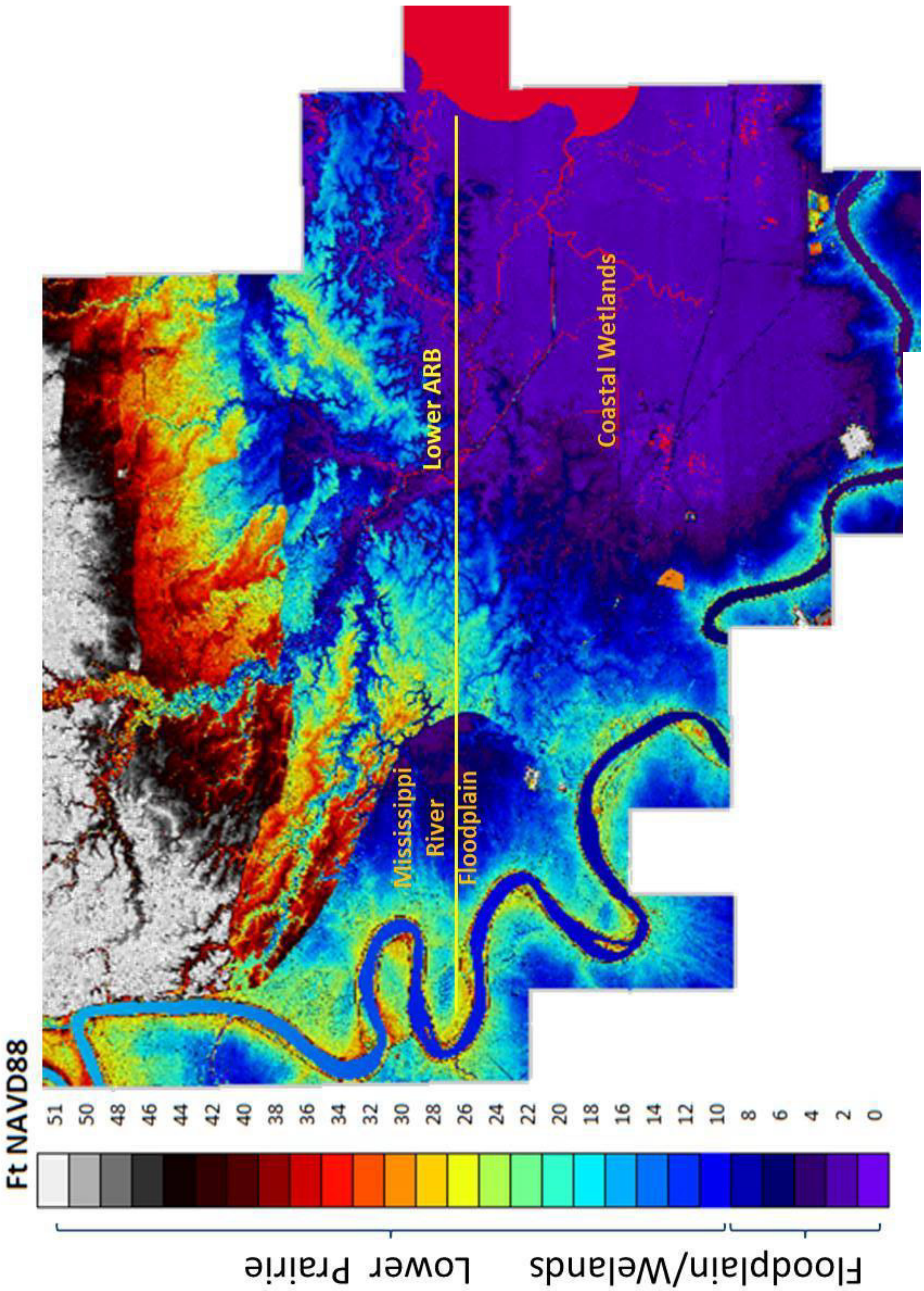
Figures 4 and 5 illustrate the topography of the ARB based on LIDAR Digital Elevation Models (DEMs) (Louisiana 2001, Mississippi 2016). The ARB is characterized by a drop in elevation of about 500 ft from north to south. This drop follows remnant pre-Ice Age (Pliocene/Pleistocene) terraces. The topography can be described in terms of five general topographic zones, which in turn characterize the relief in the eight sub-basins:

1. The Upland Hills includes the northern third of the ARB and over half of the ARB elevation drop—from about 500 ft to 200 ft NAVD88. The Upland Hills features some fairly steeper terrain in the north. This zone extends down to mid-East Feliciana and St. Helena Parish—just south of LA Highway 10 and contains all of the Upper Amite River sub-basin and the northern portions of the Middle Amite River and Comite River sub-basins. In the Upland Hills the major streams are deeply incised within the terrain and floodplains are fairly narrow.
2. The Middle Prairie extends down through northern East Baton Rouge and Livingston Parishes and consists of gentler terrain with elevation falling from roughly 200 ft to 50 ft NAVD88. This zone includes the middle portions of the Comite River sub-basin to about Greenwell Springs Rd, the Middle Amite River sub-basin to Magnolia Bridge, and the Grays/Colyell Creeks sub-basin to about Arnold Road (LA Highway 1025). As the regional slope becomes milder in the Middle Prairie, the floodplains of the Amite and Comite River and major tributaries begin to widen substantially. Figure 4a shows that with its confluence with Sandy Creek, the Amite River floodplain broadens considerably.
3. The Lower Prairie includes most of the rest of East Baton Rouge and Livingston Parishes and western Ascension Parish and is depicted in more detail in Figure 4b (but note the smaller scale increments). In this zone the terrain continues falling—from 50 down to 10 ft NAVD88 southward and eastward following remnant Pleistocene features, including surface expressions of major geologic faults—and flattening. Just below the junction of the Amite and Comite Rivers the regional ground falls notably (from white/gray to red in Figure 5), particularly to the east (Livingston Parish). This zone encompasses the remainder of the Comite River, Middle Amite River, and Grays/Colyell Creeks sub-basins; the Honey Cut Bayou/Jones Creek/Clay Cut Bayou sub-basin; the eastern portion of Bayou Manchac sub-basin (east of Highland and Bluff Roads); the northwestern portion of the Blind River sub-basin; and finally some elevated terrain within the Lower Amite River sub-basin. Figure 5 illustrates that in the Lower Prairie as the elevation drops toward sea level, stream floodplains widen even further.
4. The Mississippi River Floodplain and Natural Levee. Figure 4b shows the Mississippi River floodplain (dark blue and some purple) in western Bayou Manchac sub-basin (west of Highland and Bluff Roads in East Baton Rouge, Iberville, and Ascension Parishes), as well as the band of higher natural levee ground that extends along the entire east bank south of downtown Baton Rouge. (Figure 4b also illustrates that Bayou Duplantier, Wards Creek, and Bayou Manchac once served as Mississippi River overbank distributaries.)
5. The Coastal Wetlands and Margins include the additional purple area in Figure 4b occupying a large portion of the Lower Amite River and Blind River sub-basins (St. James Parish apart from the Mississippi River natural levee, Livingston Parish below French Settlement-Maurepas, and southeastern Ascension Parish). This zone consists of very flat low-lying land, with elevations below 4 ft dominated by coastal cypress swamp.



a. Full ARB

Figure 4. ARB Topographic Digital Elevation Model
Louisiana Oil Spill Coordinators Office 2001



b. Lower ARB

Figure 4. ARB Topographic Digital Elevation Model
Note change in scale from Figure 4a

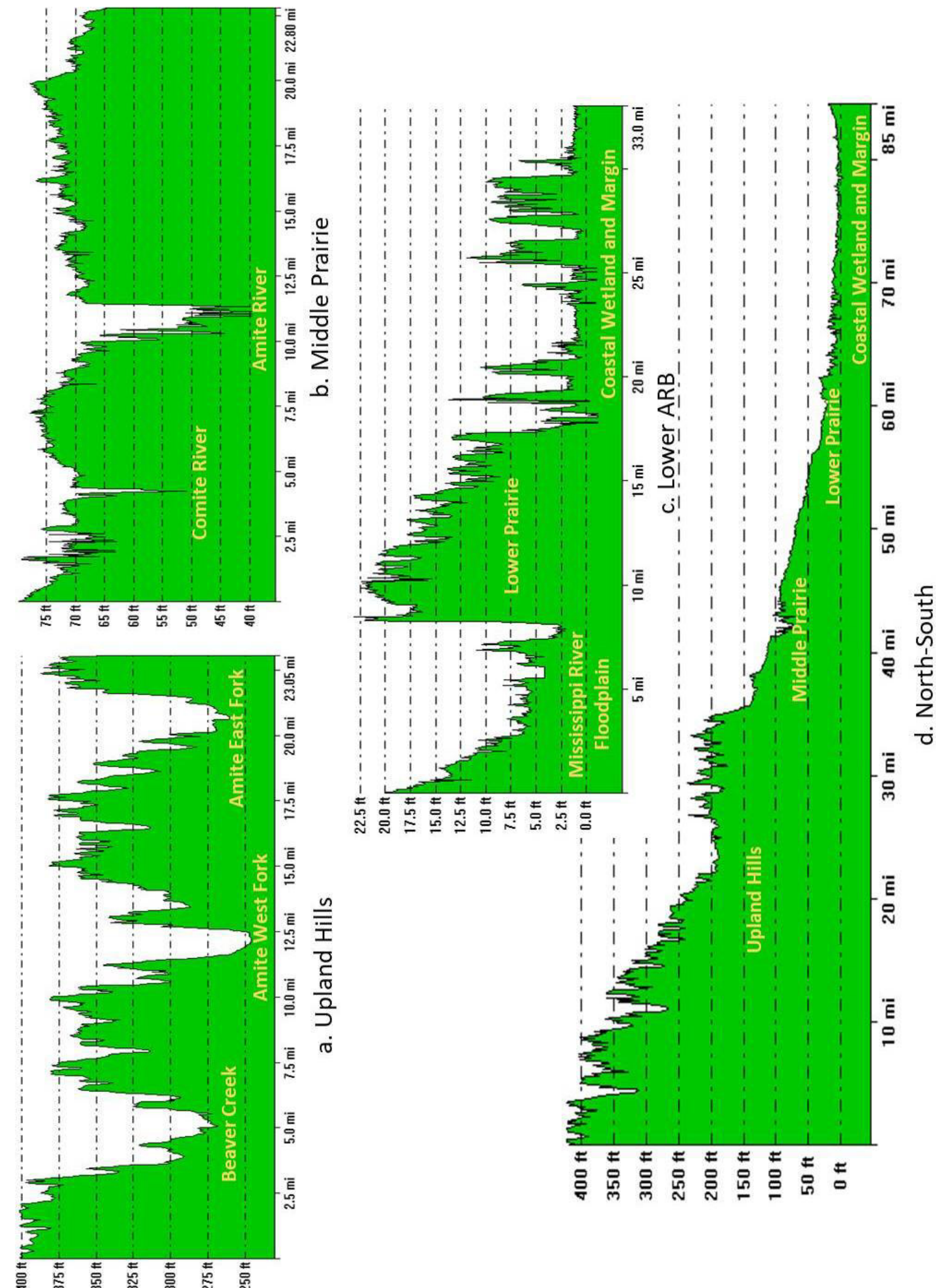


Figure 5. Topographic Profiles

Figure 6 illustrates the current ARB land cover based on the NOAA C-CAP Atlas. Areas shown as Low, Medium, and High Intensity Developed include increasing density of buildings and surface paving. Most ARB development is concentrated within the Middle Prairie and Lower Prairie zones.

Streams are comprised of channels and adjacent lateral floodplains which are described in terms of reaches (segments) from their upstream to downstream limits—head to mouth. Reaches are typically designated where there is a major change in natural *morphology* (the basic geometry, shape, or form)—the channel/floodplain in cross section (width/depth), the degree of meandering, and the longitudinal bed slope along the reach. Reach limits are also designated at major man-made channel modifications—such as at bridges and control structures (weirs and gates) and channel "improvements" (dredging, straightening, lining, or diversions into man-made channels).

Two key reach characteristics closely associated with reach morphology are:

1. The capacity for the channel and floodplain to carry various flood flows (discharges)—i.e., a stage-discharge relationship.
2. Sedimentation condition—type of suspended and bottom sediments and to what degree a reach is undergoing erosion (degradation) or filling (aggradation).

Reach geometry, flood capacity, and sedimentation mutually affect each other in complex ways. Streams strive to achieve a steady long-term balance among these characteristics—matching shape/form, stage-discharge, and sedimentation to flood magnitudes/frequencies, which in turn are a function of long-term climate (rainfall, sea level) and terrain. This balance is sought both within each reach AND, crucially, between reaches, all the way through a basin stream network.

Over the past 100 years the ARB has experienced widespread:

- Man-made channel reach geometry modifications—construction of the ARDC and "improvements" on the lower Amite and Comite Rivers, Bayou Manchac, Wards Creek, Dawson Creek, Bayou Duplantier, Jones Creek, Clay Cut Bayou, Bayou Fountain, Hurricane Creek, Grays Creek, Henderson Bayou, and other streams.
- Increased rainfall runoff associated with land cover hardening with urbanization, and
- Sedimentation erosion and filling changes associated with landscape disturbance, sand and gravel mining, and channel dredging,

Recently it has become clear that the ARB is also subject to:

- Changing southeast Louisiana rainfall patterns associated with Gulf of Mexico/atmospheric warming (van der Wiel et. al. 2016), and
- Sea level rise—which controls water level at the mouth of coastal rivers (Louisiana 2017).

The combination of these five major disruptions, in turn, have set off a complicated chain reaction of *morphodynamics* throughout the ARB stream network that will affect flooding for decades to come' (see US Army Corps of Engineers 2002, Taylor Engineering 2010).

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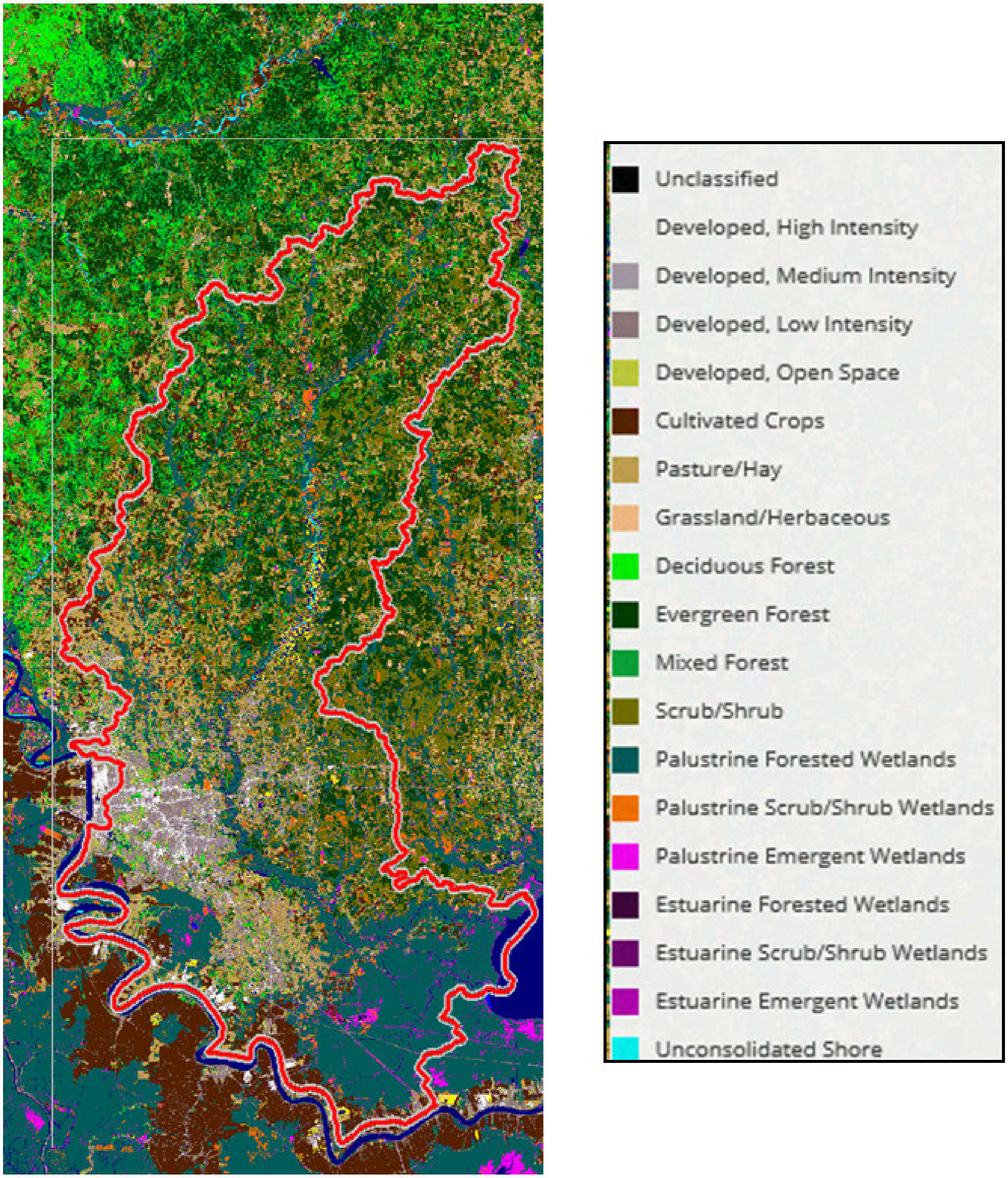

Figure 6. ARB Land Cover
US National Oceanic and Atmospheric Administration 2010

3. Types of Flooding

Flooding can be considered in terms of four basic categories, each significantly influenced by topography:

1. Flash Flooding is the direct accumulation of rainfall within small "relative" depressions in neighborhood topography—or "bowls"—where local topography and drainage network (natural and/or man-made) prevents the rainfall from running off fast enough to prevent significant accumulation. The flooding is associated with the rainfall that fell in close proximity to the location. Flash flooding can occur for any type of rainfall event capable of producing an unusual amount of rainfall over such bowls, including isolated thunderstorms that produce intense short rainfalls (e.g., a few inches in an hour) to steady, longer rains producing tens of inches of rain over several days. Local "relative" topographic bowls exist throughout the ARB, and therefore flash floods can occur somewhere in every zone.

2. Headwater River Flooding is rising water at a location in a stream channel/floodplain that depends primarily on the downstream flow rate of rainfall runoff from the watershed above that location. During a headwater flood, the water level at a location is not affected by downstream flood conditions. Headwater floods are associated primarily with upstream rainfall.

   Figure 7 shows a hydrograph of rising/falling stream "flood wave" and a typical extreme rainfall hyetograph. At any headwater flood location at any point in time, the flow rate or discharge (cubic feet per second) is correlated to flood height or elevation (feet relative to the national NAVD88 datum or to a gauge datum, also referred to as stage).[2] With increasing flow and height, flood water exceeds the immediate channel capacity and expands to fill greater and greater portions of the surrounding floodplain (Figure 8).

   The more extreme the rainfall in the watershed above the location, the more extreme the headwater flood. Steeper topography in the watershed above the location will exacerbate headwater flooding. With steeper topography and intense short-term rainfall events headwater floods tend to rise and fall rapidly. (Sometimes, meteorologists refer to extremely rapidly rising/falling headwater floods also as flash floods.) The steeper terrain in the northern third of the ARB causes any large rainfall amount over this area to funnel into the upper Amite and Comite Rivers and several tributaries (Sandy Creek, Redwood Creek, etc.). The downstream reaches of the Comite and Amite Rivers in the Upland Hills and Middle Prairie zones quickly collect runoff from 100s of square miles, and are therefore subject to notable headwater flooding.

3. Backwater River Flooding is rising water in a stream channel/floodplain that also depends on downstream conditions. The discharge:depth relationship at a location subject to "backed-up" flooding, and the nature of the flood wave, are much more complex than for headwater flooding. Three important types of downstream conditions in the ARB are:

   - A severe slowing of flow due to sudden flattening of topography. For example, the lower Comite River (beginning roughly at Hooper Road) and the Amite River (beginning roughly at I-12) flatten considerably. With more extreme flood flows the impact of severe slowing can reach farther upstream.

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[2] Flood depth conveys flood height for a specific local point on the ground; however, it is not a useful indicator for flood magnitude for an area over which ground elevations vary significantly relative to flood depth.

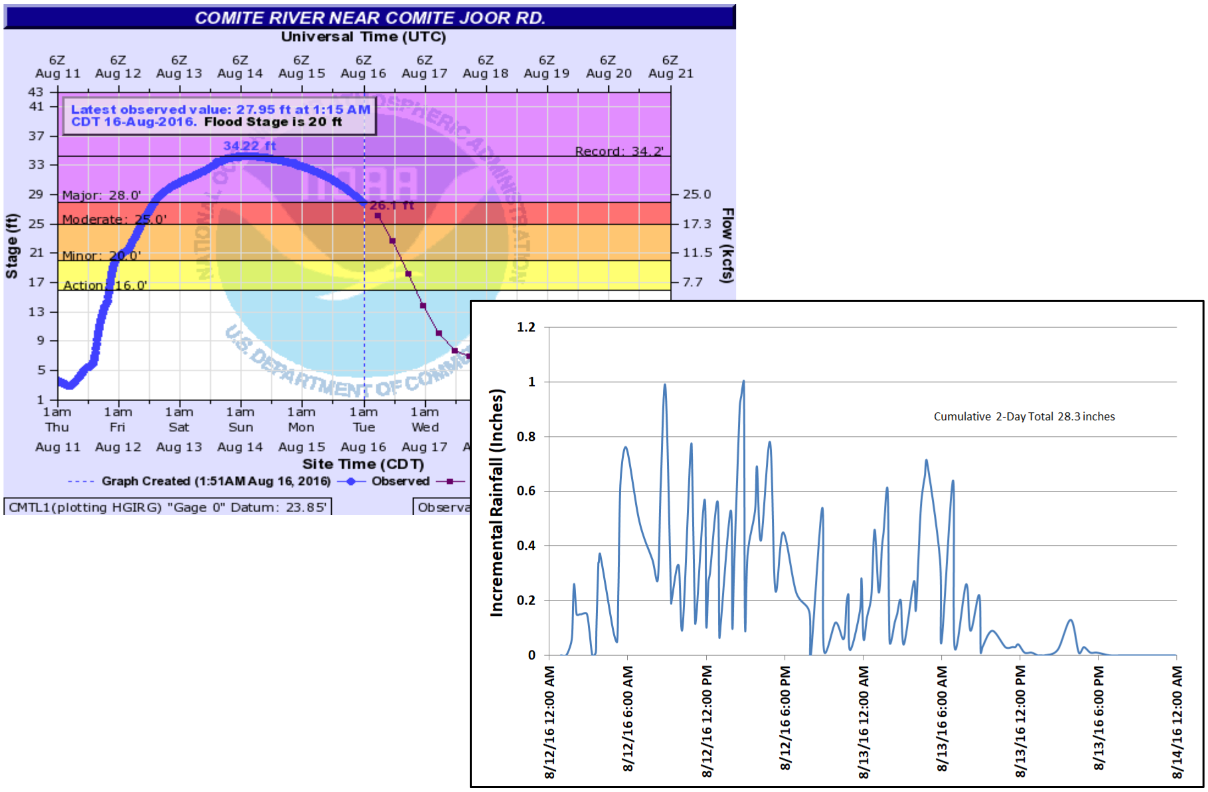


Figure 7. Comite River Hydrograph and Baton Rouge Rainfall Hyetograph
US National Weather Service 2016

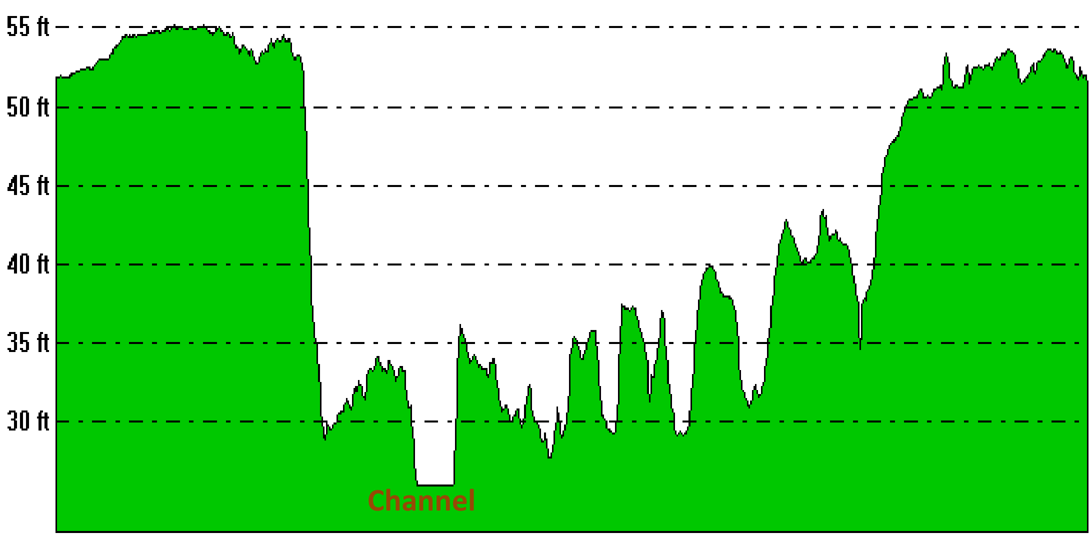


Figure 8. Cross Section of Amite River Basin Floodplain North of Denham Springs

- A major flood in a receiving stream or water body. Rising water at a downstream junction will slow the rate of rate of discharge from a tributary—which can then cause an increase in the tributary's upstream flood level. In the extreme case, the flow actually reverses—with flood water from the junction moving upstream. During severe floods, the lower Amite River flows upstream into Honey Cut Bayou, Jones Creek, Clay Cut Bayou, Bayou Manchac, Henderson Bayou, and other tributaries.
- A flow constriction/obstruction. Constrictions/obstructions may impact some flows more than others. For example:
  - The ARB includes numerous highway crossings/bridges in every sub-basin capable of impacting upstream flooding when it exceeds critical thresholds.
  - The lower Amite River includes a submerged weir structure at its junction with the Amite River Diversion Canal, which impacts upstream flow, forcing some water to continue down the original channel. However, at extreme flood conditions, when Amite River levels are well above the surrounding floodplain, the weir backwater impact is minor.
  - There are important control gates on Henderson Bayou, New River, Alligator Bayou, and Frog Bayou. In addition there are weirs on many streams associated with man-made lakes—most notably University Lake near Louisiana State University. Gate closures and weirs obviously impact extreme flood flows.

Severe floods in the ARB Lower Prairie and Mississippi River Floodplain are typically associated with backwater flooding triggered by high headwater floods in the Amite and Comite Rivers. These events also cause the Coastal Wetlands and Margins to experience significant flooding.

4. <u>Coastal Flooding</u> occurs when wind-driven water from a large coastal lake (or bay, sound, etc.) inundates adjacent low-lying land. Strong, sustained southeast winds along Louisiana's coast can "fill" and "tilt" Lakes Pontchartrain and Maurepas, raising water levels in the Coastal Wetlands and Margins of the Lower Amite River and Blind River sub-basins (see Hsu, 1997). Conditions in the early fall occasionally cause coastal flooding of up to three feet. Tropical systems with more intense winds are the most significant cause of severe flooding in the Coastal Wetlands. Hurricanes with special combinations of track, wind intensity, and wind-field size and duration are capable of generating surges approaching 10 ft in depth and impacting the Coastal Wetlands and Margins (see Figure 9).

Major rainfall events in the ARB create instances of all three types of runoff related flooding—flash flooding, headwater flooding, and backwater flooding—in various parts of the basin. It is possible for some locations in the Lower Prairie zone to experience all three types in a single event: flash flooding during the immediate rainfall, headwater flooding soon afterwards with a rise in stream flow, and a later flood peak associated with backwater. A "bad case" slow-moving tropical system could create all four types of flooding—with high wind setup of coastal water exacerbating backwater flooding.

River headwater, river backwater, and coastal flooding are all regional in scale, while flash flooding tends to be more local in scale (at the neighborhood level).

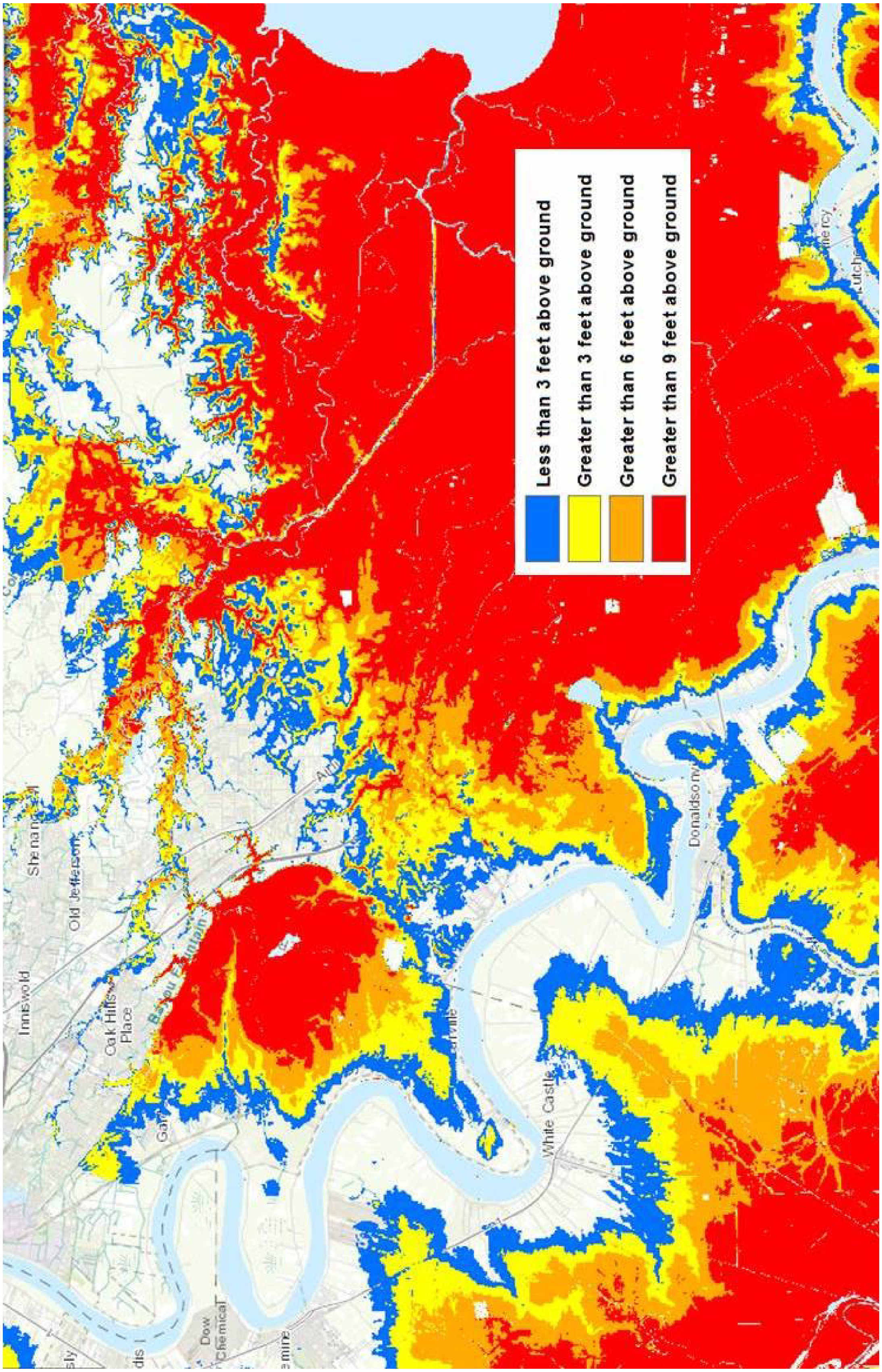


Figure 9. Hurricane Surge Inundation Depth for a Worst-Case* Category 2 Hurricane
(Landfall at coast with maximum sustained winds of 96 – 110 mph, large hurricane eye, large size/strength of extended wind-field, worst track and forward speed for western Lake Maurepas)
NOAA US National Oceanic and Atmospheric Administration, 2017

Part II.

Background—
Flood Hazard and Risk in the Amite River Basin

4. Full Spectrum Flood Hazard

Flood hazard is how high/how often flood levels rise at a specific location, typically expressed in terms of elevation (ft NAVD88) or gauge stage. In river flooding, flood hazard is associated with the reach of the nearest stream and the potential flood waves that can occur in that reach—within the channel and its lateral floodplain—under various regional rainfall events.

The concept of flood hazard (as well as wind and other hazards) is expressed quantitatively in terms of how often any particular flood height can be expected to recur—on average—over a very long time assuming conditions generally do not change. A flood height that is exceeded 100 times over a 10,000-yr time frame has an average recurrence interval of 100 years. However, given climate cycles, both much longer and shorter intervals will occur during the 10000-yr time frame.

The greater the average recurrence interval (or return period), the rarer and higher the associated flood is. Return periods are easily converted to the chance of a flood of that level or higher occurring in any given year. The 10, 20, 50, 100, 200, 500, 1,000, 2,000, 5,000, 10,000-yr return periods are equivalent to the 10, 5, 2, 1, 0.5. 0.2, 0.1, 0.05, 0.02, 0.01 percent Annual Exceedance Probabilities (AEPs). These percentages equal 0.1 to 0.0001 in decimal form. (Return period = 1/decimal-AEP).

Flood hazard is not a single AEP but the *Full Spectrum* of AEPs. Figure 10 illustrates a hypothetical *Full Spectrum* flood hazard curve. Given the large span in AEPs (return periods) a logarithmic scale is used. In this case, the flood hazard jumps substantially between 0.1 and 0.0025 (10 and 400 years). Figure 10 also illustrates the cloud of uncertainty surrounding typical estimates of the *Full Spectrum* flood hazard.

To appreciate this uncertainty and its implications consider the following five points:

1. Ideally, determining AEPS (or return periods) for rainfall, wind, flood, etc. is done using high quality historical records. However, generally a good historical determination of a hazard level requires a continuous record five to ten times longer than the return period of interest—during which conditions must have remained stable. (Flood hazard stability is affected by trends in climate, terrain, and river morphology). Thus, 500 to 1,000 years of location-specific flood data are needed to give a good estimate of the 1 percent AEP (100-yr) flood. Most locations have less than a century of reliable gauge data. In the ARB, the USGS has peak flow records for one location, the Amite River at Denham Springs, spanning 78 years. However, flood conditions have been far from stable. Thus, flood records are not a sufficient source for estimating extreme flood hazards—return periods greater than 20 years.
2. In the absence of long-term flood observations, flood hazards are defined by synthetic records—with computer simulations of floods for a range of hypothetical rainfall scenarios.[3] The best, most modern synthetic approaches—such as flood hazard studies for a

[3] The hydrodynamic modeling and statistical techniques required for good synthetic approaches have been understood for decades (and are similar to those used to evaluate wind and other hazards). However, in the past, flood hazard studies had to greatly simplify the synthetic approach due to limitations in computer capacity and the data available to drive the models. Currently, the State-of-the-Practice is undergoing a rapid evolution that is enabling the full power of the synthetic approach to be realized. These include accelerated adoption of a) new two-dimensional hydrodynamic modeling codes capturing more complete flood physics down to small sub-catchment scales; b) high resolution topographic and land-cover data to characterize flood behavior at sub-catchment scales; c) large suites of spatially realistic basin-scale rainfall scenarios to better represent the range of rainfall probabilities over a long time-frame; and d) the High Performance Computing (HPC), or “supercomputers,” to perform hundreds of high-resolution simulations in a timely fashion.

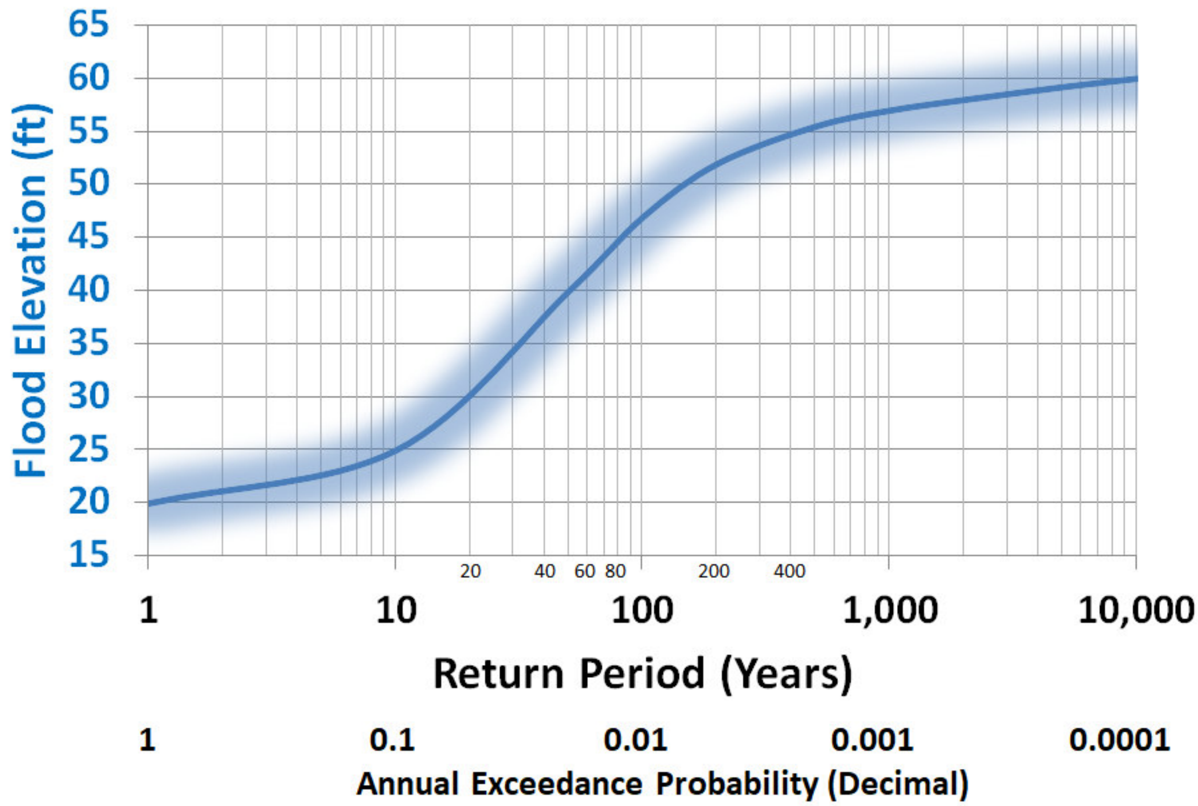
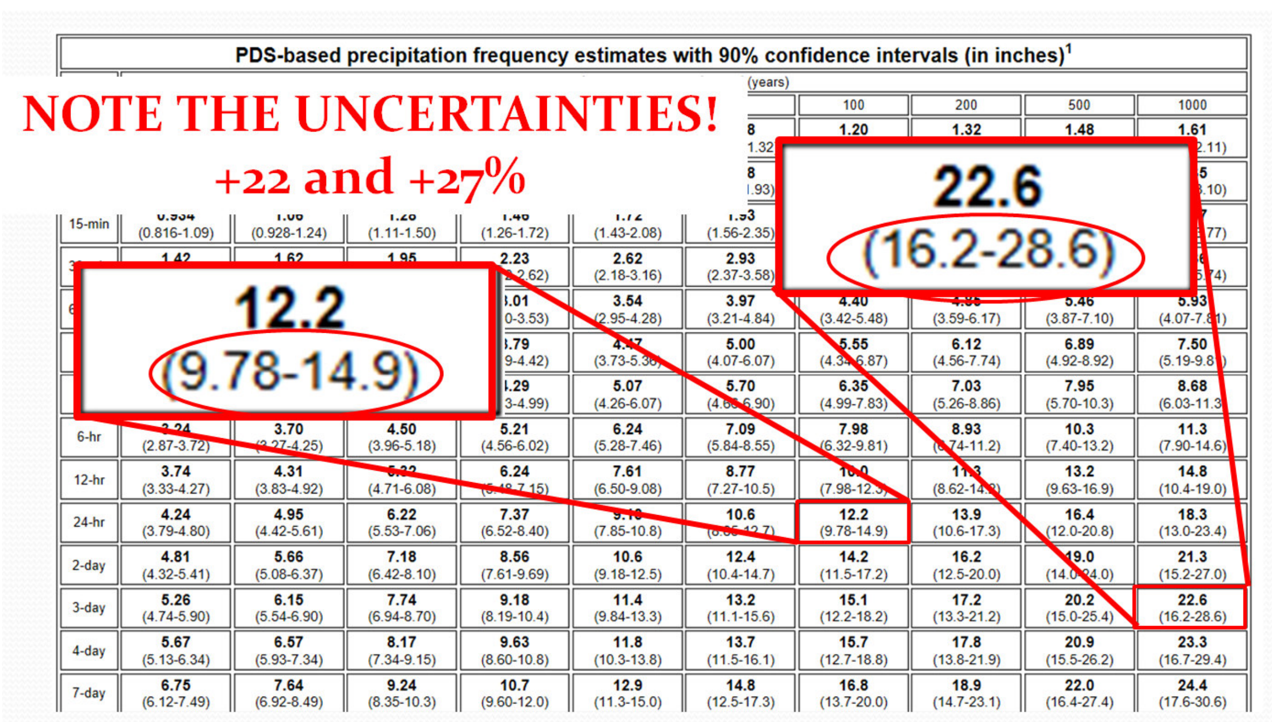


Figure 10. Example of Full Spectrum Flood Hazard



PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

						(years)				
							100	200	500	1000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.20 [illegible]	1.32 [illegible]	1.48 [illegible]	1.61 [illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15-min	0.934 (0.816-1.09)	1.06 (0.928-1.24)	1.28 (1.11-1.50)	1.46 (1.26-1.72)	1.72 (1.43-2.08)	1.93 (1.56-2.35)	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1.42 [illegible]	1.62 [illegible]	1.95 [illegible]	2.23 [illegible]	2.62 (2.18-3.16)	2.93 (2.37-3.58)	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.54 (2.95-4.28)	3.97 (3.21-4.84)	4.40 (3.42-5.48)	[illegible] (3.59-6.17)	5.46 (3.87-7.10)	5.93 [illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.00 (4.07-6.07)	5.55 [illegible]	6.12 (4.56-7.74)	6.89 (4.92-8.92)	7.50 [illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.07 (4.26-6.07)	5.70 [illegible]	6.35 (4.99-7.83)	7.03 (5.26-8.86)	7.95 (5.70-10.3)	8.68 [illegible]
6-hr	[illegible] (2.87-3.72)	3.70 [illegible]	4.50 (3.96-5.18)	5.21 (4.56-6.02)	6.24 (5.28-7.46)	7.09 (5.84-8.55)	7.98 (6.32-9.81)	8.93 [illegible]	10.3 (7.40-13.2)	11.3 (7.90-14.6)
12-hr	3.74 (3.33-4.27)	4.31 (3.83-4.92)	[illegible] (4.71-6.08)	6.24 [illegible]	7.61 (6.50-9.08)	8.77 (7.27-10.5)	[illegible]	[illegible]	13.2 (9.63-16.9)	14.8 (10.4-19.0)
24-hr	4.24 (3.79-4.80)	4.95 (4.42-5.61)	6.22 (5.53-7.06)	7.37 (6.52-8.40)	[illegible] (7.85-10.8)	10.6 [illegible]	12.2 (9.78-14.9)	13.9 (10.6-17.3)	16.4 (12.0-20.8)	18.3 (13.0-23.4)
2-day	4.81 (4.32-5.41)	5.66 (5.08-6.37)	7.18 (6.42-8.10)	8.56 (7.61-9.69)	10.6 (9.18-12.5)	12.4 (10.4-14.7)	14.2 (11.5-17.2)	16.2 (12.5-20.0)	19.0 [illegible]	21.3 (15.2-27.0)
3-day	5.26 (4.74-5.90)	6.15 (5.54-6.90)	7.74 (6.94-8.70)	9.18 (8.19-10.4)	11.4 (9.84-13.3)	13.2 (11.1-15.6)	15.1 (12.2-18.2)	17.2 (13.3-21.2)	20.2 (15.0-25.4)	22.6 (16.2-28.6)
4-day	5.67 (5.13-6.34)	6.57 (5.93-7.34)	8.17 (7.34-9.15)	9.63 (8.60-10.8)	11.8 (10.3-13.8)	13.7 (11.5-16.1)	15.7 (12.7-18.8)	17.8 (13.8-21.9)	20.9 (15.5-26.2)	23.3 (16.7-29.4)
7-day	6.75 (6.12-7.49)	7.64 (6.92-8.49)	9.24 (8.35-10.3)	10.7 (9.60-12.0)	12.9 (11.3-15.0)	14.8 (12.5-17.3)	16.8 (13.7-20.0)	18.9 (14.7-23.1)	22.0 (16.4-27.4)	24.4 (17.6-30.6)

Figure 11. Excerpt for Baton Rouge from NOAA Atlas 14
US National Oceanic and Atmospheric Administration 2013

high-risk facility like a nuclear power plant—still have significant fundamental uncertainties. Two sources of this uncertainty are a) the uncertainty in rainfall probability estimates, and b) flood modeling uncertainty. Figure 11 shows an excerpt from NOAA's Atlas 14 of Point Precipitation Frequency Estimates for Baton Rouge. Note that the expected values for the 100-yr/24-hr and 1000-yr/3-day rainfalls have upper 90 percent confidence intervals of 22 and 27 percent. Flood modeling uncertainty for any rainfall scenario is typically no better than for the hindcast of a major flood. The best hindcasts for severe floods over large basins like the ARB typically have Root Mean Square Errors for peak flood elevations of at least ± 0.5 ft. Thus, the best, most modern estimates for extreme flood hazard typically have an uncertainty greater than 1 ft (upper limit of a 90 percent confidence interval).[4]

3. Currently, the only source of published flood hazard information for locations throughout the ARB is the federal National Flood Insurance Program (NFIP), run by the Federal Emergency Management Agency (FEMA). Under the NFIP, flood insurance rates for a property are drastically affected by whether it is located below or above an estimate of the 1 percent AEP (100-yr) flood. Flood Insurance Studies (FISs) are conducted to prepare Flood Insurance Rate Maps (FIRMs) showing the limits of the 100-yr flood zone (or Special Flood Hazard Zone) and the corresponding 100-yr flood elevation. NFIP FISs do not evaluate the *Full Spectrum* flood hazard, though in recent years they have also included estimates of the 0.2 percent AEP (500-yr) flood zone. Under the NFIP a variety of floodplain regulations (implemented by local participating communities) are tied to limiting losses in the 100-yr zone. The FIRM delineations of the 100-yr zone have much greater uncertainty than State-of-the-Practice estimates due to a) usually being very outdated, as funding for frequent updating is not available, and b) a variety of FIS institutional limitations. FIS estimates of the 100-yr flood elevation can have uncertainties greater than 2 ft (upper limit of a 90 percent confidence interval). In addition to random error, FIS institutional issues also tend to introduce a bias error toward underestimating the 1 percent AEP (100-yr) flood height.

4. Uncertainty is much more imposing in terms of the AEP (return period) for a flood of given height, with a factor of two not uncommon. The NFIP designated 1 percent (100-yr) flood height might really be a 2 or 0.5 percent (50- or 200-yr) flood.

5. Over multiple years—equivalent to taking multiple chances—the odds for any flood height go up. Over a 30-yr mortgage, the odds of the 100-yr flood height occurring at a location go up from 1 percent for a single year to 26 percent (greater than the odds of drawing a heart from a deck of cards). And the odds of the 1,000-yr flood height go up to 3 percent (greater than the odds of rolling snake eyes). Suppose with uncertainty those flood heights that you are told have 100- and 1,000-yr returns really have 50- and 500-yr returns. Then their odds of occurring during a 30-yr mortgage are really almost 46 percent (close to a coin toss) and 6 percent (like rolling an eleven). And their odds of occurring over a 60-yr residence are 70 and 11 percent.

Figure 12 illustrates the current NFIP 100-yr flood zones for East Baton Rouge, Livingston, Iberville, and Ascension Parishes. Figure 12 shows that more than half of the ARB in these four parishes is within the current 100-yr NFIP flood zone. Figure 13 depicts a detail of the NFIP FIRM at the junction of the Amite and Comite Rivers near US 190.

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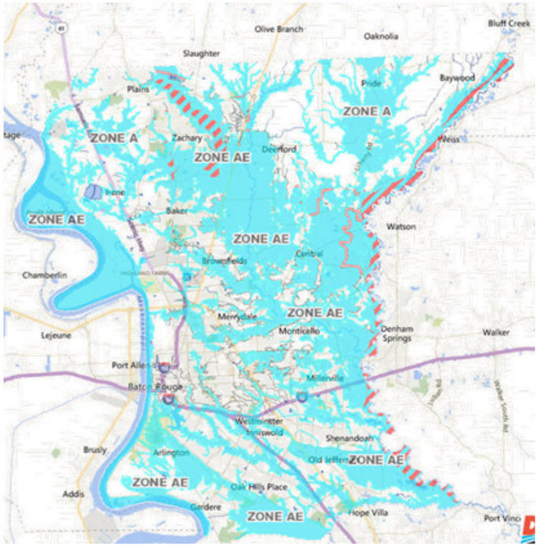
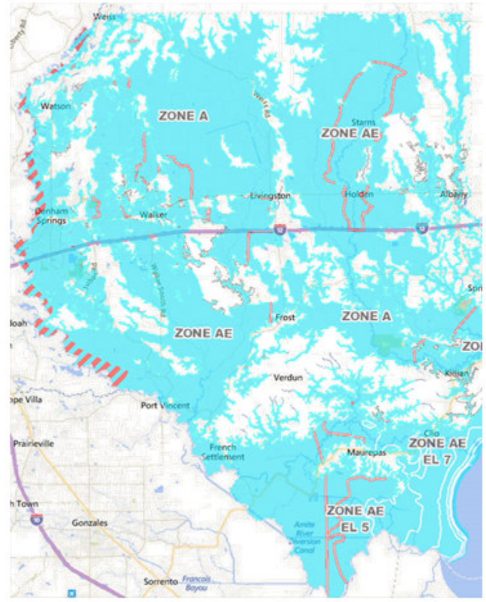
[4] Unless subject to some type of natural or man-made stage control feature.

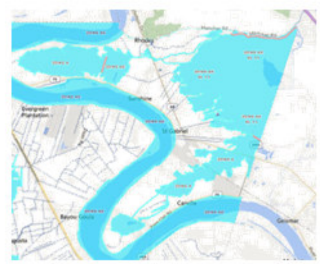


East Baton Rouge



Livingston

Ascension



Iberville

Figure 12. ARB NFIP 1 percent AEP (100-yr) Flood Zones
(shown in light blue)
Taken from http://maps.lsuagcenter.com/floodmaps
Which are based on Federal Emergency Management Agency 2001-12

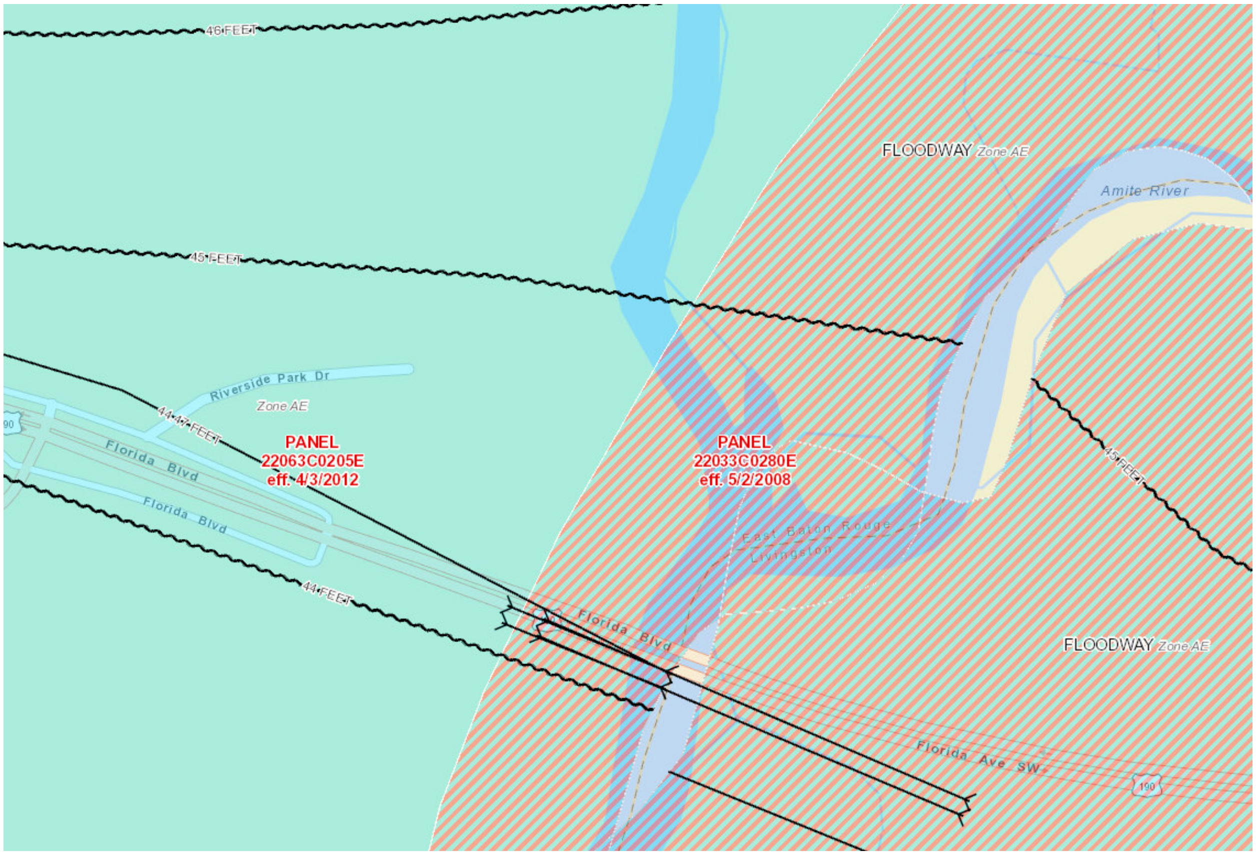


Figure 13. Detail of NFIP FIRM—Junction of Amite and Comite River

Taken from http://maps.lsuagcenter.com/floodmaps

(See portal for legend)

Table 1 includes information on the NFIP FISs conducted in the ARB. Most of these studies are over 20 years old and all are based on flood hazard analyses now considered obsolete. While many areas have had the 100-yr flood zone subsequently re-delineated in new FIRMS using LIDAR topography, the flood hazard values themselves have not been re-determined. Given FIS age and uncertainty issues, the current FIRMs almost certainly underrepresent the area and height of “true” 100-yr flood exposure. FEMA recently completed a study to prioritize ARB watersheds for new FISs (Compass PTS JV 2017). FEMA has not released a schedule for updating 100-yr flood zones. Typical new FISs use improved approaches, but not necessarily the most modern ones, and are not designed to provide the best estimates of *Full Spectrum* flood hazard.

Table 1. List of ARB FISs

(Presented by Shona Gibson PE, FEMA, October 2016)

Livingston Parish				
Flooding Source Name	Date of Engineering Analysis	Methodology	Firm date	Source
Allen Bayou	*	* / HEC-2	4/3/2012	FEMA
Amite River	1989	HEC-1 / HEC-2	4/3/2012	FEMA
Beaver Branch	*	* / HEC-2	4/3/2012	FEMA
Beaver Creek	August-01	HEC-1 / HEC-2	4/3/2012	FEMA
Clinton Allen Lateral	August-01	HEC-1 / HEC-2	4/3/2012	FEMA
Colton Creek	August-01	Reg Equ / HEC-2	4/3/2012	FEMA
Colyell Bay	*	* / HEC-2	4/3/2012	FEMA
Colyell Creek	*	* / HEC-2	4/3/2012	FEMA
Dumplin Creek	August-01	HEC-1 & Reg Equ / HEC-2	4/3/2012	FEMA
East Fork Dumplin Creek	August-01	HEC-1 & Reg Equ / HEC-2	4/3/2012	FEMA
Felders Bayou	August-01	Reg Equ / HEC-2	4/3/2012	FEMA
Felders Ditch	*	Reg Equ / HEC-2	4/3/2012	FEMA
Grays Creek	August-01	Reg Equ / HEC-2	4/3/2012	FEMA
Grays Creek Lateral	August-01	Reg Equ / HEC-2	4/3/2012	FEMA
Hornsby Creek	*	* / HEC-2	4/3/2012	FEMA
Long Slash Branch	August-01	Reg Equ / HEC-2	4/3/2012	FEMA
Middle Colyell Creek	*	Reg Equ / HEC-2	4/3/2012	FEMA
Millers Canal	August-01	Reg Equ / HEC-2	4/3/2012	FEMA
Millers Canal Tributary	August-01	Reg Equ / HEC-2	4/3/2012	FEMA
Moler Bayou	August-01	* / HEC-2	4/3/2012	FEMA
Rocky Branch	August-01	Reg Equ / HEC-2	4/3/2012	FEMA
Taylor Bayou	*	* / HEC-2	4/3/2012	FEMA
Wax Ditch	August-01	Reg Equ / HEC-2	4/3/2012	FEMA
West Colyell Creek	August-01	HEC-1 / HEC-2	4/3/2012	FEMA
West Fork Beaver Creek	August-01	HEC-1 / HEC-2	4/3/2012	FEMA

* = Not determined

Iberville Parish				
Flooding Source Name	Date of Engineering Analysis	Methodology	Firm date	Source
Bayou Maringouin	December-88	SCS / HEC-2	11/6/2013	FEMA
Bayou Manchac	December-88	SCS / HEC-2	11/6/2013	FEMA
Bayou Paul	December-88	SCS / HEC-2	11/6/2013	FEMA
Spanish Lake	December-88	Stage Records	11/6/2013	FEMA

Ascension Parish				
Flooding Source Name	Date of Engineering Analysis	Methodology	Firm date	Source
Amite River	October-87	HEC-1 / HEC-2	8/16/2007	USACE
Henderson Bayou	October-87	HEC-1 / HEC-2	8/16/2007	USACE
Muddy Creek	October-87	HEC-1 / HEC-2	8/16/2007	USACE

East Baton Rouge Parish				
Flooding Source Name	Date of Engineering Analysis	Methodology	Firm date	Source
Amite River	July-89	*/*	6/19/2012	FEMA
Bayou Duplantier	September-05	HEC-HMS / HEC-RAS	6/19/2012	FEMA
Bayou Fountain	September-05	HEC-HMS / HEC-RAS	6/19/2012	FEMA
Bayou Fountain North Branch	September-05	HEC-HMS / HEC-RAS	6/19/2012	FEMA
Bayou Fountain South Branch	September-05	HEC-HMS / HEC-RAS	6/19/2012	FEMA
Bayou Fountain Tributary 1	September-05	HEC-HMS / HEC-RAS	6/19/2012	FEMA
Beaver Bayou	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE
Blackwater Bayou	May-90	Eq by Lee / WSPRO	6/19/2012	USGS
Blackwater Bayou Tributary 1	May-90	Eq by Lee / WSPRO	6/19/2012	USGS
Blackwater Bayou Tributary 2	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE
Blackwater Bayou Tributary 3	May-90	Eq by Lee / WSPRO	6/19/2012	USGS
Clay Cut Bayou	September-05	HEC-HMS / HEC-RAS	6/19/2012	FEMA
Comite River	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE
Corporation Canal	September-05	HEC-HMS / HEC-RAS	6/19/2012	FEMA
Dawson Creek	September-05	HEC-HMS / HEC-RAS	6/19/2012	FEMA
Draughans Creek	July-89	Regional data / HEC-2	6/19/2012	USACE
East Lateral Cypress Bayou	Nov 1971 or March 1983	USACE FPI report	6/19/2012	USACE
Elbow Bayou	September-05	HEC-HMS / HEC-RAS	6/19/2012	FEMA
Engineer Depot Canal	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE
Hollywood Lateral	Nov 1971 or March 1983	USACE FPI report	6/19/2012	USACE
Honey Cut Bayou	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE
Hub Bayou	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE
Hurricane Creek	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE
Indian Bayou	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE
Jacks Bayou	September-05	HEC-HMS / HEC-RAS	6/19/2012	FEMA
Jones Bayou	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE
Jones Creek	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE
Knox Branch	Nov 1971 or March 1983	USACE FPI report	6/19/2012	USACE
Lively Bayou	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE
Lively Bayou Tributary	Nov 1971 or March 1983	USACE FPI report	6/19/2012	USACE
Lower Cypress Bayou	Nov 1971 or March 1983	USACE FPI report	6/19/2012	USACE
Lower Wards Creek Diversion Channel	September-10	Reg Eq / HEC-RAS	6/19/2012	FEMA
Lower White Bayou	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE
North Branch Wards Creek	September-05	Regional data / HEC-2	6/19/2012	USACE
Redwood Creek	September-10	Reg Eq / HEC-RAS	6/19/2012	FEMA
Robert Canal	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE
Robert Canal Tributary 1	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE
Shoe Creek	September-10	Reg Eq / HEC-RAS	6/19/2012	FEMA
Shoe Creek Tributary 1	September-10	Reg Eq / HEC-RAS	6/19/2012	FEMA
Shoe Creek Tributary 1A	September-10	Reg Eq / HEC-RAS	6/19/2012	FEMA
South Canal Diversion	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE
South Lateral	Nov 1971 or March 1983	USACE FPI report	6/19/2012	USACE
Unt 2 To North Branch Wards Creek	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE
Unt To Bayou Fountain	September-05	HEC-HMS / HEC-RAS	6/19/2012	FEMA
Unt To North Branch Wards Creek (Harelson Lateral)	September-05	HEC-HMS / HEC-RAS	6/19/2012	FEMA
Upper Wards Creek Diversion Channel	Nov 1971 or March 1983	Regional data / HEC-2	6/19/2012	USACE

5. Real Flood Risk

Flood Risk is how much/how often flood loss occurs. At a specific location—within a given stream reach and its associated *Full Spectrum* flood hazard—flood risk is influenced by the specific ground elevation and how deep flooding will be at various hazard levels. For "stakeholders" in that specific location—owners, renters, members, and taxpayers for homes, businesses, churches/non-profits, and government facilities/structures—*Real Flood Risk* is thus the total flood costs—including all repairs/replacements for physical damages, lost income, temporary relocation, and other expenses—over the *Full Spectrum* of AEPs (return periods). Figure 14 illustrates a hypothetical *Full Spectrum Real Flood Risk* for a homeowner with the *Full Spectrum* flood hazard shown in Figure 10. Figure 14 includes an uncertainty band, which reflects the uncertainty in Figure 10. Such *Full Spectrum* flood risk curves can "in theory" be readily estimated for any location.

An important aspect of *Full Spectrum Real Flood Risk* for locations is that it can be converted to a single dollar value: the Annual Cost. The Annual Cost of flood risk is essentially the same as Actuarial Cost for insurance purposes, and is roughly equivalent to the amount of money a large group of stakeholders with similar (but independent) exposure would have to save each year to create a fund large enough to cover their collective losses. For the hypothetical case in Figure 14 the Annual Cost is about $2,000.

Annual Cost is also readily converted to Present Value, the amount that would have to be set aside in a lump sum to take the place of the Annual Cost, in this hypothetical case about $40,000. Present Value of flood risk can be used to represent a deduction in property value versus a similar property with virtually no flood risk.

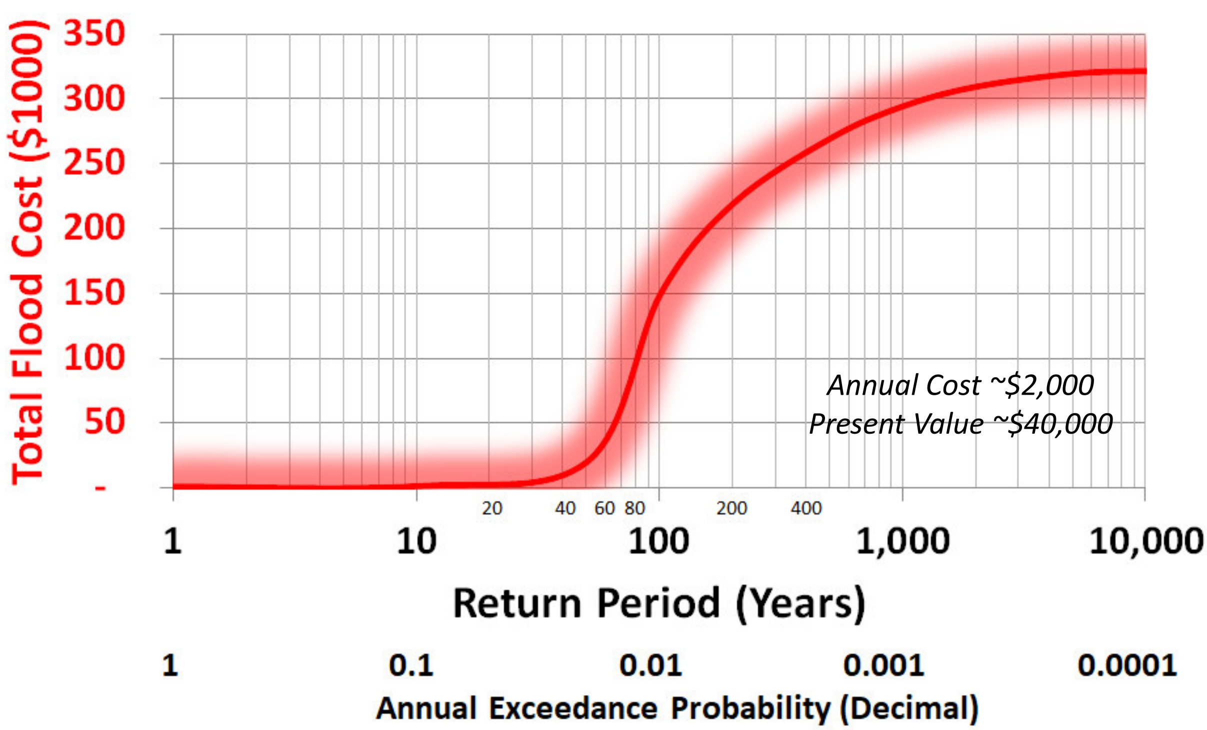


Figure 14. Example of Full Spectrum "Real Flood Risk"
Direct Economic Losses for a Household at Location in Figure 10

In estimating individual Annual Cost and Present Value using large populations with independent flood exposure, the uncertainties (but not bias errors) tend to even out—so such estimates of *Real Flood Risk* actually have much less uncertainty (given stable flood conditions) than estimates of single location-specific flood hazard levels, such as the 100-yr flood.

Annual (Actuarial) Cost and Present Value have long been used for wind, fire, and other hazards where methods for evaluating the *Full Spectrum* risk—including uncertainty—have been established. Modern flood hazard analyses are now facilitating evaluations of *Real Flood Risk* for high risk locations (see **Real Flood Risk: The Grassroots Revolution**). **Evaluations of Real Flood Risk for most properties within the ARB should start to become available in the coming decade, which will dramatically affect both individual and community flood risk management decisions.**

Real Flood Risk for individual locations can be aggregated over a catchment, sub-basin, city, parish, or other area. Past evaluations of flood control projects and other scenarios affecting flooding have employed crude estimates of change to aggregate *Real Flood Risk*. Modern flood hazard analyses coupled with "Cloud-based, Big Data" (e.g., detailed community-wide property data) and depth damage estimates will accelerate detailed examinations of aggregate *Real Flood Risk* for flood control projects, climate change, large scale land-use/cover modifications, and other scenarios.

Importantly, along with *Real Flood Risk* (direct economic losses), regional flood risk managers must also consider:

- Potential loss of life for extreme flood hazards;
- Evacuation investment and operation costs;
- Disaster preparedness, response, and recovery costs—including expenses to assist families with economic and health hardships; and
- Cultural/sociological/demographic/community viability impacts, which are not easily quantified.

6. History of Flooding Prior to August 2016[5]

Floods associated with ARB streams were most certainly a frequent and significant issue for indigenous villagers and early European settlers of the region who chose to occupy important natural transition zones at the floodplain margins. Documentation and analysis of major floods, spurred by a growing need to improve drainage in urbanized areas, emerged in the 20th Century. Professional studies beginning in the mid-1900s documented significant basin flood events in 1921, 1928, 1942, 1947, 1953, 1957, 1962, 1964, 1967, March 1973, April 1977, April 1979, April 1983, August 1983, October 1985 (Hurricane Juan), January 1990, January 1993, January 1994, June 2001 (Tropical Storm Allison), and September 2008 (Hurricane Gustav).

Table 2 presents the top ten pre-2016 crests based on USGS gauges for the Amite River at Denham Springs and Comite River at Joor Rd (with peak stage data as far back as 1921 and 1943, respectively). The peak discharge for five of the Amite River floods at Denham Springs are also shown in Table 2. Three significant pre-2016 flood events were:

1. The April 1983 Flood. A slow moving system produced 6 to 13 inches of rain over a broad portion of the ARB, with high totals in the Upland Hills. This flood established the pre-2016 record flood for the lower Amite River and backwater in associated tributaries in the Middle and Lower Prairie zones. It was the second highest flood recorded on the Comite River at Joor Road. About 5,300 homes and 200 businesses were flooded and an estimated $172

Table 2. Pre-August 2016 ARB Flood Crests for Amite and Comite Rivers

	Amite River at Denham Springs, LA US 190			**Comite River at Comite, LA Joor Road**	
	Gauge Datum (ft)	**Discharge (cfs)**	**Date**	**Gauge Datum (ft)**	**Date**
1	41.5	112,000	4/8/1983	30.99	6/9/2001
2	41.08	110,000	4/23/1977	29.72	4/7/1983
3	39.88		1/27/1990	27.58	1/21/1993
4	39.27		3/15/1921	27.45	9/4/2008
5	38.34	82,700	6/9/2001	27.22	4/28/1997
6	38.15		1/22/1993	26.54	1/26/1990
7	36.7	68,600	4/24/1979	26.38	4/12/1995
8	36.5	60,200	3/27/1973	26.16	3/12/2016
9	36.33		5/20/1953	25.99	4/23/1979
10	36.23		9/05/2008	25.64	5/19/1953
Conversion from Gauge Datum to ft NAVD88					
	- 1.35			+ 22.1	

See NOAA, Advanced Hydrologic Prediction Services websites for gauges.

[5] Portions of this section are taken from the *ARB Floodplain Management Plan* (URS 2005 and GEC 2015).

million of damages incurred (1983 dollars). Flood damages in the Comite River Sub-basin were estimated $48 million.

2. Hurricane Juan in October 1985. Hurricane Juan became stalled along the Louisiana coast for several days, producing extremely high wind-driven water levels in Lake Maurepas, reportedly above 6 ft NAVD88, and 6-day rainfall totals of five to eleven inches throughout the ARB. Record flooding occurred in the Coastal Wetlands and Margins. Upstream portions of the ARB were largely unaffected.

3. Tropical Storm Allison in June 2001. Tropical Storm Allison stalled over the region, with 7-day measured rainfall totals of 19.66 inches in Baton Rouge; 14.07 inches in Denham Springs; and, 23.29 inches in Ascension Parish. The seven day rainfall totals in parts of the lower ARB were considered a 100-year precipitation event. Due to a significant drought and very low soil moisture conditions present prior to the event, flood conditions in the upper and middle ARB were not as extreme.

Interestingly, the 8th highest stage recorded on the Comite at Joor Road was during an earlier 2016 flood in March. The March 2016 peak on the lower Comite River did not coincide with basin-wide heavy rains and significant backwater flooding did not occur in the ARB.

7. History of Regional River Flood Risk Management[6]

Table 3 presents a summary of major ARB regional river (headwater/backwater) flood risk management actions undertaken over the years. Efforts to reduce river flooding increased in the Baton Rouge area with post-World War II urbanization. Interest in flood control has accelerated since the 1983 Flood and with the expanding footprint of development into marginal floodplains in the Middle Prairie and Lower Prairie zones during recent decades.

The list in Table 3 includes several initiatives not pursued despite favorable recommendations, started construction but incomplete, or completed but not maintained:

- The Darlington Reservoir just below the upper Amite River (not pursued),
- Flood detention structures on the middle Amite River(not pursued),
- Flood control for upper Bayou Manchac watershed(not pursued),
- Amite River ecosystem and related flood mitigation (not pursued),
- The Comite River Diversion Canal (incomplete, see Louisiana Legislative Auditor 2017), and
- The Amite River Diversion Canal (not maintained),

Funding for these initiatives has been the most important challenge. Federal support is increasingly unavailable unless economic benefits strongly outweigh costs and greater local financing has been difficult to mobilize in the absence of clear *Real Flood Risk* reduction information (Annual/ Actuarial Cost and Present Value),.

In addition to financing, overcoming three adverse impacts has become a major hurdle to pursuing more traditional flood control projects:

1. <u>Increased downstream flood risk impact from major flood control projects</u>—(including the accumulation of many small projects). Channel "improvements" to move floodwater downstream faster and levees to block incoming floodwater can raise flood risk in adjacent and downstream floodplains. Early projects were politically feasible due to very low population densities in the Lower Prairie, Mississippi River Floodplain, and Coastal Wetland Margin. Population growth in potentially impacted areas now makes such projects difficult.
2. <u>Long-term stream morphological effects from channel "improvements</u>." Major clearing, snagging, straightening, dredging, lining, and diversion projects cause a drastic chain reaction of changes on upstream and downstream reaches lasting for decades. Projects on the lower Amite and Comite Rivers—including the construction of the Amite River Diversion Canal in the early 1960s—have thrown the entire river system out of balance, causing upstream reaches to undergo significant "head-cutting" erosion. This head-cutting extends as far north as reaches of the Comite and Amite Rivers in the Upland Hills—causing erosion of adjacent lands and damage to bridges. The eroded sediment transported downstream during floods then causes notable filling of the Amite River floodplain below Denham Springs. These morphological changes have been documented in an Amite River ecosystem restoration reconnaissance and feasibility studies (USACE 2002, Hood 2007, and Taylor Engineering 2010), including their effects on flood carrying capacity. Figure 15 illustrates some changing stage-discharge relationships—with lowering flood stages in the eroding upper basin and rising flood stages in the lower basin.

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[6] Portions of this section are taken from the *ARB Floodplain Management Plan* (URS 2005 and GEC 2015).

Table 3. History of Major Regional Floodplain Management Actions

Pre-World War II

Prior to 1920s	Leveeing of the Mississippi River in East Baton Rouge and Ascension Parish eliminated occasional overbank flow during extreme River floods into Bayou Manchac, as well as the Blind River tributaries. Clearing, snagging, and limited dredging of major rivers for steamboat navigation, particularly in support of lumbering activities and World War I shipbuilding. .
1928	USACE completed channel improvements in the Amite River from Denham Springs to Lake Maurepas

Post-World War II Urbanization/Pre-1983 Flood

1953 - 67	LA DPW and East Baton Rouge made improvements to Wards Creek, Clay Cut Bayou, Jack's Bayou, Bayou Duplantier, and White Bayou
1955	USACE published a flood control study of the ARB and its tributaries
1964	USACE completed channel improvements to upstream portions of Amite River, and to lower portions of Comite River, Blind River, and Bayou Manchac; including construction of the Amite River Diversion Canal
1972	USACE completed a flood control study for the Amite River and Tributaries; evaluated four reservoir plans; two diversion plans; and four channel modifications
1978	FEMA (predecessor) introduces the NFIP begins FISs for participating communities
1981	Amite River Basin Drainage and Water Conservation District (ARBD) formed

Post 1983 Flood

1984	USACE completed a reconnaissance level study of a number of flood control alternatives and initiated feasibility studies on Comite Diversion, Darlington Reservoir, East Baton Rouge Parish Watershed, and in Livingston Parish
1984	LDOTD contracted engineering studies for development of the Darlington Reservoir
1990	Governor's Interagency Task Force produced recommendations for the Amite River Basin
1990	East Baton Rouge Parish completed a Comprehensive Land Use and Development Plan (known as the Horizon Plan); study addressed current and future drainage and flood control needs
1991	USACE completed feasibility study for Comite River Diversion Canal (CRDC)
1992	USACE completed feasibility study for Darlington Reservoir; found insufficient project benefits
1995	USACE completed feasibility study for channel improvement flood control measures in East Baton Rouge Parish
1995	City of Baton Rouge Department of Public Works completed a study of flood detention structures on the Middle Amite River
1997	USACE completed feasibility study for channel improvement flood control measures in Livingston Parish
1997	ARBD and LDOTD completed additional studies to evaluate Darlington Reservoir recreational benefits

1997 USACE completed a re-evaluation of Darlington Reservoir benefits and costs; found sufficient benefits; further work on the project halted due to a lack of state and local sponsorship funds

1998 ARBD in conjunction with USGS and the LDOTD, LOEP, and the USACE established a Flood Warning System for the Amite River Basin

1999 Dr. Jim Cruise initiated development of real-time rainfall runoff and flood inundation forecasting model for ARBD.

1999 ARBD/communities completed Amite River Basin Flood Hazard Mitigation Plan

2000 USACE completed post-feasibility design studies for the CRDC

2000 USACE completed Reconnaissance Study for Amite River Basin Ecosystem Restoration—major river morphological changes due to decades of lower Amite/Comite River channel improvements and up-river sand & gravel mining.

2001 ARBD succeeded in getting property tax passed to provide local funding for CRDC

2001 CRDC Project Cooperative Agreement signed

Post TS Allison 2001 Flood

2001 USACE completed a Reconnaissance Study for Bayou Manchac Clearing and Snagging Project

2002 ARBD drafted a Watershed Management Program

2002 ARBD evaluated potential issues with flood mapping resolution and use of Light Detection and Ranging (LIDAR) technology in conjunction with LSU

2002 USACE completed a Reconnaissance Study for Bayou Manchac Watershed Flood Damage Reduction and Ecosystem Restoration

2003 FEMA/ARBD updated regional Amite River Basin Flood Hazard Mitigation Plan in response to TS Allison

2003 USACE began construction on Lilly Bayou Drop Structure for CRDC

2005 ARBD prepared Draft Floodplain Management Plan in support of the CRDC

2008 ARBD sponsored Comite River Basin H&H Study (HEC-RAS unsteady analysis of CRDC); considered impact of Comite River morphodynamics on CRDC

2009 Pontchartrain Levee District (PLD) completed feasibility study (with H&H study) for flood mitigation alternatives for upper Bayou Manchac watershed (Above Ward's Creek junction)

Since 2010

2010 PLD completed Amite River Basin Ecosystem Restoration Feasibility Study (with detailed H&H study of Amite and Comite River morphodynamics)

2010 Louisiana Coastal Protection and Restoration Authority completed H&H study for Restoring Lower Amite River (ARDC) Swamp

2011 USACE undertook additional H&H Study of the CRDC

2015 ARBD updated the Draft Floodplain Management Plan in support of the CRDC.

2016 ARBD completed H&H study for Rehabilitating the ARDC Weir

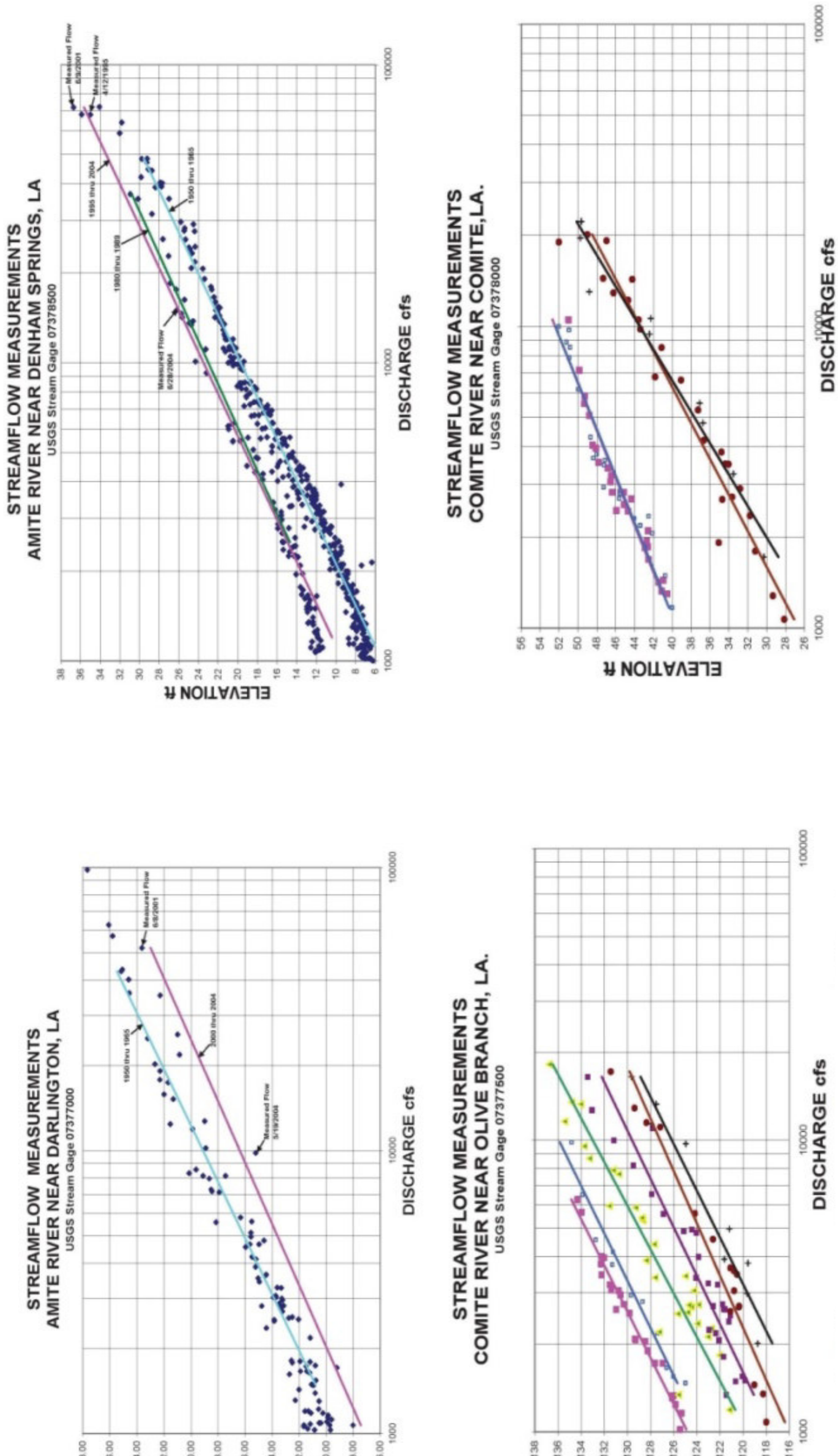


Figure 15. Changing Flood Stage (Elevation)-Discharge Relationships in the Amite and Comite Rivers
Hudson 2016

3. Degrading river bottoms, water quality, and habitat caused by major channel "improvements." The upstream/downstream erosion/sedimentation impacts, have significantly changed river fisheries and nearby wetland ecology—affecting several critical species—and contributed greatly to degrading turbidity. (see USACE 2002).

Finally, past floodplain management has been distorted by an antiquated overemphasis on the "100-yr" flood hazard threshold:

- FIRMs and insurance premium rates were originally structured around this threshold when the NFIP was first constituted nearly 50 years ago. The NFIP has never been modernized to reflect the true Full-Spectrum flood hazard and *Real Flood Risk*, or to provide a more granular set of insurance rates.
- Local development regulations are influenced by NFIP requirements and focus on controlling losses below the 100-yr flood elevation; (some include a 1-ft margin).
- Crucially, mortgage (and many commercial) lenders require flood insurance ONLY for exposure below the 100-yr flood elevation.
- **The overemphasis actually leads to the widespread assumption of a "false binary:" below the 100-yr flood elevation there is flood risk, above that elevation there is no flood risk.**
- High post-1990s ARB growth has been toward marginal floodplain areas—especially cheap, undeveloped areas with reasonable proximity to employment centers and expanding infrastructure, schools, and lifestyle amenities.
- The above factors create strong economic incentives for development just above the 100-yr flood height, which in turn concentrate greater development just above the 100-yr flood elevation. Numerous marginal floodplain developments involve optimizing excavation of soil from street and drainage footprints and filling lots, so "slab-on-grade" construction can be just above the threshold requirement.
- Ironically, development and related infrastructure projects can further raise downstream extreme floods. Although projects today must meet requirements for minimizing downstream impact for the NFIP 100-yr flood, they may not adequately account for uncertainty and the effects of higher floods. The Interstate 12 barrier is an example.
- This concentrated development in marginal areas is then susceptible to significant losses from higher floods—and even for a 100-yr flood given outdated delineations and uncertainty. Note also that a 200-yr flood has more than a 30 percent chance of occurring during a lifetime.

The distortion of decisions by the 100-yr threshold extends to a push for projects—and even locally funded FIRM re-delineations—focused on lowering the 100-yr flood hazard level. Besides being suboptimal in reducing flood losses, these make more marginal land easier to develop and further concentrate flood risk.

Communities adversely affected by the "false binary" encompass a large portion of the Baton Rouge urban area—including Zachary, Baker, Central, subdivisions subject to backwater flooding on the lower Comite River, most of eastern Livingston Parish, southeast Baton Rouge, the Bayou Fountain watershed, and western Ascension Parish. The Baton Rouge area might even be considered "ground zero" for the unintended consequences of the obsolete overemphasis of the 100-yr flood.

Part III.

The August 2016 Flood

8. The Flood Event

The August 2016 flood over southeast and southcentral Louisiana was caused by a slow moving low pressure system that had its origins as an Atlantic tropical wave. Beginning on Monday August 8, 2016 the low traversed east-to-west across northern Florida and lower Alabama/Mississippi and approached the ARB late on Thursday August 11th. The low was not considered an area of interest for development by the National Hurricane Center. The US National Weather Service (NWS) issued a flash flood watch for the region on Tuesday August 9th. Flash flood and river flood warnings were issued beginning on Wednesday August 10th and continued through the event.

The low produced torrential rains in the Florida parishes, southwest Mississippi, and westward into the Atchafalaya Basin and Acadiana. A rainfall radar loop of the "tropical looking" low can be viewed at the NWS website http://www.weather.gov/lix/August2016flood. A major contributing factor to the heavy rainfall was the extremely high atmospheric moisture over southeast Louisiana region leading up to and during the event due to warm Gulf of Mexico temperatures and prevailing southeast winds. Figure 16 shows the yearly trend and variability in NWS measurements of atmospheric precipitable moisture. The measurement at the time of the August 2016 Flood was nearly "off the chart."

Figure 17 illustrates the 2-day rainfall over the ARB—August 12 and 13. Figure 17a shows the total rainfall in inches. The majority of the ARB received in excess of 10 inches, with a large portion of the northern half of the ARB experiencing over 15 inches. Parts of the Middle Prairie zone in northern East Baton Rouge and northeastern Livingston Parishes had over 20 inches of rainfall.

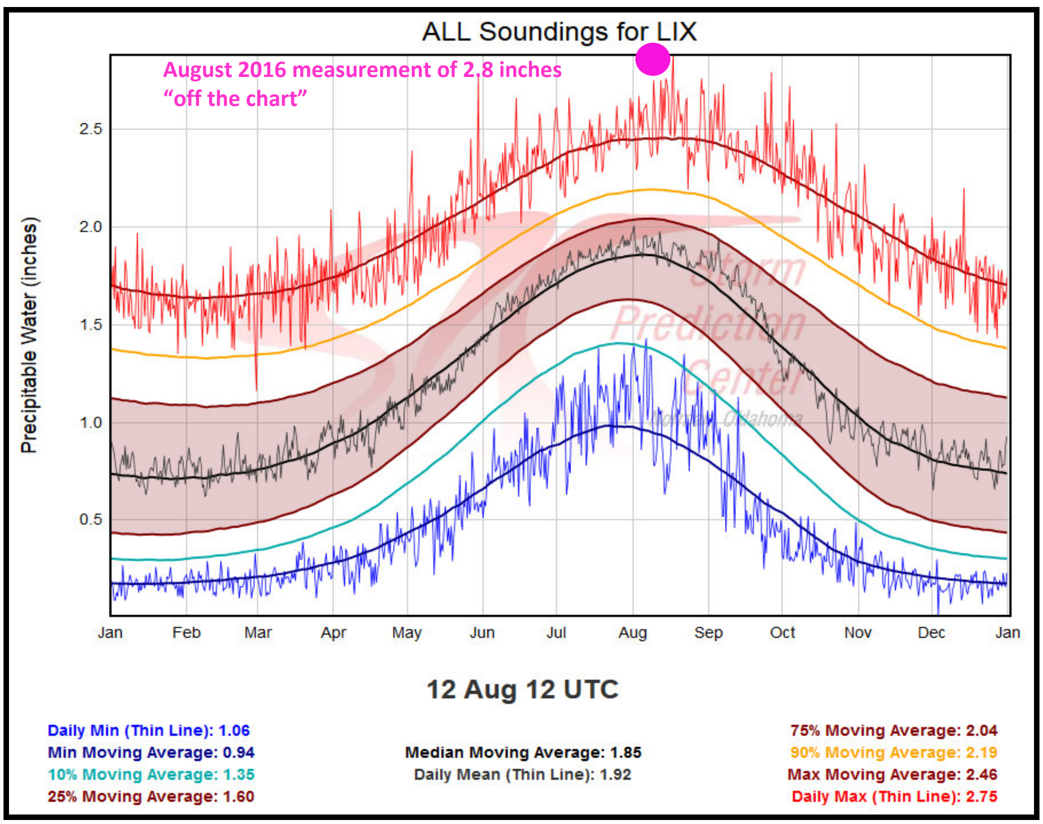
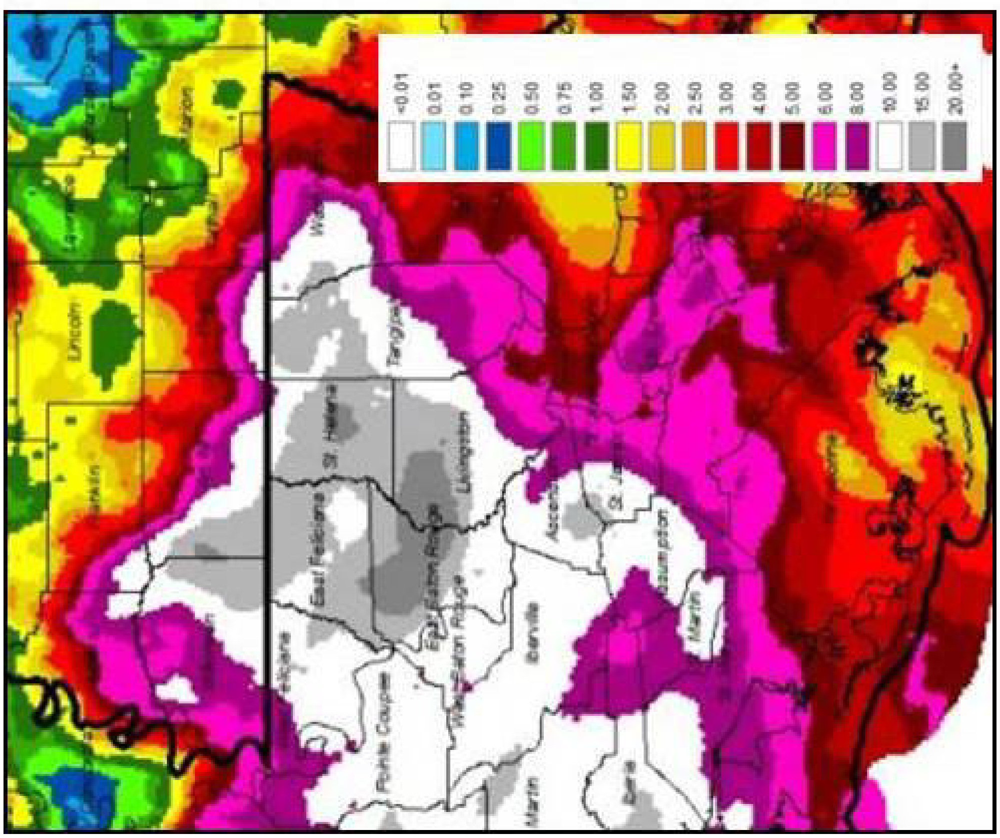
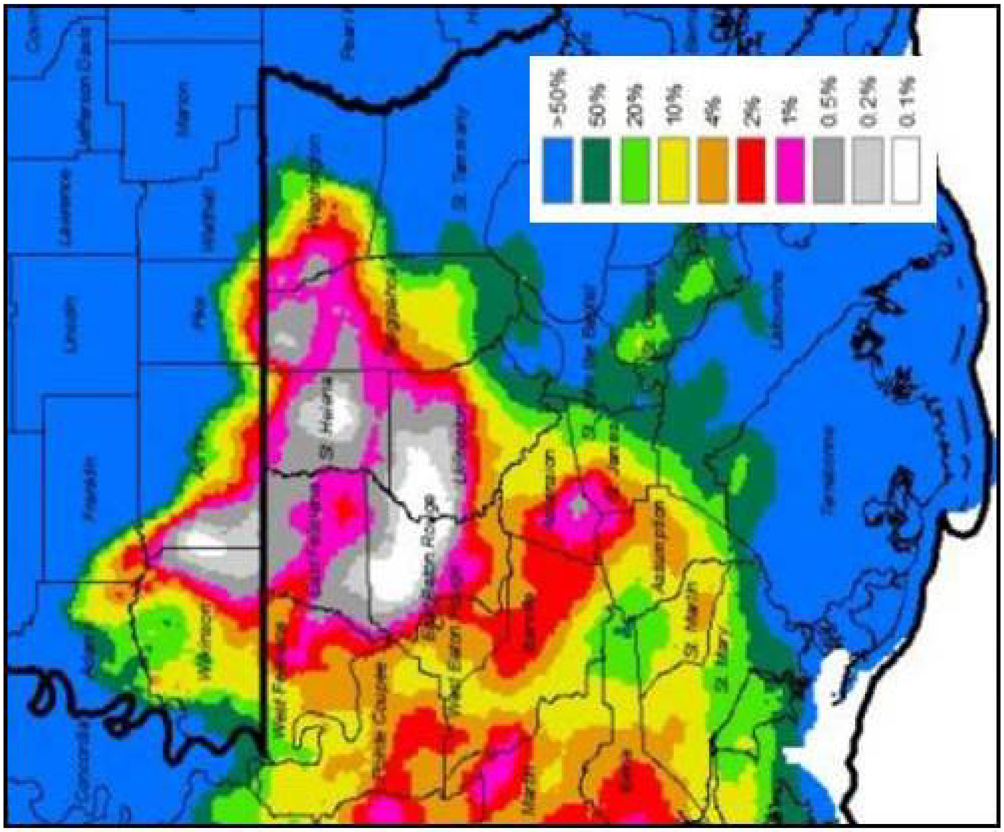


Figure 16. Range of Precipitable Moisture by Month for Southeast Louisiana
US National Weather Service 2016



a. Rainfall Total in Inches



b. Rainfall Percent AEP

Figure 17. ARB 2-Day Rainfall August 12 and 13, 2016
US National Weather Service 2016

Table 4. 2-Day Rainfall Totals at 15 ARB Locations
(Presented by Barry Keim, PhD, Louisiana State Climatologist October 2016)

Location	Event Rainfall	100-yr Rainfall	1,000-yr Rainfall
BR-Concord	14.20	14.2	21.3
BTR	14.85	14.2	21.3
BR-SHER	15.07	14.2	21.3
Livingston	21.86	14.1	20.7
Norwood	21.40	14.1	20.7
Gonzales	13.02	14.2	20.9
Watson	31.39	14.2	21.3
Brownfields	26.83	14.2	21.3
Denham Springs	25.50	14.2	21.2
Monticello	24.02	14.2	21.3
Central	22.10	14.2	21.3
Wakefield	21.20	14.1	20.7
Jackson	21.04	14.1	20.7
Gonzales	18.00	14.2	20.9
Baton Rouge	16.78	14.2	21.3

Figure 17b shows the percent AEP for the 2-day rainfall totals. The 2-day rainfall for various AEPs (return periods) varies slightly over the ARB. The values shown for Baton Rouge in Figure 11 (e.g., 14.2 inches for a 100-yr rainfall) are typical. The event had a 2-day rainfall total above 20 inches in northern East Baton Rouge and northeastern Livingston Parishes—which is estimated as having an AEP of about 0.1 percent—or a 1,000-yr return period. Importantly however, estimates of 2-day rainfall for extreme AEPs have an uncertainty over 20 percent. Figure 11 shows that a 20-inch 2-day rainfall total is clearly within the uncertainty for a 500-yr event.

Table 4 presents 2-day rainfalls at 15 ARB locations. The northeast East Baton Rouge Parish and northwest Livingston Parish locations of Brownfields and Watson reported 26.83 and 31.29 inches, respectively. A bit further south, Monticello and Denham Springs in East Baton Rouge and Livingston Parishes—west and east of the junction of the Comite and Amite Rivers—reported 24.02 and 25.5 inches. Norwood, in the Upland Hills near the head of the Comite River, noted 21.40 inches.

The volume of 2-day rainfall over the ARB was unprecedented and far exceeded quantities seen in the 1983 Flood. The heavy rainfall in the Upland Hills zone, coupled with regional soil saturated from wet preceding weeks, produced widespread flooding. East Baton Rouge Parish collected cell phone reports of GPS flood location and 911 calls records of flood reports and prepared an initial online map of the parish flood footprint, including those inside and outside the NFIP 100-yr flood zone (Figure 18).[7]

The ARBD recognized that understanding the nature and impacts of this unprecedented flood—and future flood risk management—requires a coordinated, detailed “state-of-the-practice “scientific documentation and analysis of the flood. To further these goals, in the immediate aftermath of the

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[7] For an indication of the catastrophic consequences of the flood see ***The August 2016 Flood—90 Days of Headlines in The Advocate*** **(Baton Rouge)**
Part 1 and **Part 2** ;

flood the ARBD initiated both a high quality HWM survey and sponsored a **Workshop on Improving Amite River Basin Flood Forecasting and Hazard Analysis** attended by over 100 professionals.

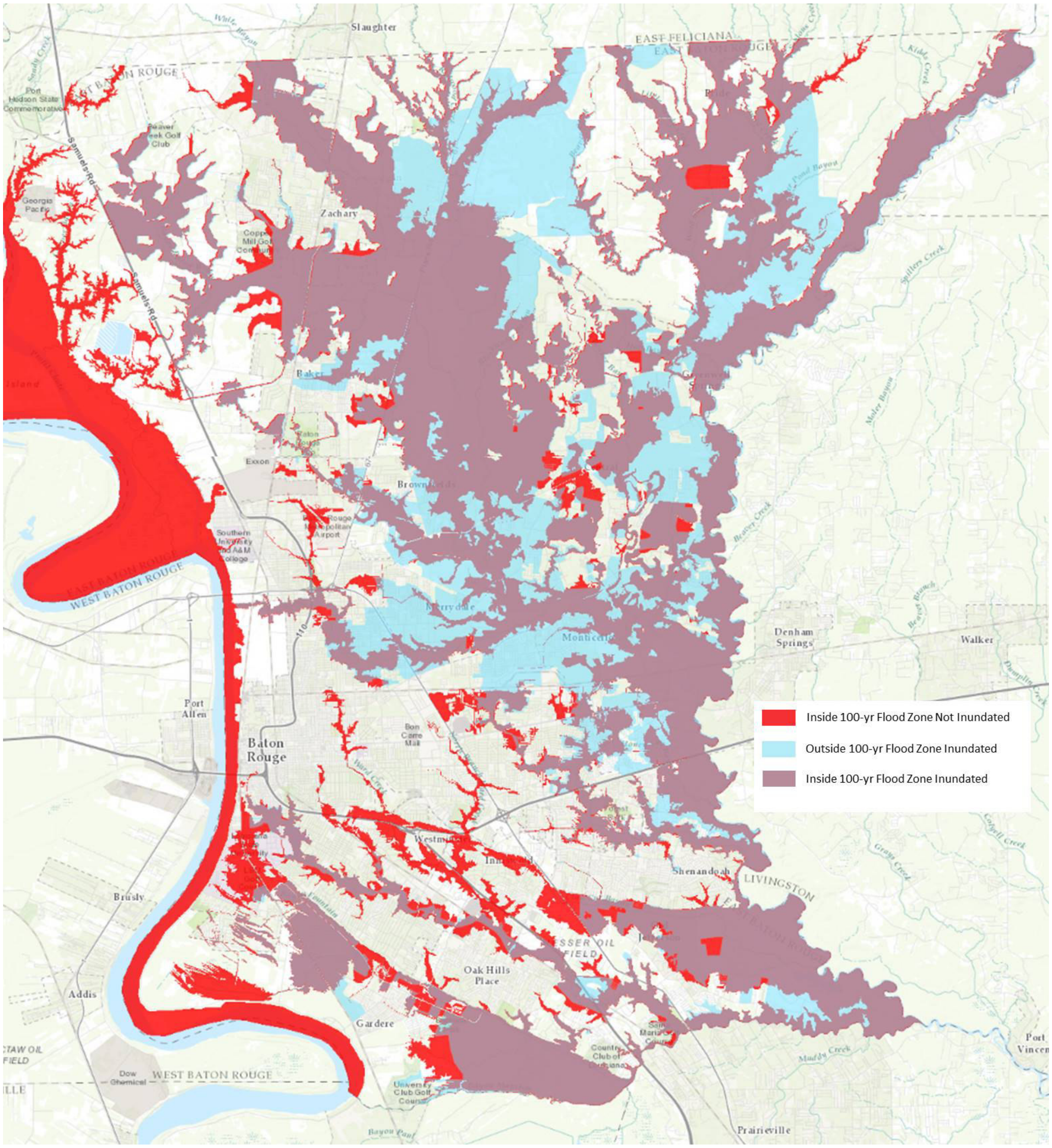


Figure 18. East Baton Rouge Parish August 2016 Flood Inundation Footprint
East Baton Rouge Parish 2016

9. USGS Data and Analysis

River Gauges

At the time of the August 2016 Flood, the USGS maintained automated continuous real-time monitoring of 44 stage gauges in the ARB, including one gauge for the Louisiana Coastal Reference Monitoring System (CRMS). The breakdown of USGS gauges by sub-basin is shown in Table 5. Figure 19a shows the location of the 44 gauges. Table 6 lists the 44 gauges and the August 2016 Flood peak (in ft NAVD88 where available).

Figure 20 presents eight NWS flood hydrographs for five USGS Amite River and two USGS Comite River gauges, plus one NWS manual reporting station at Bayou Manchac Point on the Amite River. Table 7 compares the August 2016 crests for these eight gauges and one additional USGS gauge to previous record crests. (Note Table 7 crests are in gauge not NAVD88 datum.) The August 2016 flood broke the previous record at eight of the nine locations. Table 7 shows that the new records significantly exceeded previous ones in the southern half of the ARB—roughly south of Greenwell Springs Rd, Amite River at Magnolia.

High Water Mark Survey

Under FEMA sponsored program sponsored the USGS surveyed post-flood high water marks (HWMs, in ft NAVD88) across south Louisiana, including the ARB. Bob Jacobsen PE downloaded the data and

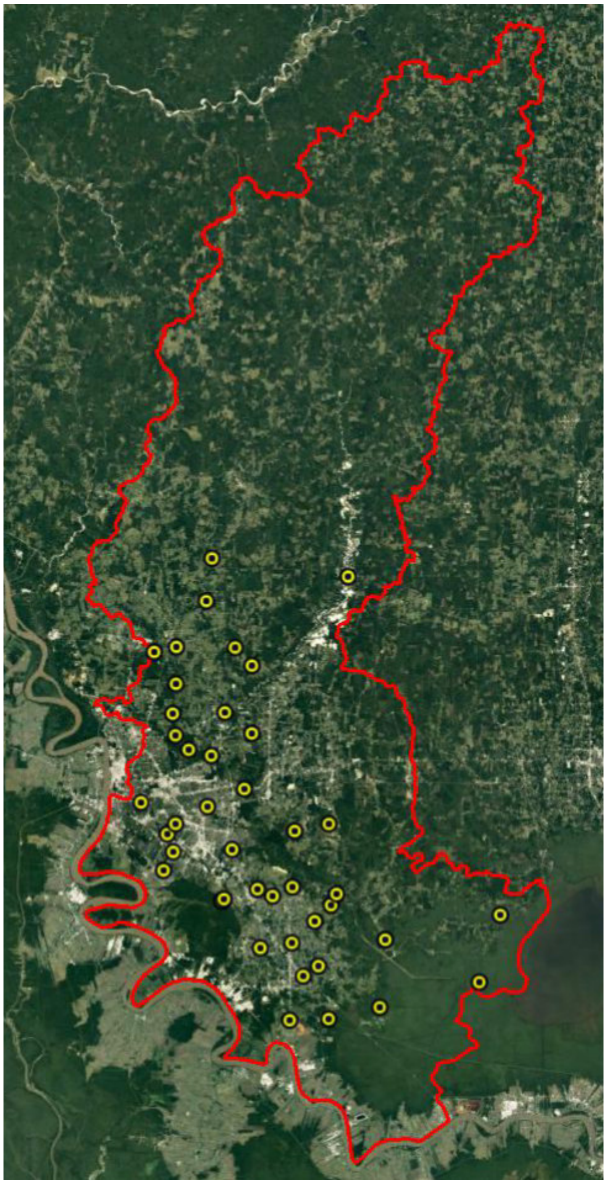
- Mapped the HWMs based on their latitude/longitude information and inspected them for obvious errors (e.g., name not matching location) and made corrections where possible;
- Assigned HWMs to the eight ARB sub-basins and streams;
- Noted as "FP" for floodplain those HWMs located far from the stream reach and which do not appear to indicate the peak elevation at the channel.

A total of 200 HWMs were assigned to the ARB. One point was listed with two identification numbers—yielding a total of 199 HWMs. The breakdown of USGS 199 HWMs by sub-basin is included in Table 5. Table 8 lists the 199 USGS HWMs by ARB sub-basin and stream and the corresponding flood elevations. Figure 19b shows the locations for the 199 HWMs.

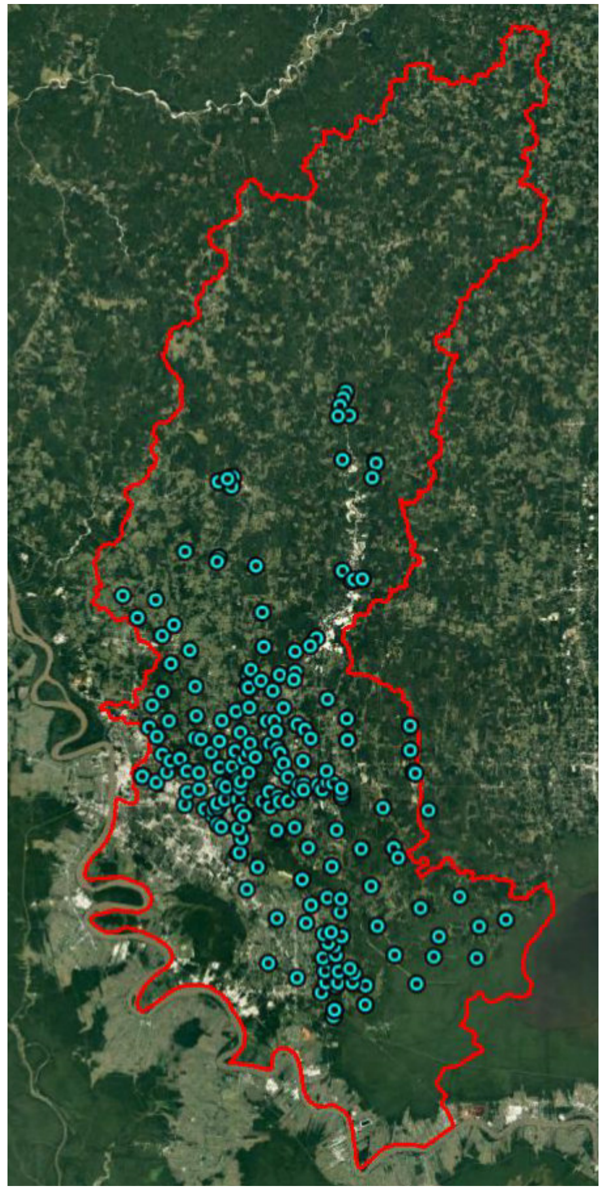
Table 5. Breakdown of Peak Flood Data Sets by Sub-basin

Sub-basin	**USGS Gauges**	**USGS HWMs**	**ARBD HWMs**	**Total**
Upper Amite River	0	3	4	**7**
Middle Amite River	5	40	26	**71**
Lower Amite River	6	28	29	**63**
Comite River	10	46	48	**104**
HCB/JC/CCB	2	21	26	**49**
Grays & Colyell Creeks	2	38	52	**92**
Bayou Manchac	11	3	40	**54**
Blind River	8*	20	27	**55**
Total	**44**	**199**	**252**	**495**

* Includes a gauge in the swamp near the mouth of Blind River funded by CRMS.



a. 44 Gauges



b. 199 HWMs

Figure 19. Location of USGS Gauges and High Water Marks

Table 6. August 2016 Peak Stage for USGS Gauges

Downloaded from http://stn.wim.usgs.gov/STNDataPortal/#

Not all crests reported by USGS are available in NAVD88. Crests reported in gauge datum and NGVD29 have been converted to NAVD88 where ARBD information is available (e.g., Comite River at Comite La, Joor Rd.). ARBD conducted additional differential static survey sessions for the Amite River gauges at Denham Springs and Maurepas which confirmed USGS conversions to NAVD88. Older conversions provided by the US Army Corps of Engineers for these two gauges have not been used.

Site Name	Crest (ft)	Datum	Note
Middle Amite River Sub-basin			
Amite River near Darlington, LA	168.35	NGVD29	
Amite River at Grangeville, LA	116.46	NAVD88	
Little Sandy Creek at Peairs Rd SE of Milldale, LA	73.84	NGVD29	Possible Equipment Issue
Sandy Ck at Alph. Forbes nr Greenwell Springs, LA	70.24	NAVD88	Highest Before Equipment Failed
Amite River at Magnolia, LA	57.42	NAVD88	
Lower Amite River Sub-basin			
Amite River near Denham Springs, LA	44.85	NAVD88	
Amite River at Port Vincent, LA	16.09	NAVD88	Highest Before Equipment Failed
Henderson Bayou near Port Vincent, LA	15.61	NAVD88	
Henderson Bayou Pump Station near Port Vincent, LA Downstream of Structure	15.93	Gauge	Peak Gauge Ht Downstream of Structure is 16.66 a few hours earlier
W Colyell Cr. at Joe May Rd near Port Vincent, LA	20.86	NAVD88	Highest Before Equipment Failed
Amite River near French Settlement, LA	8.3	NAVD88	
Amite River at Hwy 22 near Maurepas, LA	4.48	NAVD88	
Comite River Sub-basin			
Comite River near Olive Branch, LA	140.11	NAVD88	Highest After Equipment Resumed
Comite R. at Pt. Hudson-Pride Rd near Milldale, LA	118.98	NAVD88	
Comite River near Zachary, LA	88.94	NAVD88	Highest Before Equipment Failed
Comite River near Baker, LA	57.7	NAVD88	Equipment Wasn't Working During Flood
Comite River at Comite Dr near Baton Rouge, LA	66.42	NAVD88	
White Bayou at State Hwy 64 near Zachary, LA	93.87	NGVD29	
Comite River at Hooper Road near Baton Rouge, LA	60.58	NAVD88	
Comite River near Comite, LA (Joor Rd)	56.32	NAVD88	
Comite R. at Greenwell Spg Rd near Baton Rouge, LA	47.86	NGVD29	Highest Before Equipment Failed
Beaver Bayou at Hooper Road near Baton Rouge, LA	63.35	NGVD29	

HCB/JC/CCB Sub-basin			
Jones Cr. at Old Hammond Hwy near Baton Rouge, LA	33.36	NAVD88	Highest After Equipment Resumed
Claycut Bayou at Antioch Rd near Baton Rouge, LA	28.54	NAVD88	
Grays & Colyell Creeks Sub-basin			
Grays Creek at Hwy 16 near Port Vincent, LA	27.97	Gauge	Highest Before Equipment Failed
Bayou Manchac Sub-basin			
Alligator Bayou near Kleinpeter, LA	12.98	NAVD88	Equipment Disconnected Near Peak
Bayou Manchac at Alligator B. near Kleinpeter, LA	15.13	NAVD88	
Bluff Swamp near Kleinpeter, LA	13.12	NAVD88	Reached 12.8 about 0:00 12/18
Bayou Fountain at Bluebonnet Blvd near B.R., LA	15.22	NAVD88	Equipment Wasn't Working When Peak Arrived; But Stable Backwater Indicates Resumed Reading is Likely Near Peak
Ward Creek at Government St at Baton Rouge, LA	42.88	NGVD29	Lower Secondary Peaks Occurred During Succeeding Days
Ward Creek at Essen Lane near Baton Rouge, LA	25.83	NAVD88	Lower Secondary Peaks Occurred During Succeeding Days
North Branch Ward Creek at Baton Rouge, LA	25.93	NAVD88	Lower Secondary Peaks Occurred During Succeeding Days
Dawson Cr. at Bluebonnet Blvd near Baton Rouge, LA	20.06	NAVD88	Highest After Equipment Resumed (Fairly Stable--Might Be Peak)
Bayou Manchac near Little Prairie, LA	17.05	NAVD88	
Welsh Gully at J. Broussard Rd nr Prairieville, LA	14.49	NAVD88	Highest After Equipment Resumed
Muddy Creek at Manchac Acres Rd near Oak Grove, LA	19.87	NAVD88	Highest Before Equipment Failed
Blind River Sub-basin			
Panama Canal at Hwy 44 near Gonzales, LA	8.92	NAVD88	
Bayou Conway near Sorrento, LA Downstream of Structure	2.94	NAVD88	Peak Gauge Ht Downstream of Structure is 5.7 a few hours earlier
Grand Goudine at Babin Rd Near Duplessis, LA	11.5	NAVD88	
Black Bayou at Hwy 621 near Prairieville, LA	9.85	NAVD88	
Black Bayou E of Gonzales, LA	8.48	NAVD88	Highest Before Equipment Failed
Bayou Francois at Hwy 61 Near Gonzales, LA	8.24	NAVD88	
New River Canal near Sorrento, LA Upstream of Structure	7.74	NAVD88	Peak Gauge Ht Upstream of Structure is 7.88
CRMS0061-H01-RT Maurepas Swamp Alligator Bayou Near Blind River	4.58	NAVD88	

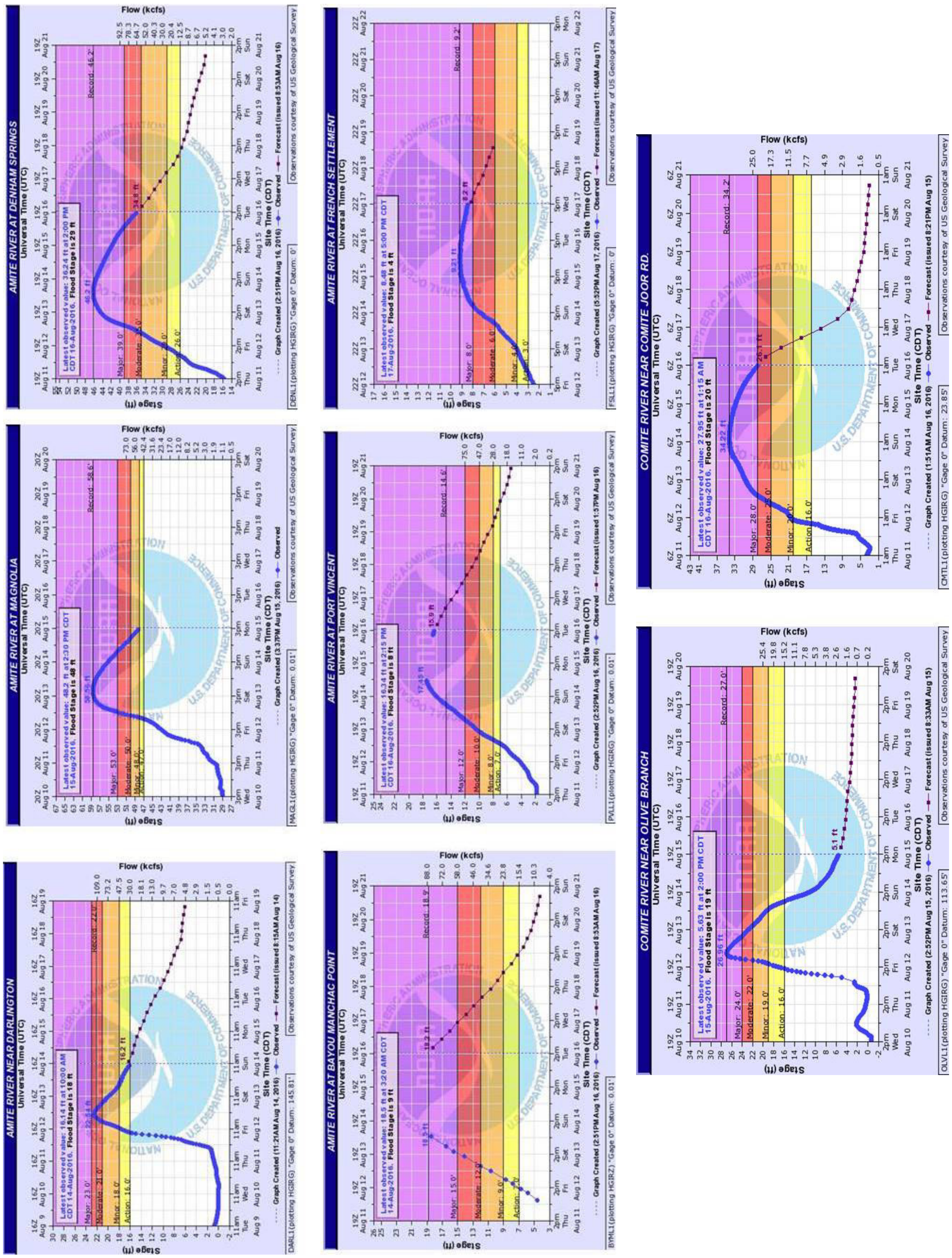


Figure 20. Hydrographs for Eight Gauges
US National Oceanic and Atmospheric Administration, 2016

Table 7. Comparison of August 2016 and Previous Crests for Nine Gauges

Gauge	August 2016 Crest ft Gauge Datum	Previous Record Flood	
		Crest	Date
Amite River-Darlington	22.54	22.05	Jan 1990
Amite River-Grangeville	44.62	46.47	Apr 1955
Amite River-Magnolia	58.56	51.91	Apr 1977
Amite River-Denham Springs	46.20	41.50	Apr 1983
Amite River- Manchac Point (NWS manual recording; may not have been actual peak)	21.5	18.85	Apr 1983
Amite River-Port Vincent	17.5	14.65	Apr 1983
Amite River-French Settlement	9.21	7.40	Apr 1977
Comite River-Olive Branch	26.96	23.37	Mar 1961
Comite River-Joor Road	34.22	30.99	June 2001

Table 8. 199 USGS High Water Marks

Sub-Basin	Stream	Longitude	Latitude	Flood Elevation Ft NAVD88
Bayou Manchac	Muddy Creek	-90.91267	30.32992	21.144
Bayou Manchac	Bayou Manchac	-90.99292	30.34252	19.353
Bayou Manchac	North Branch Ward Creek East FP	-91.08661	30.44847	44.003
Blind River	Bayou Conway	-90.86189	30.18333	5.436
Blind River	Bayou Conway	-90.85989	30.19129	6.29
Blind River	Bayou Conway	-90.86071	30.19135	6.364
Blind River	New River	-90.81534	30.19857	7.934
Blind River	Bayou Francois	-90.8802	30.21313	8.009
Blind River	New River	-90.85938	30.22202	7.625
Blind River	New River	-90.81507	30.223	8.535
Blind River	ARDC/Petite Amite River	-90.74001	30.22605	6.339
Blind River	New River	-90.87389	30.22606	8.041
Blind River	New River	-90.85628	30.22612	8.796
Blind River	New River	-90.83467	30.22659	8.664
Blind River	Bayou Francois	-90.91672	30.23144	7.87
Blind River	Black Bayou	-90.83264	30.23835	9.068
Blind River	Black Bayou North FP	-90.85557	30.24046	9.033
Blind River	Black Bayou	-90.87539	30.24064	8.999
Blind River	Black Bayou North FP	-90.83871	30.24416	8.907
Blind River	New River	-90.95947	30.24931	10.748
Blind River	Black Bayou	-90.87885	30.25732	8.986
Blind River	Bayou Chene Blanc FP	-90.651763	30.259806	5.488
Blind River	Black Bayou	-90.94767	30.3065	20.098
Comite River	Comite River	-91.00539	30.4709	46.074
Comite River	Hurricane Creek	-91.12946	30.47602	53.528
Comite River	Comite River	-91.00417	30.47886	46.839
Comite River	Comite River	-91.00792	30.48203	47.067
Comite River	Hurricane Creek	-91.15028	30.48348	53.26
Comite River	Hurricane Creek	-91.15028	30.48348	53.254
Comite River	Hurricane Creek	-91.11404	30.48914	53.601
Comite River	Hurricane Creek South FP	-91.06644	30.48949	52.628
Comite River	Comite River	-90.99315	30.49084	46.855
Comite River	Hurricane Creek	-91.08415	30.49127	53.866
Comite River	Comite River	-91.03607	30.49673	50.889
Comite River	Beaver Bayou	-91.01759	30.49779	49.637
Comite River	Robert Canal	-91.1091	30.50373	54.146
Comite River	Robert Canal	-91.09485	30.50665	55.084

Comite River	Draughan Creek	-90.99944	30.50767	49.694
Comite River	Robert Canal	-91.12135	30.51172	54.244
Comite River	Comite River Tributary	-91.04908	30.51503	54.354
Comite River	Draughan Creek/Middle Amite River	-90.99397	30.51628	51.293
Comite River	Beaver Bayou West FP/Draughan Creek East FP	-91.01336	30.51736	50.31
Comite River	Draughan Creek	-90.99169	30.52747	55.136
Comite River	Comite River Tributary	-91.03703	30.5296	52.539
Comite River	Blackwater Bayou East FP/Comite River Tributary	-91.06451	30.53151	59.186
Comite River	Blackwater Bayou	-91.07331	30.53302	61.332
Comite River	Cypress Bayou	-91.12959	30.53415	59.794
Comite River	Draughan Creek	-91.006	30.54114	57.172
Comite River	Comite River West FP trib	-91.14152	30.54575	59.831
Comite River	Old White Bayou	-91.11227	30.55417	66.133
Comite River	Beaver Bayou/Comite River Tributary	-91.03411	30.55592	63.473
Comite River	Blackwater Bayou East FP/Blackwater Bayou Tributary	-91.07188	30.56132	63.933
Comite River	Beaver Bayou	-91.01313	30.56775	64.2805
Comite River	Cypress Bayou/Old White Bayou Tributary	-91.13743	30.57389	69.101
Comite River	Old White Bayou	-91.12218	30.59129	73.635
Comite River	Blackwater Bayou	-91.07418	30.59846	76.08
Comite River	Comite River	-91.1108	30.62677	83.899
Comite River	Comite River East FP up small trib	-91.08312	30.64416	91.605
Comite River	White Bayou	-91.12436	30.66219	94.703
Comite River	Redwood Creek	-91.10737	30.67624	102.143
Comite River	Copper Mill Bayou/White Bayou	-91.16138	30.68429	104.2925
Comite River	Doyle Bayou	-91.13494	30.70728	115.145
Comite River	White Bayou/Black Creek	-91.18387	30.7119	116.4275
Comite River	Comite River	-91.04492	30.75708	139.745
Comite River	Comite River	-91.04272	30.76186	143.655
Comite River	Redwood Creek	-91.09278	30.76917	137.111
Comite River	Pretty Creek	-91.02531	30.85231	179.666
Comite River	Comite River	-91.04481	30.85828	183.002
Comite River	Pretty Creek/Comite River	-91.0315	30.86211	182.778
Comite River	Pretty Creek	-91.02378	30.86431	184.343
Grays & Colyell	Colyell Creek	-90.809215	30.349174	16.441
Grays & Colyell	Gray's Creek	-90.867764	30.373144	19.854
Grays & Colyell	Colyell Creek	-90.76989	30.38553	17.000
Grays & Colyell	Middle Colyell Creek	-90.824731	30.396229	16.652
Grays & Colyell	Gray's Creek	-90.903122	30.396603	26.864
Grays & Colyell	Colyell Creek	-90.776855	30.397925	16.901

Grays & Colyell	West Colyell Creek	-90.86159	30.41953	23.702
Grays & Colyell	Gray's Creek	-90.923561	30.422032	33.428
Grays & Colyell	Little Colyell Creek East FP	-90.72603	30.44616	28.812
Grays & Colyell	Colyell Creek	-90.793508	30.44852	27.733
Grays & Colyell	Gray's Creek	-90.93372	30.45544	38.690
Grays & Colyell	Gray's Creek	-90.93375	30.45547	38.673
Grays & Colyell	Middle Colyell Creek	-90.85413	30.46135	37.176
Grays & Colyell	Middle Colyell Creek	-90.854774	30.465578	32.248
Grays & Colyell	Gray's Creek East FP	-90.9202	30.46809	41.475
Grays & Colyell	Gray's Creek East FP	-90.92014	30.46876	41.363
Grays & Colyell	West Colyell Creek West FP	-90.9114	30.46972	40.805
Grays & Colyell	West Colyell Creek	-90.88379	30.47037	38.339
Grays & Colyell	Middle Colyell Creek	-90.855	30.47236	37.066
Grays & Colyell	West Colyell Creek	-90.88988	30.47601	39.157
Grays & Colyell	West Colyell Creek West FP	-90.91077	30.47613	40.805
Grays & Colyell	Middle Colyell Creek West FP	-90.87839	30.47616	38.339
Grays & Colyell	West Colyell Creek West FP	-90.91754	30.47633	40.949
Grays & Colyell	Middle Colyell Creek West FP	-90.868	30.47901	38.339
Grays & Colyell	Middle Colyell Creek West FP	-90.87599	30.48037	38.328
Grays & Colyell	Gray's Creek	-90.93435	30.48541	46.106
Grays & Colyell	Little Colyell Creek	-90.74634	30.49288	39.683
Grays & Colyell	Beaver Branch	-90.87785	30.49428	45.895
Grays & Colyell	Little Colyell Creek	-90.7485	30.49497	38.366
Grays & Colyell	West Colyell Creek	-90.9129	30.50636	49.606
Grays & Colyell	Colyell Creek	-90.75438	30.52201	45.932
Grays & Colyell	Middle Colyell Creek	-90.84748	30.53376	55.234
Grays & Colyell	Middle Colyell Creek	-90.84744	30.53461	55.553
Grays & Colyell	West Colyell Creek	-90.90195	30.53511	56.860
Grays & Colyell	West Colyell Creek	-90.910783	30.546339	59.642
Grays & Colyell	Colyell Creek	-90.75507	30.55313	58.109
Grays & Colyell	Middle Colyell Creek	-90.84883	30.56085	63.268
Grays & Colyell	West Colyell Creek	-90.87796	30.58508	72.329
HCB/JC/CCB	Clay Cut Bayou	-90.97734	30.37103	24.369
HCB/JC/CCB	Clay Cut Bayou	-91.006952	30.388695	27.485
HCB/JC/CCB	Clay Cut Bayou	-91.0046	30.38876	27.331
HCB/JC/CCB	Clay Cut Bayou	-91.0046	30.38876	27.598
HCB/JC/CCB	Jones Creek	-91.00156	30.40711	35.426
HCB/JC/CCB	Jones Creek	-91.007019	30.419657	36.454
HCB/JC/CCB	Jones Creek	-91.032117	30.42083	37.955
HCB/JC/CCB	Jones Creek	-91.037701	30.424739	39.02
HCB/JC/CCB	Jones Creek	-91.04406	30.43411	41.243

HCB/JC/CCB	Honey Cut Bayou	-91.00383	30.44239	39.526
HCB/JC/CCB	Honey Cut Bayou	-91.00383	30.44239	39.706
HCB/JC/CCB	Lively Bayou	-91.04389	30.44333	42.146
HCB/JC/CCB	Jones Creek	-91.05706	30.44364	42.564
HCB/JC/CCB	Lively Bayou	-91.0377	30.44614	42.83
HCB/JC/CCB	Lively Bayou	-91.03873	30.45095	42.646
HCB/JC/CCB	Lively Bayou	-91.027635	30.45558	43.546
HCB/JC/CCB	Honey Cut Bayou	-91.00771	30.45636	43.458
HCB/JC/CCB	Jones Creek	-91.08297	30.46451	47.906
HCB/JC/CCB	Jones Creek	-91.06544	30.46835	48.946
HCB/JC/CCB	Lively Bayou	-91.02601	30.47189	47.443
HCB/JC/CCB	Lively Bayou North FP	-91.03249	30.47506	52.344
Lower Amite River	Old Amite River/Chinquapin Canal	-90.715115	30.260719	6.5295
Lower Amite River	Lower Amite River West FP	-90.86006	30.26108	9.421
Lower Amite River	Lower Amite River	-90.773012	30.262263	8.175
Lower Amite River	Lower Amite River West FP	-90.86233	30.27283	14.582
Lower Amite River	Lower Amite River West FP	-90.87147	30.27597	12.46
Lower Amite River	Lower Amite River West FP	-90.87133	30.27625	12.498
Lower Amite River	Lower Amite River	-90.85147	30.28489	12.324
Lower Amite River	Lower Amite River	-90.707996	30.286479	5.589
Lower Amite River	Henderson Bayou South FP	-90.87822	30.28731	14.316
Lower Amite River	Henderson Bayou South FP	-90.86742	30.28997	12.872
Lower Amite River	Lower Amite River	-90.799159	30.298555	11.395
Lower Amite River	Lower Amite River	-90.648688	30.30005	5.504
Lower Amite River	Henderson Bayou South FP	-90.90455	30.30122	15.066
Lower Amite River	Lower Amite River	-90.609385	30.309092	4.268
Lower Amite River	Lower Amite River	-90.85392	30.31564	15.84
Lower Amite River	Lower Amite River	-90.73581	30.322236	7.289
Lower Amite River	Henderson Bayou North FP	-90.89753	30.32403	17.421
Lower Amite River	Lower Amite River	-90.85355	30.33249	16.864
Lower Amite River	Henderson Bayou	-90.87369	30.33369	16.769
Lower Amite River	Lower Amite River	-90.678305	30.337259	5.5105
Lower Amite River	Lower Amite River	-90.91139	30.35611	22.567
Lower Amite River	Lower Amite River	-90.95022	30.41801	35.568
Lower Amite River	Lower Amite River	-90.99839	30.43578	39.706
Lower Amite River	Lower Amite River	-90.99839	30.43578	39.526
Lower Amite River	Lower Amite River	-90.96066	30.44751	39.368
Lower Amite River	Lower Amite River East FP	-90.94653	30.45444	39.081
Lower Amite River	Lower Amite River	-90.97187	30.45478	43.711
Lower Amite River	Lower Amite River East FP (BAD)	-90.94872	30.46075	38.023
Middle Amite River	Middle Amite River	-90.9621	30.4669	44.476

Middle Amite River	Middle Amite River	-90.9464	30.4963	48.024
Middle Amite River	Middle Amite River	-90.9415	30.5028	51.877
Middle Amite River	Middle Amite River	-90.9835	30.5103	52.168
Middle Amite River	Middle Amite River	-90.9474	30.5158	52.227
Middle Amite River	Middle Amite River	-90.9513	30.5218	52.853
Middle Amite River	Beaver Creek	-90.9619	30.528	56.649
Middle Amite River	Beaver Creek	-90.9533	30.5435	56.826
Middle Amite River	Beaver Creek	-90.9221	30.5525	63.62
Middle Amite River	Middle Amite River	-90.9673	30.5562	60.0225
Middle Amite River	Middle Amite River	-90.9673	30.5562	60.0385
Middle Amite River	Beaver Creek	-90.9563	30.5565	59.5285
Middle Amite River	Middle Amite River	-90.9936	30.573	65.274
Middle Amite River	Beaver Creek	-90.9431	30.5733	64.471
Middle Amite River	Middle Amite River	-90.9592	30.5947	71.9105
Middle Amite River	Sandy Creek	-90.99464	30.59803	68.0855
Middle Amite River	Hub Bayou	-90.9968	30.6002	69.62
Middle Amite River	Middle Amite River	-90.9769	30.6072	71.527
Middle Amite River	Spillers Creek	-90.9282	30.6091	76.735
Middle Amite River	Sandy Creek	-90.99533	30.61308	71.3895
Middle Amite River	Middle Amite River	-90.9493	30.6149	73.611
Middle Amite River	Middle Amite River	-90.9264	30.6187	82.949
Middle Amite River	Sandy Creek	-90.9922	30.62107	73.031
Middle Amite River	Middle Amite River	-90.9272	30.6449	85.257
Middle Amite River	Sandy Creek	-90.97369	30.65025	83.485
Middle Amite River	Middle Amite River	-90.9048	30.6524	90.609
Middle Amite River	Middle Amite River	-90.8956	30.6623	91.703
Middle Amite River	Sandy Creek	-90.97669	30.69389	103.211
Middle Amite River	Middle Amite River	-90.8445	30.7349	118.71
Middle Amite River	Middle Amite River	-90.8415	30.7371	116.387
Middle Amite River	Middle Amite River	-90.8292	30.7382	123.413
Middle Amite River	Middle Amite River	-90.8585	30.7479	123.01
Middle Amite River	Little Sandy Creek 2	-90.98714	30.75242	133.845
Middle Amite River	Darling Creek	-90.8167	30.8666	181.222
Middle Amite River	Darling Creek	-90.8111	30.8851	180.204
Middle Amite River	Darling Creek	-90.8125	30.8871	183.682
Middle Amite River	Middle Amite River	-90.8613	30.8886	170.352
Middle Amite River	Middle Amite River	-90.8688	30.9439	189.032
Middle Amite River	Middle Amite River	-90.8519	30.9449	188.072
Upper Amite River	Beaver Creek	-90.86608	30.957	191.608
Upper Amite River	Beaver Creek	-90.86169	30.96681	193.995
Upper Amite River	Beaver Creek	-90.85778	30.97492	194.341

Analysis of Flood Footprint

Under the FEMA sponsored post-flood analysis program, the USGS employed gauge records, their HWMs, and some field streamflow measurements to prepare *Characterization of Peak Streamflows and Flood Inundation of Selected Areas in Louisiana from the August 2016 Flood*. The report included depictions of the ARB inundation footprint inferred from the USGS gauge and HWM data. Figure 21 reproduces the USGS inundation footprint.

Under the FEMA program, the USGS generated the inundation footprint by applying geographic spatial interpolation techniques to the flood peak data points in conjunction with topographic DEM information. No hindcast hydrodynamic modeling of the August 2016 flood (flow, stages, and inundation) was performed. The USGS inundation footprint was further limited by the use of only USGS gauge and HWM information—other information such as the East Baton Rouge Parish GPS survey and the ARBD HWM survey was not used. The USGS inundation footprint therefore does not depict flooding of key portions of the ARB—such as areas west of US 61 in East Baton Rouge, Ascension, and Iberville Parishes.

Peak Discharge (Flow) Estimates

The USGS post-flood report also included estimates of the August 2016 peak discharge for the Comite River at Olive Branch, the Amite River at Darlington, and the Amite River at Denham Springs. Table 9 summarizes this information. The peak discharge estimates were based only on the USGS data (including field streamflow measurements) and were not supported by hindcast modeling of the flood. Additional hindcast analysis using a modern hydrodynamic model is required to better account for backwater flow and other conditions.

The August 2016 Food peak discharges at all three locations were the highest on records of 74, 68, and 78 years, respectively. The peak discharge on the Amite River at Denham Springs of 205,000 cfs 1983 represents a massive 83 percent increase over the previous record 1983 Flood peak discharge of 112,000 cfs. (For some perspective, 205,000 cfs is on the order of a fairly low flow for the Mississippi River at Baton Rouge, sometimes seen in the fall.)

Estimate of Peak Discharge AEP

Table 9 also include USGS estimates of the 1, 0.5, and 0.2 percent AEP (100-, 200-, and 500-yr) peak discharges at the three locations, including uncertainty intervals. As expected, due to the limited data record, the uncertainty intervals are very large. For the Amite River at Denham Springs peak discharge of 205,000 cfs, the USGS estimated an AEP of <0.2 percent (>500-yr), but that discharge is well within the uncertainty for the 0.5 percent (200-yr).

Interestingly the Denham Springs gauge crest of 44.85 ft in NAVD88 is less than one-foot higher than the FEMA NFIP 100-yr flood elevation at that location (44 ft NAVD88, based on the Baton Rouge FIS).

Importantly, whatever the “true” AEP (or return period) of the August 2016 Flood—the 1983 Flood with an AEP of >1percent (<100-yr) is many time higher. Statistically, numerous “1983 Floods” are likely to occur before another “August 2016 Flood.”

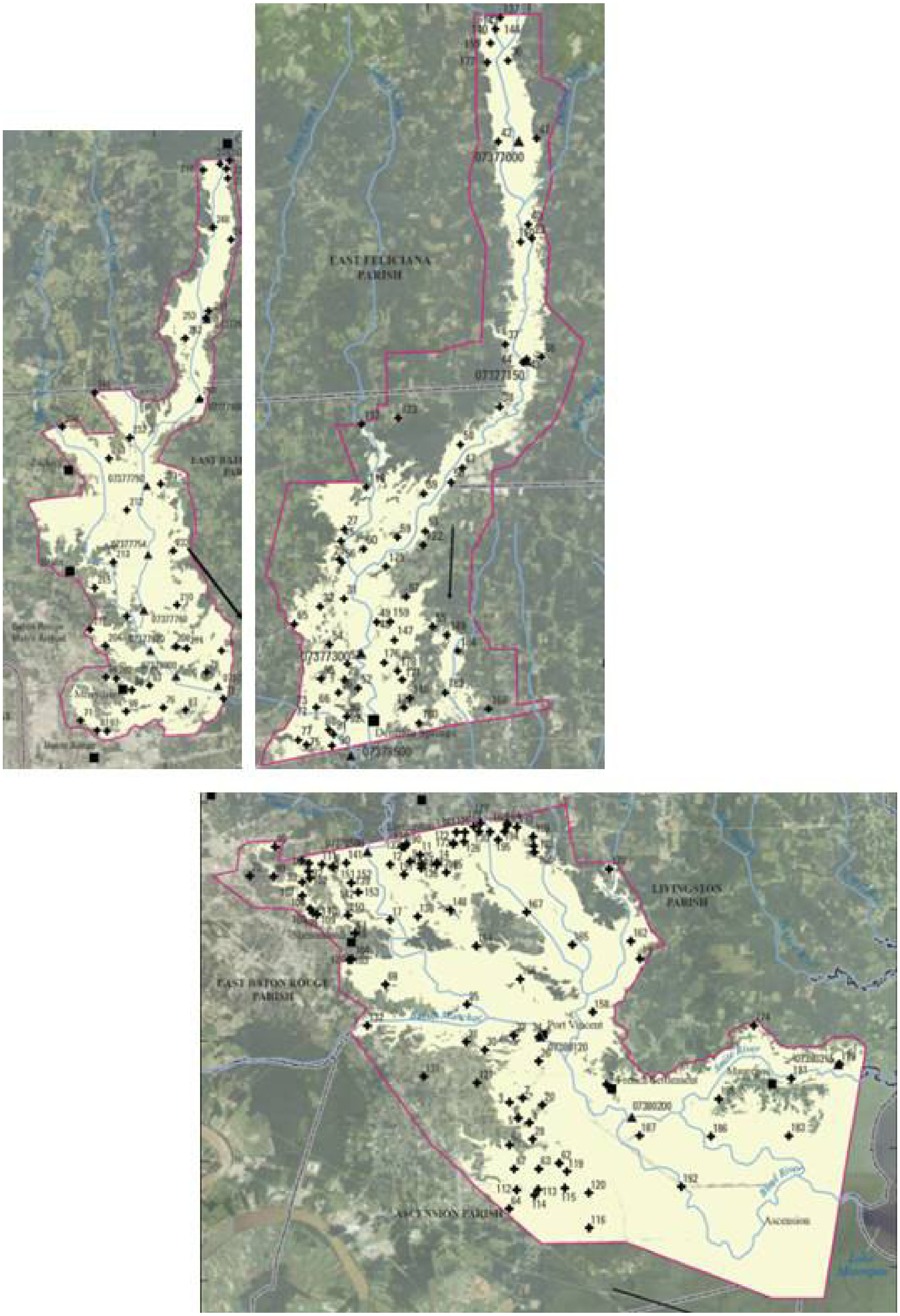


Figure 21. USGS Geospatial Interpolation of the August 2016 Flood Footprint
Reproduced from US Geological Survey 2017

Table 9. Peak Discharge and AEPs for Three Locations

US Geological Survey 2017

	Peak Discharge (cfs)		
	Comite Olive Branch	**Amite River Darlington**	**Amite River Denham Springs**
August 2016 Actual			
Estimate (cfs)	78,000	116,000	205,000
Rank/Years	1/74	1/68	1/78
1% AEP (100-yr) Discharge			
Estimate	47,600	118,000	136,000
Lower 95% Confidence Level	34,100	84,600	104,000
Upper 95% Confidence Level	82,100	199,000	200,000
0.5% AEP (200-yr) Discharge			
Estimate	57,400	139,000	154,000
Lower 95% Confidence Level	39,300	95,100	114,000
Upper 95% Confidence Level	108,000	253,000	243,000
0.2% AEP (500-yr) Discharge			
Estimate	71,900	169,000	180,000
Lower 95% Confidence Level	46,300	108,000	126,000
Upper 95% Confidence Level	153,000	341,000	307,000
Estimated AEP (RP) for August 2016 Discharge	**<0.2**	**1**	**<0.2**

10. ARBD High Water Mark Survey

Bob Jacobsen PE was retained by the ARBD to plan and coordinate their HWM survey. The ARBD HWM survey was focused on obtaining high quality records of peak flood along critical reaches of major ARB named streams. The survey priority was obtaining clearly visible, undisturbed evidence of the peak flood still water level and determining elevation for use in future basin-wide hindcast modeling of the flood and *Full Spectrum* flood hazard analysis. (The survey was not an investigation of structural flood damage.)

The ARBD HWM survey activities included:

- HWM program planning, which began on August 16 while the peak flood was still ongoing.
- Defining target reaches for HWM surveys.
- Developing high quality HWM survey procedures (see USGS 2016) and custom Excel spreadsheet forms.
- Coordination with the FEMA sponsored USGS HWM survey, and with the USACE, NWS, local parish and city governments, and the LSU AgCenter (which had a HWM flagging program).
- Identifying qualified local survey firms with extensive local experience, qualifications with Real-Time Network (RTN, ft NAVD88 Geoid 12B), HWM investigation capability, and multiple crew capacity.
- Contracting with four firms—SJB Group, Stantec, T Baker Smith, and Forte & Tablada (Louisiana Land Surveying).
- HWM survey training for survey firms/crews.
- Mobilizing survey crews—beginning on August 22.
- Completion of the initial round of HWM surveying (September 30), 300 locations investigated—234 HWMs surveyed and 66 locations investigated but no high quality HWMs available.
- Identifying additional HWM locations to incorporate some points flagged by the LSU AgCenter and a few reaches not covered during the initial round.
- Completion of the second round survey October 18, 2016, with 18 more HWMs obtained.
- Delivery of HWM survey digital reports using the Excel spreadsheet forms. The forms included photographs of the HWMs. The survey firms each provided a transmittal letter documenting that their methodologies were in accordance with standard RTN survey procedures.

The ARBD survey yielded a total of 252 HWMs. The total cost of field surveys and reports for the four firms was $132,356, or about $416 per location investigated, or $525 per HWM.

Bob Jacobsen PE reviewed the HWM reports provided by surveyors; inspected the data for obvious elevation and latitude/longitude errors; worked with surveyors to correct a few errors; and finalized assignment of HWMs to sub-basins and streams. Table 5 provides a breakdown of ARBD HWMs by sub-basin. Table 10 lists the 252 ARBD HWMs by ARB sub-basin and stream and Figure 22 shows their locations. In the stream designation, “FP” notes HWMs located in the far floodplain which are not indicative of the channel peak elevation.

Table 5 shows that the ARBD HWM program more than doubles the number of available HWMs for six sub-basins: the Upper Amite River, Lower Amite River, Comite River, HCB/JC/CCB, Grays & Colyell Creeks, and Blind River, and provides over 90 percent of the HWMs in the Bayou Manchac sub-basin.

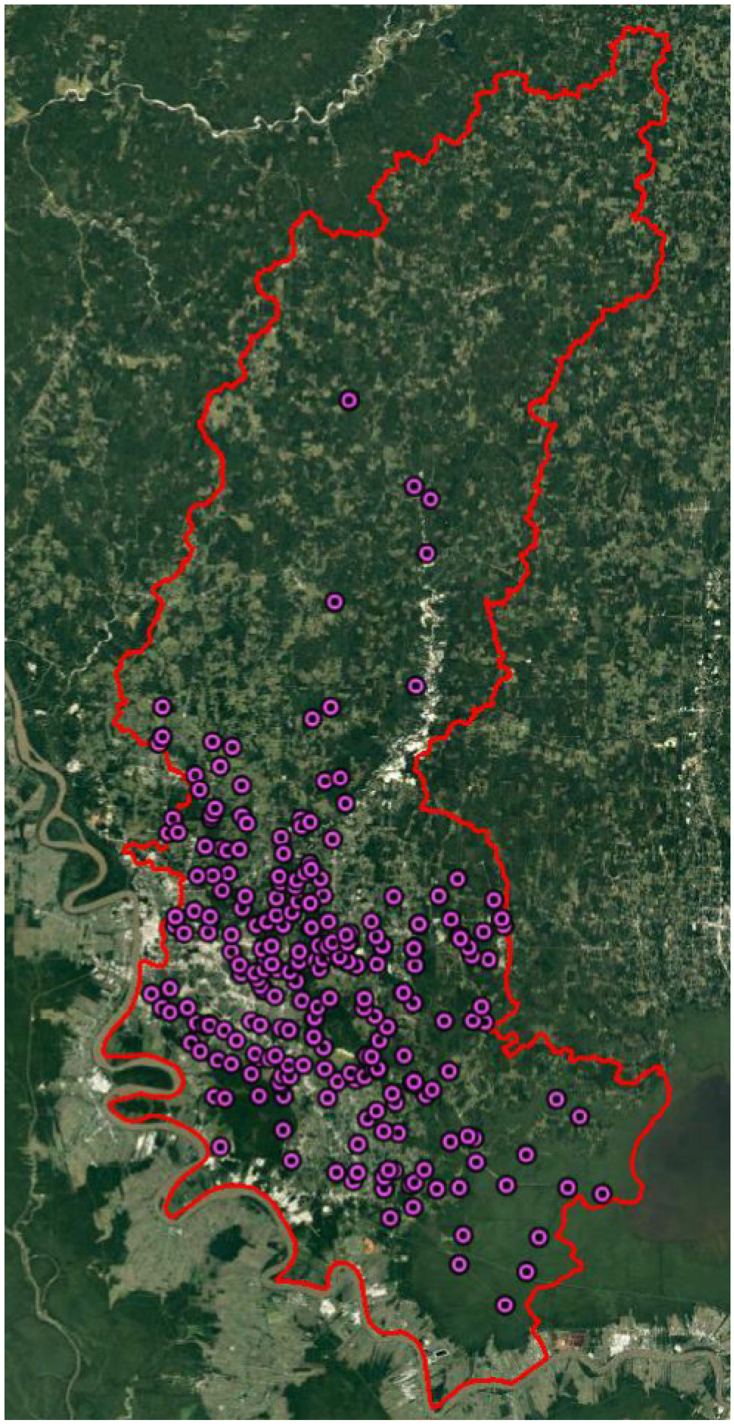


Figure 22. Location of 252 ARBD High Water Marks

Table 10. 252 ARBD High Water Marks

Sub-Basin	Stream	Longitude	Latitude	Flood Elevation Ft NAVD88
Bayou Manchac	Bayou Braud	-91.05902778	30.25613889	12.550
Bayou Manchac	Bayou Braud	-91.08666667	30.26030556	12.410
Bayou Manchac	Bayou Braud	-91.01030556	30.27936111	12.520
Bayou Manchac	Bayou Paul	-91.08222222	30.31130556	12.480
Bayou Manchac	Bayou Paul	-91.09527778	30.31269444	13.270
Bayou Manchac	Bayou Manchac	-90.9565606	30.31425505	20.870
Bayou Manchac	Alligator Bayou	-91.04055556	30.31472222	12.780
Bayou Manchac	Alligator Bayou	-91.01036111	30.31502778	12.160
Bayou Manchac	Bayou Manchac	-91.01397222	30.32688889	15.140
Bayou Manchac	Bayou Manchac	-91.01559061	30.32962034	14.870
Bayou Manchac	Muddy Creek	-90.94505854	30.3316592	21.720
Bayou Manchac	Muddy Creek	-90.92276808	30.33418383	20.780
Bayou Manchac	Bayou Manchac	-91.00338086	30.33581264	18.230
Bayou Manchac	Bayou Manchac	-91.01268227	30.3361873	17.110
Bayou Manchac	Bayou Fountain	-91.05055556	30.3375	14.410
Bayou Manchac	Bayou Manchac	-90.91222222	30.3375	21.100
Bayou Manchac	Bayou Manchac	-90.92885245	30.34079503	20.220
Bayou Manchac	Welsh Gully	-90.96066371	30.34455605	20.750
Bayou Manchac	Bayou Manchac	-90.89555556	30.34472222	20.190
Bayou Manchac	Ward Creek	-91.00532778	30.34744167	19.240
Bayou Manchac	Bayou Fountain	-91.07527778	30.3475	14.340
Bayou Manchac	Bayou Manchac	-90.98713684	30.34811512	19.910
Bayou Manchac	Bayou Fountain	-91.09222222	30.35111111	14.340
Bayou Manchac	Ward Creek	-91.02838333	30.35391667	19.200
Bayou Manchac	Ward Creek	-91.04019722	30.35439444	19.290
Bayou Manchac	Ward Creek	-91.02173333	30.357275	19.180
Bayou Manchac	Ward Creek	-91.04670278	30.35896111	17.952
Bayou Manchac	Bayou Fountain	-91.11388889	30.36	14.160
Bayou Manchac	Bayou Fountain	-91.12555556	30.36861111	16.450
Bayou Manchac	Ward Creek	-91.06965833	30.37218889	21.920
Bayou Manchac	Dawson Creek	-91.08492222	30.38256667	22.480
Bayou Manchac	Dawson Creek	-91.10297222	30.38713611	22.958
Bayou Manchac	Dawson Creek	-91.10834444	30.38721944	23.130
Bayou Manchac	Dawson Creek	-91.10348056	30.38876389	23.949
Bayou Manchac	Dawson Creek	-91.11903611	30.38969167	23.140
Bayou Manchac	Bayou Duplantier	-91.15210833	30.400075	23.584
Bayou Manchac	Bayou Duplantier	-91.16177222	30.40473611	23.558

Bayou Manchac	Dawson Creek	-91.13065833	30.40553611	23.720
Bayou Manchac	Corporation Canal	-91.174925	30.41898889	23.864
Bayou Manchac	Dawson Creek	-91.15281944	30.425	33.230
Blind River	Blind River	-90.73497222	30.10076667	4.64
Blind River	Blind River	-90.7094	30.13623889	4.57
Blind River	Bayou Conway	-90.791825	30.14236667	5.087
Blind River	Blind River	-90.69506944	30.17282222	4.64
Blind River	Blind River (Confined Swamp)	-90.78776667	30.17327222	5.47
Blind River	Bayou Conway	-90.87720556	30.18961944	5.812
Blind River	Bayou Francois	-90.84945	30.20162778	7.95
Blind River	Blind River	-90.61881667	30.21970278	4.01
Blind River	Bayou Francois	-90.88529167	30.22038889	7.75
Blind River	New River	-90.82099722	30.22138333	8.39
Blind River	Saveiro Canal	-90.79340278	30.22312778	8.638
Blind River	New River	-90.85277778	30.225	8.95
Blind River	Blind River	-90.66114167	30.22553056	4.57
Blind River	ARDC/Petite Amite River	-90.73596111	30.22671944	6.31
Blind River	Black Bayou (BAD)	-90.84828611	30.22758611	5.96
Blind River	Bayou Francois	-90.9233	30.22793056	8.85
Blind River	New River	-90.88542778	30.23263889	8.84
Blind River	New River	-90.94421111	30.23625833	10.71
Blind River	New River	-90.91829722	30.23648333	8.64
Blind River	Black Bayou (BAD)	-90.87392778	30.23960556	7.24
Blind River	Black Bayou	-90.88036944	30.23992222	8.87
Blind River	Black Bayou	-90.83676944	30.24101111	9.08
Blind River	New River	-90.99926389	30.24759722	13.91
Blind River	Amite River Diversion Canal	-90.77349722	30.25029722	7.935
Blind River	Black Bayou	-90.91835	30.26652222	9.98
Blind River	Amite River Diversion Canal	-90.80550278	30.27124722	10.26
Comite River	Comite River	-90.99498333	30.46694167	45.02
Comite River	Hurricane Creek	-91.07861111	30.48286111	53.567
Comite River	Hurricane Creek	-91.13659167	30.48320833	54.02
Comite River	Hurricane Creek	-91.10698333	30.484775	53.8
Comite River	Hurricane Creek	-91.14782778	30.49124167	53.282
Comite River	Comite River West FP trib	-91.048125	30.49329444	50.038
Comite River	Draughan Creek/Beaver Bayou	-91.01530278	30.49398056	48.48
Comite River	Comite River	-91.03532778	30.49703889	50.85
Comite River	Comite River	-91.03613611	30.49825278	51.21
Comite River	Hurricane Creek	-91.14733056	30.50039722	51.453
Comite River	Robert Canal	-91.10506111	30.50149167	53.888
Comite River	Beaver Bayou	-91.02390556	30.50469167	50.36

Comite River	Robert Canal	-91.12461111	30.50703889	54.185
Comite River	Draughan Creek	-91.00481944	30.50788333	49.59
Comite River	Comite River/Comite River Tributary	-91.065925	30.51105278	54.06
Comite River	Draughan Creek	-90.99758889	30.51983333	52.98
Comite River	Beaver Bayou	-91.02422222	30.52238333	53.1
Comite River	Comite River Tributary	-91.06251081	30.5235935	57.28
Comite River	Comite River	-91.09099444	30.52919722	59.41
Comite River	Draughan Creek	-91.00170833	30.53537778	54.31
Comite River	Beaver Bayou	-91.01940278	30.53868889	56.68
Comite River	Draughan Creek	-90.99978611	30.54171111	57.5
Comite River	Cypress Bayou	-91.12193611	30.54356111	59.61
Comite River	Comite River	-91.10294722	30.54456389	63.75
Comite River	Beaver Bayou	-91.02151111	30.54511944	59.39
Comite River	Blackwater Bayou	-91.08376667	30.547175	63.95
Comite River	Beaver Bayou	-91.01659167	30.56930833	64.53
Comite River	Blackwater Bayou	-91.08626111	30.57110278	67.72
Comite River	Blackwater Bayou Tributary	-91.07089225	30.57261403	67.67
Comite River	Comite River	-91.09358611	30.57274167	69.09
Comite River	Old White Bayou	-91.11277778	30.5748	69.7
Comite River	Beaver Bayou	-91.0201314	30.58598668	68.72
Comite River	Brushy Bayou	-91.1588418	30.58795372	78.87
Comite River	Old White Bayou/Brushy Bayou	-91.1468351	30.58892556	79.31
Comite River	Blackwater Bayou Tributary	-91.06265087	30.60028203	76.16
Comite River	Old White Bayou West FP	-91.15341066	30.60322609	79.37
Comite River	White Bayou	-91.10649444	30.60461667	78.31
Comite River	Blackwater Bayou	-91.068825	30.60753333	77.06
Comite River	White Bayou/Comite River	-91.10556389	30.60865556	79.71
Comite River	Comite River	-91.10205278	30.61502222	81.24
Comite River	White Bayou	-91.12145	30.63402778	85.91
Comite River	Saunders Bayou	-91.06986697	30.63962639	92.83
Comite River	White Bayou	-91.12708333	30.64943889	93.56
Comite River	Comite River	-91.096925	30.65898333	97.13
Comite River	Comite River	-91.08214722	30.67925	106.191
Comite River	White Bayou	-91.17311111	30.6817	104.47
Comite River	Redwood Creek	-91.10680833	30.68465833	102.98
Comite River	Copper Mill Bayou	-91.16848056	30.68866111	106.16
Comite River	Black Creek	-91.16933611	30.71982222	123.22
Grays/Colyell Creeks	Colyell Creek	-90.82896096	30.32522107	13.250
Grays/Colyell Creeks	Colyell Creek	-90.80876235	30.34514649	16.431
Grays/Colyell Creeks	Gray's Creek	-90.86413211	30.36048128	19.323
Grays/Colyell Creeks	Gray's Creek	-90.88534854	30.38978623	22.191

Grays/Colyell Creeks	Gray's Creek	-90.88534854	30.38978623	22.241
Grays/Colyell Creeks	Little Colyell Creek	-90.76607518	30.39719797	17.048
Grays/Colyell Creeks	Middle Colyell Creek	-90.81577521	30.39755278	14.227
Grays/Colyell Creeks	Colyell Creek	-90.78070043	30.39851196	14.583
Grays/Colyell Creeks	Gray's Creek	-90.90050539	30.40114517	28.425
Grays/Colyell Creeks	Gray's Creek	-90.91444444	30.40944444	35.314
Grays/Colyell Creeks	Colyell Creek	-90.77068441	30.41355413	17.455
Grays/Colyell Creeks	West Colyell Creek	-90.85398124	30.41568076	22.350
Grays/Colyell Creeks	Gray's Creek	-90.91416667	30.41916667	33.266
Grays/Colyell Creeks	West Colyell Creek	-90.86638889	30.42611111	26.252
Grays/Colyell Creeks	West Colyell Creek	-90.86644962	30.42621345	25.785
Grays/Colyell Creeks	Gray's Creek	-90.92444444	30.45333333	37.327
Grays/Colyell Creeks	Gray's Creek	-90.92444444	30.45333333	37.327
Grays/Colyell Creeks	Middle Colyell Creek	-90.85280024	30.45517513	28.611
Grays/Colyell Creeks	West Colyell Creek	-90.89944444	30.45583333	34.824
Grays/Colyell Creeks	Gray's Creek	-90.93487734	30.45750264	38.371
Grays/Colyell Creeks	Gray's Creek	-90.93495875	30.45762713	38.861
Grays/Colyell Creeks	Gray's Creek	-90.94493155	30.46206625	43.171
Grays/Colyell Creeks	Gray's Creek	-90.9450484	30.46247567	43.081
Grays/Colyell Creeks	Gray's Creek	-90.9450002	30.46247718	43.371
Grays/Colyell Creeks	Little Colyell Creek	-90.76317187	30.46307062	29.771
Grays/Colyell Creeks	Colyell Creek	-90.78332039	30.46660451	28.052
Grays/Colyell Creeks	Middle Colyell Creek	-90.85461322	30.47232437	37.948
Grays/Colyell Creeks	Middle Colyell Creek	-90.85465117	30.47290563	37.238
Grays/Colyell Creeks	Middle Colyell Creek	-90.8541186	30.47413765	37.539
Grays/Colyell Creeks	West Colyell Creek	-90.89269444	30.47452778	39.819
Grays/Colyell Creeks	West Colyell Creek	-90.89269444	30.47452778	39.829
Grays/Colyell Creeks	Hornsby Creek	-90.78750905	30.47504107	34.448
Grays/Colyell Creeks	West Colyell Creek	-90.89261111	30.47516667	39.619
Grays/Colyell Creeks	Gray's Creek	-90.93576109	30.47705669	43.459
Grays/Colyell Creeks	Gray's Creek	-90.93576109	30.47705669	43.459
Grays/Colyell Creeks	Gray's Creek	-90.93590795	30.47735507	43.459
Grays/Colyell Creeks	Hornsby Creek	-90.79792795	30.4839111	36.403
Grays/Colyell Creeks	West Colyell Creek	-90.90107503	30.48449086	43.023
Grays/Colyell Creeks	Gray's Creek	-90.93805556	30.48527778	46.809
Grays/Colyell Creeks	Hornsby Creek	-90.79947463	30.48675824	36.840
Grays/Colyell Creeks	Gray's Creek	-90.93333333	30.4875	46.464
Grays/Colyell Creeks	Colyell Creek	-90.76988889	30.49172222	37.236
Grays/Colyell Creeks	Middle Colyell Creek	-90.84900745	30.49784606	48.437
Grays/Colyell Creeks	Middle Colyell Creek	-90.84899481	30.49864062	48.587
Grays/Colyell Creeks	Little Colyell Creek	-90.74530556	30.49880556	40.631

Grays/Colyell Creeks	West Colyell Creek	-90.90746752	30.50012123	47.370
Grays/Colyell Creeks	Hornsby Creek	-90.81	30.50425	44.895
Grays/Colyell Creeks	Little Colyell Creek	-90.74780556	30.50586111	43.945
Grays/Colyell Creeks	Colyell Creek	-90.75786111	30.52552778	49.769
Grays/Colyell Creeks	Beaver Branch	-90.88083333	30.52666667	53.950
Grays/Colyell Creeks	Hornsby Creek	-90.82522222	30.52836111	51.342
Grays/Colyell Creeks	Hornsby Creek East FP	-90.80305556	30.54658333	55.477
HCB/JC/CCB	Clay Cut Bayou	-90.96261598	30.36690122	26.91
HCB/JC/CCB	Clay Cut Bayou	-90.97493915	30.37786044	27.14
HCB/JC/CCB	Clay Cut Bayou	-90.97507468	30.37799095	27.57
HCB/JC/CCB	Clay Cut Bayou	-91.00572613	30.38434861	27.36
HCB/JC/CCB	Clay Cut Bayou	-91.00582288	30.38435997	27.82
HCB/JC/CCB	Clay Cut Bayou	-91.01517681	30.38597534	28.02
HCB/JC/CCB	Clay Cut Bayou	-91.04091976	30.38909347	28.64
HCB/JC/CCB	Clay Cut Bayou	-91.05235295	30.39275026	27.02
HCB/JC/CCB	Jones Creek	-90.97116854	30.40937771	35.31
HCB/JC/CCB	Jones Creek	-90.9904478	30.41564527	36.18
HCB/JC/CCB	Jones Creek	-91.02378727	30.41978059	37.7
HCB/JC/CCB	Jones Creek	-91.03769081	30.42608872	39.3
HCB/JC/CCB	Jones Creek	-91.04141138	30.42994979	39.97
HCB/JC/CCB	Honey Cut Bayou	-90.99820939	30.43577459	40.06
HCB/JC/CCB	Jones Creek	-91.04512558	30.43730304	41.52
HCB/JC/CCB	Jones Creek	-91.06533536	30.44238688	43.71
HCB/JC/CCB	Jones Creek	-91.04901537	30.44357835	42.08
HCB/JC/CCB	Honey Cut Bayou	-91.00604657	30.44546336	43.56
HCB/JC/CCB	Honey Cut Bayou	-91.02158163	30.44745651	43.14
HCB/JC/CCB	Lively Bayou	-91.03685832	30.44745943	42.93
HCB/JC/CCB	Jones Creek	-91.0677865	30.45146732	44.71
HCB/JC/CCB	Lively Bayou	-91.02809205	30.45329501	43.56
HCB/JC/CCB	Lively Bayou	-91.03586245	30.4602111	44.66
HCB/JC/CCB	Jones Creek	-91.0781955	30.46521356	47.64
HCB/JC/CCB	Lively Bayou	-91.04059999	30.46867161	45.91
HCB/JC/CCB	Lively Bayou	-91.02906884	30.47219986	47.73
Lower Amite River	Old Amite River/Chinquapin Canal	-90.71242168	30.25933528	6.68
Lower Amite River	Lower Amite River	-90.77669343	30.27534524	8.47
Lower Amite River	Lower Amite River	-90.78419413	30.27733061	9.33
Lower Amite River	Lower Amite River West FP	-90.86929167	30.279125	12.52
Lower Amite River	Lower Amite River West FP	-90.88706111	30.28039167	13.13
Lower Amite River	Henderson Bayou	-90.90765278	30.29321667	15.1
Lower Amite River	Lower Amite River	-90.6480633	30.30027452	4.75
Lower Amite River	Henderson Bayou	-90.89644167	30.30184167	15.51

Lower Amite River	Henderson Bayou	-90.87373889	30.31145556	15.22
Lower Amite River	Lower Amite River	-90.67663445	30.31816059	6.11
Lower Amite River	Lower Amite River	-90.8365	30.31958333	14.91
Lower Amite River	Henderson Bayou North FP	-90.87773333	30.32035556	15.87
Lower Amite River	Lower Amite River	-90.85058333	30.33052778	16.38
Lower Amite River	Lower Amite River	-90.85291667	30.33247222	16.69
Lower Amite River	Lower Amite River	-90.85125	30.33316667	16.81
Lower Amite River	Lower Amite River	-90.89596111	30.34636944	20.88
Lower Amite River	Lower Amite River	-90.90111111	30.34694444	21.92
Lower Amite River	Lower Amite River	-90.90371667	30.35876111	22.13
Lower Amite River	Lower Amite River	-90.90972222	30.35916667	21.79
Lower Amite River	Lower Amite River	-90.89466667	30.37566667	22.18
Lower Amite River	Lower Amite River	-90.97486389	30.39681389	31.83
Lower Amite River	Lower Amite River	-90.97444444	30.39777778	31.67
Lower Amite River	Lower Amite River	-90.95644444	30.41894444	35.98
Lower Amite River	Lower Amite River	-90.96997222	30.44905556	41.57
Lower Amite River	Lower Amite River	-90.99651667	30.45500278	43.59
Lower Amite River	Lower Amite River	-90.995	30.45722222	44.19
Lower Amite River	Lower Amite River	-90.97483333	30.45786111	44.08
Lower Amite River	Lower Amite River	-90.96584558	30.46001572	44.24
Lower Amite River	Lower Amite River East FP	-90.95302511	30.46399188	43.67
Middle Amite River	Middle Amite River	-90.9601	30.4733	44.89
Middle Amite River	Middle Amite River	-90.971	30.4736	46.02
Middle Amite River	Middle Amite River	-90.9544	30.4773	44.4
Middle Amite River	Middle Amite River	-90.9803	30.4922	50
Middle Amite River	Middle Amite River	-90.9811	30.4931	50.25
Middle Amite River	Middle Amite River	-90.9601	30.499	50.11
Middle Amite River	Middle Amite River	-90.9824	30.5173	54.498
Middle Amite River	Middle Amite River	-90.9828	30.518	54.66
Middle Amite River	Beaver Creek	-90.9666	30.5263	53.17
Middle Amite River	Middle Amite River	-90.9704	30.5435	58.54
Middle Amite River	Middle Amite River	-90.98975118	30.54950469	59.08
Middle Amite River	Middle Amite River	-90.9825	30.5536	59.86
Middle Amite River	Middle Amite River	-90.9844	30.5588	60.853
Middle Amite River	Middle Amite River	-90.9571	30.5853	67.6
Middle Amite River	Hub Bayou	-90.9951	30.5981	69.52
Middle Amite River	Middle Amite River	-90.9851	30.6031	69.99
Middle Amite River	Sandy Creek	-90.99647498	30.60578326	69.98
Middle Amite River	Middle Amite River	-90.9421	30.6233	78.88
Middle Amite River	Sandy Creek	-90.96767703	30.64610501	83.53
Middle Amite River	Sandy Creek	-90.94915118	30.64982599	78.97

Middle Amite River	Sandy Creek	-90.98486502	30.71117558	114.24
Middle Amite River	Sandy Creek	-90.96264514	30.72346133	119.06
Middle Amite River	Middle Amite River	-90.8586	30.7478	123.63
Middle Amite River	Sandy Creek	-90.96047961	30.8338397	190.39
Middle Amite River	Middle Amite River	-90.8485	30.8868	166.79
Middle Amite River	Middle Amite River	-90.8453	30.9434	189.05
Upper Amite River	Beaver Creek	-90.86576379	30.95680101	191.83
Upper Amite River	Beaver Creek	-90.9482	31.04545556	254.73
Upper Amite River	Beaver Creek	-90.9482	31.04545556	254.62
Upper Amite River	Beaver Creek	-90.9482	31.04545556	253.02

11. Peak Flood Data Quality

Bob Jacobsen PE analyzed the USGS and ARBD information to assess peak flood data quality—specifically the repeatability (precision) of HWM field measurements. Measurement repeatability reflects two basic steps (see USGS 2016):

1. Identifying and marking high water for a given stream reach. Repeatability of this step is affected by how close the pair of HWM are located within an overall stream reach (longitudinally along the reach and laterally in the floodplain); the type of high water evidence (e.g., exterior or interior marks); and the clarity and possible disturbance of the high water evidence.
2. Surveying the mark in NAVD88 (Geoid 12B) using standard RTN survey methods. Repeatability of this step is primarily affected by any transfer of elevation from the mark to a temporary benchmark (leveling); number of global positioning system (GPS) satellites accessible; and the duration over which a point is occupied.

The following four types of data pairs reflected overall HWM uncertainty, i.e., both steps:

- The USGS had 7 pairs of duplicate HWMs in the same stream reach in reasonably close proximity (generally less than 1,000 ft apart) which allows analysis of HWM repeatability. These repeats address the combined uncertainty with both steps. Table 11 shows the 7 USGS duplicates have maximum and mean absolute differences, and root mean square difference (RMSD), of 2.32 ft, 0.43 ft, and 1.64 ft.
- The USGS had surveys of two HWMs near gauges with crest data. Repeatability in this case could reflect limitations in static differential surveying of the gauges, or the two HWM steps. Table 12 shows the absolute differences are 0.21 and 0.37 ft, which are slightly better than the above mean absolute difference in HWM replicates of 0.43 ft (as might be expected).
- The ARBD had 17 pairs of duplicate HWMs in the same stream reach in reasonably close proximity (generally less than 1,000 ft apart). Table 13 shows the 17 ARBD duplicates have maximum and mean absolute differences, and RMSD, of 0.99 ft, 0.35 ft, and 0.73 ft. The RMSD is less than half that for the USGS and may reflect greater use of interior evidence in the ARBD HWMs.
- The USGS and ARBD had 26 pairs of HWMs in the same stream reach in reasonably close proximity (generally less than 1,000 ft apart) which allowed analysis of discrepancies between the two programs. Table 14 shows the ARBD HWM is higher than the USGS HWM at 17 locations, and lower at 9. However, the greatest differences in these two cases are similar at 0.7 and -0.78 ft. The mean difference is 0.05 ft, indicating no major bias between the two programs. The mean absolute difference is 0.24 ft, lower than the mean absolute differences within the two programs. The RMSD is 0.32 ft, also less the RMSD within the two HWM programs. Figure 23 shows a graph of the comparison.

For the combined 52 pairs (7, 2, 17, 26), the overall mean absolute difference and RMSD are 0.31 and 0.47 ft. This indicates a conservative estimate of HWM uncertainty for repeatability of ±1.0 ft (based on a 95 percent confidence interval = 1.96 x RMSD = 0.92 ft).

In addition, to overall HWM repeatability, the USGS and ARBD together had 7 repeats of just the survey Step 2—2 and 5 repeats respectively. Table 15 shows that the 2 USGS repeats have maximum and mean absolute differences of 0.27 ft and 0.14 ft, while the 5 ARBD repeats have a slightly better mean absolute difference of 0.07 ft. The combined RMSD of the nine repeats is 0.15 ft, which is consistent with expected repeatability of the surveying step.

No data were available to evaluate Step 1 alone. However, the much lower mean absolute difference and RMSD for the survey step compared to the overall mean absolute difference and RMSD, indicates that the bulk of the observed overall uncertainty comes from identifying and marking reach high water, which is consistent with HWM practices.

In terms of HWM repeatability, the data are of very reasonable quality for use in flood analysis.

Table 11. USGS Duplicates HWMs in Same Reach

Sub-Basin	Stream	Elevation ft NAVD88 for Pair		Absolute Difference
Blind River	Bayou Conway	6.36	6.29	0.07
HCB/JC/CCB	Clay Cut Bayou	27.33	27.49	0.15
Lower Amite River	Lower Amite River	12.46	12.50	0.04
Grays & Colyell Creeks	Middle Colyell Creek	55.23	55.55	0.32
Grays & Colyell Creeks	Gray's Creek East FP	41.36	41.47	0.11
Grays & Colyell Creeks	Gray's Creek	38.69	38.67	0.02
Middle Amite River	Middle Amite River	118.71	116.39	2.32
Maximum Difference				**2.32**
Mean Difference				**0.43**
RMSD				**1.64**

Table 12. USGS HWM versus Gauge

Stream	Elevation ft NAVD88		Absolute Difference
	HWM	**Gauge**	
Lower Amite River	4.27	4.48	0.21
Comite River	139.75	140.11	0.37

Table 13. ARBD Duplicates HWMs in Same Reach

Sub-Basin	Stream	Elevation ft NAVD88 for Pair		Absolute Difference
HCB/JC/CCB	Clay Cut Bayou	27.36	27.82	0.46
	Clay Cut Bayou	27.14	27.57	0.43
Lower Amite River	Lower Amite River	44.19	43.59	0.60
	Lower Amite River	31.67	31.83	0.16
	Lower Amite River	16.69	16.81	0.12
Grays & Colyell Creeks	Middle Colyell Creek	37.24	37.95	0.71
	Middle Colyell Creek	48.59	48.44	0.15
	West Colyell Creek	25.79	26.25	0.47
	West Colyell Creek	39.62	39.82	0.20
	Gray's Creek	43.46	43.46	0.00
	Gray's Creek	43.37	43.17	0.20
	Gray's Creek	38.37	38.86	0.49
Middle Amite River	Middle Amite River	50.00	50.25	0.25
	Middle Amite River	54.66	54.50	0.16
Comite River	Comite River	50.85	51.21	0.36
Bayou Manchac	Bayou Manchac	15.14	14.87	0.27
	Dawson Creek	22.96	23.95	0.99
Maximum Difference				**0.99**
Mean Difference				**0.35**
RMSD				**0.73**

Table 14. Comparison of 26 Pairs of USGS/ARBD HWMs in Close Proximity

ARBD HWM ft NAVD88	**USGS HWM** ft NAVD88	**Difference** ARBD - USGS		**ARBD HWM** ft NAVD88	**USGS HWM** ft NAVD88	**Difference** ARBD - USGS
6.68	6.53	0.15		38.86	38.67	0.19
4.75	5.50	-0.75		69.52	69.62	-0.10
191.83	191.61	0.22		15.14	15.13	0.01
39.30	39.02	0.28		64.53	64.28	0.25
41.52	41.24	0.28		50.85	50.89	-0.04
47.64	47.91	-0.27		6.31	6.34	-0.03
42.93	42.83	0.10		8.95	8.80	0.15
43.56	43.55	0.01		9.08	9.07	0.01
47.73	47.44	0.29		9.98	9.85	0.13
44.08	43.71	0.37				
21.79	22.57	-0.78		**ARBD > USGS**		**17**
16.69	16.86	-0.17		**USGS > ARBD**		**9**
16.43	16.44	-0.01		**Highest +Diff**		**0.70**
37.24	37.07	0.17		**Highest -Diff**		**-0.78**
39.62	39.16	0.46		**Mean Difference**		**0.05**
46.81	46.11	0.70		**Mean Absolute Difference**		**0.24**
38.37	38.69	-0.32		**RMSD**		**0.32**

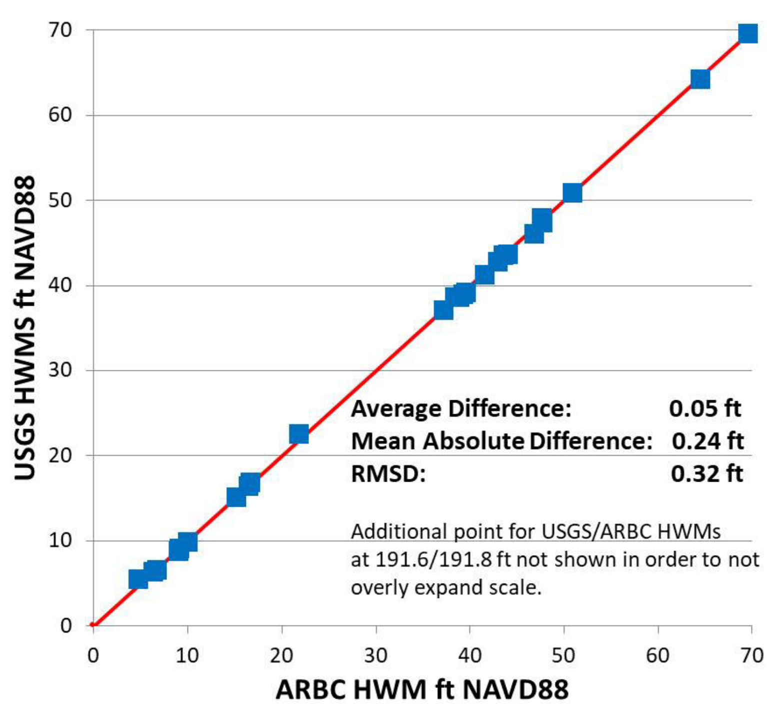


Figure 23. Comparison of 26 Pairs of USGS/ARBD HWMs in Close Proximity

Table 15. USGS and ARBD Repeat RTN Surveys

Sub-Basin	Stream	Elevation ft NAVD88 for Pair		Absolute Difference
USGS HWMs				
HCB/JC/CCB	Clay Cut Bayou	27.33	27.60	0.27
Middle Amite River	Middle Amite River	60.02	60.04	0.02
Maximum Difference				**0.27**
Mean Difference				**0.14**
ARBD HWMs				
Grays & Colyell Creeks	West Colyell Creek	39.82	39.83	0.01
	Gray's Creek	43.46	43.46	0.00
	Gray's Creek	43.37	43.08	0.29
	Gray's Creek	37.33	37.33	0.00
	Gray's Creek	22.19	22.24	0.05
Maximum Difference				**0.29**
Mean Difference				**0.07**
Combined RMSD				**0.15**

12. Preliminary Peak Flood Profiles

In May 2017 the ARBD tasked Bob Jacobsen PE to prepare preliminary peak flood profiles for major ARB streams in the eight sub-basin using the August 2016 Flood peak flood data summarized in Table 5. As shown by the example in Figure 24, peak flood profiles graph the flood crest elevation (in ft NAVD88) in a stream channel over the channel length.

Why Prepare Preliminary Peak Flood Profiles?

Preparing preliminary flood profiles for the August 2016 Flood soon after HWM collection facilitates analysis of the flood. Preliminary profiles are important to:

1. Start examining the flood height characteristics throughout the ARB—what impacted flood height, where, and how much. **The first and most fundamental element in understanding a flood is to begin describing and studying the flood peak elevation trend along major stream channels.**
2. Identifying crucial remaining HWM gaps that pose major challenges to understanding, analyzing, and modeling the August 2016 Flood, especially those HWM gaps that are still amenable to a follow-up field program. And implementing that follow-up field program as soon as practical.
3. Developing a high quality flood hindcast model (computer simulation). Modern hindcast models are now considered necessary tools in flood analysis—allowing flood height, flow, and other conditions throughout the course of the event and across the basin to be carefully evaluated together. They are the best way to provide a total flood picture that is as

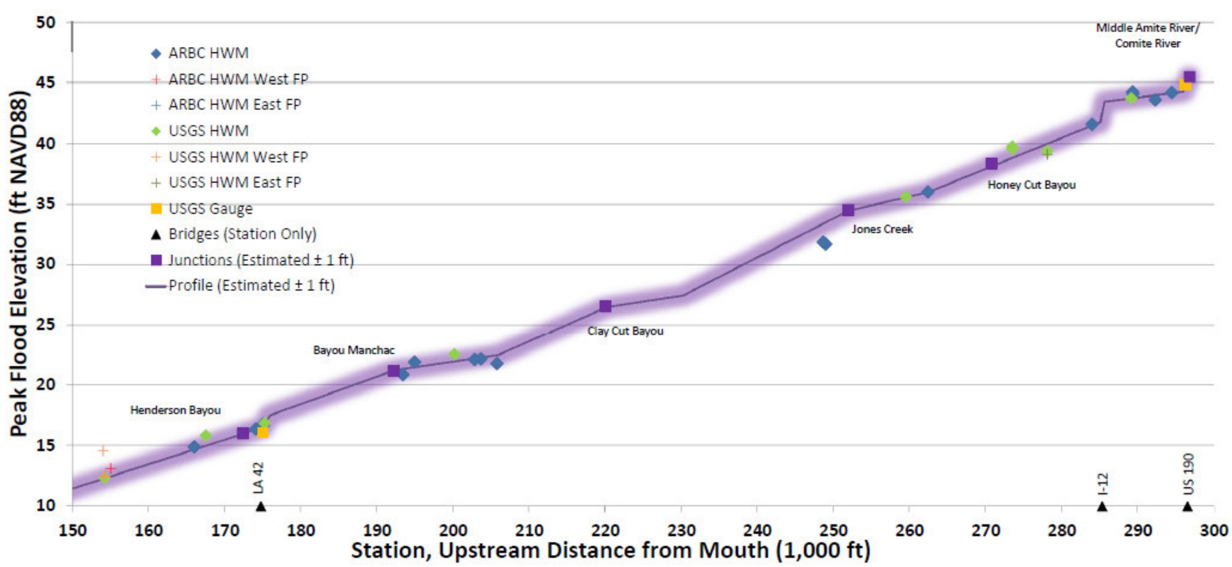


Figure 24. Example of ARB Preliminary Peak Flood Profile (portion of Lower Amite River)

accurate as possible.[8] Early development of peak profiles and study of the August 2016 Flood characteristics will aid in addressing key hindcast issues—including selection of an appropriate model code (different codes are more suitable for different kinds of floods) and model setup.

Ultimately, finalizing good peak profiles the complex August 2016 Flood requires the further analysis afforded by a modern hindcast model. The profiles prepared in this Report are therefore considered "preliminary." By extension, good maps of flood peak inundation (elevation and/or depth) across the full stream floodplain also need to be prepared with the aid of a modern hindcast model.

Today, there are many important regulatory and planning uses for high quality flood profiles and inundation maps finalized with a modern hindcast model. Some ARB communities have building requirements tied to the peak elevation of past floods. Modern hindcast models are a major tool in evaluating "what if" scenarios. The models can be adjusted to assess the impact of climate change, sea level rise, land-use modifications, flood control projects, development and infrastructure proposals, and other conditions on the flood peak profiles and inundation maps. In addition, a high quality hindcast model can be run with probabilistic storms and used to develop more reliable *Full Spectrum* flood hazard information.

<u>Methodology</u>

Preparing preliminary peak flood profiles for the August 2016 Flood involved the following steps:

1. The major sub-basin streams were defined using the USGS NHD files for the Amite and Blind River basins. Major streams are depicted in Figure 3. Stream lines consist of a set of points (vertices). Station values begin with 0 at the vertex located at the stream mouth and increase with the cumulative length upstream. Stationing for streams was determined using the linear distance between vertices. Table 16 summarizes 70 major streams by sub-basin for which peak flood profiles were prepared and notes the stream lengths. Altogether, the 70 streams total close to 1,060 miles [Inspection of the NHD files in Google Earth using 2016 imagery showed numerous instances of misalignment in the NHD stream lines. Figure 25 illustrates the example of Bayou Conway at I-10. Future development of a high quality ARB hindcast model should update the stream lines.]
2. Stream reach stations were identified for a) junction vertices (intersections of major streams) and b) vertices representing bridges and control structures (gates or weirs). Table 16 shows the number of junctions and bridges/control structures for each of the 70 streams. The full Amite River and the Comite River had 25 and 13 junctions respectively. Of the 70 major streams, 22 had more than 10 identified bridges/control structures, with a basin-wide total of 555. [In the case of misaligned streams at bridges—as in the I-10 bridge over Bayou Conway in Figure 25—the bridge (center) was identified at the nearest NHD stream vertex.]
3. The 44 USGS gauges were translated to the nearest respective stream vertices consistent with the bridge location for each gauge—typically to vertices just downstream of those representing the bridge centers. The USGS gauge peak elevations were thus assigned to the stations along the stream which corresponded those vertices. Table 16 shows the number of USGS gauges for each of the 70 streams.

[8] In addition to HWMs, other forms of flood data (hydrographs, discharge measurements, etc.) are used to ensure the hindcast is appropriate. Attention to hindcast model quality is often focused on key locations where key changes in flood stages and flow, or major damages, occurred. Getting the model to match reliable observations flood HWMs, hydrographs, and discharge measurements near these locations is usually a priority.

4. USGS and ARBD HWMs were projected to the nearest points on the stream lines. The stations for those points were then calculated. The algorithm that projected the HWM stations would occasionally assign a HWM to a point on the opposite side of a bridge from where the HWM was actually located. Due to the impact of bridges on channel profiles these HWM were manually reassigned to a station on the correct side of the bridge. Table 16 includes the number of HWMs used for each of the 70 major streams. Some HWMs located near junctions were shared by more than one stream. The top five streams in number of gauges plus HWMs were:

Lower Amite River	50
Middle Amite River	45
Comite River	31
Grays Creek	27
West Colyell Creek	20

5. Plots were then developed for each of the 70 major streams in Table 16, showing, USGS gauges, USGS HWMs, and ARBD HWMs. The plots provide peak flood elevation (ft NAVD88) on the vertical axis vs station (1,000 ft) on the horizontal axis as shown in Figure 24. USGS gauges with peak flood data only available in NGVD29 were plotted for using those values. Far floodplain HWMs were included on the plot but designated separately as FP. The bridge/control structures locations were plotted on the horizontal axis.

6. A preliminary profile line was then manually fitted based on qualitative engineering judgment to the data points considered representative of channel peak flood (see Figure 24). The far floodplain (FP) points were excluded in fitting the profile line but were retained on the chart. The profile lines were fitted to

   - Achieve an appropriate overall visual fit of the line to all of the data.
   - Closely match peak values for USGS gauges that were operating at flood peak and had values in NAVD88.
   - Assign the same estimated flood elevation for a stream junction for both stream profiles on which it appears. Junctions were also plotted on the profiles (as shown on Figure 24).
   - Achieve appropriate general line slopes and changes in line slopes based on reach terrain—especially for reaches without HWMs (e.g., in the Upland Hills).
   - Reflect abrupt flood peak elevation changes at bridges indicated by upstream/ downstream HWMs and HWMs at similar bridges.

   Due to the complexity of profile fitting a least squares fitting technique was not employed. Hydraulic calculations for peak flood profile slopes, slope changes, and bridge impacts were also not employed as they require estimates of stream flood flow, which were not available for this Report. **Further hydraulic evaluation and adjustment of profile line slopes, slope changes, and bridge impacts—employing estimates of stream flood flow—are crucial to finalizing profiles. This is best accomplished with the aid of a high quality hindcast model.**

7. A ± 1 ft uncertainty “cloud” was added to the plot of the profile line, consistent with the findings regarding HWM repeatability. (Note that the apparent width of the cloud differs with the vertical scale.)

The Preliminary Peak Flood Profiles for all 70 streams are included as Appendix A.

Table 16. Summary of Data Points for Preliminary Peak Flood Profiles

Sub-basin	Miles	Junctions	Bridges & Control Structures	USGS Gauges	USGS HWMs	ARBD HWMs
Upper Amite River						
Upper Amite River	4.5	3	0	0	0	0
Beaver Creek	36.3	1	7	0	3	4
West Fork Amite River	46.1	1	5	0	0	0
East Fork Amite River	50.4	1	7	0	0	0
Total	**137.3**	**6**	**19**	**0**	**3**	**4**
Middle Amite River						
Middle Amite River	112.8	10	5	3	24	18
Beaver Creek (Livingston)	7.3	1	11	0	5	1
Hub Bayou	4.5	1	1	0	1	1
Spillers Creek	6.2	1	2	0	1	0
Darling Creek	21.7	1	3	0	3	0
Sandy Creek	48.6	3	6	1	5	6
Little Sandy Creek	15.6	1	5	1	0	0
Little Sandy Creek (2)	7.9	1	1	0	1	0
Total	**216.8**	**18**	**33**	**5**	**40**	**26**
Lower Amite River						
Lower Amite River	56.2	12	5	4	22	24
Henderson Bayou	7.4	1	6	2	5	4
Old Amite River	5.5	4	1	0	1	1
Total	**69.1**	**17**	**12**	**6**	**28**	**29**
Number of Streams	3					
Comite River						
Comite River	51.6	13	13	8	11	12
Draughan Creek	4.8	1	4	0	5	5
Beaver Bayou	12.3	1	13	1	4	7
Comite River Drainage Tributary	5.3	1	5	0	4	2
Blackwater Bayou	10.2	2	11	0	4	5
Blackwater Bayou Drainage Tributary	6.0	1	7	0	1	2
Hurricane Creek	7.5	2	13	0	6	5
Robert Canal	6.2	1	8	0	3	2
Cypress Bayou	7.5	1	8	0	3	1
White Bayou	21.8	5	10	1	3	5
Old White Bayou	14.4	4	4	0	2	3
Old White Bayou Tributary	2.3	1	2	0	1	0

Brushy Bayou	1.0	1	2	0	0	2
Copper Mill Bayou	7.5	1	5	0	1	1
Black Creek	14.3	1	6	0	1	1
Saunders Bayou	3.3	1	3	0	0	1
Redwood Creek	29.0	3	9	0	2	1
Doyle Bayou	10.9	1	5	0	1	0
Pretty Creek	11.0	2	2	0	3	0
Total	**226.9**	**43**	**130**	**10**	**55**	**55**
Number Used for Two Streams				0	8	6
Adjusted Total for Sub-basin					**47**	**49**
HCB/JC/CCB						
Jones Creek	11.1	4	18	1	8	10
Clay Cut Bayou	10.3	3	16	1	4	8
Honey Cut Bayou	4.9	2	6	0	3	3
Lively Bayou	3.9	2	6	0	6	5
Total	**30.1**	**11**	**46**	**2**	**21**	**26**
Grays & Colyell Creeks						
Grays Creek	18.7	4	13	1	8	18
West Colyell Creek	23.2	5	16	1	10	9
Middle Colyell Creek	24.1	3	11	0	10	7
Colyell Creek	26.4	8	12	0	6	7
Little Colyell Creek	15.3	1	16	0	3	4
Hornsby Creek	13.3	2	9	0	0	6
Beaver Branch	6.8	1	4	0	1	1
Total	**127.7**	**24**	**81**	**2**	**38**	**52**
Bayou Manchac						
Bayou Manchac	18.5	7	16	2	1	9
Muddy Creek	5.6	1	7	1	1	2
Welsh Gully	3.4	1	7	1	0	1
Alligator Bayou	3.0	1	1	2	0	2
Bayou Braud	11.6	2	5	0	0	3
Bayou Paul	9.1	1	7	0	0	2
Bayou Fountain	12.3	3	12	1	0	5
Ward Creek	16.6	5	15	2	0	6
Ward Creek Bypass	1.7	2	3	0	0	0
North Branch Ward Creek	5.1	1	7	1	1	0
Dawson Creek	8.3	2	25	1	0	7
Bayou Duplantier	3.9	3	3	0	0	2
Corporation Canal	3.0	2	12	0	0	1
Total	**102.0**	**31**	**120**	**11**	**3**	**40**

Blind River						
Blind River	25.3	5	3	1	0	6
Bayou Chene Blanc	6.1	2	0	0	1	0
Chinquapin Canal	2.5	2	1	0	1	1
Amite River Diversion Canal	10.3	4	2	0	1	3
Petite Amite River	11.0	5	3	0	1	1
New River	28.1	4	39	1	7	6
Saverio Canal	5.2	2	2	0	0	1
Black Bayou	12.3	1	26	2	6	5
Bayou Conway	23.6	3	13	1	3	2
Bayou Francois	10.5	1	9	1	2	3
Panama Canal	8.4	2	4	1	0	0
Grand Goudine Bayou	5.2	1	12	1	0	0
Total	**148.6**	**32**	**114**	**8**	**22**	**28**
Number Used for Two Streams					1	1
Adjusted Total for Sub-basin					21	27

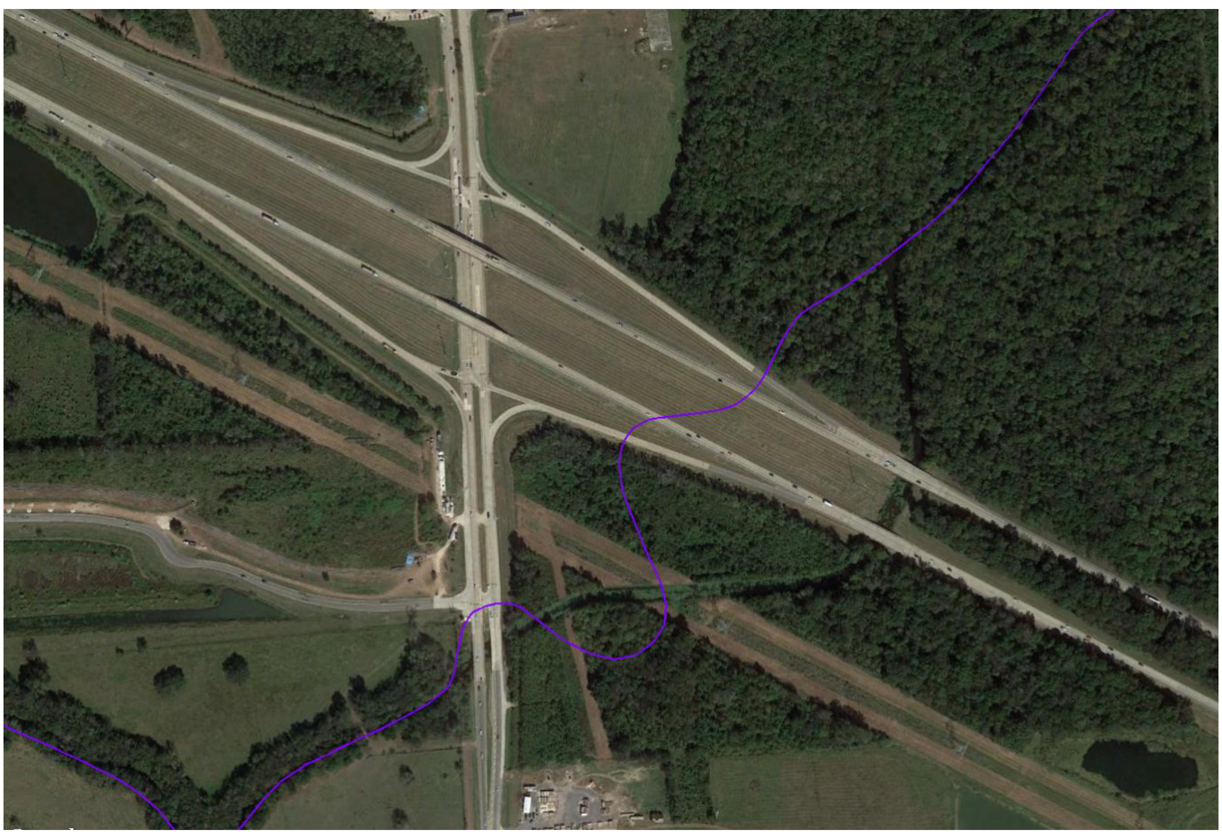


Figure 25. Example of Misaligned Stream in USGS NHD (Bayou Conway at I-10)

Part IV.

Conclusions and Recommendations

13. August 2016 Flood—Preliminary Conclusions

<u>Findings</u>

The preliminary profiles in Appendix A show that good manual fits were developed for most portions of the 70 major streams using the reach information, USGS gauge data, and USGS and ARBD HWMs. During the development of the profiles only one USGS HWM (in the lower Amite River east floodplain) and 2 ARBD HWMs (both on Black Bayou) were determined to be outliers—likely due to errors in identifying the high water mark; these three HWMs were not included on plots. Ten USGS gauges were notable outliers due to gauge failure; however, all 44 gauges were plotted.

The following are important findings regarding the flood profiles—including notable characteristics and critical HWM gaps—by sub-basin.

<u>Upper Amite River Sub-basin</u> (4 profiles) The peak flood data for this sub-basin includes only 7 HWMs. Three HWMs near the mouth of Beaver Creek allow an elevation to be estimated for the junction with the Upper Amite River. The upper Amite River profile is thus based on the estimated flood peak elevations at its upstream and downstream ends. The remaining profiles for the sub-basin streams are roughly estimated on the basis of the surrounding terrain elevation—with significantly steepening profiles upstream. There is insufficient HWM data in this sub-basin to identify major impacts of bridges on profiles. Additional HWMs for each stream (estimate 10 total)—particularly at any nearby flooded structures in the middle reaches—would be useful in finalizing the peak flood profiles.

<u>Middle Amite River Sub-basin</u> (8 profiles) Half the streams have only one or two HWMs and some profiles are roughly estimated on the basis of the surrounding terrain elevation. Profile impacts are indicated in this sub-basin at more than 12 bridges—such as the CN Railroad and Greenwell Springs Road bridges on the Amite River. Additional HWMs in this sub-basin (estimate 10 total)—particularly at any nearby flooded structures in the middle reaches—would be useful in finalizing the profiles.

<u>Lower Amite River Sub-basin</u> (3 profiles) The profiles show substantial backwater flooding throughout the sub-basin. Reverse flow profiles are shown for Henderson Bayou and a portion of Old Amite River (which flows into Chinquapin Canal near its midpoint). Profile impacts are indicated at 4 lower Amite River bridges (LA 16, LA 42, I-12, and US 190) and at junctions of the lower Amite River with Jones Creek, Clay Cut Bayou, Bayou Manchac and the ARDC. Additional HWMs in these areas (estimate 5 total) would be useful in finalizing profiles.

<u>Comite River Sub-basin</u> (19 profiles) Major backwater impacts are indicated in Hurricane Creek and Robert Canal. Profile impacts are indicated at more than 40 bridges. Impacts are indicated at all eight bridges on the Comite River from the junction with the Amite River upstream to the Greenwell Springs-Port Hudson Road. Additional HWMs in the upper sub-basin—Copper Mill Bayou, Black Creek, Redwood Creek, Doyle Bayou, Pretty Creek, Comite Creek (estimate 15 total) would be useful in finalizing profiles.

<u>Honey Cut Bayou/Jones Creek/Clay Cut Bayou Sub-basin</u> (4 profiles) All profiles were influenced by backwatering from the lower Amite River. Honey Cut Bayou and Jones Creek profiles show a strong backwater influence in the lower 10,000 ft of the streams, while the Clay Cut Bayou profile shows strong backwater influence over most of its length. (Clay Cut Bayou joins the lower Amite River the furthest downstream.) The profiles for these three streams indicate impacts from several bridges—including I-12 on Honey Cut Bayou and Antioch Road and US 61 (reverse

flow) on Clay Cut Bayou. Additional HWMs in this sub-basin, including two each along Jacks Bayou, Weiner Creek, and upper Clay Cut Bayou, would be useful in finalizing profiles (estimate 10 total).

Grays and Colyell Creeks Sub-basin (7 profiles) The profiles show that the lower portions of Grays and Colyell Creeks were strongly influenced by backwater flooding. The profiles indicate impacts from more than 15 bridges—most notably I-12. On Grays Creek at I-12 the HWMs indicate an impact of about 4 ft from the I-12 bridge/barrier. Additional HWMs for the upper portions of Middle and Little Colyell Creeks, Beaver Branch, Hornsby Creek, Antioch Creek, Canada Branch, and Moler Bayou (estimate 15 total) would be useful in finalizing profiles.

Bayou Manchac Sub-basin (13 profiles) The Bayou Manchac profile shows a sizeable backwater impact, with a steep reverse gradient. From the Amite River to I-10, the Bayou Manchac profile indicates significant impacts on reverse flow from 5 bridges and the Bayou Manchac Road. The Alligator Bayou profile shows the overtopping of Bayou Manchac Road. The gradual backwater profile throughout lower Ward Creek, Bayou Fountain, Muddy Bayou, and Welsh Gully showed little impact from bridges on these streams. Additional HWMs along upper portions of Bayou Fountain (and along Elbow and Selene Bayous, for which no profile information was available), Ward Creek, North Branch Ward Creek, and Corporation Canal would be useful in finalizing the profiles (estimate 15 total).

Blind River Sub-basin (12 profiles) The profiles in this basin are dominated by backwater flooding. Due to relatively low flow velocities of backwater flooding in this area, the profiles indicate minimal impact from the sub-basin's 100+ bridges—one exception being the Highway 22 bridge on the ARDC. The profile for New River reflects the impact of the Marvin Braud Pump Station gate. Additional HWMs would be useful in portions of Bayou Conway, Panama Canal, Black Bayou, Grand Goudine Bayou to finalize profiles (estimate 10 total).

Preliminary Conclusions

In sum, the peak flood data and profiles yielded eight major preliminary conclusions:

1. Peak flood data for the August 2016 Flood exhibit good coverage, particularly of flooded areas. Due to limitations of survey time/funds and available/accessible evidence, the USGS and ARBD could not obtain HWMs for some major stream reaches (especially in the Hilly Uplands portion of the ARB). A total of 482 measurements (34 USGS gauges; 198 USGS HWMs; and 250 ARBD HWMs) were used to generate 1,060 miles of preliminary peak flood profiles for 70 major streams—on average 7 points per stream or one every half mile.
2. In terms of HWM repeatability, the peak flood data are of very reasonable quality for use in flood analysis. A conservative estimate of uncertainty in the combined USGS/ARBD HWMs is ± 1 ft.
3. More than half the data were provided by the ARBD HWMs. In addition, the ARBD HWMs showed better repeatability than USGS HWMs. The ARBD HWMs will be a crucial resource for studying the August 2016 Flood and analyzing ARB flood hazards for decades to come.
4. Reasonable preliminary profiles were defined using engineering judgment for most reaches along the 70 selected major streams, manually fitting profiles to the peak flood data. Preliminary profiles were estimated using the regional terrain in reaches that lacked HWMs.

5. Many reach profiles in the ARB were influenced by backwater flooding. Those strongly affected by backwater flooding included Hurricane Creek; Robert Canal; lower portions of Honey Cut Bayou, Jones Creek; Grays Creek, and Colyell Creek; most of Clay Cut Bayou; Bayou Manchac and most of its tributaries; and the remaining lower Amite and Blind Rivers and their tributaries.
6. Bridges had a widespread impact on peak flood levels throughout the ARB—preliminary profiles indicate more than 80 bridges. Bridge impacts exceeded 1 foot at many locations. The most significant impact was the I-12 bridge/barrier at Grays Creek—about 4 ft. Bridge impacts were negligible in areas with more sluggish backwater flow. The widespread bridge impacts indicated by the August 2016 Flood preliminary profiles are consistent with the general limitation of bridges with respect to very extreme floods.
7. At least two other structures markedly influenced the peak flood: Bayou Manchac Road (which restricted flow into Spanish Lake/Bluff Swamp) and the gate at the Marvin Braud Pump Station on New River (which restricted flow to the Petite Amite River).
8. Additional HWMs for many reaches—particularly in the Upland Hills and Middle Prairie—would likely improve the quality of a hindcast model of the August 2016 Flood and finalizing stream peak flood profiles and basin-wide inundation maps.

14. Further Objectives and Recommendations

Further Objectives

ARB leaders, planning officials, and the public need the results of a finalized analysis available online and accurate down to the parcel level, as soon as possible, in order to develop and implement a holistic strategy for ARB flood risk management. Such a strategy must seek to economically manage *Real Flood Risk* with minimal adverse impact, and must receive strong, basin-wide public support.

Finalizing the post-flood analysis includes:

1. Preparing high quality ARB-wide inundation maps for the August 2016 Flood (online, showing both peak flood elevation ft NAVD88 and depth above ground) and finish a detailed study of flood characteristics and the impacts of terrain and man-made features (e.g., bridges).
2. Determining the *Full Spectrum* flood hazard and *Real Flood Risk* for current conditions throughout the ARB.
3. Evaluating changes to the *Full Spectrum* flood hazard and *Real Flood Risk* for “what if” scenarios.

Five Recommendations to Finalize Analysis

FIRST: Formalize coordination of the diverse technical programs and activities among the numerous entities with roles in ARB flood risk management:

- Federal government—FEMA, USACE, NOAA, NWS
- State government—Governor’s Office of Homeland Security and Emergency Preparedness (GOHSEP), Division of Administration-Office of Community Development (OCD), Louisiana Department of Transportation and Development (DOTD), and Coastal Protection and Restoration Authority (CPRA).
- Regional/Local government—ARBD, Capital Regional Planning Commission (CRPC), parishes and cities
- Researchers—LSU Center for River Studies, LSU Stephenson Disaster Management Institute (SDMI), LSU Coastal Sustainability Studio, the Water Institute of the Gulf, and others.

This coordination will require well-supported leadership. Real priority must be given to sharing information and ideas—through regular workshops (such as the one sponsored by the ARBD on October 5, 2016) and work groups (such as modeling) —to avoid duplicating efforts and to maximize overall productivity.

SECOND: Develop and maintain an online ARB Geographic Information System (GIS) portal—to provide users and the public easy access to important reliable data and analysis, including the results of *Full Spectrum* flood hazard and *Real Flood Risk* analyses for current and “what if” scenarios. A comprehensive, well-designed online GIS portal with consistent interagency cooperation enhances transparency and optimization of investments in data and analyses. FEMA is initiating work related to an online GIS through its *Louisiana Watershed Resiliency Study* (Gibson 2016) and ARBD has had discussions about developing the online GIS with representatives of LSU-SDMI and the State Office of Technology Services.

THIRD: Develop a *State-of-the-Practice* hindcast model of the August 2016 Flood. Such a hindcast should incorporate the most modern approaches:

- Driving flood model with spatially distributed (gridded) rainfall data.
- High resolution representation of channel and floodplain terrain, reflecting up-to-date topographic and land-cover data—to characterize runoff and flood behavior at sub-catchment scales.
- Two -dimensional hydrodynamic modeling of channels/floodplains to avoid assuming one-dimensional flow lines.
- Modeling code capable of capturing complete flood physics and dynamics down to small sub-catchment scales—including flash, river headwater, river backwater, and wind-driven flooding on various terrains and interaction with various features (e.g., overtopping).
- Ability to address critical stream/floodplain morphodynamics and their effect on flooding.
- Capability to take advantage of High Performance Computers.

Such a hindcast should produce very high quality maps of the August 2016 Flood for local regulatory and public purposes. In addition the hindcast will allow better characterization of

- Peak discharges (flows)—such as refining the USGS estimate of 205,000 cfs for the Amite River at Denham Springs given variation in flow conditions across the full floodplain.
- Backwater flood conditions.
- Impacts from bridges and other structures.

Developing this high quality hindcast model can be optimized by approaching it in phases. Less rigorous, cheaper, quicker to develop, interim models are crucial for studying critical modeling problems and are an effective and efficient step. Bob Jacobsen PE recommends two Interim Models:

1. A HEC-RAS 5.0 ARB models, incorporating one or more sub-basins. These models will experiment with using some two-dimensional areas and the advantages and disadvantages of coupling with hydrologic models versus using “rain-on-grid.” Ascension Parish and DOTD are developing HEC-RAS 5.0 models and East Baton Rouge Parish has plans to also.
2. A fully two-dimensional catchment-scale model (not sub-catchment scale) of the full ARB and major channels (including the Upper Amite River and Blind River sub-basins and Lake Maurepas). This model will allow greater experimenting with “rain-on-grid,” coastal wind forcing, and simulation of two-dimensional channel/floodplain morphodynamics.

Ideally, the interim models would be scheduled to support completing and a *State-of-the-Practice* hindcast model by 2020. DOTD’s scope for their Interim Model 1 is schedule for completion in 2019. Interim Model 2 should therefore be scoped for sooner delivery—to provide synergies to the development of Interim Model 1 and the *State-of-the-Practice* hindcast model.

FOURTH: To support interim and final hindcast model development, obtain additional HWMs as defined in Section 13. Conducted outreach to neighborhood stakeholders who can assist in identifying best locations (and possibly time-series information). These additional HWMs can be completed in about one month.

In addition, consider two additional data collection activities to support Interim Model 2:

1. DOTD is obtaining some new channel channel/floodplain surveys as part of its Interim Model 1 development. A technical work group should be organized—to include professionals experienced in ARB channel/floodplains—to review and contribute to the planning of this survey. Some channel/floodplain surveys may be added or accelerated to facilitate Interim Model 2. In addition, NHD streamline information for all named streams in the ARB should be updated.
2. DOTD is planning to acquire new LIDAR for portions of the ARB as part of its Interim Model 1 development. An adjusted DEM should be prepared for use in Interim Model 2 until the new LIDAR DEM is available. Several vehicle-based cross-regional elevation surveys (profiles) should be obtained along major highways and employed to evaluate discrepancy trends in the current regional LIDAR DEM. Adjustments can then be made to the DEM to reduce the current LIDAR DEM error.

FIFTH: Develop additional tools to complete *Full Spectrum* flood hazard and *Real Flood Risk* analyses and scenario assessments, including:

1. Work with climatologists to develop a suite of spatially distributed synthetic rainfall/coastal wind events that can be simulated with the State-of-the-Practice model.
2. Develop a risk software program that couples the *Full Spectrum* Hazard Analysis with parcel databases and depth-damage estimators to provide *Real Flood Risk* at the parcel and aggregated levels. This is similar to the Coastal Louisiana Risk Assessment (CLARA) program used by CPRA in developing the State's Coastal Master Plan (Louisiana CPRA 2017).
3. Develop scenarios and associated variations in model setup and inputs to simulate conditions for
   - Climate change,
   - Sea level rise,
   - River morphodynamics,
   - Land-use modifications,
   - Flood risk reduction projects and programs, and
   - Future development and infrastructure.

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