National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Jean Lafitte National Historical Park and Preserve

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2019/2019

ON THE COVER
On 6 July 2017, this stunning photograph, which highlights the Atchafalaya and Wax Lake deltas, appeared as NASA Earth Observatory's "Image of the Day." The Operational Land Imager (OLI) on Landsat 8 captured the false-color image on 1 December 2016. The colors emphasize the difference between land and water while allowing viewers to observe waterborne sediment, which is typically absent from false-color imagery. The image spans the area between Lafayette, Louisiana (location of the Acadian Cultural Center of Jean Lafitte National Historical Park and Preserve) to the west (left of image) and Thibodaux, Louisiana (location of the Wetlands Acadian Cultural Center) to the east (right of image). NASA Earth Observatory photograph available at https://earthobservatory.nasa.gov/images/90522/winds-trigger-pond-growth (accessed 25 March 2019).

THIS PAGE
This aerial photograph captures a distinctive portion of the St. Bernard delta lobe, which is the largest of six former and present-day lobes of the Mississippi River Delta. Deposits of the St. Bernard delta lobe occur within Barataria Preserve of Jean Lafitte National Historical Park and Preserve, though the area shown in the photograph is south of the preserve. The "curve" in the photograph marks the location of a former meander belt of a Mississippi River distributary. The "lines" within the curved area are ridge-and-swale topography, which records the shifting nature of a river bend and is useful for geologic mapping of the Mississippi River Delta. Photograph, St. Bernard Parish (48, 22087, 180-77; taken in 1979) by USDA Agricultural Stabilization and Conservation Service. Courtesy of Cartographic Information Center, Department of Geography and Anthropology, Louisiana State University.

Jean Lafitte National Historical Park and Preserve

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2019/2019

Courtney A. Schupp
Geologic Resources Division

Katie KellerLynn
Colorado State University

National Park Service
Geologic Resources Inventory
PO Box 25287
Denver, CO 80225

September 2019

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

This report is available from the http://go.nps.gov/gripubs, and the https://www.nps.gov/im/publication-series.htm. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov

Please cite this publication as:

Schupp, C. A., and K. KellerLynn 2019. Jean Lafitte National Park and Preserve: Geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2019/2019. National Park Service, Fort Collins, Colorado.

NPS 467/165264, September 2019

Contents

Figures

Tables

Executive Summary

The Geologic Resources Inventory (GRI) provides geologic map data and pertinent geologic information to support resource management and science-informed decision making in more than 270 natural resource parks throughout the National Park System. The GRI is one of 12 inventories funded by the National Park Service (NPS) Inventory & Monitoring Program. The Geologic Resources Division of the NPS Natural Resource Stewardship and Science (NRSS) Directorate administers the GRI.

This report synthesizes discussions from a scoping meeting held in 2010 and a follow-up conference call in 2017 (see Appendix A). Chapters of this report discuss the geologic setting of Jean Lafitte National Historical Park and Preserve (referred to as the "park" throughout this report), highlight distinctive geologic features and processes in the park, address geologic issues facing resource managers, describe the geologic history leading to the present-day landscape, and provide information about the previously completed GRI map data. Four posters (in pocket) illustrate these data.

This report is supported by GRI GIS data that compiled parts of seven source maps that were produced by the Louisiana Geological Survey to cover seven 30 × 60 minute quadrangles (New Orleans, Ponchatoula, Gulfport, Baton Rouge, Black Bay, Crowley, and Ville Platte) in the Louisiana Mississippi River Delta area. Mapping took place at a scale of 1:100,000. Selected 7.5 minute quadrangles (i.e., those containing park units or other areas of interest) contained within these 30 × 60 minute quadrangles were included in the GRI GIS data. The data incorporate 23 map units that show the evolution of the landscape during the Pleistocene (2.6 million–11,700 years ago) and Holocene (the past 11,700 years) Epochs. The "Geologic Map Data" chapter of this report discusses the GRI GIS data.

The terminology used in this report reflects the source maps; the hierarchy is as follows: delta complex (Mississippi River Delta), delta lobe (Maringouin, Teche, St. Bernard, Lafourche, Plaquemines-Balize, and Atchafalaya/Wax Lake), sublobe, and crevasse complex. Although crevasse complexes (e.g., map units **Hmc1** and **Hmc3u**) are a significant geologic feature, the focus of this report is at the delta lobe level. Notably, currently accepted nomenclature, as outlined in Roberts (1997), raises the "status" of the delta lobe (as used in this report) to the delta complex level (e.g., St. Bernard delta complex). The Louisiana Geological Survey now follows Roberts (1997) in its mapping efforts (Richard McCulloch, Louisiana Geological Survey, research associate, email communication, 1 February 2019), but the GRI GIS data and this report retain the usage as published on the source maps.

Jean Lafitte National Historical Park and Preserve protects and interprets the Mississippi River Delta's rich cultural and natural resources that demonstrate the interaction of this region's distinctive environment, complex history, and diverse communities, lifeways, and traditions. The park encompasses six sites: Barataria Preserve, including the Fleming Plantation Area; Chalmette Battlefield and Chalmette National Cemetery (referred to as the "Chalmette Unit" in this report); the French Quarter Visitor Center; and three Acadian cultural centers, from east to west, Wetlands Acadian Cultural Center in Thibodaux, Acadian Cultural Center in Lafayette, and Prairie Acadian Cultural Center in Eunice.

The Mississippi River is the unifying geomorphic feature of the park's geologic setting. All six of the park sites lie atop sediments deposited by the Mississippi River and its distributaries (on the delta) or its tributaries such as the Red and Vermillion Rivers. Combined, the six park sites cover more than 10,000 ha (25,000 ac) and incorporate portions of two delta lobes (Lafourche and St. Bernard) and associated features, two Mississippi River meander belts (1 and 3), deposits of tributaries, Peoria Loess (windblown silt), and the Prairie Terrace (widespread, coast-parallel surface built by overlapping floodplains of the Mississippi River, Red River, and smaller streams). In addition, the park includes estuarine and coastal shoreline and open water. The "Geologic Features and Processes" chapter of this report discusses these features.

Distinct ecological zones, which are a result of small changes in elevation, are an example of the geologic significance of the park and its connections to other natural and cultural resources. Elevational changes are primarily a result of delta progradation (building outward towards the Gulf of Mexico when the rate of sediment supply exceeds the rate of sea level rise) and aggradation (building upward of the land surface). In places, aggradation had a human component, for example, major clamshell midden complexes provide evidence of Native American use in Barataria Preserve, with humans literally "eating their way to higher ground." Three of the park sites interpret the interconnectedness of the landscape and people, namely the Acadian culture. The "Geologic Setting and Significance" chapter of this report discusses these connections.

Tectonic, oceanic, and fluvial processes drove geologic events that led to the development of the present landscape. The geologic history marked by these events started about 200 million years ago as the Gulf of Mexico basin was forming. A primary feature of the geologic story is the chronology of the delta lobes, which is discussed in the "Geologic History" chapter of this report.

The delta cycle itself is discussed in the "Geologic Features and Processes" chapter, along with geologic features (and associated map units) of the GRI GIS data. In addition to backswamp deposits (map unit **Hb**), more information about wetlands from a geologic perspective is provided in that chapter. Also, discussions of faults and salt domes are included as is a discussion of the park's potential for paleontological resources.

The "Geologic Resource Management Issues" chapter discusses climate change impacts, including sea level rise; coastal resource management and planning; data, research, and planning needs; disturbed lands, including coastal engineering, abandoned mineral lands, canals and spoil banks, artificial waterways, and artificial levees; earthquakes; hurricanes; land loss; oil and gas operations; recreational and watershed land use; restoration and coastal protection projects; and subsidence. Discussions of issues were based on the 2010 scoping meeting (see scoping summary by KellerLynn 2010a), the monument's foundation document (NPS 2015), the 2017 conference call, and reviewers' comments to the first draft of this report.

"Literature Cited" is a bibliography of references cited in this GRI report; many of these references are available online, as indicated by an Internet address included as part of the reference citation. If monument managers are interested in other investigations and/or a broader search of the scientific literature, the NPS Geologic Resources Division has collaborated with—and funded—the NPS Technical Information Center (TIC) to maintain a subscription to GEOREF (the premier online geologic citation database). Multiple portals are available for NPS staff to access this database. Monument staff should contact Tim Connors (NPS Geologic Resources Division) for instructions to access GEOREF.

"Additional Resources" provides online sources of information related to the geologic resource management issues discussed in this report, including climate change resources, Louisiana coastal restoration resources and coastal data, subsidence rates, and US Geological Survey (USGS) reference tools. In addition, "Additional Resources" suggests online sources and books for geologic interpretation at the park.

Appendix A of this report provides a list of people who participated in the scoping meeting for the park in 2010 as well as those who participated in a follow-up conference call in 2017. The list serves as a legacy document and reflects participants' affiliations and positions at the time of scoping and the conference call.

Appendix B of this report lists laws, regulations, and NPS policies that specifically apply to geologic resources in the National Park System. The NPS Geologic Resources Division can provide policy assistance, as well as technical expertise, regarding the park's geologic resources. The division is a primary contact for geologic resource management issues and assistance (see http://go.nps.gov/grd).

Products and Acknowledgments

The NPS Geologic Resources Division partners with the Colorado State University Department of Geosciences to produce GRI products. The US Geological Survey, state geological surveys, and local geoscientists developed the source maps or reviewed GRI content. This chapter describes GRI products and acknowledges contributors to this report.

GRI Products

The GRI team undertakes three tasks for each park in the Inventory & Monitoring Program: (1) conduct a scoping meeting and provide a summary document, (2) provide digital geologic map data in a geographic information system (GIS) format, and (3) provide a GRI report (this document). These products are designed and written for nongeoscientists.

Scoping meetings bring together park staff and geologic experts to review and assess available geologic maps, develop a geologic mapping plan, and discuss geologic features, processes, and resource management issues that should be addressed in the GRI report. Following the scoping meeting, the GRI map team converts the geologic maps identified in the mapping plan to GIS data in accordance with the GRI data model. After the map is completed, the GRI report team uses these data, as well as the scoping summary and additional research, to prepare the GRI report. The GRI team conducts no new fieldwork in association with their products.

The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (§ 204), NPS *Management Policies 2006*, and the Natural Resources Inventory & Monitoring Guideline (NPS-75). The "Additional References" chapter and Appendix B provide links to these and other resource management documents and information.

Additional information regarding the GRI, including contact information, is available at the GRI program website: http://go.nps.gov/gri.

Acknowledgments

The GRI team thanks the participants of the 2010 scoping meeting and 2017 conference call (see Appendix A) for their assistance in this inventory. Thanks very much to the Louisiana Geological Survey for its maps of the area; this report and accompanying GRI GIS data could not have been completed without them. In particular, thanks to Richard McCulloh and Paul Heinrich (Louisiana Geological Survey) for their input and guidance on the timing of deposition of the Mississippi River delta lobes, meander belts, and associated deposits, as well as information about nomenclature and usage of particular map units and the significance of ridge-and-swale topography. Thanks to Trista Thornberry-Ehrlich (Colorado State University) for producing many of the graphics in this report. Also, thanks goes to Michael Barthelmes (NPS Geologic Resources Division) for his assistance during the preliminary writing of this report as well as its final edit. Guy Hughes, Dusty Pate, Kristy Wallisch, and Julie Whitbeck (Jean Lafitte National Historical Park and Preserve) provided additional information and photographs used in this report, as did Jeff Bracewell (Gulf Islands National Seashore). Finally, thanks goes to Mark Ford (NPS Southeast Regional Office) for orientation to Barataria Preserve.

Review

Mark Byrnes (Applied Coastal Research and Engineering)
Jim Flocks (US Geological Survey)
Dusty Pate (Jean Lafitte National Historical Park and Preserve)
Denise Reed (Jean Lafitte National Historical Park and Preserve)
Martha Segura (NPS Gulf Coast Inventory & Monitoring Network)
Jason Kenworthy (NPS Geologic Resources Division)

Editing

Katie KellerLynn (Colorado State University)
Michael Barthelmes (Colorado State University)

Report Formatting and Distribution

Chelsea Bitting (NPS Geologic Resources Division)

Source Maps

Paul V. Heinrich (Louisiana Geological Survey)
Marty Horn (Louisiana Geological Survey)
Richard P. McCulloh (Louisiana Geological Survey)
John Snead (Louisiana Geological Survey)
Whitney J. Autin (Louisiana Geological Survey)

GRI GIS Data Production

Stephanie O'Meara (Colorado State University)
Rachel Yoder (Colorado State University)
James Winter (Colorado State University)

GRI Map Poster Design

Dalton Meyer (Colorado State University)
Georgia Hybels (Colorado State University)

GRI Map Poster Editing

Georgia Hybels (Colorado State University)
Rebecca Port (NPS Geologic Resources Division)
Michael Barthelmes (Colorado State University)
Jason Kenworthy (NPS Geologic Resources Division)
Courtney Schupp (NPS Geologic Resources Division)
Chelsea Bitting (NPS Geologic Resources Division)

Geologic Setting and Significance

This chapter describes the regional geologic setting of the park and summarizes connections among geologic resources, other park resources, and park stories.

Park Establishment

Jean Lafitte National Historical Park and Preserve (referred to as the "park" throughout this report) is located in the Mississippi River Delta region of Louisiana. Between 1997 and 2017, an average of 540,082 people visited the park annually (NPS 2019). The park comprises six sites: (1) Barataria Preserve, including the Fleming Plantation Area, is south of New Orleans, Louisiana, and protects 10,378 ha (25,643 ac) of marsh and forested swamp. (2) Chalmette Battlefield and Chalmette National Cemetery (referred to as the "Chalmette Unit" in this report), east of New Orleans, commemorates the 1815 Battle of New Orleans, which was part of the War of 1812. (3) French Quarter Visitor Center, which also houses the park's headquarters, focuses on the cultural resources of the port city of New Orleans. (4) Prairie Acadian Cultural Center in Eunice, (5) Acadian Cultural Center in Lafayette, and (6) Wetlands Acadian Cultural Center in Thibodaux interpret the Acadian culture of the Mississippi River Delta region (fig. 1).

The Acadian story, which began in the Vendee region of western France, also took place in Acadie (now Nova Scotia, Canada) and the Mississippi River Delta region. The story tells of Acadians (primarily farmers and anglers) who became Cajuns as they adapted their lifeways to the Mississippi River Delta. Today's Cajuns of Louisiana are renowned for their music, food, and ability to hold on to tradition while making the most of the present (NPS 2016a).

The purpose of the park is to protect and interpret significant examples of the Mississippi River Delta's rich cultural and natural resources that demonstrate the interaction of this region's distinctive environment, complex history, and diverse communities, lifeways, and traditions (NPS 2015). The park was created in 1978 (Public Law 95-625, 10 November 1978) and incorporated the previously established Chalmette National Historical Park (Public Law 640, 10 August 1939). The three Acadian cultural centers were added in 1988 (Public Law 100-250, 16 February 1988).

Figure 1. Location map for Jean Lafitte National Historical Park and Preserve.
This map shows locations and features discussed in this GRI report. The French Quarter Visitor Center, which houses the park's headquarters, is in New Orleans. Barataria Preserve, including the Fleming Plantation Area, and the Chalmette Unit, including Chalmette Battlefield and Chalmette National Cemetery, are southwest and east of New Orleans, respectively. The three cultural centers lie west of New Orleans: Wetlands Cultural Center is in Thibodaux. Acadian Cultural Center is in Lafayette. Prairie Acadian Cultural Center is in Eunice. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

Figure 2. Location map for Barataria Preserve and vicinity.
Significant features, both natural and artificial, are marked on the map. Red shading highlights NPS areas such as Barataria Preserve and the Chalmette Unit. Orange dots mark the Ama and Mid-Barataria sediment diversions structures; these features are planned and not currently present on the landscape. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

The Bayou aux Carpes wetland area on the eastern side of Barataria Preserve (fig. 2) was transferred to the National Park Service in 2009. The functions and values of this 1,176-ha (2,905-ac) area are of such high quality that it was one of the first areas protected by the EPA under Section 404(c) of the Clean Water Act, prohibiting, restricting, or denying the discharge of dredged or fill material into its waters (NPS 2009). The 1,398-ha (3,455-ac) Fleming Plantation Area was added to Barataria Preserve in October 2018. The park's general management plan (GMP) requires that Barataria Preserve is managed as part of the larger Barataria basin ecosystem for the purpose of restoration of natural hydrology and to reestablish the natural flow of freshwater and sediment (NPS 1995).

Geologic Setting

The park is part of the Mississippi River Delta—an area of national significance in terms of its natural and cultural (archeological and historical) resources. The Mississippi River Delta region contains the largest and most productive estuarine and wetland system on the continent. The park's fundamental resources and values include productive wetland ecosystems and the dynamic delta landscape (NPS 2015).

The Mississippi River Delta covers about 30,000 km^2 (12,000 mi^2) (Roberts 1997). Commonly cited studies (e.g., Frazier 1967) show that the Mississippi River delta plain is composed of six delta lobes: (1) Maringouin, (2) Teche, (3) St. Bernard, (4) Lafourche, (5) Plaquemines-Balize, and (6) Atchafalaya/Wax Lake (fig. 3; table 1).

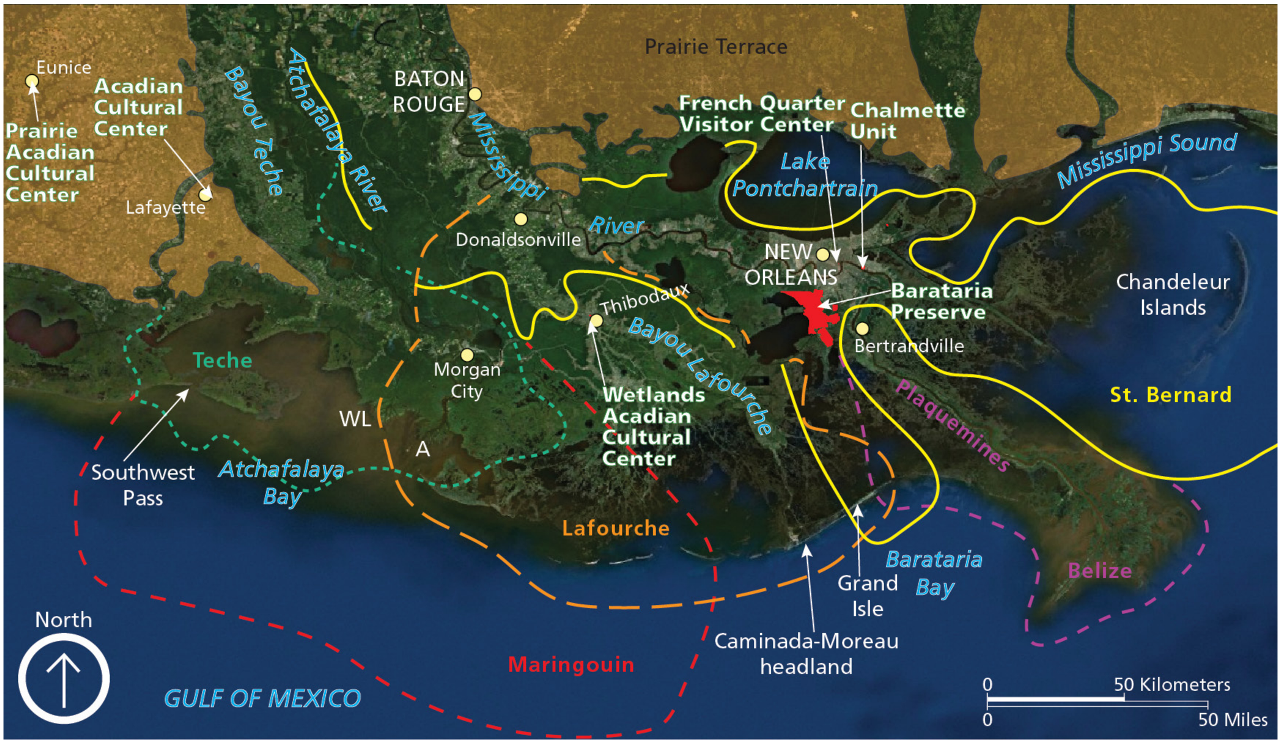

Figure 3. Graphic of the Mississippi River Delta.
The Mississippi River delta plain extends across coastal Louisiana from west of Southwest Pass to east of the Chandeleur Islands. Between 17,000 and 20,000 years ago, sea level began to rise as a result of glacial melting and regional subsidence of the coast. As sea level rose, glacial outwash (sands and gravel) was deposited in a braided stream environment. Sea level continued to rise until about 7,000 years ago when it decelerated. As a consequence of a stationary sea level, which was slightly lower than the present level, the Mississippi River began building a series of lobate deltas into the Gulf of Mexico. The delta plain is composed of both active—Belize, Atchafalaya ("A" on figure), and Wax Lake ("WL" on figure)—and inactive delta lobes, including from oldest to youngest, the Maringouin, Teche, St. Bernard, Lafourche, and Plaquemines. See table 1 for ages and source citations of the delta lobes. Graphic by Trista Thornberry-Ehrlich (Colorado State University) after Frazier (1967, figure 1).

Fuvial, lacustrine, coastal, and marine features and processes coalesce on the delta plain, though fluvial processes have dominated over the past 7,000 years. Tides penetrate landward less than 50 km (30 mi) during high (river) flow (February–June) but travel 350–400 km (220–250 mi) up river during low flow (September–October), a distance that reaches well past park units in the Greater New Orleans Area. Tidal currents, however, are not strong enough to reverse the direction of river flow (Allison and Meselhe 2010).

The delta plain, which developed through the delta cycle (see "Delta Cycle"), is essentially flat. More than 70% of the Holocene (the past 11,700 years; see geologic time scale [fig. 4]) delta plain and adjacent chenier plain (consisting of narrow shore-parallel beach ridges) is less than 0.4 m (16 in) above sea level. The only landforms that are higher than 1 m (40 in) are levees (see "Natural Levees"). This GRI report focuses on the delta, rather than the chenier plain; resource managers are directed to McBride et al. (2007), which discussed the Chenier Plain of Southwest Louisiana and provided a model for its evolution. In addition, Bentley et al. (2016) included a detailed summary of the Atchafalaya and Wax Lake deltas, which built upon the Maringouin and Teche delta lobes, and discussed sediment supply from these deltas to the chenier plain.

The French Quarter Visitor Center and Chalmette Unit are along the banks of the Mississippi River; both park sites are situated on a natural levee of Mississippi River meander belt 1 (map unit **Hml1**; table 2). The Chalmette Unit is nearly flat and, except for an artificial levee that rises to 6 m (20 ft) above sea level, has an elevation of 3 m (10 ft) above sea level (fig. 5). The artificial levee reduces flooding throughout most of the Chalmette Unit, though about 2 ha (5 ac) of land located between the artificial levee and the river is subject to frequent inundation (NPS 1995).

Table 1. Ages of Mississippi River delta lobes.

Delta Lobe	Lobe Deposition Begins	Lobe Abandoned	Source
Atchafalaya	1952 CE	n/a (ongoing deposition)	Shlemon (1975). ***Note***: 1952 is the date of notable emergence of the delta. Natural avulsion of the Mississippi River into the Atchafalaya basin had begun by the 1500s CE (Fisk 1952).
Plaquemines-Balize	Balize: 400 years ago Plaquemines: 1,300–1,200 years ago	n/a (ongoing deposition)	Balize begin date is from Frazier (1967). Plaquemines begin date reflects BC or AD date provided in Törnqvist et al. (1996), which was then calculated for this GRI report into years before present (where present is 1950 CE) using an online calculator (Casio Computer Company 2018).
Lafourche	1,380–1,340 years ago	1904 CE	Begin date reflects BC or AD date provided in Törnqvist et al. (1996), which was then calculated for this GRI report into years before present (where present is 1950 CE) using an online calculator (Casio Computer Company 2018). Abandonment date is from Frazier (1967).
St. Bernard	3,900–3,780 years ago	1,440–980 years ago	Begin date reflects BC or AD date provided in Törnqvist et al. (1996), which was then calculated for this GRI report into years before present (where present is 1950 CE) using an online calculator (Casio Computer Company 2018). Abandonment date (1,325 ± 105 ^{14}C years before present) is from Saucier (1963) and reported in Törnqvist et al. (1996), which was then calculated for this GRI report into years before present (where present is 1950 CE) using online calculator (University of Oxford 2018).
Teche	5,800 years ago	3,900 years ago	Weinstein and Gagliano (1985); Saucier (1994)
Maringouin	9,000 years ago	6,500 years ago	Weinstein and Gagliano (1985); Saucier (1994)

Barataria Preserve is part of the Mississippi River delta plain, a massive wedge of Holocene sediment extending for almost 320 km (515 mi) along the coast of Louisiana and more than 100 km (160 mi) inland (Pearson and Davis 1995). The preserve lies on the St. Bernard delta lobe (fig. 3). It is in the upper Barataria estuarine basin between the Mississippi River and Bayou Lafourche. Its core is an older distributary arm, the Bayou des Familles/Bayou Barataria, which was once 0.5 km (0.3 mi) wide and carried a third of the Mississippi River's flow. The bayou is now a narrow tidal stream; its channel was filled in by sediments as the river slowly changed course, leaving natural levees that reach an elevation of about 2 m (5 ft) above mean sea level (NPS 1995). The Fleming Plantation Area is south of the previously established portion of the preserve and south of the Gulf Intracoastal Waterway.

The Wetlands Acadian Cultural Center in Thibodaux is on the banks (natural levee, map unit **Hll**; table 2) of Bayou Lafourche. Deposits of the Lafourche delta lobe (**Hdl**) are in the vicinity of the cultural center (see Wetland Acadian Cultural Center poster, in pocket).

The Acadian Cultural Center in Lafayette lies along Vermilion Bayou (see "Acadian Cultural Center poster, in pocket). Notably, the Pleistocene Avoyelles alloformation (**PEpav**) underlies the southern part of the Acadian Cultural Center. Most of the map units in the park were deposited during the Holocene Epoch (the last 11,700 years), so Pleistocene (2.6-million-to-11,700-year-old) units are distinctive. An alloformation is a mappable body of sedimentary rock with roughly parallel layers that are defined and identified on the basis of bounding discontinuities (any interruption in sedimentation) (see "Prairie Terrace"). Considerations such as the scale of base maps, purpose of the project and time assigned for completing the mapping, kind and number of exposures of the strata, the experience and skill of the mapper(s), and extent of the previous geologic study and mapping of surrounding areas determine the mappability of unit. Like the Acadian Cultural Center in Lafayette, Pleistocene deposits of the Beaumont alloformation (**PEpbe**), underlie the Prairie Acadian Cultural Center in Eunice. The Avoyelles and Beaumont alloformations are part of the Prairie Terrace (see "Prairie Terrace"), which predates the modern Mississippi River Delta (Heinrich and Autin 2000; Snead et al. 2002; Heinrich et al. 2003). The Beaumont alloformation is associated with the ancestral Red River whereas the Avoyelles alloformation is associated with the ancestral Mississippi River. Peoria Loess

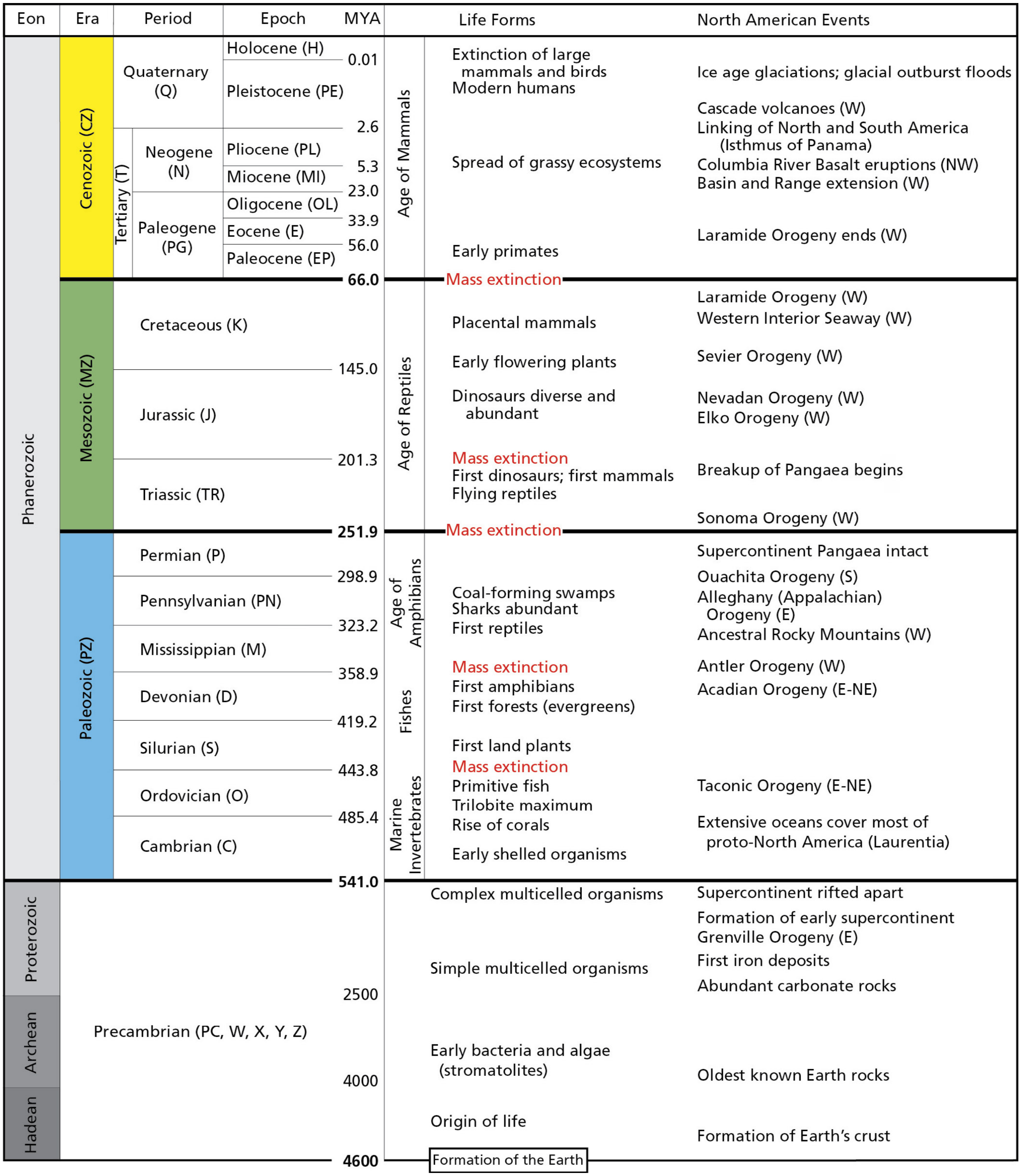

Figure 4. Geologic time scale.
The divisions of geologic time are organized stratigraphically, with the oldest divisions at the bottom and the youngest at the top of the scale. GRI map abbreviations for each time division are in parentheses. Deposits in the GRI GIS data are from the Quaternary (Q) Period, namely deposits of the Mississippi River and Mississippi River Delta, which are Holocene (H), but also Pleistocene (PE) alloformations. Compass directions in parentheses indicate the regional locations of events. Boundary ages are millions of years ago (MYA). NPS graphic using dates from the International Commission on Stratigraphy (http://stratigraphy.org/index.php/ics-chart-timescale).

Table 2. Map units in the GRI GIS data for the park.

Gray-shading indicates map units within the park. The "Park Unit" column lists the park unit(s) where the map unit is mapped. "n/a" indicates that unit is not mapped within the park. Colors are standard colors approved by the USGS to indicate different time periods on geologic maps

*See table 1 for the full range of timing and source-paper citations.

**See "Prairie Terrace" for discussion of alloformations and nomenclature.

[1]Date from Paul Heinrich (Louisiana Geological Survey, research associate, email communication, 28 November 2018) with reference to Kesel (2008).

[2]Beginning date from Prokocki (2009); ending date from Goodwin et al. (1991).

[3]Date from Prokocki (2009).

[4]Date from Pye and Johnson (1988) and Rutledge et al. (1996).

[5]Information from Paul Heinrich (Louisiana Geological Survey, research associate, email communication, 31 January 2019).

[6]Dates from Shen et al. (2012) correlated to marine isotope stage (MIS) 5a or 5c as recorded by Rasmussen et al. (2014) and Újvária et al. (2019).

Epoch	Approximate Timing of Deposition in Years Ago	Map Unit Name (map unit symbol)	Park Unit
Holocene (H)	1,300 to present*	Deposits of the Plaquemines delta lobe, Mississippi River (**Hdp**)	n/a
Holocene (H)	1,300 to present*	Natural levee complex of the Plaquemines delta lobe, Mississippi River (**Hdpl**)	n/a
Holocene (H)	1,380 to 1904 CE*	Natural levee deposits of the Lafourche meander belt (**Hll**)	Wetlands Acadian Cultural Center
Holocene (H)	1,380 to 1904 CE*	Deposits of Lafourche delta lobe, Mississippi River (**Hdl**)	n/a
Holocene (H)	3,900 to 1,400*	Deposits of the St. Bernard delta lobe, Mississippi River (**Hds**)	Barataria Preserve
Holocene (H)	3,900 to 1,400*	Natural levee deposits of the St. Bernard delta lobe, Mississippi River (**Hdsl**)	Barataria Preserve
Holocene (H)	3,900 to 1,400*	Meander belt of the St. Bernard delta lobe, Mississippi River (**Hdsm**)	n/a
Holocene (H)	> 4,000[1] to present	Holocene alluvium, undifferentiated (**Hua**)	n/a
Holocene (H)	> 4,000[1] to present	Backswamp deposit (**Hb**)	n/a
Holocene (H)	> 4,000[1] to present	Small river deposits, undifferentiated (**Hs**)	Acadian Cultural Center
Holocene (H)	4,500 to 1,800[2]	Meander belt of the Teche course [i.e., Bayou Teche] of the Red River (**Hrm**)	n/a
Holocene (H)	4,500–4,200 to present[3]	Mississippi River meander belt 1 (**Hmm1**)	n/a
Holocene (H)	4,500–4,200 to present[3]	Natural levee complex of Mississippi River meander belt 1 (**Hml1**)	French Quarter Visitor Center; Chalmette Unit
Holocene (H)	4,500–4,200 to present[3]	Crevasse complex of Mississippi River meander belt 1 (**Hmc1**)	n/a

Table 2 (continued). Map units in the GRI GIS data for the park.

Epoch	Approximate Timing of Deposition in Years Ago	Map Unit Name (map unit symbol)	Park Unit
Holocene (H)	7,850 to 4,320[3]	Mississippi River meander belt 3, upper deposits (**Hmm3u**)	n/a
Holocene (H)	7,850 to 4,320[3]	Natural levee complex of Mississippi River meander belt 3, upper deposits (**Hml3u**)	n/a
Holocene (H)	7,850 to 4,320[3]	Crevasse complex of Mississippi River meander belt 3, upper deposits (**Hmc3u**)	n/a
Holocene (H)	7,850 to 4,320[3]	Mississippi River meander belt 3, lower deposits (**Hmm3l**)	n/a
Pleistocene (PE)	25,000–9,000[4]	Peoria Loess (**PEpl**)	Acadian and Prairie Acadian Cultural Centers
Pleistocene (PE)	No known reliable dates[5]	Upper Big Cane alloformation** (**PEpbcu**)	n/a
Pleistocene (PE)	No known reliable dates[5]	Lower Big Cane alloformation** (**PEpbcl**)	n/a
Pleistocene (PE)	115,370–108,280[6]	Avoyelles alloformation** (**PEpav**)	Acadian Cultural Center
Pleistocene (PE)	104,520–108,280 or 115,370–108,280[6]	Beaumont alloformation** (**PEpbe**)	Prairie Acadian Cultural Center

Figure 5. Photograph of the Mississippi River at the Chalmette Unit.
The Chalmette Unit lies along the Mississippi River, specifically a natural levee complex of the Mississippi River meander belt 1 (Hml1). The natural levee has been built up artificially, resulting in the surface of the river often lying higher than the adjacent Chalmette landscape. Note the stairs that visitors use to access the river. A steamship is floating on the river, in the background of the photograph behind the trees. Photograph by Katie KellerLynn (Colorado State University).

(windblown silt, map unit **PEpl**) covers portions of the Prairie Terrace (see "Peoria Loess").

Geologic Connections to Other Park Resources

Within the Mississippi River delta plain, and evident within Barataria Preserve, small changes in elevation create distinct depositional environments and habitats (see "Wetlands"; Visser 1998). In general, the habitats at Barataria Preserve can be classified as marsh and forested swamps, but investigators have subdivided these into six ecological zones: (1) natural levee live oak forest; (2) ridge-and-swale bottomland hardwoods; (3) backslope transitional red maple swamp forest; (4) baldcypress-water tupelo swamp; (5) fresh marsh and intermediate marshes, including large expanses of flotant (floating marsh) and shrub communities; and (6) bayous, ponds, and estuarine lakes (Cooper et al. 2005). The park's vegetation report (Urbatsch et al. 2009) is an excellent source of information on the plants and soils associated with each of these zones. The park's vegetation inventory (Hop et al. 2017) is a similarly excellent resource for vegetation communities.

In-depth discussion of soils is beyond the scope of this report, but soil data and information are available in a geodatabase and report created by the NPS Soils Resources Inventory (NPS 2013). Table 3 of this GRI report summarizes the soils at the park. Discussion including the vegetation associated with each type of soil is available in Urbatsch et al. (2009) and Hatt et al. (2015).

Stratigraphy, carbon-14 dating of peats, and the distribution of archeological sites, which suggest a chronology for the formation of deltaic landforms, informed the geologic history of the area (Kniffen 1936; Russell 1936; Holmes 1986). Geologists used the evidence left by Native American inhabitants, such as pottery shards and shell middens, to date the relative age of these landforms; this information may be useful for inferring rates of subsidence (see "Subsidence").

Deltaic processes drove cultural patterns: prehistoric peoples inhabited higher ground composed of natural levees and crevasse splays (see "Geologic Features of the GRI GIS Data"). Evidence of Native American use of Barataria Preserve includes major midden complexes at the confluence of Bayou des Familles and Bayou Coquille (from 200 BCE) and the Isle Bonne Site on Jones Island at the confluence of Bayou Villars and Bayou Barataria (400–1000 CE). The Chenier Grand Coquilles site (from about 700 CE) is a 12-ha (30-ac) clamshell midden on the northeast shore of Lake Salvador between the openings to Bayou Bardeaux and an access canal. It has an elevation of 0.6 to 1.5 m (2 to 5 ft) above mean sea level (fig. 6). Mining activities removed much of the Chenier Grand Coquilles midden, and the remaining portion has been severely eroded (NPS 1995). In 2005, this significant cultural resource was protected by the construction of offshore rock dikes and artificial islands (Dusty Pate, Jean Lafitte National Historical Park and Preserve, natural resource manager, written communication, 11 May 2018).

Table 3. Soils at Jean Lafitte National Historical Park and Preserve.

Sources: Sasser et al. (1996); NPS (2013); Hatt et al. (2015). Urbatsch et al. (2009) provided plant community associations.

Soil type	Description	Landform Association	Park Location
Memphis silt loam	Well-drained	1%–5% slopes. Terraces on uplands.	Acadian Cultural Center
Sharkey clay	Frequently flooded	Natural levees	Acadian Cultural Center
Sharkey-Commerce	Firm mineral soils. Very deep, level to gently undulating, somewhat poorly drained soils formed in clayey alluvium that is moderately to slowly permeable.	Higher elevation, Holocene natural levee alluvial deposits from the Bayou Barataria/Bayou des Familles Mississippi River distributary	Barataria Preserve
Kenner muck	Very deep, very poorly drained, very slowly permeable, organic soil. Formed from herbaceous plant remains stratified with clayey alluvium in freshwater marshes. Frequently flooded.	Fresh marshes	Barataria Preserve
Allemands muck	Thick organic layers underlain by thin clay layers. Poorly drained, frequently flooded.	Fresh marshes	Barataria Preserve
Barbary muck	Semi-fluid mineral soils deposited on the back slope of natural levees. Poorly drained, frequently flooded.	Swamps	Barataria Preserve

Table 3 (continued). Soils at Jean Lafitte National Historical Park and Preserve.

Soil type	Description	Landform Association	Park Location
Lafitte-Clovelly clay	Semi-fluid organic soils. Poorly drained, frequently flooded.	Intermediate to brackish marshes	Barataria Preserve
Schriever clay	Very deep, poorly drained, slowly permeable soils	Lower portions of the back slopes of natural levee ridges on the lower Mississippi River alluvial plain	Barataria Preserve Chalmette Unit
Cancienne silt loam Cancienne silty clay loam	Very deep, level to gently undulating, somewhat poorly drained mineral soils that are moderately permeable	High and intermediate positions on natural levees and deltaic fans of the Mississippi River and its distributaries	Barataria Preserve Wetlands Acadian Cultural Center
Organic floating mat soils	A mat root zone of fibrous roots and an underlying mat peat zone. Substrate depth of 10–30 cm (4–12 in), low bulk density, and high (>80%) organic dry mass.	Fresh marshes	Barataria Preserve
Crowley silt loam	Clayey, fluvial-marine deposits. Pleistocene age. Somewhat poorly drained.	Meander scrolls on coastal plain	Prairie Acadian Cultural Center

Figure 6. Photograph of Chenier Grand Coquilles. Chenier Grand Coquilles in Barataria Preserve is a large shell midden made of oyster shells discarded by prehistoric peoples. The midden was later mined for lime. Photograph from Urbatsch et al. (2009, figure 19).

Geologic History

This chapter describes the chronology of geologic events that formed the present landscape. Table 4 lists the major events in the geologic history of the park.

Although the deposits that make up the park's landscape are very young (fig. 4; table 2), the geologic history of the Gulf of Mexico basin reaches much farther back in geologic time. Table 4 highlights the significant geologic and human events for the park's geologic history. A more detailed description of the development of the Mississippi River delta plain ("Chronology of Delta Lobes") follows the table.

Table 4. Significant events in the formation of the park's landscape.

Note: The events in this table are ordered chronologically, rather than stratigraphically, with the older events listed before (above) younger events. Colors are standard colors approved by the USGS to indicate different time periods on geologic maps

Age	Timing of Event	Event	Sources of Information
Jurassic Period	About 200 million years ago	Gulf of Mexico basin formed as the supercontinent Pangaea was undergoing continental rifting and break up.	Pindell (1985); Kious and Tilling (1996)
Jurassic Period	About 150 million years ago	Gulf of Mexico basin stabilized. Fluctuating sea levels and ocean currents promoted the precipitation of large salt masses along the basin floor. Later, these salt masses rise upwards through sedimentary deposits of the Mississippi River Delta, creating salt domes.	Gagliano et al. (2003a)
Paleogene Period	66 million–23 million years ago	Regional-scale river systems, including what became the Mississippi River, entered the Gulf of Mexico in what is now south Louisiana and deposited large volumes of sediment.	Galloway et al. (2011)
Oligocene and Miocene Epochs	Mostly during about 34 million–5 million years ago	Normal faults in south Louisiana likely formed as a result of extension, causing rapid basin subsidence and sediment accumulation.	Stevenson and McCulloh (2001)
Oligocene Epoch	About 25 million years ago	The continental shelf margin was at the latitude of present-day New Orleans.	Blum and Roberts (2012)
Miocene Epoch	Between 23 million and 5 million years ago	The Mississippi River system emerged as the primary focus for sediment input into the Gulf of Mexico, with about 200 km (120 mi) of subsequent shelf-margin progradation, which became the foundation of the modern Mississippi Delta region.	Blum and Roberts (2012)
Pleistocene Epoch	2.6 million–11,700 years ago	Global climate changes triggered the advance of great ice sheets from the north (in what is now Saskatchewan and North Dakota). Global climate fluctuated between cold periods (glacial periods or "ice ages") when glaciers advanced over much of North America and warm periods (interglacial periods) when glaciers retreated. During ice ages, sea level fluctuated between about 20 and 125 m (70 and 410 ft) below modern levels (figs. 7 and 8) due to an uptake of water into continental ice sheets that resulted in lowstands in sea level. Progradation (advance of shoreline) into the Gulf of Mexico accompanied lowstands. The Mississippi River system was subject to both upstream controls of water and sediment flux and downstream controls of base level.	Fairbanks (1989); Bentley et al. (2016)
Pleistocene Epoch	2.6 million–11,700 years ago	Sea level lowstands and massive meltwater discharges resulted in incision of deep-sea canyons into shelf and slope deposits.	Prather et al. (1998); Bentley et al. (2016)

Table 4 (continued). Significant events in the formation of the park's landscape.

Age	Timing of Event	Event	Sources of Information
Pleistocene Epoch	By 640,000 years ago	Advancing ice diverted the ancestral Missouri and Ohio Rivers to the south from their former courses toward Hudson Bay, adding to the Mississippi River drainage (see GRI report about Theodore Roosevelt National Park by KellerLynn 2007). As the modern Mississippi River became fully integrated, sediment was deposited for 400 km (250 mi) along the Mississippi and Louisiana coasts. Fluvial to shallow marine sediments were more than 500 m (1,640 ft) thick at the latitude of New Orleans, increasing to more than 4 km (2.5 mi) thick at the shelf margin.	Biek and Gonzalez (2001); Blum and Roberts (2012)
Pleistocene Epoch	Starting as much as 104,000 years ago	The Prairie Terrace was built by overlapping floodplains of the ancestral Mississippi River, Red River, and smaller streams flowing from the north.	Shen et al. (2012)
Pleistocene and Holocene Epochs	80,000–11,000 years ago	During the Wisconsinan (last glacial period), a lowstand in sea level occurred and the shoreline advanced hundreds of kilometers. Meltwater from ice sheets drained down the Mississippi River system.	Fisk and McFarlan (1955); Blum and Roberts (2012)
Pleistocene Epoch	25,000–21,000 years ago ***Note***: Age is from Otvos (2015).	During the last glacial maximum (LGM), the late Wisconsinan glaciation reached its greatest extent sometime between 35,000 and 15,000 years ago. Estimates of maximum sea level withdrawal range from 90 to 134 m (295 to 440 ft) below present level. Shoreline was located at the shelf margin. The northern Mississippi River alluvial valley transformed from a meandering (nonglacial) to a braided (glacial) system, transporting glaciogenic water and sediment from the Rocky Mountains and Laurentide ice sheet margins, while the southern valley responded to global sea level fall, incising into the Prairie Terrace. Incision created accommodation space that would later be filled by Holocene fluvial and deltaic sediments.	Penland et al. (2002 and references therein, especially for LGM age estimates and sea level withdrawal); Blum and Roberts (2012); Anderson et al. (2014); Bentley et al. (2016); Sweet et al. (2017b)
Pleistocene Epoch	Beginning 18,000 years ago	Deglaciation resulted in rapid sea level rise, 12 mm/yr (0.5 in/yr), after which time ice volumes remained relatively stable, and rates of sea level rise decelerated significantly.	Penland et al. (2002); Bentley et al. (2016); Sweet et al. (2017b)
Pleistocene Epoch	18,000–12,000 years ago	Periods of incision and braided stream deposition were a response to meltwater discharges that were an order of magnitude greater than that of the post–glacial Holocene Mississippi River and are comparable in scale to the present-day Amazon River.	Bentley et al. (2016)
Pleistocene and Holocene Epochs	12,800–11,400 years ago	Younger Dryas cooling event caused a temporary advance of the ice sheet and a slowing or reversal in the rate of sea level rise.	Balsillie and Donoghue (2011)
Holocene Epoch	About 11,000 years ago	Slowing of eustatic sea level rise corresponded to worldwide delta formation. The conditions of delta formation were enhanced by the presence of huge accommodation space that had largely developed along the continental margin during the early Holocene marine transgression (sea level rise).	Turner et al. (2018)
Holocene Epoch	About 10,000 years ago	Wide, rapidly migrating, and laterally amalgamated meander belts of the Mississippi River first developed. Meander belt 5 marks the change from braided (glacial) to meandering (nonglacial) at 9,190–8,070 years ago. Downvalley, avulsion (abandonment of all or part of a fluvial channel in favor of a new advantageous course at a lower elevation on its adjacent floodplain) is linked to construction of deltaic headlands on the inner shelf (i.e., the delta cycle).	Fisk (1944); Prokocki (2009); Bentley et al. (2016)

Table 4 (continued). Significant events in the formation of the park's landscape.

Age	Timing of Event	Event	Sources of Information
Holocene Epoch	9,160 years ago	Last major meltwater event took place by which time sea level had risen to within about 24 m (79 ft) of its present elevation.	Bentley et al. (2016)
Holocene Epoch	8,400–8,000 years ago	Worldwide delta formation initiated when eustatic sea level rise decelerated by 50% (10 mm/yr) to 75% (5 mm/yr); this is referred to as the "8.2-ka event." Deposition of a recognizable Mississippi River Delta began at this time.	Turner et al. (2018)
Holocene Epoch	About 9,000 years ago	The Maringouin delta—the first of six major delta lobes (see table 1; fig. 3)—formed on the Gulf of Mexico mid-shelf. The main channel of the Mississippi River will relocate approximately every 1,000–2,000 years. Avulsion of the Mississippi (and Atchafalaya) River system, followed by complete abandonment of one deltaic headland and development of another, does not happen instantaneously but takes centuries to go to completion.	Weinstein and Gagliano (1985); Saucier (1994); Roberts (1997); Day et al. (2007); Blum and Roberts (2012); Bentley et al. (2016)
Holocene Epoch	Since 7,000 years ago	Growth faulting corresponds to the construction and extension of the Mississippi River delta plain southward into the Gulf of Mexico.	Roberts et al. (1994)
Holocene Epoch	By 4,000 years ago	The Teche delta formed on the inner-shelf.	Blum and Roberts (2012)
Holocene Epoch	After 4,000 years ago	Avulsion relocated the Mississippi River to the eastern valley margins, where the St. Bernard delta formed to the east of present-day New Orleans.	Blum and Roberts (2012)
Holocene Epoch	Starting about 1,300 years ago until 1904 CE	The Lafourche delta formed to the west of New Orleans.	Blum and Roberts (2012)
Holocene Epoch	About 1,300 years ago	The modern Mississippi River channel flowed between the St. Bernard and Lafourche courses and started constructing the shelf-margin Plaquemines-Balize delta.	Blum and Roberts (2012)
Holocene Epoch	About 400 years ago	Natural avulsion of the Mississippi River into the Atchafalaya basin.	Fisk (1952)
Holocene Epoch	1537–1807	During Spanish and French exploration of the region, major distributaries of the Mississippi River discharged abundant freshwater through the St. Bernard, Lafourche, and Plaquemines-Balize delta lobes, as well as the Atchafalaya River.	Bentley et al. (2016)
Holocene Epoch	1597 CE	First recorded hurricane in Louisiana; landfall was at the mouth of the Mississippi River.	Roth (2010)
Holocene Epoch	1717–1727	First artificial enhancements of natural levees for flood control, privately maintained.	Barry (1997); Bentley et al. (2016)
Holocene Epoch	1718 CE	New Orleans founded. Subsequent levee construction around the city included French and Spanish Colonial requirements for Louisiana landowners to construct levees on the portions of their properties fronting waterways, state government requirements that farmers build levees along the Mississippi River, and the Swamp Land Act of 1849 that granted wetlands to Louisiana for the purpose of aiding construction of levees and drainage to reclaim those lands.	Dusty Pate (Jean Lafitte National Historical Park and Preserve, natural resource manager, written communication, 19 November 2018)
Holocene Epoch	1814 CE	Begin severing connection between the Mississippi River and its delta plain when Bayou Manchac was closed off for defense purposes (at the recommendation of one-time pirate, Jean Lafitte). Later (in 1904), the connection between the river and delta is severed at Bayou Lafourche.	Barry (1997); Bentley et al. (2016)

Table 4 (continued). Significant events in the formation of the park's landscape.

Age	Timing of Event	Event	Sources of Information
Holocene Epoch	1864 CE	Establishment of Chalmette National Cemetery.	NPS (no date)
Holocene Epoch	1879 CE	Creation of the Mississippi River Commission (MRC), which replaced previous State Board of Levee Commissioners. MRC works with the US Army Corps of Engineers (USACE) to deepen the Mississippi River channel, lessening flood potential and increasing navigability.	Barry (1997); USACE (2018)
Holocene Epoch	1904 CE	Dam built across the head of Bayou Lafourche in Donaldsonville, cutting off all flow from the Mississippi River.	Van Heerden et al. (1996); Gagliano et al. (2003b)
Holocene Epoch	1927 CE	Flood of 1927, which remained in flood stage for 153 consecutive days, inundated approximately 70,000 km^2 (27,000 mi^2) of the Mississippi River, tributary, and distributary floodplains, and displaced 700,000 people.	Barry (1997)
Holocene Epoch	1928 CE	Congress passed the Flood Control Act (updated in 1936 and 1944) that initiated the Mississippi River and Tributaries System, including levees, flood gates, and bank revetments, by which floodwaters and navigation are maintained in the lower Mississippi River valley.	Barry (1997)
Holocene Epoch	1927–1928 CE	As authorized in the Flood Control Act following the flood of 1927, the USACE begins to build and maintain the following: artificial levees along the Mississippi and Atchafalaya channels, floodways and spillways to divert floodwaters out of the Mississippi channel above New Orleans, and channel improvements and bank stabilization. These activities mark the engineered isolation of the Mississippi River and its sediment from the delta plain.	Allison et al. (2012); Bentley et al. (2016)
Holocene Epoch	1930s CE	Gulf Intracoastal Waterway is dredged on the southern boundary of Barataria Preserve, altering the area's hydrology by changing natural flow conditions and creating spoil banks that prevent sheet flow and storm surge.	NPS (2008); Coburn et al. (2010)
Holocene Epoch	1939 CE	Chalmette National Historical Park is established. Since then, many tropical storms and hurricanes have affected park sites.	See table 10.
Holocene Epoch	1940s–1970s CE	Exploratory and operational oil wells created in and around Barataria Preserve, with associated canal dredging and wetland disturbance.	NPS (1995)
Holocene Epoch	1944 CE	Wax Lake Outlet of the Atchafalaya River constructed to provide flood relief to Morgan City, resulting in eventual development of the Wax Lake delta at the mouth of the outlet.	Bentley et al. (2016)
Holocene Epoch	1952–1955	Large dams constructed on Missouri River, reducing sediment supply.	Bentley et al. (2016)
Holocene Epoch	1952 CE	Diversion of the Atchafalaya River resulted in emergence of the Atchafalaya and Wax Lake deltas in Atchafalaya Bay by the mid-20th century. Development of the Atchafalaya distributary initiated the present delta cycle, which, without continued intervention, will result in abandonment and reworking of the Plaquemines-Balize delta and construction of a new deltaic headland focused in Atchafalaya Bay.	Fisk (1952); Shlemon (1975); Roberts (1997); Aslan et al. (2005); Neill and Allison (2005); Blum and Roberts (2012)
Holocene Epoch	1963 CE	USACE built the Old River Control Structure at Simmesport. Approximately 30% of the Mississippi River's water and sediment discharge is diverted to the Atchafalaya River. Abandonment of the Mississippi River's current path is prevented.	Kesel et al. (1992); Meade and Moody (2010); Allison et al. (2012)

Table 4 (continued). Significant events in the formation of the park's landscape.

Age	Timing of Event	Event	Sources of Information
Holocene Epoch	1973 CE	Major flooding on the Mississippi River weakens and nearly undermines the Old River Control Structure, resulting in redesign and expansion during subsequent years.	Bentley et al. (2016)
Holocene Epoch	2005 CE	While hurricanes have long affected the Louisiana coastline, the 2005 hurricane season was extraordinarily active, destructive, and costly. Hurricane Katrina caused significant coastal erosion and flooding across south Louisiana including erosion along the Lake Salvador shoreline in Barataria Preserve. Levees in greater New Orleans fail.	Beavers and Selleck (2006); KellerLynn (2010a)
Holocene Epoch	2005–2018 CE	Failure of levees prompted the subsequent authorization and funding of the Hurricane and Storm Damage Risk Reduction System (HSDRRS), which built upon and expanded previously authorized federal levees, including about 30 km (20 mi) of levees near or within Barataria Preserve. Beneficial use of dredged material and compensatory mitigation for damage to wetlands inside and outside the preserve associated with HSDRSS leads to the creation of fresh marsh and bottomland hardwood forest, shoreline protection, and swamp enhancement projects.	USACE (2019)
Holocene Epoch	2010 CE	Deepwater Horizon oil spill necessitated release of above-normal volume of river water from the Davis Pond freshwater diversion to prevent oil from migrating into Barataria Bay. Resulting turbidity and salinity changes caused loss of submerged aquatic vegetation (SAV) within Barataria Preserve.	Deepwater Horizon Natural Resource Damage Assessment Trustees (2016)
Holocene Epoch	2010–2018 CE	Natural Resource Damage Assessment and other Deepwater Horizon settlement funds (e.g., RESTORE Act and NFWF Gulf Environmental Benefit Fund) used to build coastal protection and restoration projects within Barataria Preserve and elsewhere along the Gulf coast.	Dusty Pate (Jean Lafitte National Historical Park and Preserve, natural resource manager, written communication, 19 November 2018)

Chronology of Delta Lobes

From 11,000 to 8,000 years ago, sea level was rising at a rate of 16.7 mm/yr (0.66 in/yr) and resulted in 50 m (160 ft) of sea level rise (figs. 7 and 8). This 11,000-years-ago date is significant because it marks the beginning of the last rapid rise in sea level preceding the slowdown around 7,500–7,000 years ago. Moreover, approximately 8,200 years ago, when the rate of sea level rise was between 10 and 5 mm/yr (0.4 and 0.2 in/yr), worldwide delta formation was triggered (Turner et al. 2018). Since 7,000 years ago, the rate of sea level rise slowed to less than 1.0 mm/yr (0.04 in/yr), marking a period of stabilized sea level until the 20th century when the rate of mean sea level rise increased to 1.7 mm/yr (0.07 in/yr) (Blum and Roberts 2012).

Rapid sea level rise since the last glacial maximum (about 25,000–21,000 years ago; Otvos 2015) created accommodation space for delta formation. Stabilized sea level then allowed for nearshore accumulation of fluvial sediment and development of the Mississippi River delta plain. The Maringouin delta (Frazier 1967) was the first of six major delta lobes (fig. 3; table 1). Deposits from the Maringouin delta are found as deep as 43 m (140 ft) below the surface at the Acadian Cultural Center in Lafayette (fig. 9, cross section 1). The preserved delta lobe is not known to contain deltaic distributaries (waterways that diverge from a primary channel by distributing flow away from the main course), but Frazier (1967) documented two zones of interdistributary peats (i.e., delta-plain peaty clays that overlie braided-stream sands), which represent two discrete depositional cycles. Sands and shell debris, representative of transgression (marine inundation; see "Delta Cycle"), overlie the delta-plain sequence of deposits (Frazier 1967).

The Maringouin delta was abandoned as it entered the transgressive (marine dominated) phase of the delta cycle (see "Delta Cycle). As a result of submergence and reworking of sediments by marine processes, the Maringouin delta was transformed into the Tiger, Ship, and Trinity Shoals (fig. 1; Goodwin et al. 1991;

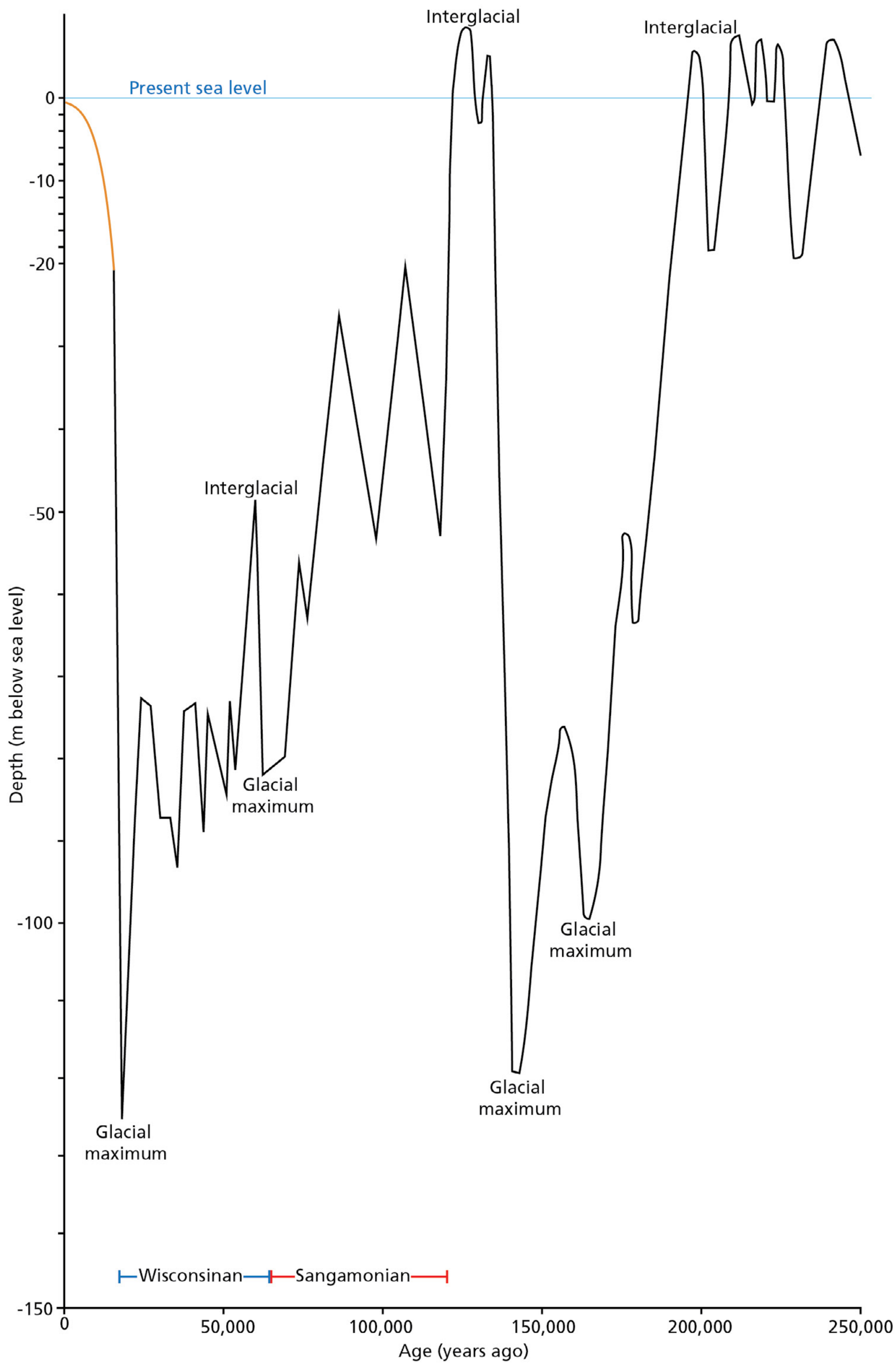

Figure 7. Graph showing global sea level during the past 250,000 years.
The black line shows a portion of the Pleistocene global sea level curve as reported by Otvos (2005c, figure 5). Pleistocene sediments that compose the Prairie Terrace were deposited during the Sangamonian (interglacial) and into the Wisconsinan (glacial). Erosion, entrenchment, oxidation, desiccation, and consolidation of the Prairie Terrace took place at the time of the last glacial maximum when sea level was low. Holocene sediments were deposited as sea level rose towards its present-day level. The orange line shows the Holocene sea level curve for the northern Gulf of Mexico as reported by Anderson et al. (2014, figure 13). Figure 8 of this report provides a detailed curve of the past 22,000 years by Balsillie and Donoghue (2011). Graphic by Trista Thornberry-Ehrlich (Colorado State University).

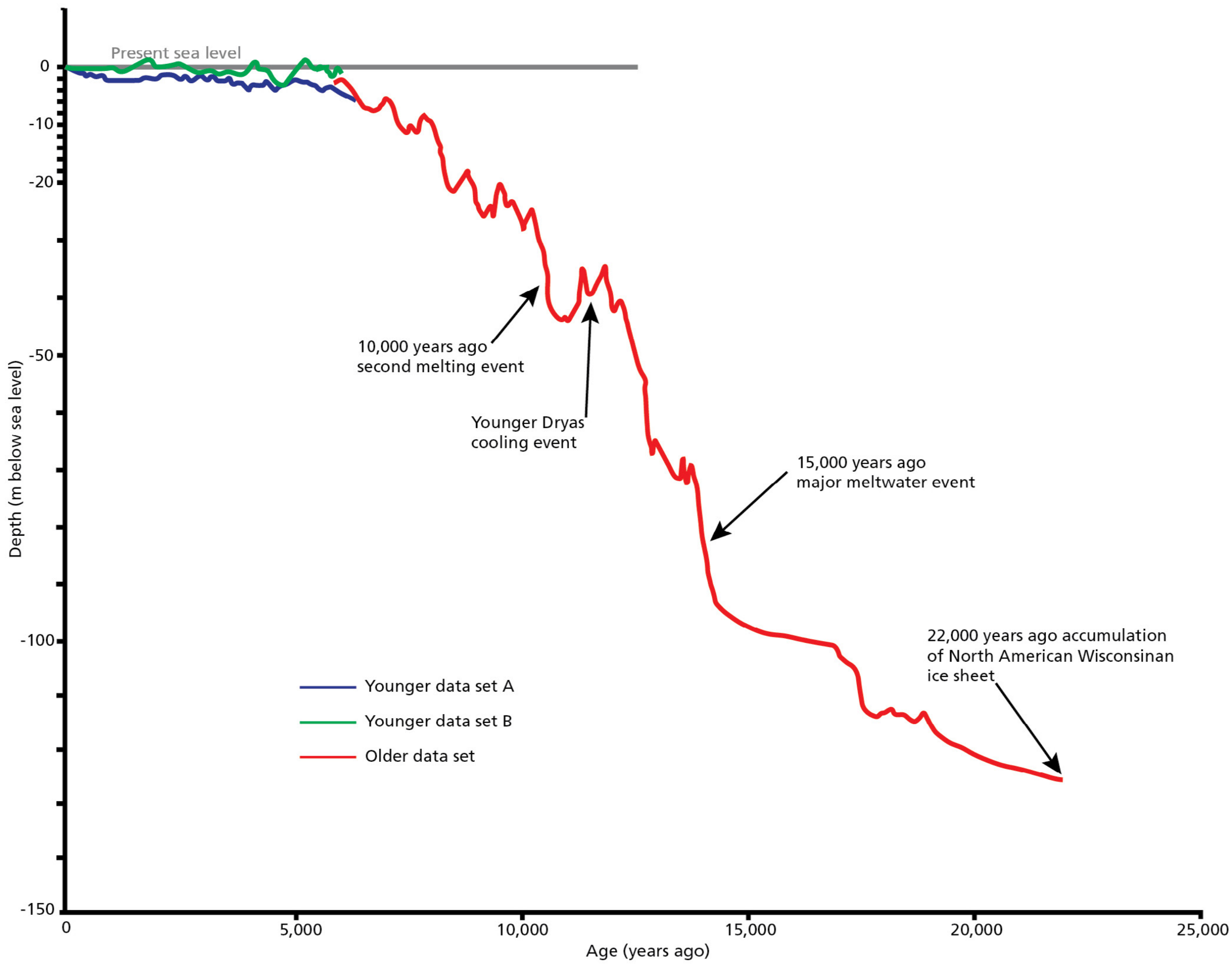

Figure 8. Sea level curve for the Gulf of Mexico over the past 22,000 years.
Sea level change and glacial melting played significant roles in fluvial and coastal processes during the late Pleistocene and Holocene Epochs. Beginning about 22,000 years ago and continuing until about 7,000 years ago, glacial melting caused rapid sea level rise (red line). About 15,000 years ago, a major meltwater event took place, and meltwater entered the northern Gulf of Mexico via the Mississippi River. Approximately 12,800 to 11,400 years ago, the Younger Dryas cooling event included temporary advance of the ice sheet and a slowing or reversal in the rate of sea level rise. A second pulse of meltwater occurred approximately 10,000 years ago (Fairbanks 1989). Between 8,000 and 3,000 years ago, relative sea level rise in the Mississippi River Delta rose continuously (Balsillie and Donoghue 2011), though small (<1 m [3 ft]) fluctuations at a centuries-scale may have taken place during that time period (Törnqvist et al. 2004). The rate of relative sea level rise was higher between 8,000 and 7,000 years ago (approximately 3.5 mm/yr [0.14 in/yr]), and then dropped to a rate of approximately 1.5 mm/yr (0.04 in/yr) since that time (Törnqvist et al. 2004). The green and blue lines on the graph represent two data sets for relative sea level in the past 7,000 years; the data were divided into two subsets based on sampling location: Younger data set A (blue line) is for samples collected offshore. Younger data set B (green line) is for samples collected onshore. According to studies in Texas (Morton et al. 2000) and Florida (Froede 2002), relative sea level may have risen 0.5 m (1.6 ft) higher than present sea level approximately 1,500 years ago. Graphic by Trista Thornberry-Ehrlich (Colorado State University) after graph in Balsillie and Donoghue (2011, figure 4.4).

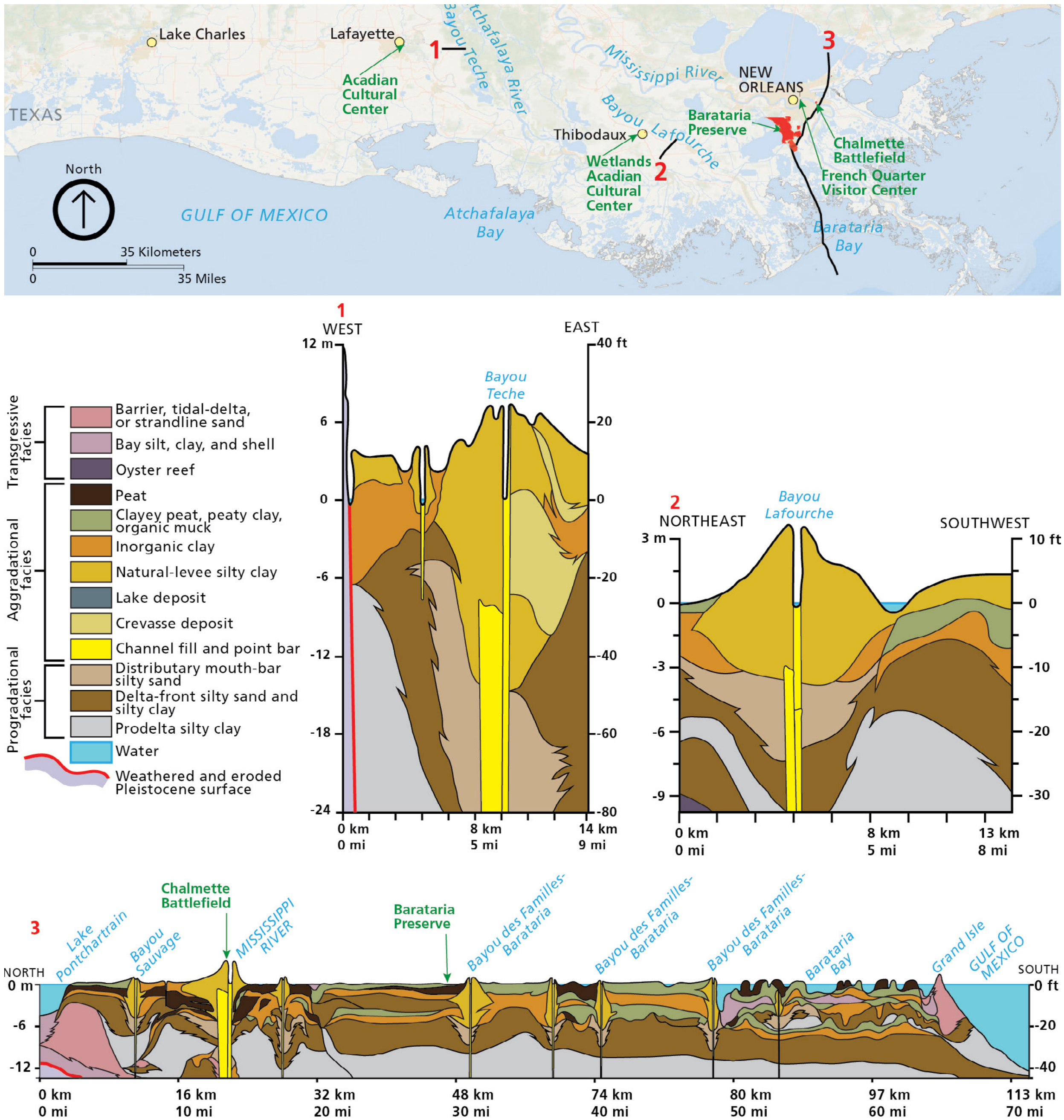

Figure 9. Cross sections and location map of Holocene subsurface geology.
The location map shows the locations of the three cross sections. Cross section 1 crosses Bayou Teche east of the Acadian Cultural Center. Cross section 2 crosses Bayou Lafourche southeast of the Wetlands Acadian Cultural Center. Cross section 3 captures the modern Plaquemines-Balize delta, extending from the Gulf of Mexico through Barataria Bay, along Barataria Preserve and the Chalmette Unit, and into Lake Pontchartrain. Progradational facies relate to delta-building sequences where the delta is built forward and outward to sea. Aggradational facies relate to delta-building sequences where the delta is built upward. Transgressive facies relate to sequences where the river is changing course, a delta lobe is abandoned, and marine processes prevail. Left axis indicates sea level. Graphics by Trista Thornberry-Ehrlich (Colorado State University) after Frazier (1967, figures 6, 7, and 8).

Van Heerden et al. 1996). At present, the Atchafalaya delta-building event is burying these shoals with a thin blanket of fine-grained sediment, relegating them to the geologic record (Roberts 1997).

The trunk channel for the Teche delta was the same as the Maringouin delta (i.e., Bayou Teche) (fig. 9, cross section 1). The Mississippi River course followed Bayou Teche and deposited sediments on top of the Maringouin delta to the south, as well as into open water to the east. The base of the Teche channel-fill and point-bar deposits is more than 40 m (140 ft) below the modern surface (Frazier 1967).

Some studies indicate that when the Mississippi River began an eastward migration and abandonment of Bayou Teche, the Red River entered the abandoned bayou and continued to supply sediment to the southern Teche delta, possibly until as recently as 1,800 years ago (Goodwin et al. 1991). The GRI GIS data include a deposit of a meander belt of the Teche course (Bayou Teche) of the Red River (**Hrm**; see Acadian Cultural Center poster, in pocket).

The St. Bernard delta of the Mississippi River became active as distributaries from the Teche delta shifted eastward (Frazier 1967; Törnqvist et al. 1996). The GRI GIS data include three units deposited as part of the St. Bernard delta: (1) meander belt (**Hdsm**), (2) natural levee deposits (**Hdsl**), and (3) deposits of the St. Bernard lobe (**Hds**). Within Barataria Preserve, delta lobe deposits (**Hds**) and natural levee deposits (**Hdsl**) compose marsh and occur within Bayou des Familles, respectively. Deposits of the meander belt (**Hdsm**) occur within Bayou Terre aux Boeufs, southeast of the Chalmette Unit (see Chalmette Unit, French Quarter Visitor Center, and Barataria Preserve poster, in pocket). During the regressive phase (active building) of the St. Bernard delta lobe, distributaries of the Mississippi River created six subdeltas (Frazier 1967). Cumulatively, the St. Bernard delta lobe achieved the largest areal extent of any of the Holocene delta lobes, which is primarily a reflection of the shallowness of the receiving water body (Saucier 1994). The St. Bernard subdelta of primary interest for the Barataria area was Bayou des Familles (see Levin 1991). The Bayou des Familles subdelta prograded into and through what is now New Orleans and the Barataria basin, including the French Quarter Visitor Center, Chalmette Unit, and Barataria Preserve areas of the park (fig. 9, cross section 3). The most recent subdelta is Bayou Sauvage, which developed along the southern shore of Lake Pontchartrain. After the St. Bernard delta was abandoned and entered the transgressive phase of the delta cycle, local tectonic subsidence substantially added to the local sea level rise rate in the St. Bernard subdelta areas (Otvos and Giardino 2004; Otvos and Carter 2008).

The Lafourche delta, which underlies the Wetlands Acadian Cultural Center in Thibodaux (fig. 9, cross section 2), consists of five subdeltas that built on top of and around the older Teche delta and then prograded into the open Gulf of Mexico (Gagliano et al. 2003a). The Lafourche Ridge, which underlies Thibodaux and the Wetlands Acadian Cultural Center, is composed of a natural levee deposit (**Hll**) of the Lafourche delta lobe. Other deposits of the delta lobe (**Hdl**) occur north and south of the cultural center (see Wetlands Acadian Cultural Center poster, in pocket).

The initial subdelta of the Lafourche delta lobe prograded into Barataria Basin from the northwest. This early Lafourche subdelta extended over the subsided distal end of the Bayou des Familles subdelta of the St. Bernard delta lobe. Bayou Blue, which developed from a crevasse along the east side of Bayou Lafourche and extended 50 km (30 mi) southeast to present-day Grand Isle, was a main distributary contributing to the development of the Lafourche delta (Penland and Boyd 1985; Levin 1991). During the transgressive phase, sediments from the Lafourche delta lobe developed into the Caminada-Moreau headland at Bayou Lafourche (Kulp et al. 2005). Marine processes transported sediments from the abandoned delta lobe, also creating Grande Isle from reworked deltaic deposits (fig. 9, cross section 3).

Concurrent with progradation and abandonment of the Lafourche delta lobe, the Mississippi River began building the Plaquemines delta lobe in the eastern part of the Barataria basin (Penland and Boyd 1985). East of Barataria Preserve, the natural levee (**Hdpl**) on either side of the Mississippi River as well as proximal deposits (**Hdp**) there were deposited during development of the Plaquemines delta lobe. The Plaquemines delta lobe began to prograde into the basin from the northeast as a complex system of multiple branching distributary channels (Flocks et al. 2006). The Plaquemines delta lobe prograded on top of the St. Bernard interlobe basin (the basin lying between lobes of the St. Bernard delta) and continued depositing material until the delta front began approaching the edge of the continental shelf. When the delta front reached the continental shelf margin, it began depositing sediment into open water as deep as 90 m (300 ft), which dramatically changed the physiographic character of the delta lobe as well as its sedimentary framework (Saucier 1994). Thus began the regressive (delta-building) phase of the Balize delta with its distinctive “bird-foot” shape (Kolb and Van Lopik 1966).

The Plaquemines delta lobe remained active until artificial levees eliminated overbank flow (Byrnes et al. 2018); it is now abandoned (Penland et al. 1988). In addition, the Bayou Lafourche distributary was damned at Donaldson in 1904, ending flow through Bayou Lafourche and forcing most flow into the current course of the Mississippi River (Frazier 1967), effectively ending growth of the Lafourche delta lobe.

Today the delta plain consists of two areas of regression or active delta formation. These areas cover about 20% of the delta plain. The remainder of the delta plain consists of abandoned delta lobes (Penland et al. 1988). Delta building is taking place at the Balize and Atchafalaya/Wax Lake deltas. The Balize delta has only a few distributaries, and those tend to be wide and shallow. Sediments are being deposited in deep water at the shelf edge, resulting in a geographically restricted but thick (100 m [330 ft]) accumulation of material (Kulp et al. 2005). This is in contrast to the older abandoned deltas, such as the St. Bernard delta lobe, that prograded into water 9 to 45 m (30 to 150 ft) deep and had many deep and narrow distributaries (Kolb and Van Lopik 1966).

Beginning about 500 years ago (1500s CE), the Atchafalaya delta began prograding across remnants of the Maringouin and Teche delta lobes, leaving deltaic deposits just east of the Acadian Cultural Center (Frazier 1967). By the mid-20th century, the Atchafalaya delta had advanced into Atchafalaya Bay and Wax Lake (Fisk 1952; Aslan et al. 2005; Neill and Allison 2005; Blum and Roberts 2012). The Atchafalaya delta, a bayhead delta (see "Delta Cycle"), is currently forming at the mouth of the Atchafalaya River; the delta has been prograding across Atchafalaya Bay at a rate of 400 m/yr (1,300 ft/yr). In 1944 the US Army Corps of Engineers dug a flood relief outlet, called the "Wax Lake Outlet," from the Atchafalaya River that extended out to the coastline. This outlet provided a constant flow of water to be diverted from the river before reaching the banks of Morgan City, which had experienced several devastating floods. Following the creation of the Wax Lake Outlet, water began to carry sediment through the outlet, depositing it at the outlet's mouth. Following a flood in 1973, which deposited a significant amount of sediment, a visible delta appeared breaking the surface of the water near the mouth of the outlet. The Atchafalaya and Wax Lake deltas provide an opportunity to observe delta formation in real time (Blum and Roberts 2012).

Geologic Features and Processes

These geologic features and processes are significant to the park's landscape and history.

- Delta cycle
- Geologic features of the GRI GIS data (including Prairie Terrace, Peoria Loess, meander belts, backswamp deposits, small river deposits, natural levees, crevasse complexes, alluvium, and delta lobe deposits)
- Wetlands
- Faults
- Salt domes
- Paleontological resources

Delta Cycle

Since their publication in 1988 and 1997, two figures have dominated subsequent discussions of the genesis and development of the Mississippi River Delta. Figure 14 of Penland et al. (1988) (modified and shown as fig. 10 in this report) focused on the transgressive (marine dominated) phase of the delta cycle, highlighting a three-stage model wherein an active delta develops, is abandoned, and becomes submerged below sea level. Figure 2 of Roberts (1997) (modified and shown as fig. 11 in this report) introduced a graphic representation of the entire delta cycle, including both regressive (fluvial dominated) and transgressive (marine dominated) phases of delta development. The following text serves as an extended caption for these two figures.

A delta complex, such as the Mississippi River Delta, may be composed of one or more delta lobes. A delta lobe may be subdivided further into subdeltas and even smaller crevasse splays. Larger and smaller features of a delta operate on a variety of temporal and spatial scales (table 5).

Because of distributary switching, which is a naturally occurring event that favors a shorter, more hydraulically efficient route to base level (i.e., the Gulf of Mexico), the Mississippi River Delta consists of laterally offset and stacked delta lobes. Commonly cited studies (e.g., Frazier 1967) indicate that the Mississippi River delta plain is composed of six delta lobes: (1) Maringouin, (2) Teche, (3) St. Bernard, (4) Lafourche, (5) Plaquemines-Balize, and (6) Atchafalaya/Wax Lake (fig. 3). Delta lobes typically have a duration of 1,000–2,000 years, produce marshlands that cover as much as 15,000 km^2 (5,800 mi2), and develop sedimentary sequences up to 30 m (300 ft) thick on the inner shelf (table 5).

Initiation of a delta lobe starts with the availability of sediment associated with stream capture (natural diversion of one stream into the channel of another stream that has greater erosional activity and/or flows at a lower level). As the Roberts (1997) model illustrated, delta building begins by sediment infilling of inland lakes; this stage is referred to this as the "lacustrine delta" stage (fig. 11). An example of this stage is the filling of Grand Lake–Six Mile Lake in the southern Atchafalaya basin, starting in the 1500s and ending in the 1970s. The lacustrine delta stage is followed by delta building on the coast, which Roberts (1997) referred to as building of a "bayhead delta." Today's Atchafalaya delta is an example of a bayhead delta. Over time with increasing discharge and sediment input from the distributary, delta building takes place on the marine shelf (referred to as a "shelf delta" by Roberts 1997). The Balize delta is a present-day example of a shelf delta.

These three stages—lacustrine, bayhead, and shelf (included in the model by Roberts 1997)—are all part of the development of an "active delta" (regressive phase in the model by Penland et al. 1988). As the delta progrades (builds outward), coarser sediments are deposited at the distributary mouths, and as the delta advances, sand is transported laterally to form beach ridges (see "Active Delta" block in fig. 10). At the head of the delta, most of the coarse material such as sand drops into the water body and is buried by more sand; finer-grained sediments such as silt or clay are carried farther from the distributary mouth until they too settle out of suspension. This creates a vertical sequence (fig. 12) with prodelta silty clays overlain by alternate layers of delta-front silty sands and clayey silts. Prodelta deposits consist of fine-grained suspended sediments carried out into a lake or seaward from delta lobes and deposited in relatively deep waters. They are firm to medium stiff, gray clays, and may include fine organic fragments and shell fragments. Clays are compacted under the weight of overlying sands (Frazier 1967). The water depth of the receiving basin controls the rate of delta progradation and the thickness of the fine-grained prodelta layers (Frazier 1967).

In addition to progradation, aggradation (building up of the delta surface) occurs during the regressive phase. Aggradation takes place landward of the prograding part of the delta as distributaries deposit fine-grained clastic sediments (see "Crevasse Complexes") on top of the delta surface. Each influx of sediment elevates the surface slightly. Abandonment of a delta lobe results in a hiatus in sedimentation but an accumulation of organic deposits. Initially, plant communities colonize

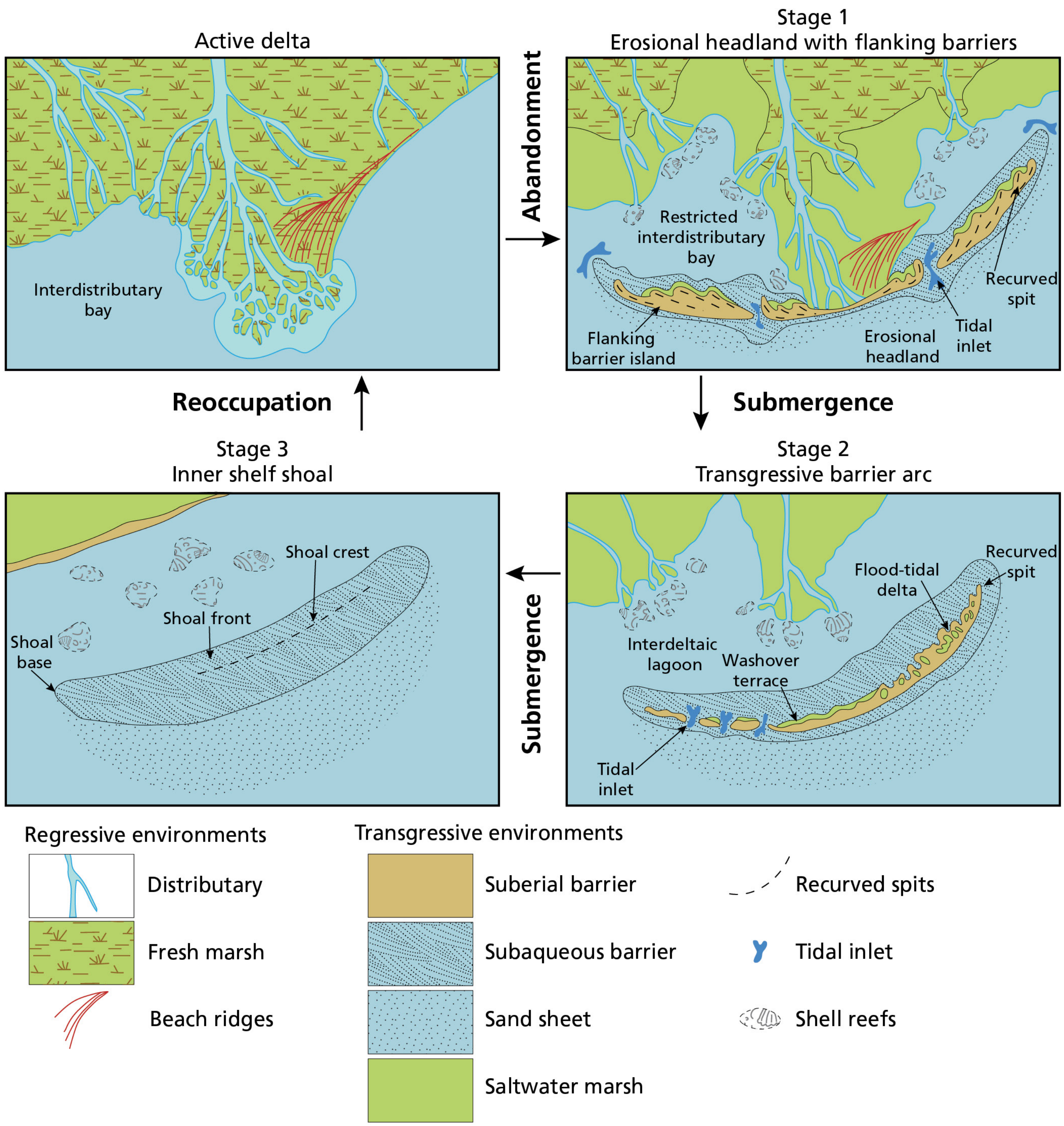

Figure 10. Conceptual model of the delta cycle by Penland et al (1988).
The model by Penland et al. (1988) focuses on the transgressive (marine dominated) phase of the delta cycle, subdividing the cycle into three stages: stage 1—erosional headland with flanking barriers, stage 2—transgressive barrier arc, and stage 3—inner-shelf shoal. At present, the Lafourche delta lobe exemplifies stage 1; associated spits and barrier islands include the Caminada-Moreau headland and Grand Isle (see figs. 1 and 3). A present-day example of stage 2 is the St. Bernard delta lobe and Chandeleur Islands. The Maringouin delta lobe and Ship Shoal illustrate stage 3 (see figs. 1 and 3). The "active delta" represents the regressive (fluvial dominated) phase. Graphic by Trista Thornberry-Ehrlich (Colorado State University) after Penland et al. (1988, figure 14).

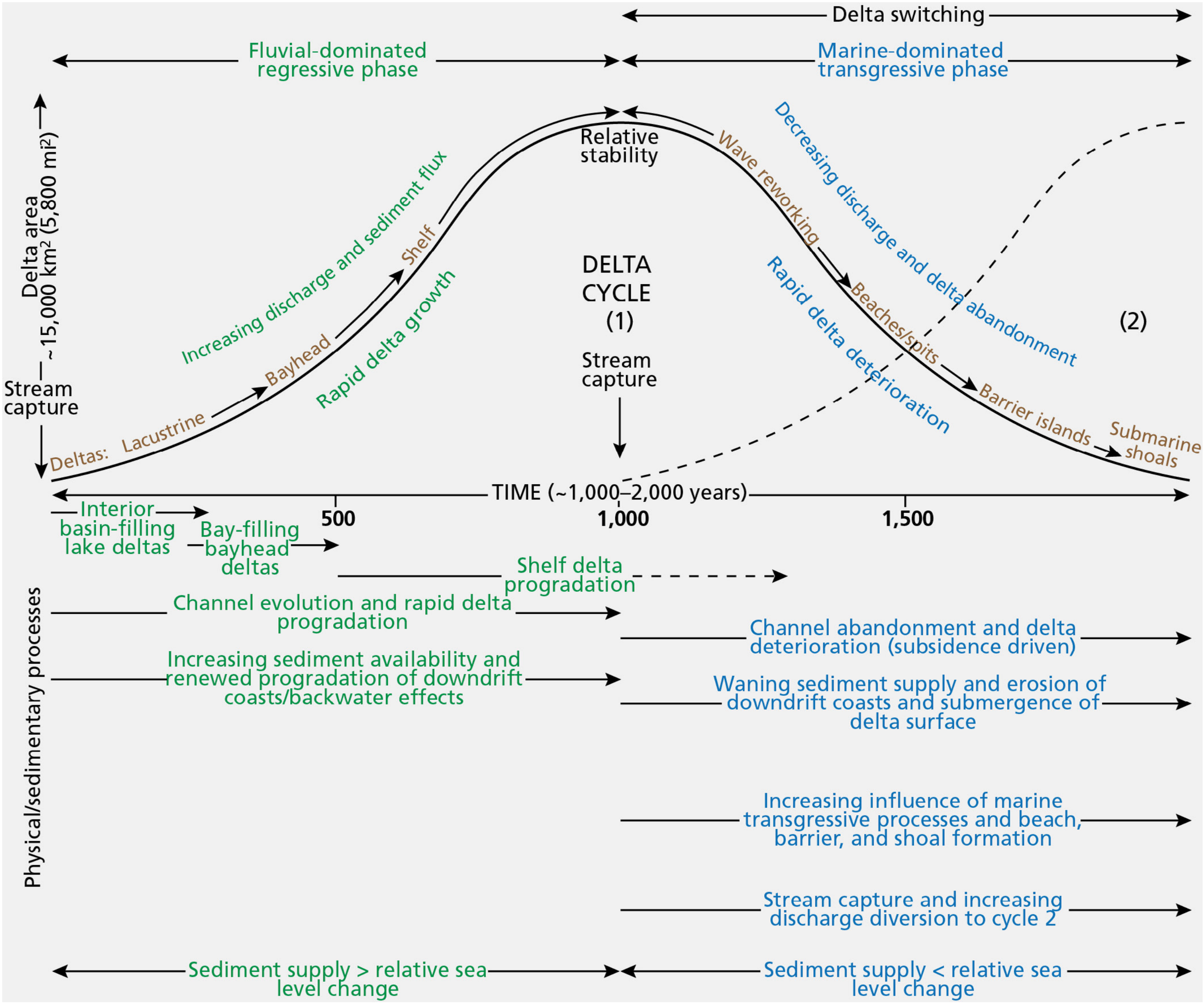

Figure 11. Conceptual model of the delta cycle by Roberts (1997).
Whereas the model by Penland et al. (1988) (see fig. 10) focuses on the transgressive phase, the model by Roberts (1997) shown here incorporates both regression (fluvial dominated phase) and transgression (marine dominated phase). Regression progresses through basin filling by a lake delta, bay filling by a bayhead delta, and progradation of a shelf delta during a time when sediment supply provided by the river outpaces relative sea level. Transgression takes place because of an increasing influence of marine processes wherein the delta deteriorates and is abandoned by its distributary stream. Regression and transgression of a delta lobe occurs on a time scale of approximately 1,000 to 2,000 years. Graphic by Trista Thornberry-Ehrlich (Colorado State University) after Roberts (1997, figure 2).

an abandoned delta lobe then peat begins to accumulate (Kosters 1989).

An active delta enters the abandonment phase as discharge and sediment supply within a distributary channel decrease. At the same time, progradation of the delta lobe reduces the gradient of the delta's surface, which in turn promotes abandonment via eventual stream capture upriver. Substrate subsidence of the delta lobe, which causes a relative rise in sea level (transgression), is another factor in abandonment.

Following abandonment of a delta lobe by a distributary, minor amounts of sediment may be delivered by subsequent flooding through crevasse and distributary channels or during tropical storms, but sediment accumulation is primarily from organic accumulation such as marsh peats (Cahoon et al. 1995; Turner et al. 2006).

Table 5. Hierarchy of delta features.

Feature	Dimensions	Time Scale (builds and deteriorates)
Delta lobe	~15,000 km^2 (5,800 mi^2) 10–100 m (30–300 ft) thick	~1,000–2,000 years
Subdelta	~300 km^2 (120 mi^2) <10 m (30 ft) thick	150–200 years
Crevasse splay	1–3 km^2 (0.4–1 mi^2) <5 m (16 ft) thick	Every few decades

Transgression (marine inundation) of an active delta begins while abandonment is taking place. In stage 1 of the transgressive phase, marine processes (waves and currents) rework delta-front sands to form erosional headlands with flanking barrier islands (fig. 10). Salt marshes develop behind the sand barriers. Bays develop at the detriment of fresh marshes. As marine conditions predominate, shell reefs develop; reefs found in the sedimentary record indicate the locations of former bays and sounds (Saucier 1994). As transgression progresses and salt marshes deteriorate, a barrier island arc forms (fig. 10, stage 2). Because of the development of tidal inlets over time, the barrier island arc fragments into smaller islands, which move landward as sand is transported in washover fans, which are produced by storm waves breaking over low parts of a barrier and depositing sediment on the landward side. Extensive washover terraces or sandy shoals form landward of the islands, eventually producing a submerged complex of shoals and sand sheets (fig. 10, stage 3). Transgression continues until another distributary channel captures enough water and sediment for regression to begin again.

For more than 7,000 years (see “Chronology of Delta Lobes”), regression outpaced transgression, creating the massive Mississippi River Delta, with the delta plain experiencing an overall net growth (Day et al. 2007). Beginning in the 1700s, however, engineering activities (see table 4 in “Geologic History”) have had a major impact on many key elements of the delta cycle, and as natural delta-building processes have become constrained, transgressive processes such as relative sea level rise and wave erosion have begun to outpace regressive processes.

Geologic Features of the GRI GIS Data

Many geologic features make up the lower Mississippi River valley and Mississippi River delta plain. Those highlighted here were mapped by investigators from the Louisiana Geological Survey (see “Geologic Map Data”) and are part of the GRI GIS data for the park (table 2). The following text reflects the map unit descriptions of the source maps; original descriptions are included in the GRI ancillary map information document (jela_geology.pdf). Additional information is included to provide a context for the features and make connections to the delta cycle, the park’s geologic history and setting, and in some cases, geologic resource management issues, which are discussed in the “Geologic Resource Management Issues” chapter.

Prairie Terrace

First recognized by Fisk (1938) in the Red River valley (fig. 1), the Prairie Terrace was identified as the youngest of four major Pleistocene interglacial fluvial morphostratigraphic (now allostratigraphic) units (fig. 13). Investigators soon extended the Prairie Terrace to include the broad, coast-parallel Prairie surface in southwestern Louisiana, a comparable belt in Florida, and isolated terraces in northeastern Louisiana (Fisk 1939).

Overlapping floodplains of the Mississippi River, Red River, and smaller streams flowing from the north built the Prairie Terrace. The late Pleistocene distributary channels of the Red River and Mississippi River now serve as shallow creeks that meander across the surface of the Prairie Terrace (Mange and Otvos 2005). The sediments that make up the terrace are 60–70 m (200–230 ft) thick and consist of sand and lesser amounts of gravel overlain by 10–20 m (30–70 ft) of mud (Autin and Aslan 2001). The surface of the Prairie Terrace is as much as 35 km (22 mi) wide (north–south) and gently inclined towards the Gulf of Mexico (Otvos 2005). The surface rises in elevation from near sea level, where it meets the coastal marsh and chenier plain (wooded beach ridge), to as much as 26 m (85 ft) above sea level. Its relatively high elevation may result from continuing uplift following deposition (Mange and Otvos 2005).

Sediments of the Prairie Terrace accumulated over the latter part of the Pleistocene Epoch during the Sangamonian interglacial period to Wisconsinan glacial period (Autin et al. 1991; McCulloh et al. 2003; Heinrich et al. 2004; Otvos 2005). A large portion of the Prairie Terrace aggraded in association with a significant sea level highstand (corresponding to marine isotope

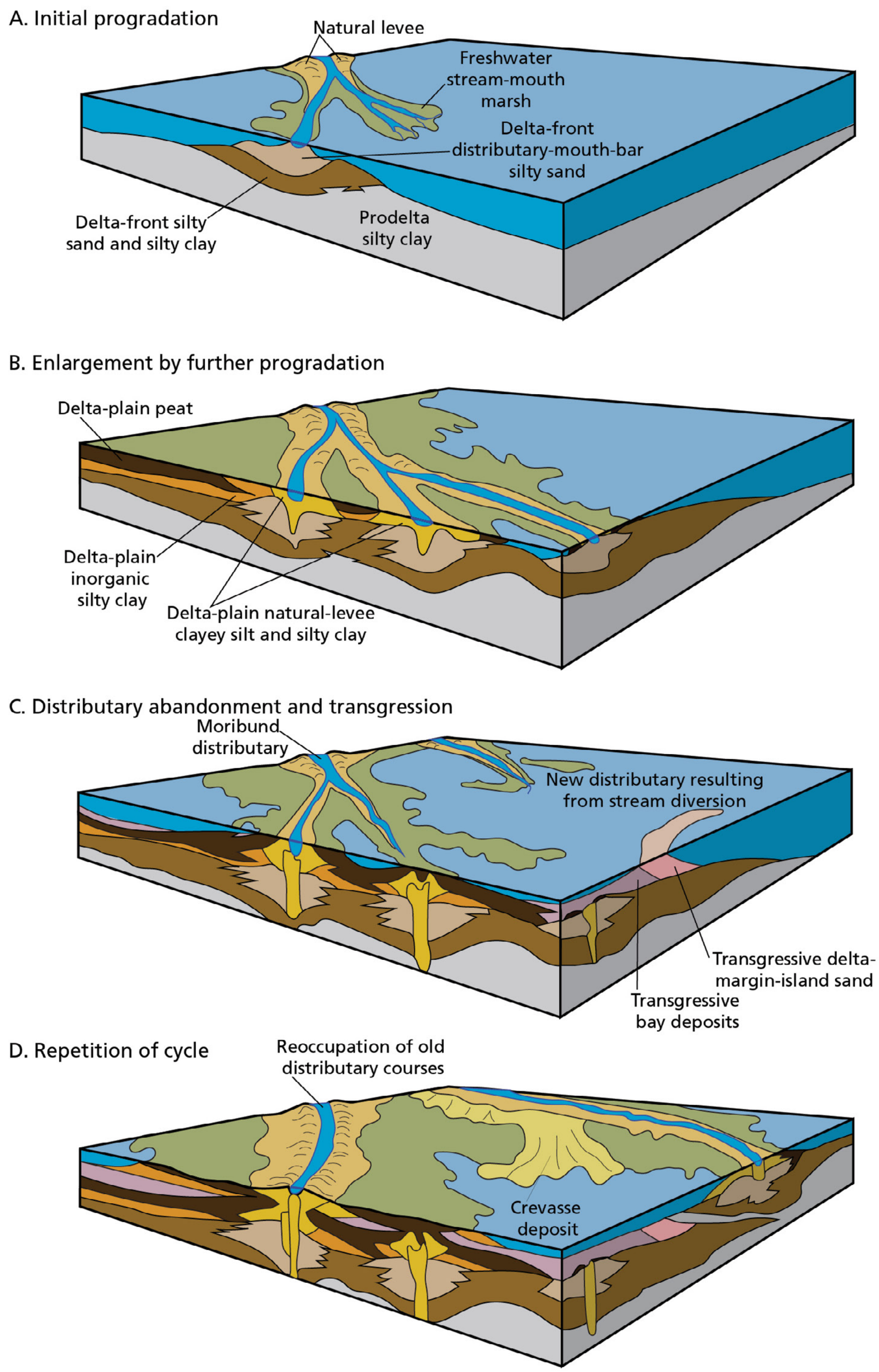

Figure 12. Vertical sedimentary sequence resulting from the delta cycle.
The four successive diagrams (A–D) illustrate the development of repetitive deltaic sedimentary packages (referred to as "facies") in the coastal portion of a typical delta complex. Delta formation begins with the progradational phase (A) as a stream distributes its sediment load into a standing body of water. As progradation continues, the delta plain is enlarged (B). Continued progradation leads to an overextension of the distributary network. Under these conditions, stream diversion into a steeper gradient course takes place. As depicted in diagram C, an underdeveloped upstream distributary has diverted more and more floodwaters and finally has been reopened and developed as a favored course. The older, moribund distributary network no longer is capable of prograding or aggrading the delta plain. Commonly, the principal distributary of the abandoned network is reoccupied. When this occurs, as shown in diagram D, a repetition of depositional phases results, and the vertical sequence of deltaic facies is repeated. Graphic by Trista Thornberry-Ehrlich after Frazier (1967, figure 2).

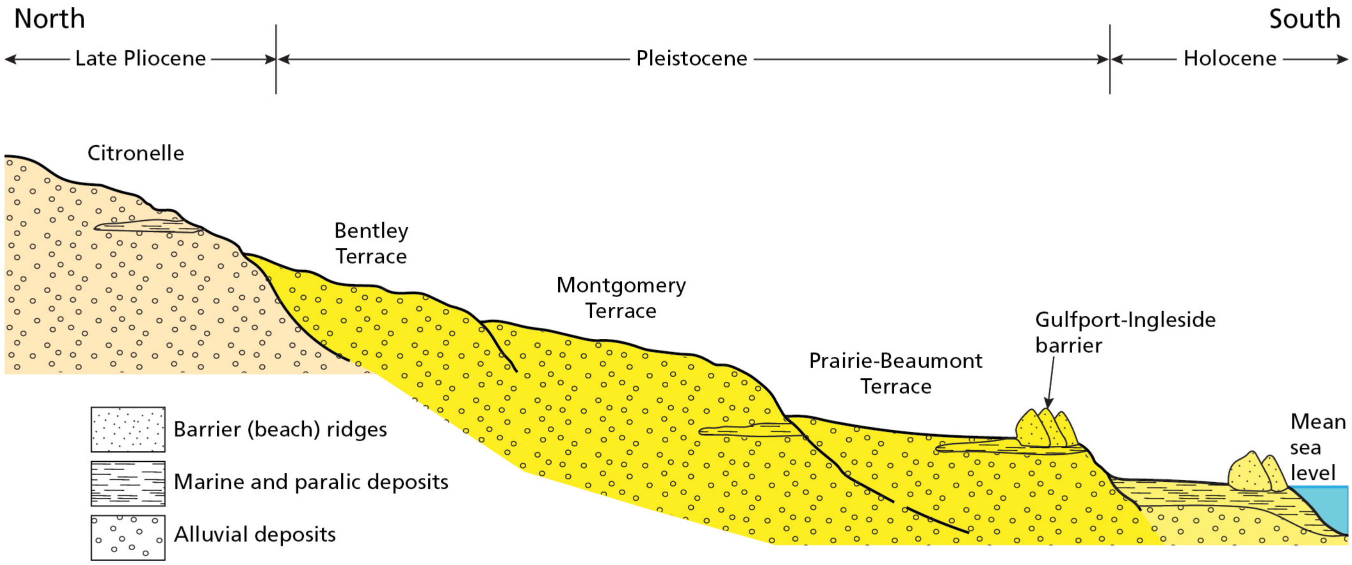

Figure 13. Generalized composite cross section across northern Gulf coastal plain terrace units. No scale. This combination of the major coastal landforms—barrier islands, terraces, and bedrock outcrop—is not found in site-specific shore-normal cross sections; elevation and width are highly variable between locations. The Prairie Terrace is of primary interest to the park. It underlies the Acadian and Prairie Acadian Cultural Centers. Although not within the area included in the GRI GIS data for the park, the Pliocene Citronelle Formation consists of deeply dissected alluvial deposits of streams originating from nonglacial sources. The Citronelle Formation crops out north of Lake Pontchartrain in the Gulfport 30 × 60 minute quadrangle (Heinrich et al. 2004). Paralic deposits are "by the sea" but not marine. Alluvial deposits are associated with rivers and streams. Graphic by Trista Thornberry-Ehrlich (Colorado State University) after Otvos (2005, figure 1).

stage [MIS 5a]; see Lisiecki and Raymo 2005) during the last glacial–interglacial cycle (Shen et al. 2012, 2013).

The Prairie Terrace is formally referred to as the "Prairie Allogroup" in the US Geologic Names Lexicon ("Geolex"), which is a national compilation of names and descriptions of geologic units. The Prairie Allogroup consists of a collection of late-Pleistocene depositional sequences of alloformation rank (Autin et al. 1991; Heinrich et al. 2004). An alloformation is the fundamental allostratigraphic unit, which is a mappable layer, bed, or stratum consisting of roughly parallel bands or sheets of sediment; it is defined and identified on the basis of its bounding discontinuities (any interruption in sedimentation) rather than on the basis of lithologic (rock characteristics such as color, mineral composition, and grain size) change. Like rock formations, alloformations may be separated into members or lumped into a group.

During detailed and reconnaissance mapping (scales 1:24,000 and 1:100,000) by the Louisiana Geological Survey between 2000 and 2014, the Prairie Allogroup was subdivided into formal and informal alloformations. US Geologic Names Committee (2010) noted the usage of alloformations on a variety of 30 × 60 minute quadrangles in Louisiana. With respect to the GRI GIS data for the park, Heinrich and Autin (2000) mapped the Beaumont, Avoyelles, and Big Cane Alloformations as formal units on the Baton Rouge 30 × 60 minute quadrangle; as a consequence, the term "Alloformation" was capitalized to indicate a formal rank. In the Ville Platte (Snead et al. 2002) and Crowley (Heinrich et al. 2003) 30 × 60 minute quadrangles, however, only the Beaumont Alloformation was mapped as formal; the Avoyelles alloformation and Big Cane alloformation were mapped as informal units (note the lowercase "a" in alloformation). Capitalizing the name of an alloformation is a way of indicating the status of these units. For consistency—and to reflect the informal rank of these units as listed in the US Geologic Names Lexicon ("Geolex"), which only recognizes the Prairie Allogroup as formal—the term "alloformation" is spelled with a lowercase "a" in this GRI report and in the GRI GIS data.

Three alloformations of the Prairie Allogroup are included in the GRI GIS data for the park, from oldest to youngest: (1) Beaumont (map unit **PEpbe**), (2) Avoyelles (**PEpav**), and (3) Big Cane (**PEbpcl** and **PEpbcu**). The Beaumont alloformation underlies the Prairie Acadian Cultural Center (see Prairie Acadian Cultural Center poster, in pocket). The Avoyelles alloformation underlies the southern part of the Acadian Cultural Center (see Acadian Cultural Center poster, in pocket). The Big Cane alloformation does not occur within the park.

The Avoyelles alloformation is associated with the ancestral Mississippi River; meander belt deposits of the late Pleistocene Mississippi River are terraced above and parallel to its alluvial valley in central L ouisiana. The Beaumont and Big Cane alloformations are associated with the ancestral Red River. The Beaumont alloformation is the oldest and topographically highest of the Prairie surfaces west of the Mississippi River valley; it is composed of coastal plain deposits of late to middle Pleistocene streams. The Big Cane alloformation appears to be a former Red River meander belt; it is divided into a lower (**PEbpcl**) and upper (**PEpbcu**) unit (see table 2). The lower Big Cane alloformation (**PEbpcl**) is the older and highest of the two terraces found within the Big Cane alloformation. The upper Big Cane alloformation (**PEpbcu**) is the younger and lowest of the two terraces found within the Big Cane alloformation.

Peoria Loess

As much as 4 m (13 ft) of Peoria Loess (widespread deposit of windblown silt) buries the Pleistocene alluvium along the eastern escarpment of the Prairie Terrace (Autin and Aslan 2001). Loess deposits represent silt deflated from active and abandoned glacial outwash plains of the Wisconsinan and earlier glacial periods. The Peoria Loess was deposited 25,000–9,000 years ago (Pye and Johnson 1988; Rutledge et al. 1996).

Loess deposits blanket and obscure underlying Pleistocene units, making stratigraphic studies difficult. Nevertheless, loess deposits are a valuable chronstratigraphic indicator because of their distinctive morphology and widespread nature. Loess extends in a band, generally 25 to 30 km (16 to 19 mi) wide, from western Kentucky to south of Baton Rouge, Louisiana, and flanks both sides of the lower Mississippi River valley. Deposits attain their greatest thickness and continuity east of the river. Near the Mississippi River bluffs, the thickness of Peoria Loess averages 15 m (50 ft), with maximum thickness of about 27 m (89 ft) in the Natchez–Vicksburg area (see GRI scoping summaries about Natchez Trace Parkway and Vicksburg National Military Park by KellerLynn 2010b and 2010c, respectively).Within the park, Peoria Loess mantles the Avoyelles (**PEpav**) and Beaumont (**PEpbe**) alloformations (i.e., Prairie Terrace) at the Acadian and Prairie Acadian Cultural Centers, respectively. Peoria Loess was mapped in the following 30 × 60 minute quadrangles: Baton Rouge (Heinrich and Autin 2000), Ville Platte (Snead et al. 2002), Crowley (Heinrich et al. 2003), and Ponchatoula (McCulloh et al. 2003). These maps show loess deposits with thicknesses of 1 m (3 ft) or greater. Heinrich and Autin (2000; i.e., Baton Rouge quadrangle) described the Peoria Loess as an eolian silt veneer of late Wisconsinan age mantling Pleistocene strata. The GRI GIS data include the Peoria Loess as map unit **PEpl**.

Meander Belts

Mississippi River meander belts may be many kilometers wide and hundreds of kilometers long. Five meander belts have been recognized in the lower Mississippi River valley. The oldest deposits, which are part of meander belt 5, are an estimated 9,190 to 8,070 years old. The GRI GIS data for the park contain deposits of meander belts 3 and 1. Mississippi River meander belt 3 (lower and upper deposits [**Hmm3l** and **Hmm3u**]) is near the Acadian Cultural Center (see poster, in pocket). Mississippi River meander belt 1 (**Hmm1**) lies west of the French Quarter Visitor Center (see poster, in pocket). In addition, a natural levee complex of Mississippi River meander belt 1 (**Hml1**) underlies the French Quarter Visitor Center and Chalmette Unit. Meander belt 3 is about 7,850 to 4,320 years old. Meander belt 1 is 4,500 to 4,200 years old (Prokocki 2009).

The GRI GIS data also include a meander belt of the St. Bernard delta lobe (**Hdsm**); these sandy point bar deposits were mapped along the Bayou des Familles and Bayou La Loutre distributary courses (see Chalmette Unit, French Quarter Visitor Center, and Barataria Preserve poster, in pocket). In addition, the data include the meander belt of the Teche course (Bayou Teche) of the Red River (**Hrm**) (see Acadian Cultural Center poster, in pocket).

Meander belts are characterized by natural levees (see “Natural Levees”), crevasse splays (see “Crevasse Complexes”), distributaries (waterways that diverge from a primary channel by distributing flow away from the main course), abandoned channels, and point bar accretion (Saucier 1994).

Point bars form on the inside (“point”) of a bend in the river channel, where water velocity slows and allows the sediment load to drop out of or settle to the channel bed. Lateral migration of the river channel creates narrow sequences of sandy point bar sediments that are 20 to 30 m (70 to 110 ft) thick. The sand in the baseof the point bar is deposited through lateral accretion (channel migration), and the finer silt and clay deposits overlying the coarse base are the product of vertical accretion during floods (Byrnes et al. 2018).

Where multiple point bars develop, they create ridge-and-swale sequences that also are referred to as "scrolls," "meander scrolls," or "scroll-bar sequences" (fig. 14). These features record the directions of river-bend migration and are a characteristic pattern of a meandering stream (Saucier 1994). Collectively, the series of ridges and swales comprises a point bar landform that commonly dominates the landscape of an alluvial valley formed by an actively meandering river (Byrnes et al. 2018).

Meander belt deposits of the St. Bernard delta lobe (**Hdsm**) were mapped where overlying natural levee deposits (**Hdsl**) are sufficiently thin that "scroll marks" of ridge-and-swale topography, however faint, are perceptible as a surface indicator of point bars and thus Mississippi River meander belts. The Chalmette Unit, French Quarter Visitor Center, and Barataria Preserve poster (in pocket) shows four meander belt deposits (**Hdsm**) south of Barataria Preserve where ridge-and-swale features were used in geologic mapping. Ridge-and-swale topography also was used to map a deposit of Mississippi River meander belt 1 (**Hmm1**) about 20 km (12 mi) west of the French Quarter Visitor Center (see poster, in pocket). All these ridge-and-swale instances were interpreted from lidar elevation data (fig. 15) that suggest average amplitude as small as 50 cm (20 in) (Richard McCulloh, Louisiana Geological Survey, research associate, email communication, 13 February 2019).

Backswamp Deposits

Backswamps are flat, shallow, poorly drained marshy floodplains bounded by natural levees. Overbank flooding allows slow, incremental sedimentation of backswamps.

Backswamp deposits (**Hb**) underlie floodplains between meander belts and consist of fine-grained, usually clayey, and commonly organically rich sediments. Such deposits occur north of the Wetlands Acadian Cultural Center (see poster, in pocket) and are located behind the natural levee deposits of Mississippi River meander belt 1 (**Hml1**). Some backswamp deposits are located northeast of the Acadian Cultural Center (see poster, in pocket); these particular deposits are associated with the Vermillion River (**Hs**). Other nearby backswamp deposits in the Baton Rouge quadrangle (Heinrich and Autin 2000) occur between Bayou Teche (**Hrm**) and the Atchafalaya River.

Small River Deposits

Small river deposits, undifferentiated (**Hs**) consist of alluvial deposits of small rivers that were grouped together during mapping. The map unit contains natural levees, distributaries, and abandoned channels that are recognizable in the field but too small to have been mapped individually at a scale of 1:100,000 (Heinrich and Autin 2000). Small river deposits (**Hs**) of the Vermillion River were mapped at the Acadian Cultural Center (see poster, in pocket).

Natural Levees

Over thousands of years, repeated overbank flooding forms natural levees, which are the highest elevation features and the most prominent landforms of the New Orleans and southern Louisiana areas. The lowest natural elevations in the area are in the interdistributary basins between natural levees, which are usually under brackish water conditions. Natural levees make up the ridges flanking both sides of the channels of the Mississippi River, the trunk channels of abandoned delta lobes, and the distributaries that branch off them. Natural levees are highest adjacent to the banks of their associated channel and slope downward away from it, laterally merging with the surrounding wetlands.

Natural levees are composed of coarse sediments along river channels. Sediment sorting results in lateral fining of flood deposits, so that the floodplains beyond the natural levee have finer sediments. This results in a landform that slopes toward lower lying floodplain bottoms (Hudson 2005). Areas adjacent to the levee have clayey peat, whereas areas farthest from the levees (seldom reached by floodwaters), have peat with very little inorganic material (Frazier 1967).

Because of their elevation, natural levees are the sites of nearly all of the major inhabited and cultivated areas within the Mississippi River Delta. The lack of space on natural levees, which are narrow, has prompted the draining of adjacent marshes and swamps in favor of the expansion of urban development (Kolb and Saucier 1982; Saucier 1994). In the Chalmette Unit and Barataria Preserve, bottomland hardwood forests (fig. 16) have grown on the abandoned natural levee and backslope of a former Mississippi River distributary and Bayou des Familles (**Hdsl**). Old networks of ditches drain these areas.

The GRI GIS data for the park contain natural levee deposits of the distributaries of the St. Bernard (**Hdsl**), Lafourche (**Hll**), and Plaquemines (**Hdpl**) delta lobes. The natural levees of the St. Bernard (**Hdsl**) and Plaquemines (**Hdpl**) distributary courses (see Chalmette Unit, French Quarter, and Barataria Preserve poster, in pocket) consist predominantly of silt, silty clay, and clay. The natural levees of the Lafourche distributary course (**Hll**) consist of sandy silts and silt that grade downstream and away from their crests into silty clay and clay. Deposits of the Lafourche distributary course (**Hll**) underlie the Wetlands Acadian Center (see poster, in pocket) and were mapped southwest of Barataria

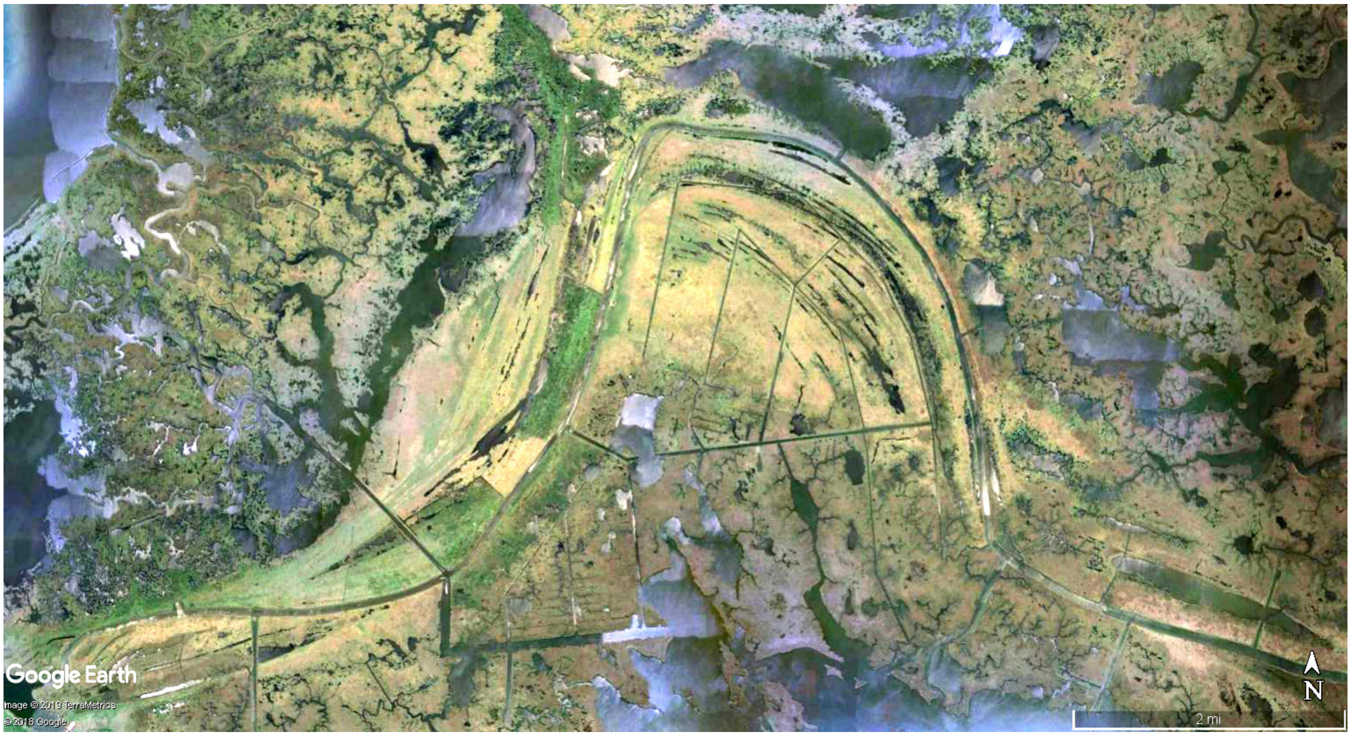

Figure 14. Satellite imagery of ridge-and-swale topography.
Distinctive ridge-and-swale features mark the former locations of meandering distributary streams, in particular, point bar deposits. The closest "visible" ridge-and-swale topography to the park is at Bayou La Loutre, St. Bernard Parish. This particular feature lies on the St. Bernard delta lobe. Ridge-and-swale features also occur in the New Orleans area, but urbanization has hidden these features from detection in remote imagery. Paul Heinrich (Louisiana Geological Survey) provided inspiration and information about this feature. Google Earth imagery © TerraMetrics (accessed 13 February 2019).

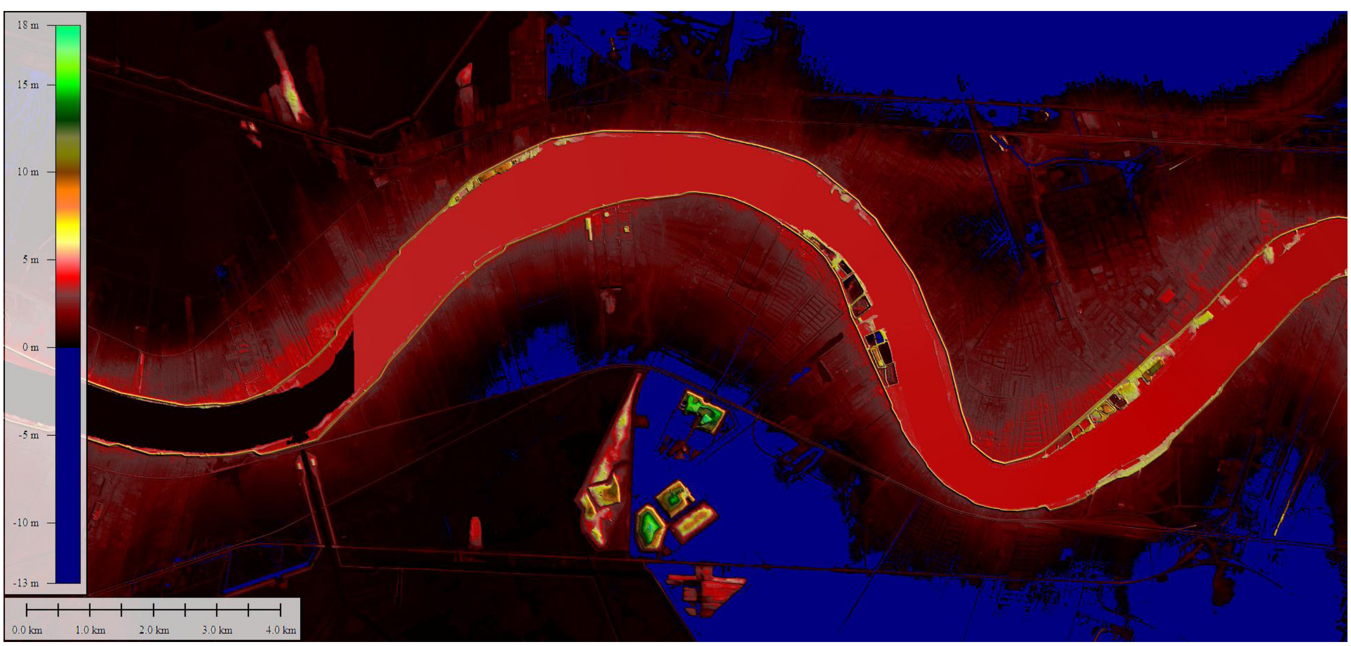

Figure 15. Lidar imagery of Mississippi River meander belt 1.
This image reveals the subtle topography of a 4,500-year-old meander of the Mississippi River (map unit Hmm1). This meander belt, which is the youngest of five that have been recognized in the lower Mississippi River valley, is about 20 km (12 km) west of the French Quarter Visitor Center. Imagery by US Army Corps of Engineers, Saint Louis District, 2001.

Figure 16. Photograph of Bayou Coquille Trail in Barataria Preserve.
Bottomland hardwood forest along the Bayou Coquille Trail in Barataria Preserve is a type of ecological zone found on point-bar, ridge-and-swale topography of natural levees (map units Hml1, Hml3u, Hdpl, Hll, and Hdsl). NPS photograph by Jeff Bracewell (Gulf Islands National Seashore) taken in September 2006.

Preserve and Lake Salvador (see Chalmette Unit, French Quarter, and Barataria Preserve poster, in pocket).

The GRI GIS data also contain levee deposits associated with the Mississippi River meander belts 3 and 1 (**Hml3u** and **Hml1**). Deposits of the natural levees flanking Mississippi River meander belt 3 (**Hml3u**) are silty to less commonly sandy overbank deposits that compose the low natural levees that flank the Bayou Teche occupation of meander belt 3. Some of these deposits (**Hml3u**) are located east of the Acadian Cultural Center along Bayou Teche (**Hrm**) (see poster, in pocket). Deposits of the natural levees flanking Mississippi River meander belt 1 (**Hml1**) typically consist of sandy silt, silt, clayey silt, silty clay, and clay. These deposits underlie the French Quarter Visitor Center and the Chalmette Unit (see Chalmette Unit, French Quarter, and Barataria Preserve poster, in pocket).

Crevasse Complexes

The GRI GIS data for the park contain crevasse complexes that are composed of crevasse channel and splay deposits of Mississippi River meander belts 3 (**Hmc3u** [upper deposits]) and 1 (**Hmc1**). Silty to sandy deposits of crevasse splays originating from the Bayou Teche occupation of meander belt 3 occur east of the Acadian Cultural Center (see poster, in pocket), and crevasse channel and splay deposits of Mississippi River meander belt 1 occur upstream from (west of) the French Quarter Visitor Center (see poster, in pocket).

Crevasse complexes occur where a river breaks through a natural levee and deposits sediment, creating higher ground (fig. 12). They are associated with distributary channels that diverge from the main course. Crevasse complexes (channel and splay deposits) are small-scale depositional landforms (table 5) that develop from floodwaters flowing out of the channel bank, overtopping and scouring the natural levee, and building a fan-shaped extension of the levee surface flanking the channel. This class of depositional feature is rarely active for more than two or three decades, usually has a thickness of 2 to 3 m (7 to 10 ft), and covers an area of less than 15 km^2 (6 mi^2) (Roberts 1997). If flooding is of sufficient duration, however, a permanent distributary channel can become established through an initial crevasse channel (Saucier 1994).

Alluvium

Holocene alluvium, undifferentiated (**Hua**) consists of deposits of minor streams and creeks that are filling valleys cut into older deposits. Notable Holocene alluvium occurs near the Acadian and Prairie Acadian Cultural Centers (see posters, in pocket). These Holocene streams have cut into the Prairie Terrace (**PEpav** and **PEpbe**). The modern floodplain within these valleys constitutes the surface of these alluvial deposits. The lithology (rock types and characteristics) of these deposits reflects the reworked lithology of their adjacent source.

Delta Lobe Deposits

The GRI GIS data for the park contain delta lobe deposits of the St. Bernard (**Hds**), Lafourche (**Hdl**), and Plaquemines (**Hdp**) delta lobes. These deposits are part of the Mississippi River delta plain and are composed of cyclically interbedded interdistributary peat and clay, natural levee silt and clay, distributary sand, delta-front sand, and prodelta mud and clay. Where discontinuous sandy beaches were too narrow and thin to be mapped separately, they were included as part of deposits of the Plaquemines delta lobe (**Hdp**) (Heinrich 2014).

Deposits of the St. Bernard delta lobe (**Hds**) underlie most of Barataria Preserve, though a small part of the preserve is underlain by deposits of the Plaquemines delta lobe (**Hdp**) (see poster, in pocket). Deposits of the Lafourche delta lobe (**Hdl**) occur in the vicinity of the Wetlands Arcadian Cultural Center (see poster, in pocket).

Delta lobe deposits make up narrow and linear but topographically prominent deltaic distributaries, which form the framework of a delta plain. In more coastal areas, broad expanses of intertidal marshes separate distributaries. In more inland areas, swamps separate distributaries (Saucier 1994). Like natural levees elsewhere (see "Natural Levees"), natural levees adjacent to deltaic distributaries have dictated the location and configuration of human settlement patterns as well as communication/transportation routes in both prehistoric and historic times (Saucier 1994).

Wetlands

Growth of the Mississippi River delta plain over the past 7,000 years has produced more than 2.5 million ha (6.2 million ac) of wetlands that form and degrade as the river switches course every 1,000 to 2,000 years (Coleman et al. 1998; Mendellson et al. 2017). Wetlands of the Mississippi River Delta account for 60% of the coastal wetlands in the lower 48 states (Boesch et al. 1994). Within the park (and with respect to the GRI GIS data), wetlands (i.e., "marsh" as identified on the USGS topographic base of the New Orleans 30 × 60 minute quadrangle used by Heinrich et al. 2011) are associated with the St. Bernard delta lobe, namely "deposits of the delta lobe" (**Hds**). Additionally, marsh appears to have impinged upon some low-lying areas of natural levee deposits of the delta lobe (**Hdsl**).

An in-depth discussion of the classification of marsh and vegetation type is beyond the scope of this GRI report. Resource managers are directed to work by Penfound and Hathaway (1938), Chabreck (1970), and Chabreck and Linscombe (1982), which categorized the marshes of coastal Louisiana into four types: saline, brackish, intermediate, and fresh; and Visser et al. (1998), which expanded on this "salinity scheme," providing nine vegetation types to describe mashes of the Mississippi River delta plain. In addition, Kosters (1989) provided a useful summary of terminology used in describing wetlands, which may be of use or interest to resource managers.

In general geomorphic terms, wetlands of the Mississippi River Delta can be divided into three categories: marsh, forested swamp, and barrier island. The park contains marsh and swamp (figs. 17 and 18). Descriptions of marshes in the geologic literature commonly include "fresh," "brackish," and "saline" in reference to the water within a marsh: Freshwater has <1,000 mg/L of dissolved solids. Saline (or salt) water has >1,000 mg/L of dissolved solids. Brackish water is an indefinite term for water with a salinity indeterminate between that of average seawater (35) and freshwater (0) (Neuendorf et al. 2005). Byrnes et al. (2018, p. 17) provided the following geologically relevant descriptions of wetlands for the Barataria basin:

- Marsh deposits generally form when interdistributary deposits fill an area to approximately sea level forming shallow water areas and subaerial land where grasses can grow. They are typically composed of soft to very soft clays, organic clays, and peat. In areas lacking a source of inorganic sediment, thick sequences of organic peat will accumulate. Fresh marshes generally contain more organic and less inorganic material than brackish and saline marshes. Brackish and saline marshes receive inorganic

Figure 17. Photographs of marshes in Barataria Preserve.
The top photograph shows a freshwater marsh. The bottom photograph shows a more saline marsh near the confluence of Bayou Villars with Lake Salvador. Photographs from Urbatsch et al. (2009, figures 9 [top] and 3 [bottom]).

Figure 18. Photographs of swamps in Barataria Preserve.
Bald cypress–tupelo swamp occurs on geologic units Hds and Hdsl in Barataria Preserve. Top photograph from Urbatsch et al. (2009, figure 10). Bottom photograph by Katie KellerLynn (Colorado State University) taken in April 2010.

sediments from lakes and bays during storms and floods, resulting in higher bulk densities relative to fresh marshes.

- Swamp environments form by vertical accretion of sediment that is deposited during times of high freshwater flow, when the natural levees are crested and suspended sediment in floodwaters is deposited. Swamps are low, commonly poorly drained, tree-covered areas flanking natural levees of distributary channels. Elevation is sufficiently high to allow woody vegetation to develop and become stable. Swamp deposits are mainly located in the northern portion of the Barataria basin as 3- to 6-m- (10- to 20-ft-) thick deposits primarily of silty clay and clay. Deposits typically contain moderate to high organic content in the form of decayed roots, wood, and peat; soils generally have high water content.

The majority of the fresh marsh in Barataria Preserve is flotant, which consists of a thick (15–30 cm [6–12 in]) floating mat of living and dead organic material held together by intertwined plant roots (fig. 19). The mat detaches from the substrate then rises and falls with the water level beneath it. Sometimes flotant is submerged. Flotant occurs in areas relatively protected from clastic influx (of sediment) in quiet, protected, low-energy environments (Kosters 1989; Sasser et al. 1995). Flotant within and around Barataria Preserve is extensive and comparable in area to other floating marsh communities found in other major river deltas of the world such as the Amazon, Congo, Danube, Nile, and Okavango Rivers (Sasser et al. 1995). Studies of flotant in the Mississippi River delta plain have been predominantly ecological and biological in nature (Kosters 1989), though Russell (1942) studied flotant from a geomorphic perspective.

Barataria Preserve also has bald cypress-tupelo swamps (fig. 18) in areas that are inundated most of the year, including areas located east of Kenta Canal extending north and south through the preserve and in poorly drained areas along Bayous des Familles. These areas were mapped as **Hds**.

Faults

A fault is a surface or zone along which displacement has taken place. Movement may be horizontal (a strike-slip fault) or vertical (a dip-slip fault). Most faults in southern Louisiana are normal faults (a type of dip-slip fault), which are associated with extension (pulling apart) of Earth's crust (fig. 20). Snead et al. (2002) and Heinrich et al. (2003) mapped normal faults in the Ville Platte and Crowley 30 × 60 minute quadrangles, respectively. One of these fault segments is about 5 km (3 mi) south of the Prairie Acadian Cultural Center (see poster, in pocket).

Most faults in southern Louisiana are growth faults (fig. 21), which form contemporaneously with deposition f sediments so that strata on the downthrown side are thicker than correlative strata on the upthrown side of the fault. Investigators (e.g., Roberts et al. 1994) have attributed growth faulting to the construction and extension of the Mississippi River delta plain southward into the Gulf of Mexico. Growth faults form as sedimentary deposits creating the delta prograde down an inclined basement of underlying rocks. Downslope overextension of the prograding delta front may induce detachment and the formation of fault zones that slip by breakaway and gravitational slumping (Gagliano et al. 2003a; Dokka 2006).

In addition, Louisiana has a series of deep-seated (7,600–9,100 m [25,000–30,000 ft] below the surface), east–west-trending faults (fig. 21). Movement has been taking place on some regional faults for more than 100 million years and continuing into recent decades (Gagliano 2005a). Oligocene faults (movement taking place between 33.9 million and 23.0 million years ago) underlie Lake Pontchartrain and the New Orleans area near Barataria Preserve and the Chalmette Unit. Salt domes (see "Salt Domes") are associated with many of the faults in southeast Louisiana but are absent or rare in the area near Barataria Preserve (Gagliano 2005b).

On the surface, faulting usually causes subtle changes, such as a slump rather than a defined scarp, because the overlying sediments are soft and unconsolidated. Subsurface faults, however, have left linear and arc-shaped traces that are 5 to 8 km (3 to 5 mi) long, which are associated with areas of rapid land loss on the down-dropped blocks that tilt toward the fault and have vertical displacements of 0.3 to 1.1 m (1 to 3.5 ft) (Gagliano et al. 2003a).

Lake Salvador may have formed as a result of a pre-1800 earthquake along the Lake Salvador fault zone, which runs along the north side of the lake (fig. 22); the lake's south side is bordered by the Lake Hatch fault zone (Gagliano et al. 2003a). The Lake Sand-Thibodaux fault may have created the arc of deep holes extending from Morgan City to Thibodaux (fig. 22; Gagliano et al. 2003a).

Salt Domes

During the Jurassic Period (201.3 million–145.0 million years ago), fluctuating sea levels and ocean currents promoted the precipitation (formation out of solution) of large salt masses along the ocean basin floor. Later, growth and expansion of the Mississippi River Delta buried these deposits. Due to its relative low density, the salt rose through the overlying deltaic sediments, creating salt domes, also referred to as "salt diapirs."

Figure 19. Photograph of flotant in Barataria Preserve.
The majority of freshwater marsh within the preserve is flotant—a floating mat of living and dead organic material held together by intertwined plant roots. The mat detaches from the substrate then rises and falls with the water level beneath it. Some flotant is submerged. NPS photograph by Jeff Bracewell (Gulf Islands National Seashore) taken in September 2006.

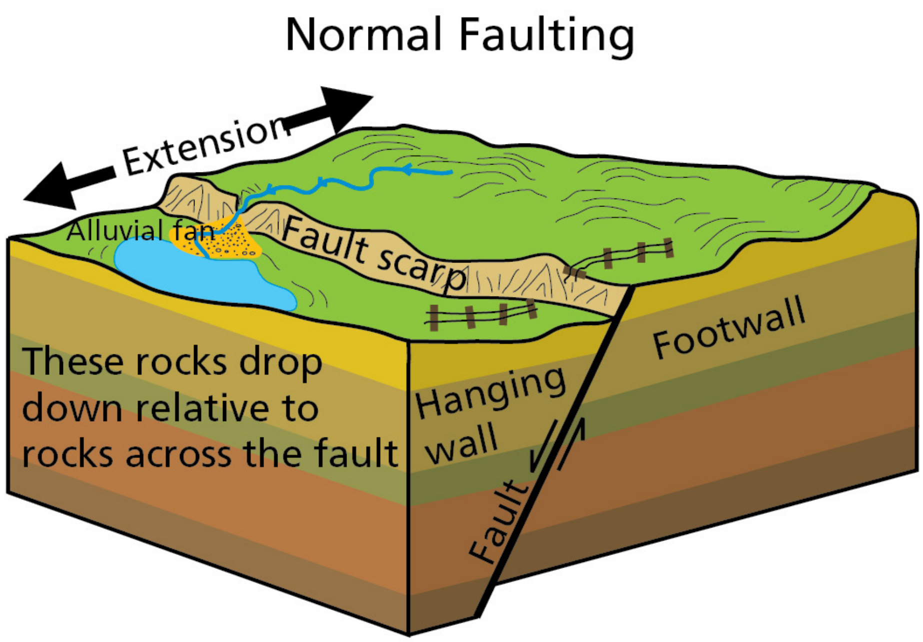

Figure 20. Graphic of normal fault.
Movement occurs along a fault plane. Footwalls are below the fault plane and hanging walls are above. In a normal fault, crustal extension (pulling apart) moves the hanging wall down relative to the footwall. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

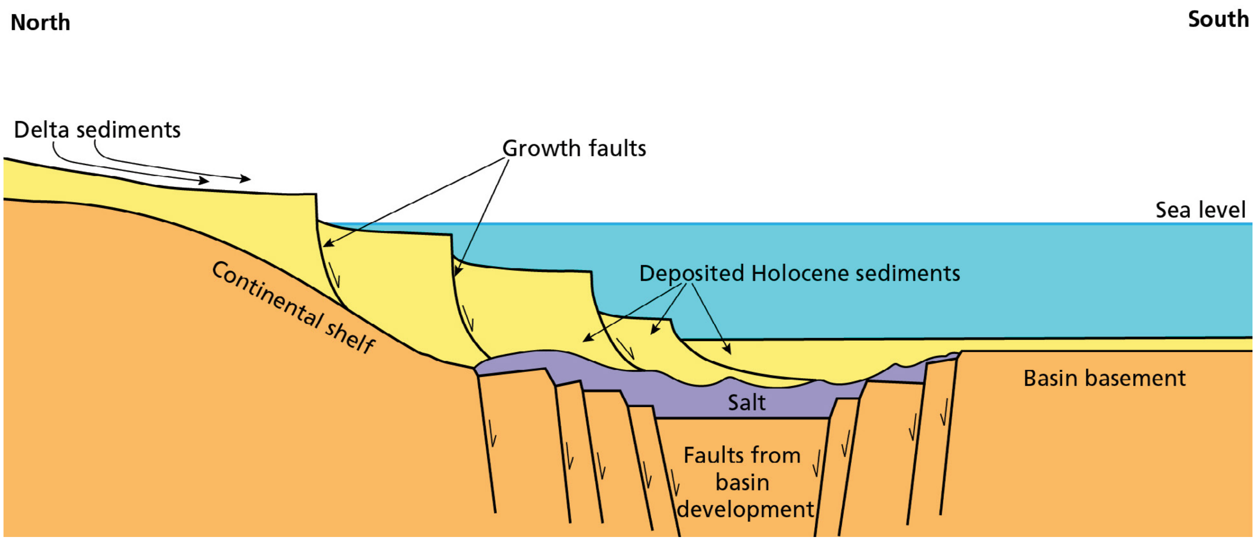

Figure 21. Generalized cross section across coastal Louisiana and the Gulf of Mexico. **Old, deep-seated faults within the Gulf of Mexico basin basement are associated with its initial formation. Throughout much of the Jurassic Period, fluctuating sea levels and ocean currents promoted the precipitation of large masses of salt along the basin floor, which remained under shallow water. Development of the Mississippi River Delta covered the salt deposits with sediments. Growth faulting is attributed to the construction and extension of the Mississippi River delta plain southward over the continental shelf edge into the Gulf of Mexico basin. Graphic by Trista Thornberry-Ehrlich (Colorado State University) after Yuill et al. (2009, figure 1).**

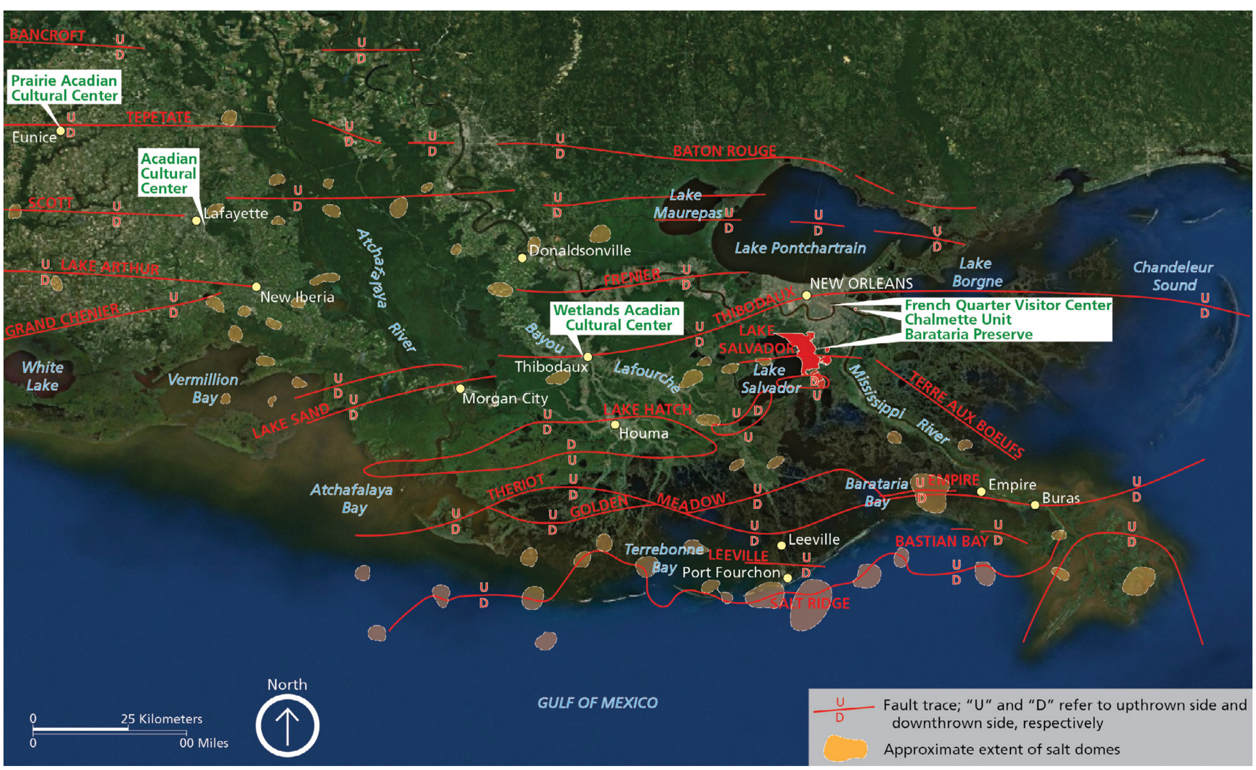

Figure 22. Graphic showing locations of growth faults and salt domes in southeast Louisiana. **The red lines on the graphic represent recognized growth faults. Round, shaded areas delineate the location and extent of salt domes. The bright red area marks Barataria Preserve. Other park sites also are labeled. Graphic by Trista Thornberry-Ehrlich (Colorado State University) based on information in Gagliano et al. (2003b).**

Most of the shallow salt bodies within coastal Louisiana are beyond the continental shelf margin (fig. 22). Some breach the base of the Pleistocene–Holocene contact, which is 549 to 1,311 m (1,800 to 4,300 ft) below the surface in southeast Louisiana. Some of these salt domes near the modern surface (Gagliano et al. 2003a).

Where salt intrudes into fault zones, movement can be triggered (Yuill et al. 2009). Little evidence directly links salt migration with the magnitude of current subsidence rates in coastal Louisiana (see "Subsidence"), though relevant research on the topic has been minimal (Yuill et al. 2009).

Paleontological Resources

Kenworthy et al. (2007) summarized known paleontological resources and the potential for discovery of such resources for all parks in the Gulf Coast Inventory & Monitoring Network, including Jean Lafitte National Historical Park and Preserve. The park's museum collection contains no paleontological specimens, and because of the young age (Holocene; fig. 4) of the sedimentary deposits (table 2) within Barataria Preserve, the Chalmette Unit, French Quarter Visitor Center, and the Wetlands Acadian Cultural Center, the potential is low for discovery of paleontological resources at these park sites (Kenworthy et al. 2007).

The Pleistocene deposits at the Prairie Acadian Cultural Center (Beaumont alloformation, **PEpbe**) and Acadian Cultural Center (Avoyelles alloformation, **PEpav**), however, have potential for fossil resources. Significantly, the Beaumont alloformation, which underlies the Prairie Acadian Cultural Center, correlates with the Beaumont Formation of Texas, which crops out in Big Thicket National Preserve (see GRI report by Trista Thornberry-Ehrlich 2018). The Beaumont Formation has yielded fossils; for example, rhinoceros and mammoth material were recovered from these Miocene and Pleistocene river deposits near or within Big Thicket National Preserve (Kenworthy et al. 2007). Fossils are not yet reported from the Avoyelles alloformation (**PEpav**) at the Acadian Cultural Center.

In addition, loess (see "Peoria Loess") is very fossiliferous; for example, loess deposits in Vicksburg, Mississippi, about 320 km (200 mi) north-northeast of Lafayette, have yielded gastropods and mammoth remains (see GRI scoping summary about Vicksburg National Military Park by KellerLynn 2010c). Thus, loess deposits that cover the Beaumont and Avoyelles alloformations at the cultural centers in Eunice and Lafayette may be fossiliferous. According to Kenworthy et al. (2007), road cuts and excavations of loess deposits in both Mississippi and Louisiana have yielded fossils, though none are yet reported near the Acadian Cultural Center in Lafayette or the Prairie Acadian Cultural Center in Eunice.

Geologic Resource Management Issues

Some geologic features, processes, or human activities may require management for human safety, protection of infrastructure, and preservation of natural and cultural resources. The NPS Geologic Resources Division can provide technical and policy assistance.

Participants at the 2010 scoping meeting (see GRI scoping summary by KellerLynn 2010a) and 2017 conference call identified the following resource management issues of importance for the park. Additional issues were identified and added during the research, writing, and review process of this report. The issues are listed in alphabetical order.

- Climate change impacts (including sea level rise)
- Coastal resources management and planning
- Data, research, and planning needs
- Disturbed lands (including coastal engineering, abandoned mineral lands, canals and spoil banks, artificial waterways, and artificial levees)
- Earthquakes
- Hurricanes
- Land loss
- Oil and gas operations
- Recreational and watershed land use
- Restoration and coastal protection projects
- Subsidence

In October 2018, 1,398 ha (3,455 ac) of the Fleming Plantation were added to the park's boundary. This area is south of the Gulf Intracoastal Waterway and consists of delta deposits (**Hds**) and natural levee deposits (**Hdsl**) of the St. Bernard delta lobe (see table 2 and "Geologic Features of the GRI GIS Data"). The area contains fresh, intermediate, and brackish water wetlands (see "Wetlands"). Discussions in this chapter do not specifically address the Fleming Plantation Area, but park managers anticipate similar geologic resource management issues to those in the previously established portions of Barataria Preserve. The main recognized issue that the boundary expansion created is the inclusion of additional active oil and gas operations and nonfederal oil and gas rights within the park's boundary (see "Oil and Gas Operations").

Climate Change Impacts

As measured at the park, recent climatic conditions have shifted beyond the historical range of variability (Monahan and Fisichelli 2014). Although Louisiana has exhibited little overall warming in surface temperatures over the past century, the past decade has been extremely warm compared to the last century, as measured by multiple temperature variables at the park; these variables include annual mean temperature, maximum temperature of the warmest month, and mean temperature of the warmest quarter (Monahan and Fisichelli 2014). Furthermore, increased emissions are projected to cause historically unprecedented warming by the end of the 21st century (Frankson et al. 2017).

The park also experienced extreme dry and extreme wet conditions in the last decade (Monahan and Fisichelli 2014). In southeast Louisiana, precipitation averages about 178 cm/yr (70 in/yr). Summer precipitation in Louisiana is projected to decrease, but only by an amount that is smaller than natural variations. Drought intensity is likely to increase due to higher temperatures that will increase the loss of soil moisture during dry periods (Frankson et al. 2017).

Hurricane wind speeds, rainfall intensity, and storm surge height and strength are projected to increase in response to climate change (Carter et al. 2014). Future storm surge and wave runup will be superimposed on rising mean sea level (discussed below), which increases the impact of storm events (Tebaldi et al. 2012; Goldstein and Moore 2016). Changes in wind speeds and directions already affect saltwater intrusion on Barataria Preserve marshes. Analysis of wind data from 1958 to 2013 shows an increase over the last 20 years in the frequency of 6–69 m/s (20–226 ft/s) winds, with a significant increasing trend of 1.0% per decade. Northerly winds blow water out of the park, lowering water levels, whereas strong winds from the south can cause saltwater incursion (Hatt et al. 2015).

Sea Level Rise

Among all the climate change impacts, sea level rise is of highest concern for park managers (Julie Whitbeck, Jean Lafitte National Historical Park and Preserve, ecologist, email communication, 18 April 2017). Scoping participants noted that sea level rise has implications for wave and tidal impacts, land loss, species shifts, sediment accumulation and transport (see Lentz et al. 2016), methane emission (see Yu et al. 2006), and carbon sequestration (see Baustian et al. 2017). Moreover, coastal flooding enhanced by sea level rise may cause damage to infrastructure, salinization of coastal aquifers, mobilization of pollutants, alterations of sediment budgets, coastal erosion, and ecosystem changes such as marsh loss (Sweet et al. 2017b).

While this report was in final review, the NPS published *Sea Level Rise and Storm Surge Projections for the National Park Service* (Caffrey et al. 2018), report authors analyzed and downscaled datasets from NOAA and the IPCC relative to national park units, including Jean Lafitte National Historical Park and Preserve. Servicewide, the results illustrate the potential for permanent coastal inundation and flooding due to sea level rise and storm surge under varying greenhouse gas emissions scenarios. Results of the analysis were used to create a suite of storm surge maps for each site included in the study. Data are available via an interactive map viewer (https://maps.nps.gov/slr/) and the storm surge maps are available separately via Flickr (https://www.flickr.com/photos/125040673@N03/albums).

Results from the Caffrey et al. (2018) study for the park include the following (refer to table C2b in Caffrey et al. 2018):

- Sea level rise by 2030 between 0.12 m and 0.14 m (4.7 in and 5.5 in), depending on emission scenario.
- Sea level rise by 2050 between 0.23 m and 0.24 m (9.1 in and 9.4 in), depending on emission scenario.
- Sea level rise by 2100 between 0.48 m and 0.68 m (19 in and 27 in), depending on emission scenario.

Caffrey et al. (2018) project that Jean Lafitte National Historical Park and Preserve to have the greatest relative sea level increase based on the current rate of land movement (subsidence).

According to the *Fourth National Climate Assessment, Volume II* (Reidmiller et al. 2018), the US Southeast will experience the following impacts as a result of sea level rise:

- Rapid conversion of coastal, terrestrial, and freshwater ecosystems to tidal saline habitats.
- Increased coastal flooding and high-tide flooding (fig. 23), which already pose daily risks to businesses, neighborhoods, infrastructure, transportation, and ecosystems in the region. In addition, more extreme coastal flooding events are projected to increase in frequency and duration; for example, water levels that currently have a 1% chance of occurring each year (known as a 100-year event) will be more frequent with sea level rise.
- Storm surges from tropical storms (on a "rising base"; see Heinrich 2018) will travel farther inland than in the past, impacting more coastal properties.
- The loss of more than 13,000 recorded historic and prehistoric archeological sites and more than 1,000 locations currently eligible for inclusion on the National Register of Historic Places (see Anderson et al. 2014).

Similar impacts are likely to affect the park, and in some cases already are. Scoping participants noted that inundation of forests in Barataria Preserve is increasing due to sea level rise. Furthermore, plant species have already been lost from higher-elevation features such as natural levees in part due to increased flooding, as well as land loss (Hatt et al. 2015). None of these species are federally listed, but the preserve has some state listed plant species. In addition, the plant community on the highest elevations (i.e., live oak natural levee forest) is ranked S1 (extremely rare, critically imperiled) by the Louisiana Natural Heritage Program, and the freshwater marsh plant community is ranked S2 (rare, imperiled) (see http://www.wlf.louisiana.gov/wildlife/explanation-endangered-species-rankings).

Since 1900, global mean sea level has increased by 0.17–0.20 m (7–8 in), with about 0.08 m (3 in) occurring since 1993 (Sweet et al. 2017b) (figs. 24 and 25). Global sea level rise accelerated over the latter part of the 20th century (Church and White 2006), with the primary driver since 1970 being the release of anthropogenic greenhouse gases (Slangen et al. 2016). The Gulf of Mexico record is similar to the global record, though the timing of the sea level events in the Gulf of Mexico lags slightly behind the global timing (Balsillie and Donoghue 2011).

As estimated in scenarios of the US Interagency Sea Level Rise Task Force (see Sweet et al. 2017a), global sea level is likely to rise 0.06–0.11 m (2.4–4.3 in) by 2020, 0.09–0.24 m (3.5–9.4 in) by 2030, 0.16–0.63 (6.3–25 in) by 2050, and 0.3–2.5 m (12–98 in) by 2100 (table 6). The model used in association with *Louisiana's Comprehensive Master Plan for a Sustainable Coast* (Coastal Protection and Restoration Authority of Louisiana [CPRA] 2017) predicted sea level rise of between 0.3 and 2.0 m (12 and 79 in) by 2100. In other words, global sea level rise exceeding 2 m (6 ft) or even 2.5 m (8 ft) in the next 80 years is a distinct possibility.

The major causes of sea level rise by the year 2100 are melting of the Antarctic and Greenland ice sheets. Each of these ice sheets will contribute 0.1–0.2 m (4–8 in) to sea level rise. Glacier and ice cap melting will contribute 0.2 m (8 in). Oceanic processes such as thermal expansion and regional atmospheric/ocean dynamics will contribute 0.4–0.5 m (16–20 in) (Sweet et al. 2017c). Additionally, subsidence of the Gulf coast will contribute 0.003–0.005 m/yr (0.1–0.2 in/yr) (Sweet et al. 2017c). Subsidence of southeast Louisiana (Mississippi Delta) will contribute 0.0112 m/yr (0.4 in/yr) (Jankowski et al. 2017).

Projections of sea level rise for the park must consider both global mean sea level rise and relative sea level rise

Figure 23. Photographs of Barataria Preserve during high water events.
In Barataria Preserve, infrastructure including a park sign along the Bayou Segnette Waterway (bottom photograph) and boat launch at Bayou Segnette State Park (top photograph), one of several public boat launches that allow visitation by water to the preserve, are flooded by high water. Relative sea level rise has increased the frequency of intermittent flooding associated with unusually high tides. Two pumping stations, floodwalls, and a portion of a sector gate at Bayou Segnette State Park are in the background of the bottom photograph. NPS photographs by Courtney Schupp (NPS Geologic Resources Division) taken 28 October 2015.

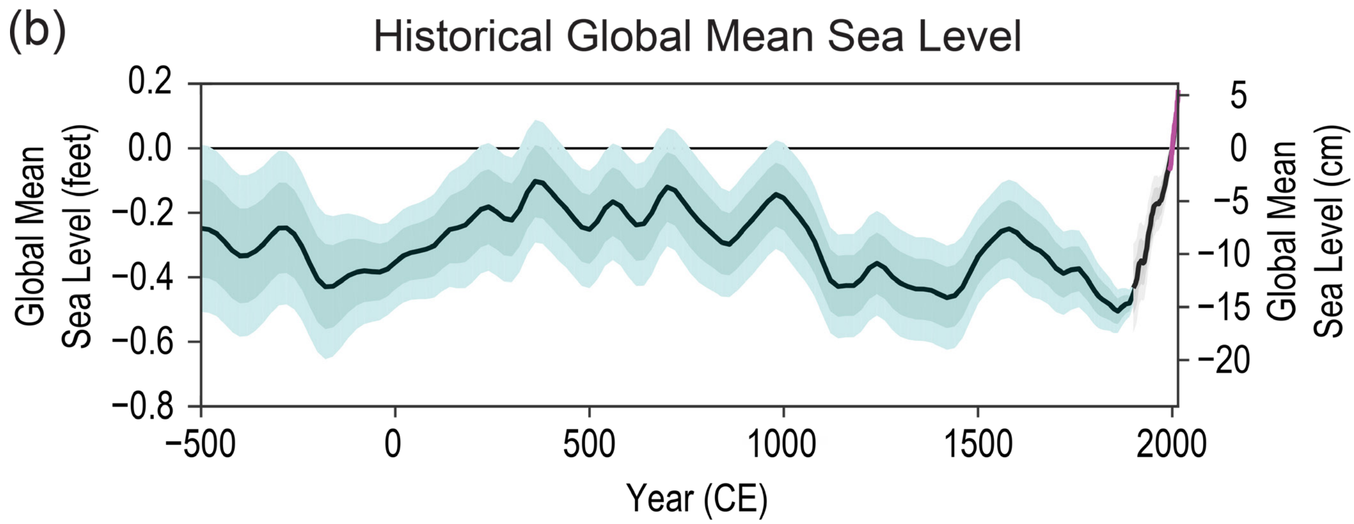

Figure 24. Graph of global mean sea level for the past 2,500 years.
Sea level has fluctuated over geologic time and over the past millennia. The record for the Gulf of Mexico (see fig. 8 of this report) is similar to the global record, though the timing of changes in the Gulf of Mexico lags slightly behind global timing. Graphic from Sweet et al. (2017a, figure 12.2).

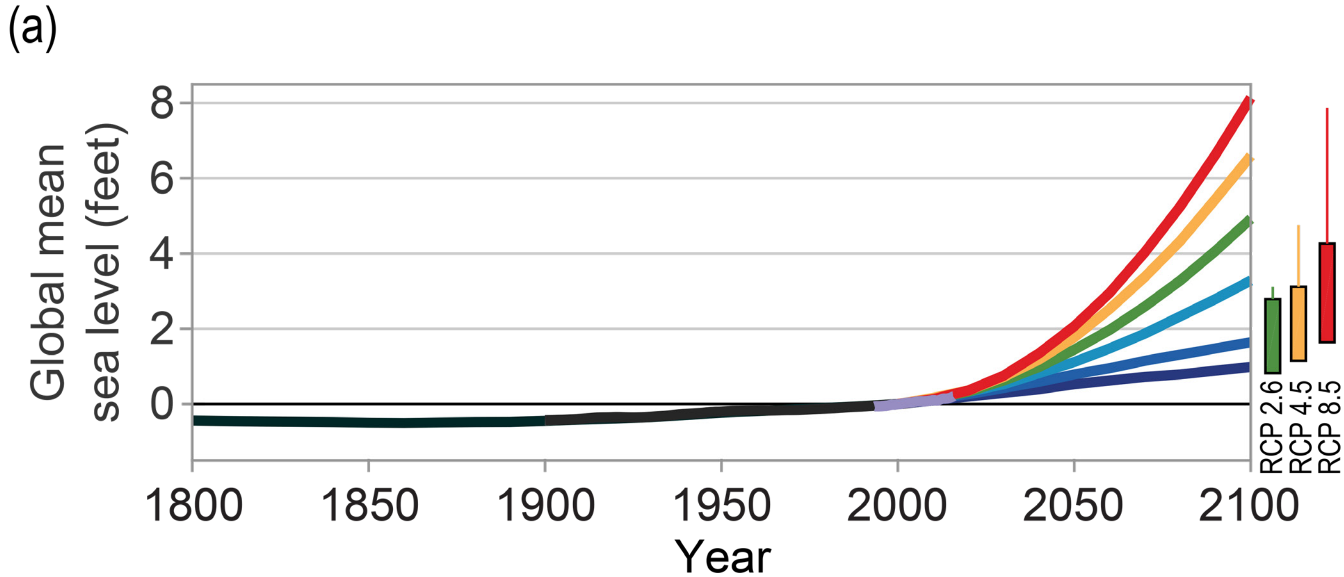

Figure 25. Graph showing measured and projected sea level change.
The graph shows the measured global mean sea level (MSL) from 1800 to 2015 and the projected "very likely" ranges through 2100. The black–magenta line shows global MSL based on recent geologic, tide gauge, and satellite altimeter reconstructions. The six colored lines beyond 2015 represent various modeled emissions scenarios and melting of Antarctic ice. Green, yellow, and red boxes to the right of the graph indicate the central 90% probability ranges of representative concentration pathways (RCP) of greenhouse gases based on Intergovernmental Panel on Climate Change (IPCC) scenarios. Graphic from Sweet et al. (2017a, figure 12.4).

Table 6. Projected global sea level rise relative to the year 2000.

Source: Six scenarios by the US Interagency Sea Level Rise Task Force (see Sweet et al. 2017a).

*RCPs are representative concentration pathways or modeled emission scenarios used by the Intergovernmental Panel on Climate Change (IPCC).

Scenario	Description	2020	2030	2050	2100
Low	Continuing current rate of global sea level rise, as calculated since 1993 Low end of RCP2.6*	0.06 m (2.4 in)	0.09 m (3.5 in)	0.16 m (6.3 in)	0.30 m (12 in)
Intermediate-Low	Modest increase in rate Middle of likely range under RCP2.6* Low end of likely range under RCP4.5* Low end of very likely range under RCP8.5*	0.08 m (3.1 in)	0.13 m (5.1 in)	0.24 m (9.4 in)	0.50 m (20 in)
Intermediate	High end of very likely range under RCP4.5* High end of likely range under RCP8.5* Middle of likely range under RCP4.5* when accounting for possible ice cliff instabilities	0.10 m (3.9 in)	0.16 m (6.3 in)	0.34 m (13 in)	1.0 m (39 in)
Intermediate-High	Slightly above high end of very likely range under RCP8.5* Middle of likely range under RCP8.5* when accounting for possible ice cliff instabilities	0.10 m (3.9 in)	0.19 m (7.5 in)	0.44 m (17 in)	1.5 m (59 in)
High	High end of very likely range under RCP8.5* when accounting for possible ice cliff instabilities	0.11 m (4.3 in)	0.21 m (8.3 in)	0.54 m (21 in)	2.0 m (79 in)
Extreme	Consistent with estimates of physically possible "worst case"	0.11 m (4.3 in)	0.24 m (9.4 in)	0.63 m (25 in)	2.5 m (98 in)

(Sweet et al. 2017b). The following three tables provide various projected amounts (table 6) and rates of global sea level rise (table 7), as well as rates of sea level rise affecting Barataria Preserve (table 8).

Resource Management Response to Climate Change

The park's foundation document (NPS 2015) identified climate change impacts as one of the key issues for park management and planning. Specifically, a climate change vulnerability assessment and climate change adaptation plan are high priorities to aid park managers in responding to the realized and predicted impacts of climate change and relative sea level rise on park ecosystems. Park managers would also like to understand the role of climate drivers on ecosystem changes at the park, specifically the role of changes in air and water temperatures, changes in water quality at local to regional (and Mississippi River watershed) scales, and increasing urban/wildland interface. Also, clear documentation is needed with respect to causal linkage between any one or several climate change factors and invasive species presence, abundance, or impacts (Julie Whitbeck, Jean Lafitte National Historical Park and Preserve, ecologist, email communication, 18 April 2017).

To develop climate change monitoring protocols, the NPS Northeast Coastal and Barrier Network strategy (Stevens et al. 2010) can serve as a template.

To address and prepare for climate change impacts, including sea level rise, park managers have taken the following actions:

- The NPS Climate Friendly Parks process has resulted in a vulnerability assessment of park infrastructure to multiple coastal hazards and climate change factors (i.e., erosion, flooding, storm surge, sea level rise, and historical flooding) over a 35-year planning horizon (2050). Twenty-seven (42%) of all assets analyzed at the park have high vulnerability to coastal hazards and climate change factors; most of the high vulnerability assets are within Barataria Preserve. Peek (2017) identified potential adaptation strategies.

- Park managers established an interdivisional Climate Change Working Group.
- Park managers created an interpretive wayside exhibit that describes relative sea level rise in Barataria Preserve (fig. 26).
- Park managers are pursuing an integrated park improvement planning process focused on facilities at Barataria Preserve with an emphasis on climate change vulnerability, adaptation, and response.
- In many cases, trails within the park, primarily at Barataria Preserve, are increasingly flooded, and park managers anticipate more of the same. Through an integrated park improvement plan, park managers are taking a comprehensive look at the park's trails. The process will provide recommendations and project statements for elevating some trails and reclassifying others in the direction of minimal maintenance input (Dusty Pate, Jean Lafitte National Historical Park and Preserve, natural resource manager, written communication, 11 May 2018).
- The Gulf Coast Inventory & Monitoring Network works with partners to collect lidar data that help to monitor changes related to relative sea level rise and climate change impacts on coastal geomorphology, shoreline position, and vegetation.

Coastal Resources Management and Planning

The park contains at least 140 km (87 mi) of estuarine and coastal shoreline and 626 ha (1,546 ac) of open water (Curdts 2011). Two state agencies handle coastal zone management in Louisiana. First, the Coastal Protection and Restoration Authority (http://coastal.la.gov/) integrates other state agencies into its work to develop and implement comprehensive coastal protection and restoration. Second, the Louisiana Department of Natural Resources' Office of Coastal Management (http://www.dnr.louisiana.gov) regulates development activities and manages the resources of the coastal zone. A coastal use permit is required for certain projects in the coastal zone, including but not limited to dredge and fill work, bulkhead construction, shoreline modification, and other development projects such as marinas, subdivisions, drainage facilities, and energy infrastructure.

Park managers may benefit from a variety of databases and guidance that the National Park Service has developed for managing coastal resources and planning for the impacts of climate change in coastal parks. These are highlighted below. In addition, Appendix B lists laws, regulations, and NPS policies pertaining to park coastal resources.

The NPS *Coastal Adaptation Strategies Handbook* (Beavers et al. 2016a) provides guidance about climate change adaptation to coastal park managers in the 118 parks that regional offices have identified as potentially vulnerable to sea level change; Jean Lafitte National Historical Park and Preserve is one of these 118 parks. Focus topics of the handbook include NPS policies relevant to climate change; guidance on evaluating appropriate adaptation actions; and adaptation opportunities for planning, incident response, cultural resources, natural resources, facilities and assets, and infrastructure. The handbook also provides guidance on developing communication and education materials about climate change impacts and details case studies of the many ways that park managers are implementing adaptation strategies for threatened resources throughout the National Park System.

The NPS *Ocean and Coastal Park Jurisdiction Handbook* (NPS 2016b) guides coastal resource management by providing insight for parks with boundaries that may shift with changing shorelines.

The NPS *Cultural Resources Climate Change Strategy* (Rockman et al. 2016) is related to coastal resource management and planning (see "Climate Change Impacts"). The strategy connects climate science with historic preservation planning. It identifies and describes seven options for climate change adaptation of cultural resources and cultural landscapes: (1) no active intervention, (2) offset stress, (3) improve resilience, (4) manage change, (5) relocate or facilitate movement, (6) document and prepare for loss, and (7) interpret the change.

Multiple NPS efforts to develop data and models are producing useful datasets for coastal parks. These efforts include sea level rise projections, coastal engineering inventories, asset vulnerability assessments, and long-term monitoring. "Additional References" of this report lists links to coastal datasets.

The NPS Gulf Coast Inventory & Monitoring Network (https://go.nps.gov/guln/) collects multiple datasets at the park, including shoreline position through remote (lidar) surveys every few years. The NPS Natural Resource Stewardship and Science Directorate (https://www.nps.gov/orgs/1778/index.htm) funded a natural resource condition assessment (Hatt et al. 2015) that summarized trends and conditions in a variety of resources including geomorphological resources.

Resource managers may find Geological Monitoring (Young and Norby 2009; http://go.nps.gov/geomonitoring) useful for addressing resource management issues. The manual provides guidance for monitoring vital signs (measurable parameters of the

Table 7. Projected rates of global sea level rise.

Source: Six scenarios by the US Interagency Sea Level Rise Task Force (see Sweet et al. 2017a).

*See table 6 for descriptions.

Note: In addition to these rates, local subsidence rates must be considered when calculating relative sea level rise for the park.

Scenario*	2020	2030	2050	2090
Low	3.0 mm/yr (0.1 in/yr)	3.0 mm/yr (0.1 in/yr)	3.0 mm/yr (0.1 in/yr)	3.0 mm/yr (0.1 in/yr)
Intermediate-Low	5.0 mm/yr (0.2 in.yr)	5.0 mm/yr (0.2 in.yr)	5.0 mm/yr (0.2 in.yr)	5.0 mm/yr (0.2 in.yr)
Intermediate	6.0 mm/yr (0.2 in/yr)	7.0 mm/yr (0.3 in/yr)	10.0 mm/yr (0.4 in.yr)	15.0 mm/yr (0.6 in/yr)
Intermediate-High	7.0 mm/yr (0.3 in/yr)	10.0 mm/yr (0.4 in/yr)	15.0 mm/yr (0.6 in/yr)	24.0 mm/yr (0.9 in/yr)
High	8.0 mm/yr (0.3 in/yr)	13.0 mm/yr (0.5 in/yr)	20.0 mm/yr (0.8 in/yr)	35.0 mm/yr (1.4 in/yr)
Extreme	10.0 mm/yr (0.4 in/yr)	15.0 mm/yr (0.6 in/yr)	25.0 mm/yr (1.0 in/yr)	44.0 mm/yr (1.7 in/yr)

Table 8. Rates of sea level rise (SLR) of interest for Barataria Preserve.

Time Period	Type	Rate	Source
600–1600 CE	Coastal Louisiana relative SLR (primarily the glacio-isostatic contribution to subsidence)	550 mm (22 in) over the 1,000-year period or an average of 0.55 mm/yr (0.02 in/yr)	González and Törnqvist (2006), basal peat on a highly consolidated, mostly Pleistocene basement
1947–2016	Relative SLR at Grand Isle, Louisiana	9.09 mm/yr (0.358 in/yr)	National Oceanic and Atmospheric Administration (2017), tide gauge
1992–2011	Relative SLR of coastal Louisiana	12.0 ± 8.3 mm/yr (0.47 ± 0.33 in/yr)	Jankowski et al. (2017), Coastwide Reference Monitoring System (CRMS) sites
1992–2011	Relative SLR of Mississippi Delta	13.2 ± 8.8 mm/yr (0.52 ± 0.35 in/yr)	Jankowski et al. (2017), CRMS sites
1985–2017	Global SLR	3–3.3 mm/yr (0.12–0.13 in/yr)	Cazenave et al. (2014); Fasullo et al. (2016); Sweet et al. (2017c)

Figure 26. Photograph of wayside exhibit in Barataria Preserve.
A wayside exhibit interprets the effects of relative sea level change on Barataria Preserve. NPS photograph by Courtney Schupp (NPS Geologic Resources Division) taken 28 October 2015.

overall condition of natural resources). Each chapter covers a different geologic resource and includes detailed recommendations for resource managers, suggested methods of monitoring, and case studies. Specifically, information in the "Coastal Features and Processes" chapter (Bush and Young 2009) may be of use. That chapter discusses vital signs for monitoring the following coastal features and processes: (1) shoreline change, (2) coastal vegetation cover, (3) wetland position/acreage, and (4) coastal wetland accretion. Since publication of Geological Monitoring in 2009, researchers have developed new methodologies for monitoring coastal features and processes; park managers could consider working with partners such as the US Geological Survey to utilize methodologies that reflect new advances and approaches (Jim Flocks, US Geological Survey, coastal geologist, written communication, 13 November 2018). To develop additional monitoring protocols for coastal resources, park managers can work with the Gulf Coast Inventory & Monitoring Network.

Assistance with coastal science and management projects is available through the NPS Natural Resource Stewardship and Science Directorate. The NPS Water Resources Division, Ocean and Coastal Resources Branch website (http://go.nps.gov/oceancoastal/) provides information about servicewide programs for ocean, coastal, and Great Lakes parks. Shoreline maps of each of these parks, along with shoreline and water acreage statistics from Curdts (2011), are available at http://nature.nps.gov/water/oceancoastal/shorelinemaps.cfm.

Data, Research, and Planning Needs

GRI scoping (see GRI scoping summary by KellerLynn 2010a), communication with park staff, and preparation of this GRI report, including the 2017 conference call (see Appendix A), identified many needs for data collection and analysis, research, and planning. The park's foundation document (NPS 2015) also identified needs. Table 9 of this report summarizes these needs. Additional discussion of these needs are included in the relevant sections of this report.

The NPS Geologic Resources Division provides technical and policy support for geologic resource management issues in three emphasis areas: (1) geologic heritage, (2) active processes and hazards, and (3) energy and minerals management. Park managers are encouraged to contact the Geologic Resources Division (http://go.nps.gov/geology) for assistance with resource inventories, assessments, and monitoring; impact mitigation, restoration, and adaptation; hazards risk management; law, policy, and guidance; resource management planning; data and information management; and public outreach. Park staff can formally request assistance via https://irma.nps.gov/Star/.

Short-term research and resource-management projects, as well as geologic interpretation, may be addressed with the help of the Geoscientists-in-the-Parks (GIP) and Mosaics in Science programs. These internship programs place scientists (typically undergraduate students) in parks to complete science-related projects that may address geologic resource management issues. As of April 2019, neither a GIP nor Mosaics in Science participant had been stationed at the park. The programs' websites have additional information: http://go.nps.gov/gip and https://go.nps.gov/mosaics.htm.

Disturbed Lands

Many human activities have resulted in disturbed lands in the park. GRI scoping and conference call participants (see Appendix A) noted the following:

Coastal Engineering

Fifty-two coastal engineering projects were identified in and immediately adjacent to Barataria Preserve and the Chalmette Unit (fig. 27). These include 26 bulkheads (fig. 28), one floodwall, three levees, six revetments, and 16 dredge/fill projects (Coburn et al. 2010).

Abandoned Mineral Lands and Past Shell Mining

According to a National Park Service inventory and assessment of abandoned mineral lands (AML; Burghardt et al. 2014), the park has 11 AML features at eight sites. All of these features are oil and gas wells dating back primarily to the 1960s and 1970s. Mitigation is complete on seven features. Mitigation of the remaining four features at four sites is a high priority (NPS 2015). Some of these features are underwater or hard to locate (e.g., vegetation obscures them or they are now completely submerged).

Although not considered an AML feature, shell mining in the park warrants mention in this GRI report. Large quantities of clamshells were mined from lake bottoms and shell beaches in order to make lime for mortar and for road base and other construction material. Removal of these materials from the system resulted in degradation of the hard lake bottom and beach substrate.

Native American middens also were mined for shells. Prior to mining, middens were as much as 9 m (30 ft) high (above sea level) and some covered more than 0.4 ha (1 ac). Most of the middens are now greatly reduced in size or gone completely (KellerLynn 2010a).

Table 9. List of geology-related needs for improved monitoring and management of park geologic resources.

Type of Need	Description of Need	Application	Status	Sources of Information
Data	Shoreline change rate along Lake Cataouatche, Lake Salvador, and Bayou Bardeaux	Shoreline protection, property jurisdictions, climate change response plan, and desired future conditions at Barataria Preserve	Shoreline protection projects are headed toward engineering and design.	Routine aerial imagery collected in coastal Louisiana and the change analyses that are conducted using those images is the most useful technique (Martha Segura, Gulf Coast Inventory & Monitoring Network [GULN], coordinator, written communication, 1 May 2018)
Data	Subsidence	Monitoring of elevation and hydrology dynamics across Barataria Preserve	Implemented 2017–2018	GULN monitoring program
Data	Sea level change	Monitoring of subsidence, elevation, and hydrology dynamics across Barataria Preserve	Park managers have implemented a network of water-level, elevation, and accretion/subsidence monitoring stations at Barataria Preserve.	National Oceanic and Atmospheric Administration tide gauges; Coastwide Reference Monitoring System (CRMS) monitoring sites
Data	Long-term monitoring plot along a topographic/flooding gradient in a key ecosystem	Measure changes related to sea level rise and climate change	Implemented 1998; 20-year re-measurement planned for 2018; additional intermittent work	TBD
Data	Landscape-wide water level/flooding monitoring array	Measure changes related to sea level rise and climate change	Initiated 2013; ongoing	TBD
Data	Topography/elevation	Climate change adaptation plan	Park managers have implemented a network of water-level, elevation, and accretion/subsidence monitoring stations at Barataria Preserve; ongoing	CRMS site data Lidar
Data	Hydrodynamics	Climate change adaptation plan	Park managers have implemented a network of water-level, elevation, and accretion/subsidence monitoring stations at Barataria Preserve; ongoing	TBD
Data	Landscape-wide surface hydrologic monitoring	Ecosystem and landscape adaptive management of biological and biogeochemical properties and processes	GULN conducts routine water-quality monitoring at five sites in Barataria Preserve but does not measure water level. Park managers have implemented a network of water-level, elevation, and accretion/subsidence monitoring stations at Barataria Preserve; ongoing	USGS gauge in Lake Cataouatche measures temperature, gauge height, and specific conductance (https://mail.google.com/mail/u/0/#drafts/162f8f527f526b49); USGS gauge associated with the Davis Pond diversion measures temperature, discharge, and gauge height (https://waterdata.usgs.gov/la/nwis/uv?site_no=295501090190400); STAR technical assistance request from NPS Water Resources Division

Table 9 (continued). List of geology-related needs for improved monitoring and management of park geologic resources.

Type of Need	Description of Need	Application	Status	Sources of Information
Research	Research the role(s) of invasive floating aquatic vegetation in floating peat marsh	Vegetation management plan	TBD	PMIS funding proposal; CESU partners
Research	Integrate and reconcile existing hydrologic models	Influence of levee construction on a range of temporal and spatial scales (major systems along the river and structures on private property). Levee-associated pumping station development. Development of canal networks. Road construction (e.g., Hwy 3134).	TBD	PMIS funding proposal; CESU partners; STAR technical assistance request from NPS Water Resources Division
Research	Climate change vulnerability assessment	Climate change adaptation plan. Storm recovery planning.	Completed 2017	TBD
Research	Role of climate drivers on invasive species presence, abundance, or impacts	Invasive species management. Prioritization of natural resource management actions.	TBD	GULN; NPS Northeast Coastal and Barrier Network climate change monitoring strategy (Stevens et al. 2010); PMIS funding proposal; CESU partners
Planning	Climate change monitoring plan	Identification of needs for monitoring and trend analysis	TBD	GULN; NPS Northeast Coastal and Barrier Network climate change monitoring strategy (Stevens et al. 2010)
Planning	Climate change adaptation plan	Long-term resource management. Identification of monitoring needs.	Initiated 2017; in progress	Climate Friendly Parks action plan
Planning	Integrated park improvement plan	Barataria Preserve facilities. Storm recovery planning.	Initiated 2018; in progress	TBD
Planning	Resource stewardship strategy	Long-term resource management	Initiated 2018; in progress	NPS Natural Resource Stewardship and Science Directorate; Southeast Regional Office (SERO); GULN
Planning	Cultural resource stewardship assessment	Long-term resource management	Initiated 2018; largely complete	SERO; Southeast Archeological Center; Cultural Resources, Partnerships and Science Directorate
Planning	Minerals management plan	Anticipate future energy demands. Establish procedures to minimize impacts of nonfederal oil and gas activities.	TBD	Oil and gas well point data from SONRIS; pipeline data from the National Mapping Pipeline System; wells inventory from the NPS Geologic Resources Division
Planning	Address landscape-scale impacts of hydrological change	Long-term resource management	Ongoing	Work collaboratively with USACE, local parishes municipalities, and stakeholder groups

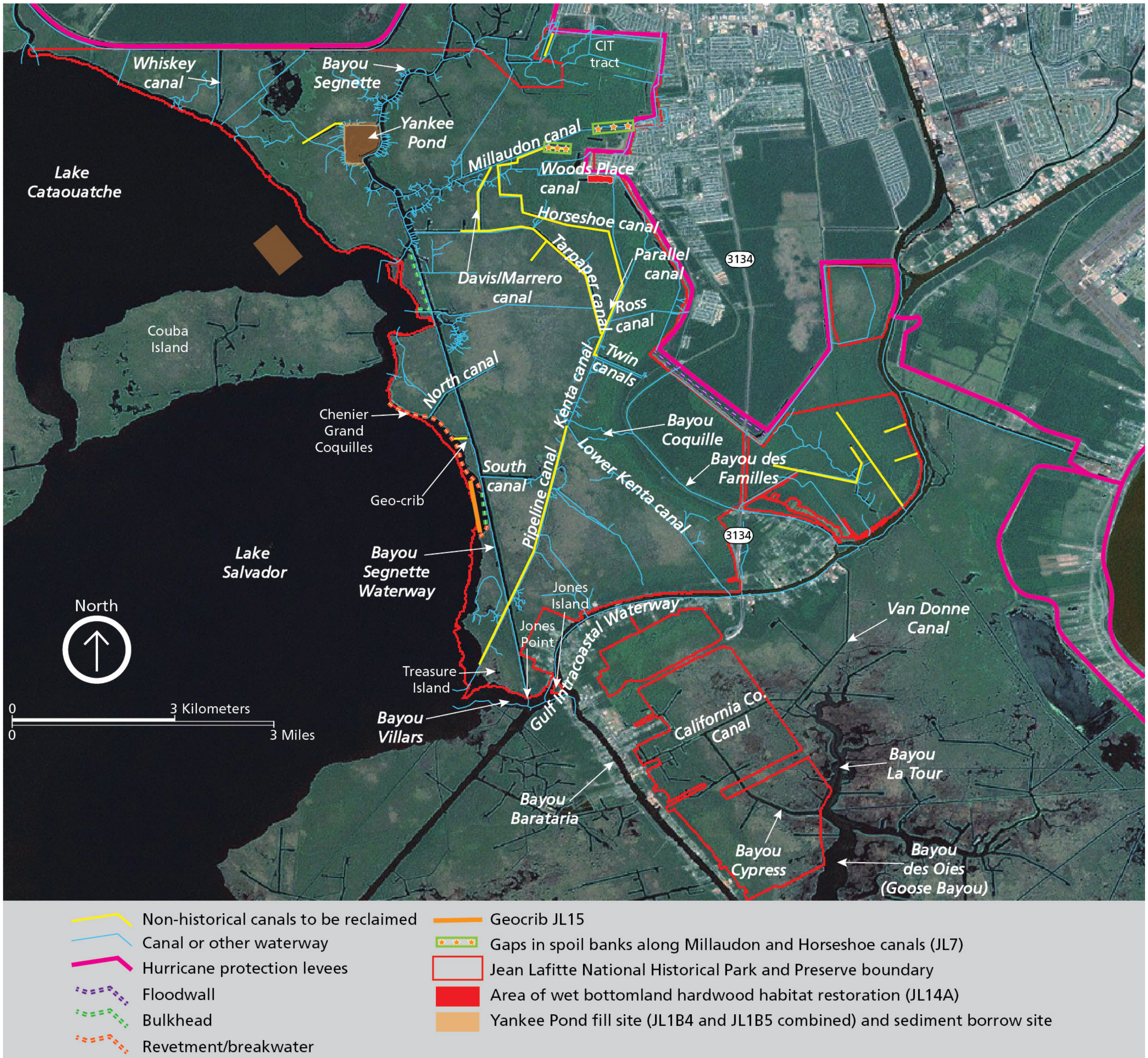

Figure 27. Graphic of reclamation projects in Barataria Preserve.
Disturbed lands in the park include engineered structures and non-historical canals, many of which are undergoing reclamation. The red line marks the boundary of Barataria Preserve, including the Fleming Plantation Area (south of the Gulf Intracoastal Waterway). Graphic by Trista Thornberry-Ehrlich (Colorado State University) based on information from Coburn et al. (2010), USACE (2015b), NPS Gulf Coast Inventory & Monitoring Network (waterways dataset), and NPS (2009, figure 3).

Figure 28. Photograph of bulkhead in Barataria Preserve.
Along the northern Bayou Segnette Waterway at Barataria Preserve, bulkheads protect inholdings including this fishing camp. NPS photograph by Courtney Schupp (NPS Geologic Resources Division) taken 28 October 2015.

Canals and Spoil Banks

Prior to canal building in the Barataria basin, two natural waterways—Bayou Barataria and Bayou Perot—connected the upper basin (which includes Barataria Preserve) to the lower basin and the Gulf of Mexico. In addition, sheet flow moved freely across the marsh surface between the upper and lower basins (NPS 2008). Now, Barataria Preserve is crossed by 77 km (48 mi) of canals (figs. 27 and 29) dredged through the wetlands and lined with spoil banks built with the dredged material. This count does not include the canals in the Fleming Plantation Area. Many more canals cross other parts of the Barataria basin.

Canals and associated spoils banks adversely affect the marsh ecosystem in many ways. Dredging creates 1.2 ha (3 ac) of spoil bank for every 1 ha (2.5 ac) of canal (Turner and Streever 2002). Canals allow saltwater to invade deeper into coastal basins (CPRA 2017) and convert marshes and swamps to open water. Canals exacerbate erosion by increasing tidal volume, tidal reach, and salinities, and they decrease the retention of freshwater and sediments (KellerLynn 2010a; Ford 2014). Instead of filtering slowly through the marsh, canals allow nutrient runoff to reach waterbodies, stimulating eutrophication (enrichment with minerals and nutrients that induce excessive growth of plants and algae). Canals also allow brackish water and storm surges to infiltrate the fresh systems more easily, causing mortality to native plants, increased erosion, and potential loss of fish habitat (NPS 2009; Hatt et al. 2015).

Spoil banks have replaced marsh with an upland environment (Craig et al. 1979). They alter the natural hydrology of the area by restricting water flow, which leads to increased flooding and drying of marsh (Swenson and Turner 1987). This exacerbates wetland erosion by limiting sediment deposition, stressing marsh vegetation, and increasing subsidence (Turner 1987, 2004; Baustian and Turner 2006). In addition, spoil banks are prime habitat for Chinese tallow (*Triadica sebifera*, an invasive plant that displaces native species and changes vegetation communities). Park managers are actively working to remove these plants (KellerLynn 2010a; Hatt et al. 2015).

Notable canals include Twin canals, which were dredged in 1974 along with Parallel and Horseshoe canals, to drain swamps and marshes on the west side of the Bayou des Familles ridge (fig. 27). The spoil was piled between the new canals over a 2 ha (5 ac) area atop the western natural levee of Bayou des Familles. The spoil mound now averages about 2 m (6 ft) above mean sea level (NPS 1995). In addition, about 22 km (14 mi) of straight and wide canals were constructed for oil and gas exploration and an additional 10 km (6 mi) for

Figure 29. Photograph of canal in Barataria Preserve.
Canals served many purposes, including accommodating oil and gas pipelines. The creation of canals converted marshes and swamps into open water and spoil banks. NPS photograph by Courtney Schupp (NPS Geologic Resources Division) taken on 28 October 2015.

pipeline canals (figs. 27 and 29). Access canals for oil and gas operations end in a distinctive, wide rectangular section, known as a “keyhole,” where well drilling took place (Coburn et al. 2010). Excavation of oil and gas exploration and pipeline canals penetrated the spoil banks of the Gulf Intracoastal and Bayou Segnette Waterways (see “Artificial Waterways”), creating tidal connections with water bodies to the south (NPS 1995).

Approximately 24 km (15 mi) of the canals within the preserve are historical, built beginning in the 1700s for drainage, navigation, and logging access to bald cypress forests. The park’s Marsh Overlook Trail traverses a spoil bank of the Kenta canal (a plantation-based irrigation canal that was widened in the late 1800s as part of a logging operation) (KellerLynn 2010a). Along the southern end of Kenta canal as well as Bayou des Familles, large plantations were cleared and farmed for sugar, rice, and possibly indigo (Holmes 1986). Millaudon and Woods Place canals were drainage canals that were extended to allow small craft navigation between plantations and bayous or lakes. Other canals were dredged to cut off meanders (shorten the distance) of natural waterways such as Bayou Segnette (Coburn et al. 2010).

Park managers have identified 32 km (20 mi) of non-historical, abandoned canals in need of reclamation in order to restore wetland functions and values. As of 2010, 9 km (6 mi) of these canals had been restored by backfilling; BP Deepwater Horizon settlement funds have been committed to restore an additional 26 km (17 mi) of canals (Dusty Pate, Jean Lafitte National Historical Park and Preserve, natural resource manager, email communication, 29 September 2017).

Canal restoration is pursued through partial backfilling (removal of the spoil banks and depositing the sediment and vegetation into the canals), allowing reversion to freshwater wetlands (fig. 30). Elevation changes are important: where spoil banks are not lowered to the appropriate elevation, shrubs and trees can recolonize them, but if lowered too much, they can convert to open water (Baustian and Turner 2006). The goals of backfilling are to restore marsh to the spoil-bank areas, to create beneficial shallow-water habitat in the canal areas, and to restore hydrologic flow by removing the spoil banks. The material in the spoil banks usually lacks the volume needed to completely fill the canal with sediment, due to dewatering and oxidation since they were dredged (Gosselink 1984). Nevertheless, this method has improved the marsh ecology in two backfilled canals—North canal and South canal (fig. 27). These canals were dredged in the 1950s to move drilling equipment for oil wells; the canals extended from the eastern shoreline of Lake Salvador across the Bayou Segnette Waterway and into the marsh (Baustian et al. 2009).

Artificial Waterways

The construction of artificial waterways has a long history in the Barataria basin. In the 20th century, natural waterways were widened and deepened for navigation. In the 1930s (i.e., before the park was established), the Gulf Intracoastal Waterway (GIWW) was dredged. The GIWW now separates the Fleming Plantation Area from the more northern part of

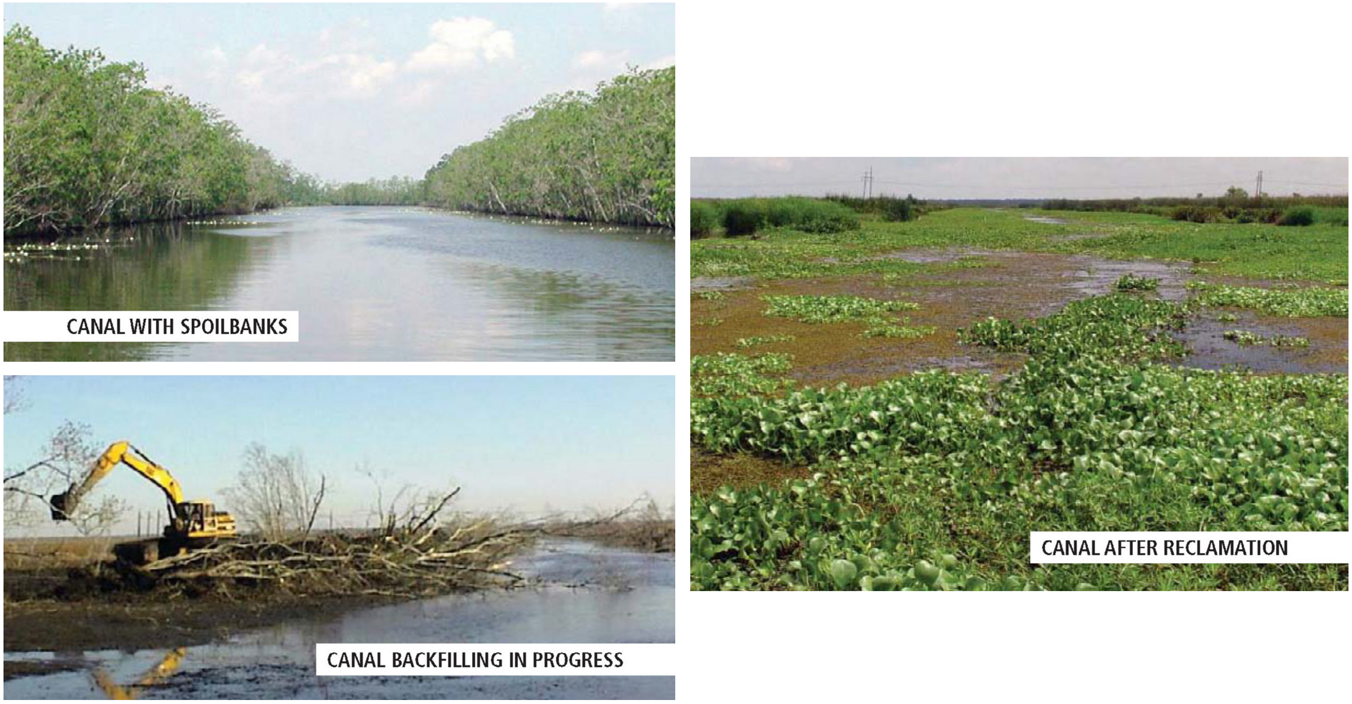

Figure 30. Photographs of canal backfilling in Barataria Preserve.
Spoil banks, which were created as a result of canal building, are pushed into the canals along with associated vegetation. Such reclamation methods allow reversion to freshwater wetlands. NPS photographs from NPS (2009, Appendix A).

Barataria Preserve (fig. 27). The GIWW fundamentally changed the area's hydrology by creating an east–west conduit for water perpendicular to the natural line of flow (Coburn et al. 2010). Construction also created spoil banks along the waterway that prevent sheet flow and storm surge (NPS 2008) from supplying sediment. Dredging activities and beneficial uses of dredged sediment are directed by the US Army Corps of Engineers (USACE), as part of its responsibility for maintaining navigation channels in the lower Mississippi River valley (Julie Whitbeck, Jean Lafitte National Historical Park and Preserve, ecologist, email communication, 18 April 2017). Maintenance of the waterway is ongoing.

The GIWW links directly to the Gulf of Mexico via the Barataria Bay Waterway, as well as links to the town of Westwego via the Bayou Segnette Waterway (BSWW), which runs roughly parallel to the eastern shorelines of Lakes Cataouatche and Salvador. The wakes of boat traffic using these two large waterways, in addition to the 12-km (7-mi) channelized portion of Bayou Barataria, erode adjacent wetlands (Coburn et al. 2010; KellerLynn 2010a).

GIWW spoil deposits were placed on Jones Point, which formed at the confluence of Bayou Barataria and Bayou Villars and is now bounded by the GIWW on the south and east, the BSWW on the west, and wetland on the north (fig. 27). Jones Point now rises up to 3 m (10 ft) above mean sea level. About 300 m (1,000 ft) of rock revetment lines the north bank of the GIWW there. Dredging the GIWW separated Jones Point from Jones Island (also known as Isle Bonne). The 4-ha (10-ac) island rises up to 3 m (10 ft) above mean sea level, and a wet swale occupies the center of the island. Bank erosion is altering a prehistoric Indian mound and midden complex there; the complex dates from about 400 to 1200 CE (NPS 1995).

Artificial Levees

Before human interference, hydrology in the Barataria basin was primarily affected by the Mississippi River, tidal action, and precipitation. Construction of artificial levees, as well as closing of natural channels to prevent overbank flooding, has kept river water and sediment from entering the upper basin, blocking freshwater inputs into the marshes and lakes through surface flow (NPS 2012).

The last time that the constructed levee system was breached, allowing water into the Barataria basin, was during the Mississippi River flood of 1927. In response, the USACE funded and coordinated the basin-wide Mississippi River and Tributaries Project to minimize the impact of large floods. The project has three main elements relevant to the park: (1) earthen levees along the Mississippi River and Atchafalaya River channels, (2) floodways and spillways to divert floodwaters out of the Mississippi River channel above New Orleans, and (3) channel improvements and bank stabilization (Allison et al. 2012).

At the Chalmette Unit, a 783-m- (2,570-ft-) long artificial levee, which was originally built before the Battle of New Orleans and extended by the USACE following the flood of 1927, is now raised, faced with concrete, and topped by a low concrete floodwall built in the 1980s (fig. 31). The park's administrative history (Blythe 2012, p. 35–36) summarizes changes made to this levee. In addition, a partially demolished rectangular concrete bulkhead and stone riprap revetment stabilize 133 m (437 ft) of the river shoreline at the Chalmette Unit; the other 591 m (1,940 ft) of riverbank are stabilized by concrete and a stone riprap revetment (NPS 2008; Coburn et al. 2010).

Built by the USACE for hurricane protection, 65 km (35 mi) of artificial levees mark the boundary between Barataria Preserve and adjacent Jefferson Parish (fig. 27). The Southeast Louisiana Flood Protection Authority–West, West Jefferson Levee District, maintains these levees. Many of these levees were constructed with sediment from adjacent borrow pits or borrow canals (Coburn et al. 2010).

Before the park was established, landowners built levees and dikes within Barataria Preserve. These features are not continuous and therefore do not create a complete hydrologic barrier, but they did lead to drainage and subsidence of 280 ha (700 ac) of bald cypress swamp in the northeast area of the preserve known as the "CIT tract" (fig. 27; Coburn et al. 2010).

Back levees were developed to create storm-water drainage basins and provide hurricane protection to communities within the basins. The back levees have interrupted sheet flow from the upper parts of natural levees to fringing wetlands. Rainwater within these drainage basins is collected through interior drains and canals and carried over fringing levees by large pumping stations, which concentrate drain water and pollutants, and discharge them into canals that serve as conduits through fringing wetlands. Fifteen pumping stations drain water from surrounding communities by lifting the water over the levees and discharging it through outfall canals into park waters. This has changed the water flow from its previously gradual downslope sheet flow to what are now highly concentrated point sources of contaminated urban or agricultural runoff (NPS 2008).

Loss of sheet flow and crevasse-splay processes results in a loss of sediment deposition that would otherwise help to combat subsidence in the basins between levees. This subsidence places residential areas at increasingly low elevations relative to sea level, and significantly increases vulnerability to massive storm events such as Hurricanes Katrina and Rita (Day et al. 2007).

The regional Hurricane and Storm Damage Risk Reduction System (HSDRRS) is a levee-building project developed in response to hurricane impacts in 2005. The USACE leads the HSDRRS project, and mitigation projects are ongoing.

The West Bank and Vicinity Hurricane and Storm Damage Risk Reduction System (WBV HSDRRS) has raised and extended levees along the boundary of Barataria Preserve, impacting park wetlands and placing the largest drainage pumping station in the world, the West Closure Complex, directly adjacent to park lands. Multiple compensatory wetland mitigation projects within the park are under construction (see "Restoration and Coastal Protection Projects").

Earthquakes

Earthquakes sometimes occur along the Lake Sand–Thibodaux fault zone, affecting the greater New Orleans area near Barataria Preserve; the most recent occurred in 1958. Aside from a few small earthquakes (magnitude 3–4 on the Richter Scale), seismic activity has been rare since the 1960s (Yuill et al. 2009).

Fault movement has displaced the top of the Pleistocene surface up to 1.5 m (5 ft) and has cracked and offset highways that cross these faults (Gagliano 2005b). Movement along faults allows liquids and gases to migrate upwards, causing instability for buildings, levees, and floodwalls at the surface, and sheet pilings beneath the surface (Gagliano 2005b). Minor earthquakes and resulting liquefaction, in which subsurface sand expels water and compacts, leads to breakup of flotant, causes structural damage, and creates "sand fountains" in which sandy water shoots out of surface cracks (Gagliano 2005b). Large areas can become inundated, creating lakes and bays and inducing land submergence, adding to the land loss rate in Louisiana (Gagliano 2005b). Gagliano et al. (2003a, b), Gagliano (2005a), and Yeager et al. (2012) identified faulting as a significant driver of tectonic subsidence in coastal Louisiana (see "Subsidence").

Hurricanes

Hurricanes strike Louisiana an average of once every three years (Frankson et al. 2017), with wind and storm surge regularly affecting park units. Since 1939, when Chalmette National Historical Park was established, wind, rain, flooding, and storm surge associated with 38 hurricanes and tropical storms have affected the six park sites (table 10).

Figure 31. Photograph of fortified wall at the Chalmette Unit.
The Chalmette Unit of the park is on a natural levee complex of Mississippi River meander belt 1 (Hml1). An artificial levee was built atop the natural levee, and a fortified wall was constructed atop the artificial levee. The wall runs through Chalmette Battlefield. The wood debris along the levee was deposited there during high water levels on the river. Photograph from Peek (2017, figure 10).

Table 10. Hurricanes and Tropical Storms since 1939.

1The table includes storms since the establishment of Chalmette National Historical Park in 1939. Entries in the table that took place prior to the establishment of Jean Lafitte National Historical Park and Preserve in 1978 are based on hurricane tracks and reported tornadoes, wind damages, flooding, and storm surge in the areas.

2See table 11 for descriptions of categories.

3ACC = Acadian Cultural Center. BP = Barataria Preserve. CHAL = Chalmette Unit. FQVC = French Quarter Visitor Center. PACC = Prairie Acadian Cultural Center. WACC = Wetlands Acadian Cultural Center.

Storm Name	Year[1]	Month	Category at Landfall[2]	Sustained Wind Speed (mph)	Landfall Location	Park Sites Affected[3]	Data Source
Number 2	1940	August	1	80	Cameron	BP, CHAL, FQVC, WACC	Roth (2010)
Unnamed	1943	September	Tropical storm	Unknown	Unknown	BP, CHAL, FQVC, WACC	Roth (2010)
Unnamed	1947	August	Unknown	Unknown	Grand Isle	BP, CHAL, FQVC, WACC	Roth (2010)
Number 4	1947	September	1	80	New Orleans	BP, CHAL, FQVC	Roth (2010)
George	1947	September	1	125	New Orleans	BP, CHAL, FQVC, ACC, WACC, PACC	Roth (2010)
Number 5	1948	September	1	80	Timbalier Bay	WACC, BP, CHAL, FQVC	Roth (2010)

Table 10 (continued). Hurricanes and Tropical Storms since 1939.

Storm Name	Year[1]	Month	Category at Landfall[2]	Sustained Wind Speed (mph)	Landfall Location	Park Sites Affected[3]	Data Source
Flossy	1956	September	2	100	Grand Isle	WACC, BP, CHAL, FQVC	Roth (2010)
Audrey	1957	June	4	145	Sabine Pass, TX	PACC, ACC	Roth (2010)
Carla	1961	September	4	145	Port Lavaca, TX	PACC, ACC	Roth (2010)
Cindy	1963	September	Tropical storm	Unknown	Galveston	BP, CHAL, FQVC, WACC	Roth (2010)
Hilda	1964	October	3	115	Salt Point	BP, CHAL, FQVC, WACC, ACC, PACC	Roth (2010)
Betsy	1965	September	3	125	Grand Isle	BP, CHAL, FQVC, WACC	Roth (2010)
Camille	1969	August	5	190	Pass Christian, MS	BP, CHAL, FQVC	Roth (2010)
Edith	1971	September	2	100	Pecan Island	ACC, PACC, WACC	Roth (2010)
Carmen	1974	September	3	120	Point Au Fer	WACC	Roth (2010)
Babe	1977	September	1	75	Cailliou Bay	BP, CHAL, FQVC, WACC	Roth (2010)
Bob	1979	July	1	75	Terrebonne Bay	BP, CHAL, FQVC, WACC	Roth (2010)
Danny	1985	August	1	90	Pecan Island	BP, CHAL, FQVC, WACC, ACC, PACC	Roth (2010)
Juan	1985	October	1	85	Atchafalaya	BP, CHAL, FQVC, WACC, ACC, PACC	Roth (2010)
Elena	1985	September	3	115	Gulfport, MS	BP, CHAL, FQVC	Roth (2010)
Florence	1988	September	1	75	Port Eads	BP, CHAL, FQVC	Roth (2010)
Andrew	1992	August	3	115	Atchafalaya	BP, CHAL, FQVC, WACC, ACC, PACC	Roth (2010)
Opal	1995	October	3	115	Pensacola, FL	BP, CHAL, FQVC, WACC	Roth (2010)
Danny	1997	July	1	85	Grand Isle	BP, CHAL, FQVC	Roth (2010)
Frances	1998	September	Tropical storm	90 (offshore)	Matagorda, TX	BP, CHAL, FQVC, WACC, ACC, PACC	Roth (2010)
Georges	1998	September	2	110	Pascagoula, MS	BP, CHAL, FQVC, WACC	Roth (2010)
Allison	2001	June	TS	30	Morgan City	BP, CHAL, FQVC, WACC, ACC, PACC	National Weather Service (2001)

Table 10 (continued). Hurricanes and Tropical Storms since 1939.

Storm Name	Year[1]	Month	Category at Landfall[2]	Sustained Wind Speed (mph)	Landfall Location	Park Sites Affected[3]	Data Source
Lili	2002	October	1	75	Vermilion Bay	BP, CHAL, FQVC, WACC, ACC, PACC	Roth (2010)
Isidore	2002	September	TS	65 (Grand Isle)	Grand Isle	BP, CHAL, FQVC, WACC	Roth (2010)
Ivan	2004	September	3 (MS/AL); tropical depression (LA)	41	Gulf Shores, AL; Cameron	BP, CHAL, FQVC, WACC	National Weather Service (2004); National Hurricane Center (2017)
Matthew	2004	October	Tropical Storm	40	Cocodrie	BP, CHAL, FQVC, WACC	Avila (2004); Roth (2010)
Katrina	2005	August	3	125	Mouth of the Mississippi River	BP, CHAL, FQVC	Roth (2010)
Rita	2005	September	3	115	Johnson's Bayou	BP, CHAL, FQVC, WACC, ACC, PACC	Roth (2010)
Gustav	2008	September	2	100	Mouth of the Mississippi River	BP, CHAL, FQVC, WACC, ACC, PACC	Roth (2010)
Ike	2008	September	1	75	Point Bolivar, TX	BP, CHAL, FQVC	Roth (2010)
Lee	2011	September	Tropical Storm	45	Lafitte	BP, CHAL, FQVC	Brown (2011)
Isaac	2012	August	1	80	Plaquemines Parish and Port Fourchon	BP, CHAL, FQVC	National Weather Service (2017a)
Cindy	2017	June	Tropical Storm	45	Cameron	ACC, PACC	National Weather Service (2017b)

In 2005, Hurricanes Katrina, Rita, and Cindy struck the park with strong winds (fig. 32). High winds and resultant waves eroded the shoreline and canal banks, and pushed salty water and wrack into the interior marsh of Barataria Preserve (Handley 2006). The southern end of the Lake Salvador shoreline retreated approximately 305 m (1,000 ft). Moreover, winds blew down 60% of the large trees at the preserve (KellerLynn 2010a), allowing the exotic Chinese tallow (*Triadica sebifera*) to flourish in disturbed areas. The storms also damaged trails and buildings at Barataria Preserve and the French Quarter Visitor Center (KellerLynn 2010a). At the Chalmette Unit, flooding during Hurricane Katrina caused headstone upheaval, wall collapse, death of mature trees, and flooding of three park buildings (Risk and Hasty 2008). In Barataria Preserve, portions of flotant were torn apart and other areas were compacted like an accordion; also areas of marsh were converted to open water (KellerLynn 2010a). During Hurricane Isaac in 2013, Barataria Preserve experienced salty storm surge and winds that substantially impacted forest canopy (Julie Whitbeck, Jean Lafitte National Historical Park and Preserve, ecologist, email communication, 18 April 2017).

Saltwater intrusion into a fresh groundwater lens may occur when strong storm surge or winds push saline water northward into freshwater habitats (NPS 2012). In Barataria Preserve, Hurricanes Katrina and Rita in 2005 and Hurricanes Gustav and Ike in 2008 drove salty storm surge through artificial canals and across wetland surfaces, impacting plants and animals of freshwater coastal wetlands.

Table 11. The Saffir-Simpson Hurricane Wind Scale.

Notes: Category is a 1 to 5 rating based on a hurricane's sustained wind speed. This scale estimates potential property damage. Hurricanes reaching category 3 and higher are considered major because of the potential for significant loss of life and damage.

Source: National Hurricane Center at http://www.nhc.noaa.gov/aboutsshws.php (accessed 15 February 2019).

Category	Sustained Winds	Types of Damage due to Hurricane Winds
1	74–95 mph 64–82 kt 119–153 kph	**Very dangerous winds will produce some damage**: well-constructed frame homes may sustain damage to roofs, shingles, vinyl siding, and gutters. Large branches of trees will snap and shallowly rooted trees may topple. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
2	96–110 mph 83–95 kt 154–177 kph	**Extremely dangerous winds will cause extensive damage**: well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected, with outages that could last from several days to weeks.
3 (major)	111–129 mph 96–112 kt 178–208 kph	**Devastating damage will occur**: well-built frame homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4 (major)	130–156 mph 113–136 kt 209–251 kph	**Catastrophic damage will occur**: well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5 (major)	≥157 mph ≥137 kt ≥252 kph	**Catastrophic damage will occur**: a high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

Figure 32. Photograph of hurricane damage at the Chalmette Unit.
Hurricane Katrina’s winds toppled trees in Chalmette National Cemetery in the Chalmette Unit of the park. The levee (map unit Hml1) is visible in the background. NPS photograph courtesy of Kristy Wallisch (Jean Lafitte National Historical Park and Preserve), undated.

Hurricane-driven changes in salinity can cause shifts or loss of marsh and swamp habitat. Subsequent periods of freshwater input and flushing can return the habitat to normal conditions. Generally, tidal influence is minimal in the upper portion of Barataria basin. Within Barataria Preserve, intact flotant continues to buffer interior sections of the basin, but regional marsh loss has reduced the potential for buffering saltwater influx (Hatt et al. 2015).

Heavy precipitation during hurricanes can also introduce freshwater and nutrients via runoff, reducing salinity and enhancing coastal productivity, sometimes causing algal blooms (Conner et al. 1989). Hurricane-associated rainfall also re-suspends and deposits sediment on wetland surfaces, which helps to offset relative sea level rise and increase marsh elevation (Baumann et al. 1984; Cahoon et al. 1995). As the climate continues to warm, hurricane-associated rainfall rates are projected to increase, causing more flooding (Frankson et al. 2017).

Wetland elevations can change in response to storm surge, high winds, and freshwater flushing of an estuary. Storms drive eight processes that can influence soil elevation: (1) sediment deposition, (2) sediment erosion, (3) sediment compaction, (4) soil shrinkage, (5) root decomposition (due to tree mortality from high winds), (6) root growth (following flushing with freshwater), (7) soil swelling, and (8) lateral folding of the marsh root mat (Cahoon 2006).

Land Loss

Between 1932 and 2016, coastal Louisiana lost approximately 4,833 km^2 (1,866 mi^2) of land area (fig. 33). The rate of loss during this period equates to the state losing an area the size of a football field every 34 to 100 minutes. This net change in land area amounts to a decrease of approximately 25% of the 1932 land area. More than 1,100 km^2 (425 mi^2) or approximately 30% of wetlands in the Barataria basin were lost between 1932 and 2016 (Couvillion et al. 2017).

Between 1932 and 2016, wetland change rates in coastal Louisiana have varied from a high of about 83 km^2/yr (32 mi^2/yr) lost in 1975 and 1977 to a loss of about 28 km^2/yr (11 mi^2/yr) in 2013, 2014, and 2015. According to Couvillion et al (2017), the slowing rate of wetland change since its peak in the mid-1970s is noteworthy. Not only have rates of wetland loss been decreasing since that time, investigators have observed a further rate reduction since 2010. Possible reasons for this reduction include recovery from lows affected by the hurricanes of 2005 and 2008, the lack of major storms in the past eight years, a possible slowing of subsidence rates (see "Subsidence"), the reduction in and relocation of oil and gas extraction and infrastructure since the peak of such activities in the late 1960s, and restoration activities. In addition, many wetlands in more exposed positions in the landscape have already been lost. According to Couvillion et al. (2017), most notable of the factors listed above is the lack of major storms over the past eight years. The observed coastwide net "stability" in land area observed over the past 6–8 years does not imply that loss has ceased, however. Future disturbance events such as a major hurricane impact could change the trajectory of the rates. In addition, sea level rise is projected to increase (see table 6), which would expedite the rate of wetland loss. The natural resource condition assessment for the park (Hatt et al. 2015) noted that wetland loss will continue as a result of sea level rise, subsidence, and erosion that combine to drive losses in land and alter hydrology.

Both anthropogenic and natural mechanisms cause wetland loss in coastal Louisiana. The main anthropogenic causes are artificial channel cutting and subsequent expansion, pond creation, urbanization, reduction in sediment supply (particularly as a result of dam construction within the Mississippi River watershed; see Bentley et al. 2016), and hydrocarbon (oil and gas) withdrawal (Morton et al. 2003). A main natural cause is subsidence via sediment compaction (see "Subsidence"), but rates of subsidence decrease with time as the water within the sediments is depleted (Morton et al. 2003). Other primary causes of natural land loss are marsh drowning by rising relative sea level and marsh edge erosion by waves. A study by Ortiz et al. (2017) found that in the Barataria basin, open-water areas within (surrounded by) marsh are expanding due to wind-driven waves that erode the edges of the marsh at an average rate of 2.7 m/yr (8.9 ft/yr). Expansion of open-water areas is predominantly moving in the same direction as the average winds, which are to the southwest. Many researchers have reported on these and other natural causes of land loss (see Conner and Brody 1989; Britsch and Kemp 1990; Penland et al. 1992; Turner 1997; Day et al. 2000, 2007; Reed 2002; Morton et al. 2003, 2006; Barras 2006; Allison and Meselhe 2010).

A local cause of land loss in Barataria Preserve is two exotic animal species, nutria (*Myocastor coypus*, a semi-aquatic rodent native to South America) and feral pigs (*Sus scrofa*). These voracious eaters of marsh and swamp vegetation cause considerable bank erosion and the loss of organic matter that builds up peat soil. The animals prefer to eat the stems of plants, but will consume entire plants, and dig for roots and rhizomes to feed on, especially in winter. This behavior and the loss of vegetation can lead to the destabilization of soil

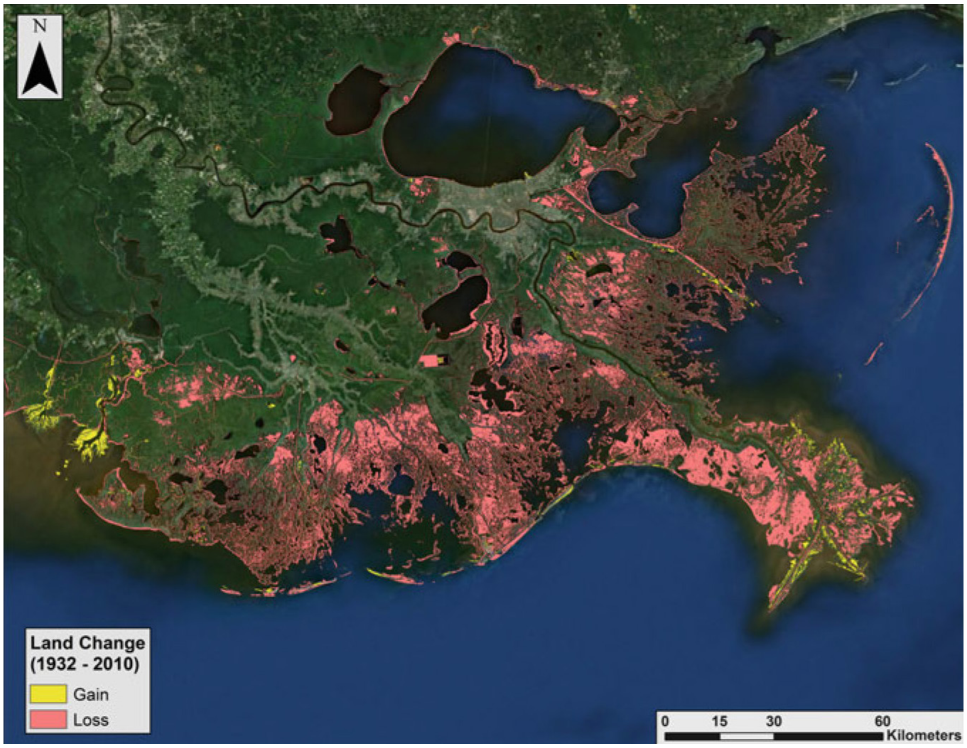

Figure 33. Graphic showing wetland change on the Mississippi River Delta, 1932–2010. The difference between land area gained (yellow) and lost (red) between 1932 and 2010 is stunning. Green areas indicate land areas sustained during these 78 years. Graphic from Mendellson et al. (2017, figure 6.89) compiled using data by Couvillion et al. (2017). Base image from ArcGIS World Imagery.

and erosion. Additionally, nutria burrow into banks, thereby impacting levees and increasing bank erosion (Hatt et al. 2015). Feral pigs spend much of their time rooting or digging with their noses in search of food, which increases erosion, and loosens soil that can wash away from banks during rains (Hatt et al. 2015).

A particular area of concern for erosion and land loss in the park is the eastern shoreline of Lake Salvador, which as shown on the map by Couvillion et al (2017) has experienced persistent land loss starting in 1956. Organic peat deposits erode most quickly (9 m/yr [30 ft/yr]); slower erosion occurs along the shell beach of Chenier Grand Coquilles (1.5 m/yr [5 ft/yr]) (fig. 34). Episodic events can cause significant erosion; for example, during Hurricane Katrina in 2005, 305 m (1,000 ft) of erosion occurred in one day (at a single location). Analysis of the eastern shoreline of Lake Salvador and the western shore of the canal that parallels the lake shoreline shows that shoreline loss rates have remained relatively constant from 1958 to 2005 with lakeside land area decreasing by 4.4–6.5 ha/yr (11–16 ac/yr), canal area changing less than 0.4 ha/yr (1 ac/yr), and open water increasing by 4.4–6.9 ha/yr (11–17 ac/yr) (Handley 2006). As a result of shoreline stabilization—for example, rock revetment and a dike, a geo-crib structure now replaced by revetment (fig. 35), and a marsh creation project—the rate of loss along Lake Salvador appears to be declining (Coburn et al. 2010; Hatt et al. 2015; Dusty Pate, Jean Lafitte National Historical Park and Preserve, natural resource manager, written communication, 11 May 2018).

The park's natural resource condition assessment (Hatt et al. 2015) evaluated the condition, status, and trends of natural resources and found that lakeside erosion and subsidence had poor condition with a negative trend; terrestrial vegetation, which includes marsh, had fair condition with a negative trend; and aquatic vegetation was of fair condition with no trend. The report advised monitoring the continuing effects of sea level rise, subsidence, and erosion using a combination of field data collection within the park and remote imagery to map land loss and habitat changes. The time-series habitat maps of Barataria Preserve that were created using aerial photography and satellite imagery (1958–2016) provide one way to monitor land loss and shoreline changes (Handley 2006).

Hatton et al. (1983) reported on vertical accretion of wetlands in the Barataria basin (as sampled in freshwater, intermediate, brackish, and salt marsh types). Rates of accretion ranged from a maximum of 1.7 cm/yr (0.67 in/yr) in streamside or natural levee deposits to as little as 0.31 cm/yr (0.12 in/yr) in

Figure 34. Photograph of Chenier Grand Coquilles in Barataria Preserve.
Erosion takes place along the shell beach of Chenier Grand Coquilles (map unit Hds) in Barataria Preserve. The eroding shoreline has reached the base of mature trees. The white feature in the background on the left side of the photograph is an offshore dike made of stone. Rock dikes and artificial islands were constructed in 2005 to provide protection to the Chenier Grand Coquilles midden. Photograph from Urbatsch et al. (2009, figure 20).

selected backmarsh areas; mean values were 1.3 cm/yr (0.51 in/yr) and 0.7 cm/yr (0.3 in/yr) in levee and adjacent backmarsh areas, respectively. Thus, many areas composed of levee deposits will keep pace with projected rates of sea level rise until 2030, even under extreme scenario conditions (i.e., 15 mm/yr [0.6 in/yr]; see table 7), but areas of backmarsh will have been submerged under similar conditions by 2030.

Significantly, Hatton et al. (1983) noted the observed persistence of marshes in the Barataria basin despite accretionary deficits. They found that substrate buoyancy of flotant is a key factor and concluded that flotant's observed independence from measured rates of accretion is "testimony to the accretionary role of organic matter in this low-energy system" (p. 501). The study pointed to a gradient of structural need for inorganic sediment input from relatively low-energy systems to higher hydraulic energy areas near the Gulf of Mexico; the preserve is somewhere in the upper-middle of this range (Dusty Pate, Jean Lafitte National Historical Park and Preserve, natural resource manager, written communication, 11 May 2018).

Oil and Gas Operations

In the National Park Service Organic Act and the acts that established individual park units, Congress authorized the Secretary of the Interior to develop regulations for managing and protecting units. Based on these authorities, the National Park Service promulgated Title 36 Code of Federal Regulations (CFR), Part 9, Subpart B ("9B regulations") that govern the exercise of nonfederal oil and gas rights in park units (see https://www.ecfr.gov/cgi-bin/ECFR?page=browse).

These 9B regulations require prospective operators to obtain NPS approval of an operations permit and to secure reclamation bonds before they commence operations. The permit application details all activities of the oil and gas development, describes how reclamation will be completed, and provides the basis for calculating performance bonds. The National Park Service uses the information to determine the effects of proposed operations on the environment, visitor use, and park management. In short, 9B regulations require operators to prevent or minimize damage to NPS resources and values.

Appendix B of this GRI report lists guidance regarding nonfederal oil and gas, federal mineral leasing (oil and gas, salable minerals, and non-locatable minerals), and nonfederal minerals other than oil and gas. The NPS Geologic Resources Division can provide park staff

Figure 35. Photographs of the eastern shoreline of Lake Salvador.
To reduce the risk of breaching between the eroding eastern shoreline of Lake Salvador into the Bayou Segnette Waterway, an earthen dike was built in 1996 and filled to reestablish the marsh. This project area is generally known as the geo-crib. In the top photograph: The straight Bayou Segnette Waterway is on the left. Lake Salvador is on right. The dike runs down the side of the canal, and the geo-crib is offshore and ties into additional rock-shoreline protection extending out of the frame of the photograph to the right. In the bottom photograph: A wooden bulkhead at the Tenneco canal originally dead-ended at a drilling location in the marsh until the lake eroded into it. Photograph [top] from USACE (1998). NPS photograph [bottom] by Courtney Schupp (NPS Geologic Resources Division), taken looking westward into Lake Salvador on 28 October 2015.

with policy and technical assistance regarding energy issues.

The NPS Geologic Resources Division Energy and Minerals website, http://go.nps.gov/grd_energyminerals, provides additional information.

Barataria Preserve includes extensive nonfederal oil and gas rights. Two active operations are currently taking place in the preserve. Production mostly took place during the 1940s–1960s, and those wells are now considered abandoned mineral lands (see “Abandoned Mineral Lands and Past Shell Mining”). In addition, four natural gas pipelines, one highly volatile liquid pipeline, and one crude oil pipeline cross Barataria Preserve, as well as five electrical transmission lines and multiple distribution lines. Operation and maintenance of these linear features result in vegetation removal and structure replacement (USACE 2015a; Dusty Pate, Jean Lafitte National Historical Park, natural resource manager, written communication, 8 March 2019).

The “Canals and Spoil Banks” section of this report discusses the construction of canals (and associated spoil banks) to accommodate pipelines and provide access for drilling. Other impacts related to oil and gas exploration, development, and production include landform modifications, subsidence resulting from fluid withdrawals, the introduction of fill (to create roads and drilling locations), and spills.

Spills of oil, production-related water, drilling fluids, and other contaminants could occur at drilling or production sites, along flowlines or pipelines, or at the refinery near the Chalmette Unit. For instance on an inholding (radio tower site) in Barataria Preserve, a 45,000-L (12,000-gal) fuel storage tank leaked in 2009. Fortunately, the spill was effectively cleaned up and has produced no noticeable lasting effects (Dusty Pate, Jean Lafitte National Historical Park and Preserve, natural resource manager, written communication, 11 May 2018).

The Oil Pollution Act of 1990 authorizes certain federal agencies, states, and Indian tribes, collectively known as the Natural Resource Trustees, to evaluate the impacts of oil spills on natural resources. The trustees are responsible for pre-assessment data collection, injury assessment, and restoration planning. This process identifies restoration activities, rehabilitation, or the need for replacement of natural resources. The responsible parties will be required to fully compensate the public for the damage to natural resources.

The 2010 BP Deepwater Horizon oil spill affected the park not with oil, which entered marshes in Barataria Bay south of the park (KellerLynn 2010a), but by a release from the Davis Pond freshwater diversion project of an above-normal volume of summer river water in an attempt to keep oil from migrating farther into Barataria Bay. The increased turbidity and decreased salinity caused the loss of 83% (20 ha [50 ac]) of submerged aquatic vegetation (SAV) and a decrease in SAV diversity along the Lake Cataouatche shoreline within the park (Deepwater Horizon Natural Resource Damage Assessment Trustees 2016). Settlement funds will support restoration projects in Barataria Preserve and elsewhere along the Gulf coast.

The park’s foundation document (NPS 2015) lists the need for a minerals management plan to anticipate future energy demands and to establish procedures by which nonfederal oil and gas rights are exercised to minimize impacts to critical park resources. Several existing datasets will be useful for developing this plan; these include GIS (point) data from the State of Louisiana for all the oil and gas wells near the park and pipeline data from the National Mapping Pipeline System. Additionally, the Geologic Resources Division completed an inventory of wells in the 1990s. Park staff should consider submitting a technical assistance request to the NPS Geologic Resources Division for assistance in developing a minerals management plan.

Recreational and Watershed Land Use

The park’s natural resource condition assessment (Hatt et al. 2015) labeled adjacent land use as the most concerning set of metrics related to Barataria Preserve because development is likely to introduce invasive species, fragment protected areas in the region, increase stream sedimentation, and impact water and air quality. However, compared to other NPS units, the 30 km (19 mi) buffer surrounding Barataria Preserve has a relatively high percentage (34.7%) of protected lands (Hatt et al. 2015).

Restoration and Coastal Protection Projects

Park managers have planned and implemented multiple restoration projects related to geologic resources within Barataria Preserve (table 12; fig. 27). NPS *Management Policies 2006* requires that natural shoreline processes be allowed to continue without interference and that anthropogenic impacts be mitigated. Exceptions require special evaluation and are granted for the protection of cultural or natural resources, safety during emergencies, and congressional directives.

Some of the projects affecting Barataria Preserve are part of Louisiana’s coastal master plan (CPRA 2017), by which the State of Louisiana directs and constrains coastal restoration activities, including water in the lower Mississippi River valley and sediment diversions. Updates to the coastal master plan take place every five

Table 12. List of planned and completed restoration projects in Barataria Preserve.

See figs. 2 and 27 for locations.

Project Name	Purpose	Location	Pertinent Dates	Information Sources
Davis Pond freshwater diversion project	Help to restore inflow from the Mississippi River. Divert river water into Lake Cataouatche through a holding area, then downstream to Lake Salvador and to the lower part of Barataria basin. Deliver water and sediments to the upper Barataria basin at 302 m^3/s (10,650 cfs). Designed to sustain land. Limit salinity intrusion via freshwater input but does not divert significant quantities of sediment. Protect wetlands in Barataria Preserve. Lower salinity, introduce sediments, and fertilize wetlands.	North of Barataria Preserve	Operational since 2002	NPS (2008); Ren et al. (2009); Allison and Meselhe (2010); Ford (2014)
Mid-Barataria sediment diversion	Build and maintain land. Capacity of 2,124 m^3/s (75,000 cfs).	Southeast of Barataria Preserve, near the town of Myrtle Grove	Engineering and design underway as of 2017. EIS in process. Permitting should be complete by 2020. Construction will take three years.	CPRA (2017)
Ama sediment diversion	Control structure provides sediment into upper Barataria basin for emergent marsh creation and freshwater to sustain existing wetlands. Capacity of 1,416 m^3/s (50,000 cfs).	Northwest of Barataria Preserve at the site of the Davis Pond freshwater diversion project	Not yet started as of 2017. Planning, design, and construction will take five years.	CPRA (2017)
Canal reclamation	Backfill canals with sediment and material from adjacent spoil piles to (1) restore functions, resources, and values related to hydrology by reclaiming 30 km (20 mi) of canals for interior coastal wetland restoration; (2) maintain integrity and improve resiliency of the ecosystems to both subsidence and climate change impacts; and (3) reduce impacts from the influence of the Gulf of Mexico in general, including the rapid rate of relative sea level rise and increased storm intensity.	Barataria Preserve	9 km (6 mi) were backfilled in 2001–2002 and 2010. Backfilling of an additional 26.5 km (16.5 mi) of canals in the preserve is planned using $8.7 million in Deepwater Horizon settlement funds.	Baustian and Turner (2006); Turner et al. (2006); Baustian et al. (2009); NPS (2009); Dusty Pate (Jean Lafitte National Historical Park and Preserve, natural resource manager, email communication, 29 September 2017)
Shoreline stabilization—Chalmette Unit	Maintain 133-m- (437-ft-) long concrete bulkhead, 591-m- (1,940-ft-) long concrete and stone riprap revetment, and 783 m (2,570 ft) of earthen concrete-faced levee topped with floodwall.	Chalmette Unit: Mississippi River shoreline	Bulkhead partially demolished and additional revetment constructed in 2014	Coburn et al. (2010)

Table 12 (continued). List of planned and completed restoration projects in Barataria Preserve.

Project Name	Purpose	Location	Pertinent Dates	Information Sources
Shoreline stabilization—geo-crib	Built to protect the eroding shoreline of Lake Salvador. 3,350 m (11,000 ft) of rock revetment and a 1,425 m (4,675 ft) geo-crib structure that encloses an area of former marsh that experienced severe erosion. Recycled Christmas trees used to build wave-dampening fences and to fill in canals to help reduce coastal erosion and reestablish the natural hydrology of the area.	Barataria Preserve: Lake Salvador and Bayou Segnette (fig. 35)	Bank stabilization beginning in 1995 with geo-crib completed in 1997. Spoils placement in 2000. Additional repairs and construction in 2003 and 2005. Christmas tree marsh restoration by Jefferson Parish, starting in 1991; conducted in 1998, 2001, 2002, and 2003 in Barataria Preserve.	USACE (2003); Coburn et al. (2010); Julie Whitbeck (Jean Lafitte National Historical Park and Preserve, ecologist, email communication, 18 April 2017); Jefferson Parish (2019)
Marsh restoration—geo-crib (NPS/USACE beneficial use of West Closure Complex spoil and project JL15 in the West Bank and Vicinity Hurricane and Storm Damage Risk Reduction System [WBV HSDRRS] IER12 and Mitigation)	382,200 m^3 (500,000 yd^3) of dredged sediment was placed behind the geo-crib to raise elevation and create marsh done as a beneficial use project during construction of the pumping station (2010–2011). Geo-crib site modified to restore existing foreshore rock dike (2.1 ha [5.1 ac]) and create fish dips (gaps) to allow water exchange and wildlife access to the marsh. Restoration of 20.4 ha (50.4 ac) of fresh marsh in the area behind the foreshore dike. Removed invasive black willows (***Salix nigra***) that are growing on higher elevation areas. Restoration of bottomland hardwood communities.	Barataria Preserve: Lake Salvador and Bayou Segnette	2010–2011 2017–2018	USACE (2015a)
Swamp restoration (beneficial use of sediment from maintenance dredging of the BSWW)	Thick layer of sediment (0.69–0.89 m [2.3–2.9 ft]) added to swamp. May have killed some trees by burial of cypress knees as well as buried fresh marsh, allowing the growth of a monoculture stand of black willow trees.	Barataria Preserve: Treasure Island	2007	Middleton and Jiang (2013); Hatt et al. (2015)
Fresh marsh restoration (project JL1B5 in WBV HSDRRS)	Restoration of fresh marsh habitats by filling 37 ha (91 ac) of open water using 459,000 m^3 (600,000 yd^3) of material dredged from Lake Cataouatche. A portion of this acreage will be composed of 2,560 m (8,400 ft) of dikes, including 945 m (3,100 ft) along Bayou Segnette.	Barataria Preserve: Yankee Pond and western shoreline of Bayou Segnette	2017–2019	USACE (2015a)
Fresh marsh restoration (project JL1B4 in WBV HSDRRS)	Restoration of fresh marsh by filling 8.3 ha (20.4 ac) of open water using 115,000 m^3 (150,000 yd^3) of material dredged from Lake Cataouatche.	Barataria Preserve: Yankee Pond southwest corner	2017–2019	USACE (2015a)

Table 12 (continued). List of planned and completed restoration projects in Barataria Preserve.

Project Name	Purpose	Location	Pertinent Dates	Information Sources
Swamp restoration (project JL7/404c in WBV HSDRRS)	Restoration of hydrologic connection and natural sheet flow across existing impounded swamp habitat to compensate for Park/404c swamp impacts. Create gaps in existing spoil banks to improve exchange of surface water between swamp habitats in the area.	Barataria Preserve: three locations along north side of the Millaudon canal and three locations along north side of the Horseshoe canal	2016–2017	USACE (2015a)
Restoration of wet bottomland hardwoods (project JL14A in WBV HSDRRS)	Fill 3.3 ha (8.1 ac) of an existing borrow pit using 160,500 m^3 (210,000 yd^3) of sand, 61,000 m^3 (80,000 yd^3) of clay, and 23,000 m^3 (30,000 yd^3) of topsoil.	Barataria Preserve	2016–2017	USACE (2015a)
Debris removal and dredging of Canoe Trails at Bayou Coquille and Kenta canal	Waterway clearing project, which affected both marsh and swamp with spray dredge deposition (although wetland nourishment was not the primary driver for this project)	Barataria Preserve	2010–2011	Julie Whitbeck (Jean Lafitte National Historical Park and Preserve, ecologist, email communication, 18 April 2017)
Cultural resource protection (Lake Salvador)	Creation of three islands linked by rock dikes to protect middens from erosion. The dikes and islands have become covered with native vegetation. Sediment is captured behind the low dikes when overtopped by waves. The dikes are laid on a geotextile material that prevents differential settling and slows subsidence.	Barataria Preserve: Chenier Grand Coquilles	2005	Hatt et al. (2015)

years; release of the most recent plan occurred in June 2017 (CPRA 2017). The plan does not list the National Park Service as a cooperating agency, but the National Park Service can participate in the public comment process for updates.

Several of the restoration projects in Louisiana's coastal master plan focus on new or increased input of sediment and water from the Mississippi River. The intention of diverting river water to flow into wetlands is to supply mineral sediments, organic matter, and dissolved nutrients that stimulate organic production rates. These additions can help to maintain marsh elevation or stimulate accretion, reducing the vulnerability of marshes to relative sea level rise (Allison and Meselhe 2010). Although not enough sediment is in the river to sustain the deltaic coast, if the diversion projects work efficiently and effectively, enough is available to sustain targeted regions (Bentley et al. 2013), although those regions may be small (Chamberlain et al. 2018).

Some of the water and sediment diversion restoration projects are expected to have substantial impacts on Barataria Preserve, including its vulnerability to tropical storm forces and relative sea level rise (Julie Whitbeck, Jean Lafitte National Historical Park and Preserve, ecologist, email communication, 18 April 2017); these are listed in table 12 and "Additional References."

Subsidence

Subsidence is the downward settling of Earth's surface; it results in observable or measurable topographic lowering, and thereby, is commonly defined in reference to a particular datum such as sea level or a ubiquitous peat layer (e.g., see Törnqvist et al. 2004, 2006). Natural and human-caused subsidence combined with low topographic relief increase the park's vulnerability to sea level rise and flooding.

Yuill et al. (2009) conducted a survey of contemporary subsidence research relating to coastal Louisiana and defined six primary "categories of processes": (1) tectonics (fault processes and salt movement), (2) Holocene sediment compaction, (3) sediment loading, (4) glacial isostatic adjustment, (5) fluid withdrawal, and (6) surface water drainage and management (table 13). These categories of processes are not fully independent

Table 13. Processes driving subsidence in coastal Louisiana.

Primary source: Yuill et al. (2009). Other sources of information include Diegel et al. (1995) and Gagliano (2007) for subsidence rates due to salt movement; Cahoon et al. (1995), Meckel et al. (2006, 2007), Törnqvist et al. (2008), and Van Asselen et al. (2009) for subsidence rates of Holocene sediment compaction; González and Törnqvist (2006) for subsidence rates of sediment loading; Cazenave et al. (2014), Fasullo et al. (2016), and Sweet et al. (2017c) for subsidence rates of glacial isostatic adjustment; Dokka (2006, 2011), Morton et al. (2006), and Kolker et al. (2011) for subsidence rates due to fluid withdrawal (including oil and gas and groundwater).

Process Category	Range of Identified Rates	Representative Area Affected
Tectonics	0.1–20.0 mm/yr	Coastal regions, continental margins, Holocene delta
Holocene sediment compaction	1.0–5.0 mm/yr	Holocene delta, lower Mississippi River valley
Sediment loading	1.0–8.0 mm/yr	Holocene delta, lower Mississippi River valley
Fluid withdrawal	As much as 23.0 mm/yr	Coastal regions
Glacial isostatic adjustment	0.6–2.0 mm/yr	Gulf region
Surface water management	0.1–10.0 mm/yr	Developed wetlands

from one another, and processes in one category may affect processes in another. In short, a continuum of processes of both spatial and temporal scales probably cause subsidence in coastal Louisiana (table 5). Consequently, discerning the precise contribution of the causal processes in any one category is difficult (Yuill et al. 2009). Louisiana Geological Survey Public Information Series 11 (McCulloh et al. 2006) discussed the geologic context of subsidence affecting the New Orleans area.

Sediment compaction (also referred to as "consolidation of Holocene deposits"; see Byrnes et al. 2018) is commonly cited as the dominant contemporary subsidence process or the primary contributor to subsidence in the Mississippi Delta region or, more specifically, on the Mississippi River delta plain (Roberts 1985; Roberts et al. 1994; Meckel et al. 2006; Törnqvist et al. 2008; Jankowski et al. 2017; Byrnes et al. 2018). As a point of clarification, sediment loading is different from sediment compaction; sediment loading refers to subsidence in the material underlying a sediment load rather than within the vertical stack of material constituting the sedimentary load.

Sediment compaction occurs primarily as a physical process, which takes place in two primary ways: (1) through the expulsion of pore fluid and (2) through the reorientation of sediment grains into a more tightly packed alignment (Yuill et al. 2009). However, biological (e.g., microbial decay of organic material; see Van Asselen et al. 2009) and chemical (e.g., oxidation of organic carbon; see Ivins et al. 2007) processes contribute to the net effect of physical sediment compaction that produces subsidence, especially in soil containing significant amounts of peat and other organic matter.

Sediment compaction is a natural process that has been taking place on the Mississippi River delta plain since delta formation began (see "Geologic History"). Most of the contribution of sediment compaction to subsidence occurs at the same temporal scale (100–1,000 years) as the primary components of the "delta cycle" that control delta evolution (Roberts 1997). In coastal Louisiana, the highest rates of sediment compaction take place in the recently deposited Holocene sediments, which are thickest near the seaward margins of the modern Plaquemines-Balize delta (Roberts et al. 1994). Thicker sediment deposits contain more interstitial water available for removal, which leads to high rates of subsidence as they consolidate (Byrnes et al. 2018). Penland and Ramsey (1990), Keucher (1994), Roberts et al. (1994), Kulp (2000), Törnqvist et al. (2008), and Byrnes et al. (2018) have described the relationship between age and thickness of deltaic deposits and resulting rates of subsidence.

In addition to composing the modern delta, Holocene sedimentary deposits, which are prone to compaction, extend north into the lower Mississippi River valley. These deposits parallel the historical course of the Mississippi River and widen nearer to the Gulf of Mexico, eventually forming the modern delta plain. In southern Louisiana, these sediments overlie a less-compactable Pleistocene basement layer (Yuill et al. 2009).

Nienhuis et al. (2017) created a subsidence map for coastal Louisiana, which may be of interest and use to park managers for identifying areas prone to higher rates of subsidence. A key finding of Nienhuis et al. (2017) was that their newly calculated present-day subsidence rates are considerably higher than other studies that relied partly or entirely on tide gauges,

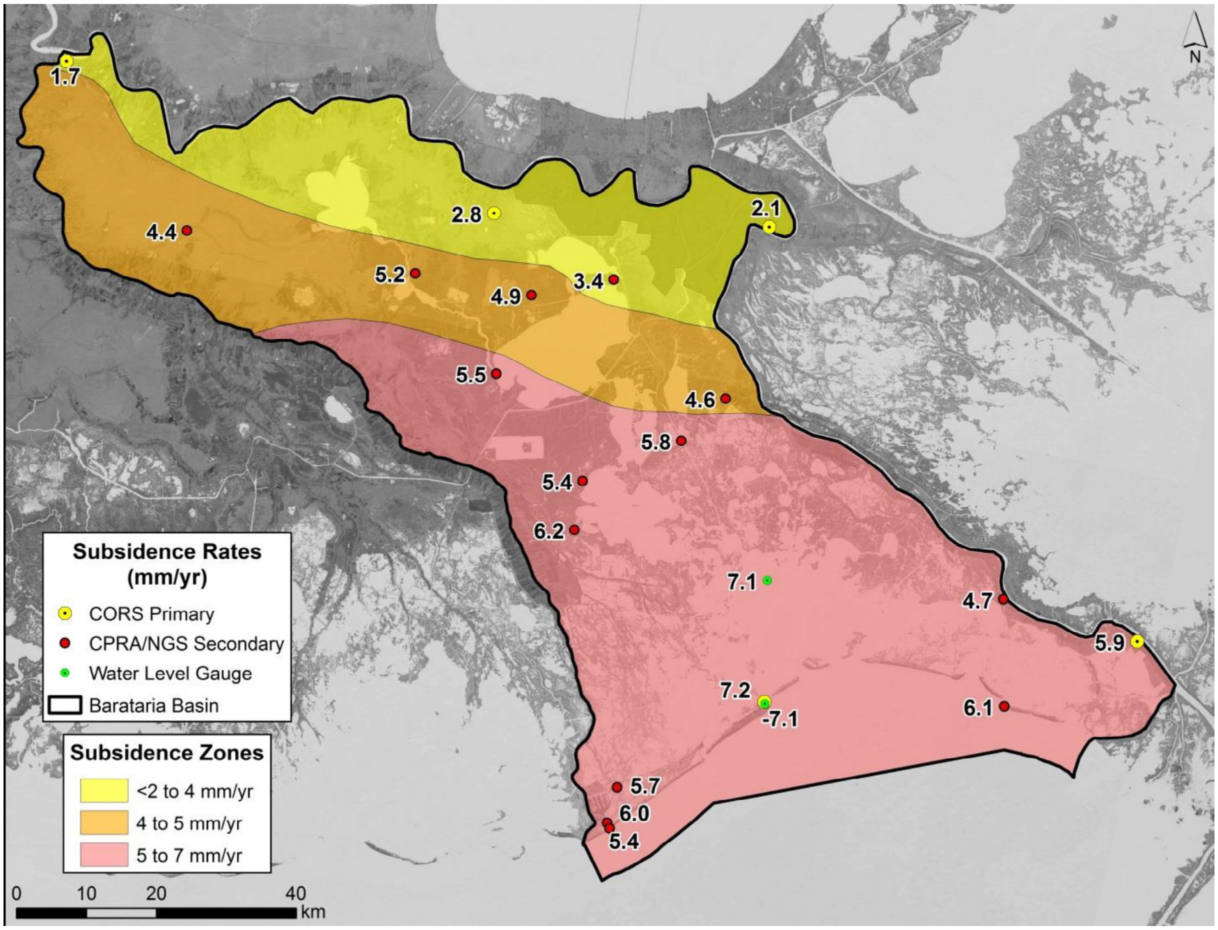

Figure 36. Map showing subsidence rates within the Barataria basin.
A study by Byrnes et al. (2018) determined recent subsidence rates in the Barataria basin by utilizing high-resolution geodetic GPS elevation measurements at primary and secondary benchmarks and water level gauges. CORS = Continuously Operating Reference Station. CPRA = Louisiana Coastal Protection and Restoration Authority. NGS = National Geodetic Survey. The National Oceanic and Atmospheric Administration, US Army Corps of Engineers, and US Geological Survey monitor the water level gauges. Based on these findings, Barataria Preserve has subsidence rates from less than 2 mm/yr to 5 mm/yr, with greater rates occurring from north to south. Graphic from Byrnes et al. (2018, figure 18).

such as Kolker et al. (2011) and Karegar et al. (2015). As a result, "worst case scenario" predictions for the Mississippi River Delta throughout the 21st century (e.g., Blum and Roberts 2009; Kim et al. 2009), which used subsidence rates of 8–10 mm/yr (0.3–0.4 in/yr), actually reflect present-day conditions in coastal Louisiana.

Of significance for Barataria Preserve, Byrnes et al. (2018) provided a range of subsidence rates for the Barataria basin between 2 and 7 mm/yr (0.08 and 0.3 in/yr) and noted a compelling relationship between rates of subsidence and the age, composition, and thickness of Holocene deltaic deposits. As Holocene sediment deposits composing the St. Bernard delta lobe (geologic unit **Hds**; see Chalmette Unit, French Quarter Visitor Center, and Barataria Preserve poster, in pocket) get thicker, from north to south, subsidence rates increase (fig. 36). In northern Barataria basin, subsidence rates are relatively low, ranging from less than 2 to 4 mm/yr (0.08 to 0.2 in/yr). This area is characterized by the oldest deposits from the St. Bernard delta lobe adjacent to the main river channel, where sediment texture is coarser and more consolidated than finer grained, more recent deposits in the southern basin. The northeastern portion of Barataria basin has relatively thin Holocene deposits, overlying shallow (close to the surface) Pleistocene deposits. The northern half of the basin also contains multiple overlapping delta lobes, which may contribute to the stability of these Holocene deltaic deposits. In the southern part of the basin, where subsidence rates increase to about 5 to 7 mm/yr (0.2 to

0.3 in/yr), deltaic deposits generally are younger and thicker, resulting in greater consolidation potential.

A key issue identified in the park's foundation document (NPS 2015) is the condition of the grave markers in some sections of Chalmette National Cemetery. The foundation document states that the condition is "compromised by subsidence and bioturbation, and thus the markers fail to meet the standards for a national cemetery" (p. 13). The scale of this particular example of subsidence, however, seems to be local and not a direct result of the topographic lowering of Earth's crust. Nevertheless, park managers may find the results of Byrnes et al. (2018) of interest and use if they embark on a cemetery management plan. The Chalmette Unit is at the northeastern edge of the area mapped by Byrnes et al. (2018); this area has an estimated subsidence rate of less 2 mm to 4 mm/yr (0.08 to 0.2 in/yr). Also, as mentioned previously, the Holocene deposits in the northeastern portion of Barataria basin are relatively thin and overlie shallow (close to the surface) Pleistocene deposits, which may provide stability. NPS cemetery policy, *Reference Manual 61: National Cemetery Operations*, does not require but strongly suggests that an individual cemetery management plan indicate management methods and maintenance schedules specific to particular environmental conditions.

Anthropogenic manipulation of the Mississippi River fluvial system and its natural sedimentation regime has significantly altered compaction-related subsidence rates in many areas of coastal Louisiana. Anthropogenic activities have included entrapment of much of the natural sediment load in upstream reservoirs and the confinement of the Mississippi River behind flood-control levees, which has eliminated overbank flooding that historically brought freshwater and mineral sediments to many deltaic marshes. In short, the volume of introduced sediment no longer offsets the loss of soil volume resulting from compaction of previously deposited sediments. In recent decades, anthropogenic modifications have reduced river sediment supply by approximately half. This deficit, combined with the increased rate of sea level rise since delta construction, means that drowning of the Mississippi River delta plain is inevitable (Blum and Roberts 2009). According to Bentley et al. (2013), given the current amount of available sediment, enough is transported through the system to maintain about 20% of the Mississippi River delta plain.

Louisiana's coastal master plan (CPRA 2017) includes strategies for increasing sediment load to the Mississippi River Delta. These strategies may help offset subsidence through the following three processes: (1) the vertical land-building capabilities of flotant through the accretion of organic soils; (2) the ability of rooted wetland systems in the delta environment to capture sediment and add organic material through nutrient enrichment from river water; and (3) the re-distribution of heavier sediment input from upstream, which will result in soil platforms at the mouths of distributary channels scaled to remain above sea level. Significantly, findings by Swarzenski et al. (2008) suggest that river diversions may not be the beneficial mitigating agent of wetland restoration and conservation that they are anticipated to be for building healthy marsh soil. That study recommended that managers carefully consider the type of marsh, the soil environment, and the organic matter quality of the wetlands with respect to the construction and operation of controlled river diversions.

The "Restoration and Coastal Protection Projects" section of this report discusses resource management response to subsidence at the park, for example, planning of the mid-Barataria basin diversion (i.e., freshwater diversion from the Mississippi River to rebuild wetlands and control salinity) and continued work to backfill canals to restore natural wetland hydrology and vegetation to improve resiliency of coastal landscape (NPS 2015).

Geologic Map Data

A geologic map in GIS format is the principal deliverable of the GRI program. GRI GIS data produced for the park follow the source maps listed here and include components described in this chapter. Four posters (in pocket) display the data over imagery of the park and surrounding areas. Complete GIS data, which are composed of five separate data sets, are available at the GRI publications website: http://go.nps.gov/gripubs.

Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at or beneath the land surface (Evans 2016). The colors on a geologic map indicate the rock types or deposits present in an area, as well as the ages of these rocks and deposits. In addition to color, a map unit symbol differentiates the various rocks and deposits on a geologic map. Usually, the map unit symbol consists of an uppercase letter indicating the age (e.g., **PE** for Pleistocene and **H** for Holocene) and lowercase letters indicating the rock formation's name or the type of deposit (see table 2). Other symbols on geologic maps depict the contacts between map units, structures such as faults, or other line features; for example, the GRI GIS data for the park mark the shoreline as a line feature. Some map units (e.g., landslide deposits) and line features (e.g., Quaternary faults) delineate locations of past geologic hazards, which may be susceptible to future activity. Anthropogenic features such as mines or quarries, as well as observation or collection localities, may be indicated on geologic maps. The American Geosciences Institute website, http://www.americangeosciences.org/environment/publications/mapping, provides more information about geologic maps and their uses.

Geologic maps are typically one of two types: surficial or bedrock. Surficial maps typically encompass deposits that are unconsolidated and formed during the past 2.6 million years (Quaternary Period). Surficial map units are differentiated by geologic process or depositional environment. Most of the map units in the GRI GIS data for the park are surficial (see table 2). Bedrock maps encompass older, typically more consolidated sedimentary, metamorphic, and/or igneous rocks. Bedrock map units commonly have a formation name and are differentiated based on age and/or rock type. A formation is a fundamental rock-stratigraphic unit that is mappable, lithologically distinct from adjoining strata, and has definable upper and lower contacts. Two "alloformations"—the Beaumont alloformation and the Avoyelles alloformation (table 2)—were mapped within the park. Like formations, alloformations may be separated into members of lumped into a group, in this case, the Prairie Allogroup (see "Prairie Terrace").

Source Maps

The GRI team does not conduct original geologic mapping. The team digitizes paper maps and/or converts digital data to compile the GRI GIS data, which conform to the GRI GIS data model. The GRI GIS data include essential elements of the source maps such as map unit descriptions, a correlation chart of units, a map legend, map notes, cross sections, figures, and references. These items are included in the GRI ancillary map information document (jela_geology.pdf). The GRI team used source maps by the Louisiana Geological Survey that cover seven 30 × 60 minute quadrangles: New Orleans, Ponchatoula, Gulfport, Baton Rouge, Black Bay, Crowley, and Ville Platte (table 14). Mapping took place at a scale of 1:100,000. Selected 7.5 minute quadrangles (i.e., those containing park units or other areas of interest) contained within these 30 × 60 minute quadrangles were included in the GRI GIS data (table 14; fig. 37).

GRI GIS Data

The GRI team standardizes map deliverables by using a data model. The GRI GIS data for the park was compiled using data model version 2.1, which is available at http://go.nps.gov/gridatamodel. This data model dictates GIS data structure, including layer architecture, feature attribution, and relationships within ESRI ArcGIS software.

GRI GIS data are available on the GRI publications website http://go.nps.gov/gripubs and through the NPS Integrated Resource Management Applications (IRMA) portal https://irma.nps.gov/App/Portal/Home. Enter "GRI" as the search text and select a park from the unit list.

The following components are part of a data set:

- A GIS readme file (jela_gis_readme.pdf) that describes the GRI data formats, naming conventions, extraction instructions, use constraints, and contact information;
- Data in ESRI geodatabase GIS format;

- Layer files with feature symbology (table 15);
- Federal Geographic Data Committee (FGDC)–compliant metadata;
- An ancillary map information document (jela_geology.pdf) that contains information captured from source maps such as map unit descriptions, geologic unit correlation tables, legends, cross sections, and figures; and
- An ESRI map document (.mxd) that display the GRI GIS data for the Acadian Cultural Center (accu_geology.mxd), Chalmette Unit (clmt_geology.mxd), French Quarter Visitor Center and Barataria Preserve (jela_geology.mxd), Prairie Acadian Cultural Center (prac_geology.mxd), and Wetlands Acadian Cultural Center (weac_geology.mxd).
- Data for the French Quarter Visitor Center and Barataria Preserve are also available in a format compatible with Google Earth (jela_geology.kmz).

GRI Map Posters

Four posters of the GRI GIS draped over a shaded relief image of the park and surrounding area are included with this report. Not all GIS feature classes are included on the posters (table 15). Geographic information and selected park features have been added to the posters. Digital elevation data and added geographic information are not included in the GRI GIS data but are available online from a variety of sources. Contact the GRI team for assistance locating these data.

Use Constraints

Graphic and written information provided in this report is not a substitute for site-specific investigations. Park managers should neither permit nor deny ground-disturbing activities based on the information provided here. Please contact the GRI team with any questions.

Minor inaccuracies may exist regarding the locations of geologic features relative to other geologic or geographic features within the data and on the posters. Based on the source map scale (1:100,000) and US National Map Accuracy Standards, geologic features represented in the GRI GIS data and on the posters are expected to be horizontally within 51 m (167 ft) of their true locations. The Chalmette Unit map is based on a 1:24,000–scale source map, resulting in an expectation that the geologic map data for that park site will be horizontally within 12 m (40 ft) of their true locations.

Table 14. Source maps for the park's GRI GIS data.

GRI GIS Data Set	Park Units Included in the Data Set	30 × 60 Minute Quadrangle	7.5 Minute Quadrangles Included in the Data Set	Source Map (scale 1:100,000)
accu_geology.mxd	Acadian Cultural Center	Baton Rouge	Broussard	Heinrich and Autin (2000)
accu_geology.mxd	Acadian Cultural Center	Crowley	Lafayette	Heinrich et al. (2003)
clmt_geology.mxd	Chalmette Unit	Black Bay	Belle Chasse, Chalmette, Delacroix, and Martello Castle	Heinrich (2014)
jela_geology.mxd	Barataria Preserve; French Quarter Visitor Center	Gulfport	Little Woods	Heinrich et al. (2004)
jela_geology.mxd	Barataria Preserve; French Quarter Visitor Center	New Orleans	Barataria, Bay L'Ours, Bayou Boeuf, Bertrandville, Catahoula Bay, Cut Off, Des Allemands, Gheens, Hahnville, Lac Des Allemands, Lafitte, Lake Cataouatche East, Lake Cataouatche West, Luling, New Orleans East, New Orleans West, and Three Bayou Bay	Heinrich et al. (2011)
jela_geology.mxd	Barataria Preserve; French Quarter Visitor Center	Ponchatoula	Indian Beach and Spanish Fort	McCulloh et al. (2003)
prac_geology.mxd	Prairie Acadian Cultural Center	Crowley	Eunice South	Heinrich et al.(2003)
prac_geology.mxd	Prairie Acadian Cultural Center	Ville Platte	Eunice North	Snead et al. (2002)

Table 14 (continued). Source maps for the park's GRI GIS data.

GRI GIS Data Set	Park Units Included in the Data Set	30 × 60 Minute Quadrangle	7.5 Minute Quadrangles Included in the Data Set	Source Map (scale 1:100,000)
weac_geology.mxd	Wetlands Acadian Cultural Center	New Orleans	Thibodaux Lake	Heinrich et al. (2011)

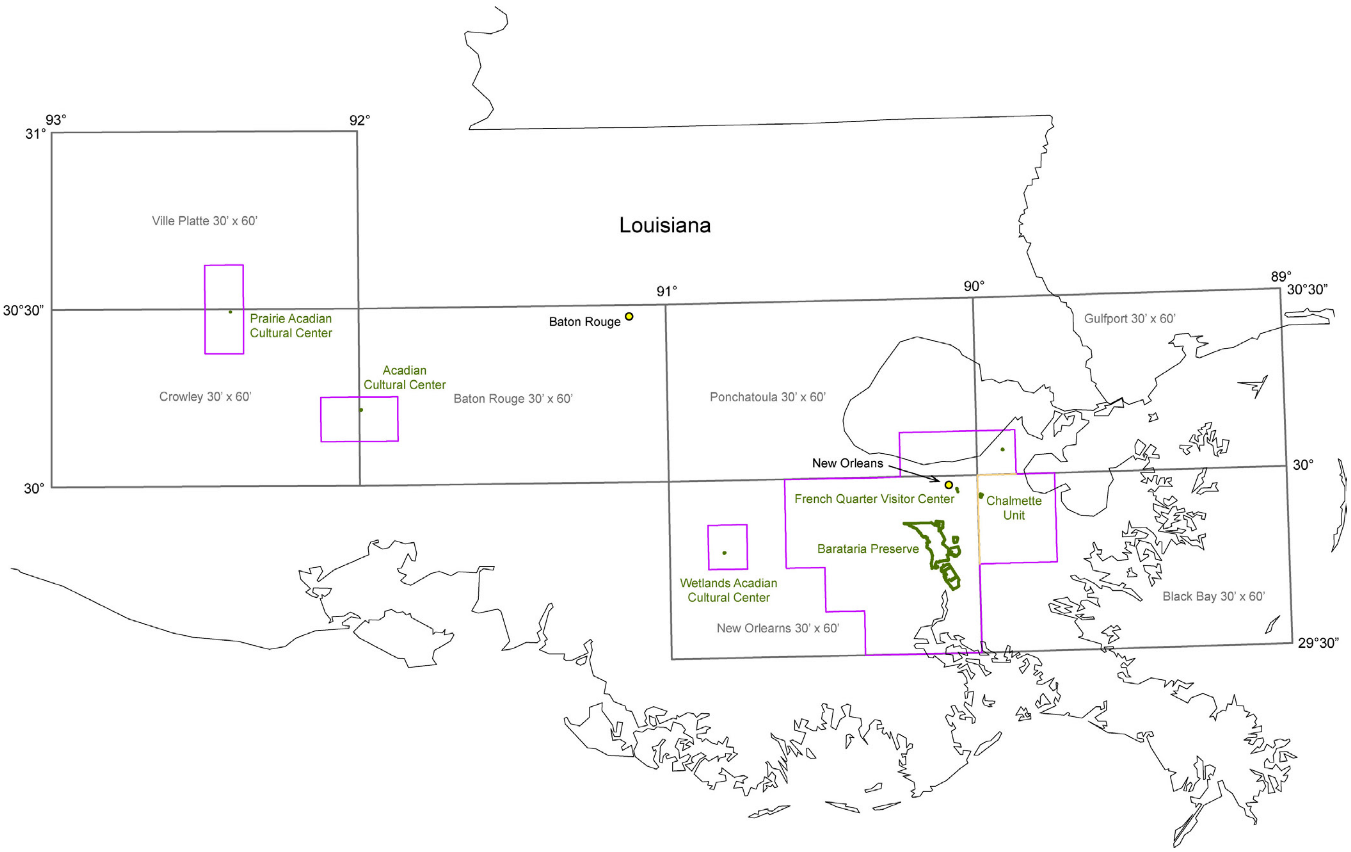

Figure 37. Index map of the 30 × 60 minute quadrangles of interest.
The base map is an outline sketch of the Mississippi River Delta in the state of Louisiana. Geologic data from thirty 7.5 minute quadrangles are included in the GRI GIS data for the park, as delineated by the pink outlines on the map. These 7.5 minute quadrangles are part of seven 30 × 60 minute quadrangles (outlined and labeled in gray): Ville Platte, Crowley, Baton Rouge, Ponchatoula, Gulfport, New Orleans, and Black Bay. The scale of the GRI GIS data is 1:100,000. The six park sites are labeled in green. Graphic by Stephanie O'Meara (Colorado State University).

Table 15. GRI GIS data layers for Jean Lafitte National Historical Park and Preserve.

*Only jela_geology data have an associated KMZ (Google Earth) file.

Data Layer	On Poster?	Google Earth Layer?*
Faults (part of jela and prac data only)	Yes	Yes (jela_geology.kmz)
Geologic Contacts	Yes	Yes (jela_geology.kmz)
Geologic Units	Yes	Yes (jela_geology.kmz)

Literature Cited

These references are cited in this report. Contact the Geologic Resources Division for assistance in obtaining them.

Allison, M. A., C. R. Demas, B. A. Ebersole, B. A. Kleiss, C. D. Little, E. A. Meselhe, N. J. Powell, T. C. Pratt, and B. M. Vosburg. 2012. A water and sediment budget for the lower Mississippi–Atchafalaya River in flood years 2008–2010: implications for sediment discharge to the oceans and coastal restoration in Louisiana. Journal of Hydrology 432–433:84–97. http://linkinghub.elsevier.com/retrieve/pii/S0022169412001205.

Allison, M. A., and E. A. Meselhe. 2010. The use of large water and sediment diversions in the lower Mississippi River (Louisiana) for coastal restoration. Journal of Hydrology 387(3–4):346–360. http://linkinghub.elsevier.com/retrieve/pii/S0022169410001824.

Anderson, J. B., D. J. Wallace, A. R. Simms, A. B. Rodriguez, and K. T. Milliken. 2014. Variable response of coastal environments of the northwestern Gulf of Mexico to sea-level rise and climate change: implications for future change. Marine Geology 352:348–366. http://linkinghub.elsevier.com/retrieve/pii/S0025322713002636.

Aslan, A., W. J. Autin, and M. D. Blum. 2005. Causes of river avulsion: insights from the late Holocene avulsion history of the Mississippi River, USA. Journal of Sedimentary Research 75:650–664.

Autin, W. J., S. F. Burns, B. J. Miller, R. T. Saucier, and J. I. Snead. 1991. Quaternary geology of the lower Mississippi Valley. Pages 547–582 *in* R. B. Morrison, editor. The Geology of North America, Volume K-2: Quaternary nonglacial geology—conterminous United States. Geological Society of America, Boulder, Colorado.

Autin, W. J., and A. Aslan. 2001. Alluvial pedogenesis in Pleistocene and Holocene Mississippi River deposits: effects of relative sea-level change. GSA Bulletin 113(11):1456–1466.

Avila, L. A. 2004. Tropical Storm Matthew, 8–10 October 2004. Tropical Cyclone Report (17 November 2004). National Hurricane Center, Miami, Florida. http://www.nhc.noaa.gov/data/tcr/AL142004_Matthew.pdf.

Balsillie, J. H., and J. F. Donoghue. 2011. Chapter 4: northern Gulf of Mexico sea-level history for the past 20,000 years. Pages 53–69 *in* N. A. Buster and C. W. Holmes, editors. Gulf of Mexico origin, waters, and biota, Volume 3: geology. Texas A&M University Press College Station, Texas.

Barras, J. 2006. Land area change in coastal Louisiana after the 2005 hurricanes: a series of three maps. Open File Report OFR-06-1274. US Geological Survey, Reston, Virginia. https://pubs.usgs.gov/of/2006/1274/.

Barry, J. M. 1997. Rising tide: the great Mississippi flood of 1927 and how it changed America. Simon and Schuster, New York.

Baumann, R. H., J. W. Day, and C. A. Miller. 1984. Mississippi deltaic wetland survival: sedimentation versus coastal submergence. Science 224(4653):1093–1095.

Baustian, J. J., and R. E. Turner. 2006. Restoration success of backfilling canals in coastal Louisiana marshes. Restoration Ecology 14(4):636–644. http://onlinelibrary.wiley.com/doi/10.1111/j.1526-100X.2006.00175.x/full.

Baustian, J. J., R. E. Turner, N. F. Walters, and D. P. Muth. 2009. Restoration of dredged canals in wetlands: a comparison of methods. Wetlands Ecology and Management 17(5):445–453. http://link.springer.com/10.1007/s11273-008-9122-6.

Baustian, M. M., C. L. Stagg, C. L. Perry, L. C. Moss, T. J. B. Carruthers, and M. Allison. 2017. Relationships between salinity and short-term soil carbon accumulation rates from marsh types across a landscape in the Mississippi River Delta. Wetlands 37(2):313–324. http://link.springer.com/10.1007/s13157-016-0871-3.

Beavers, R. L., A. L. Babson, and C. A. Schupp. 2016a. Coastal adaptation strategies handbook. NPS 999/134090. National Park Service, Washington, DC. https://www.nps.gov/subjects/climatechange/coastalhandbook.htm.

Beavers, R. L., S. Norton, M. Eissenberg, K. McDowell Peek, R. S. Young, and S. Quinn. 2016b. Chapter 6: facility management. Pages 71–88 *in* R. L. Beavers, A. L. Babson, and C. A. Schupp. Coastal adaptation strategies handbook. NPS 999/134090. National Park Service, Washington, DC.

Beavers, R., and J. Selleck. 2006. Impacts to national parks from 2005 hurricane season coming to light: a preliminary overview. Pages 13–15 *in* J. Selleck, editor, Natural Resource Year in Review—2005. Publication D-1755. National Park Service, Denver, Colorado, and Washington, DC.

Bentley, S. J. Sr., M. D. Blum, J. Maloney, L. Pond, and R. Paulsell. 2016. The Mississippi River source-to-sink system: perspectives on tectonic, climatic, and anthropogenic influences, Miocene to Anthropocene. Earth-Science Reviews 153139–174. http://dx.doi.org/10.1016/j.earscirev.2015.11.001.

Bentley, S., C. S. Willson, and A. Freeman. 2013. Chapter 1: sediment availability. Pages 6–7 in J. Day, chair. Answering 10 fundamental questions about the Mississippi River Delta. A report by the Mississippi River Delta Science and Engineering Special Team. Convened by the National Audubon Society, Environmental Defense Fund, and National Wildlife Federation, New York, New York. http://www.coastal.louisiana.gov/wp-content/uploads/2013/09/10-Fundamental-Questions-about-the-MS-River-Delta.pdf.

Biek, R. F., and M. A. Gonzalez. 2001. The geology of Theodore Roosevelt National Park, Billings and McKenzie Counties, North Dakota (scale 1:24,000). Miscellaneous Series 86. North Dakota Geological Survey, Bismarck, North Dakota.

Blum, M. D., and H. Roberts. 2009. Drowning of the Mississippi Delta due to insufficient sediment supply and global sea-level rise. Nature Geoscience 2:488–491. doi:10.1038/ngeo553.

Blum, M. D., and H. H. Roberts. 2012. The Mississippi Delta region: past, present, and future. Annual Review of Earth and Planetary Sciences 40(1):655–683. http://www.annualreviews.org/doi/10.1146/annurev-earth-042711-105248.

Blythe, R. W. 2012. Administrative history of Jean Lafitte National Historical Park and Preserve. 2012. National Park Service, Southeast Regional Office, Cultural Resources Division, Atlanta, Georgia.

Boesch, D. F., M. N. Josselyn, A. J. Mehta, J. T. Morris, W. K. Nuttle, C. A. Simenstad, and D. J. P. Swift. 1994. Scientific assessment of coastal wetland loss, restoration and management in Louisiana. Journal of Coastal Research Special Issue 20:103.

Britsch, L. D., and E. B. Kemp. 1990. Land loss rates: Mississippi River deltaic plain. Technical Report GL-90-2. US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Brown, D. P. 2011. Tropical Storm Lee (AL132011), 2–5 September 2011. Tropical Cyclone Report (15 December 2011). National Hurricane Center, Miami, Florida. http://www.nhc.noaa.gov/data/tcr/AL132011_Lee.pdf.

Burghardt, J. E., E. S. Norby, and H. S. Pranger II. 2014. Abandoned mineral lands in the National Park System: comprehensive inventory and assessment. Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2014/906. National Park Service, Fort Collins, Colorado. http://go.nps.gov/aml_publications.

Bush, D. M., and R. Young. 2009. Coastal features and processes. Pages 47–67 in R. Young and L. Norby, editors. Geological monitoring. Boulder, Colorado, Geological Society of America. http://go.nps.gov/geomonitoring.

Byrnes, M. R., L. D. Britsch, J. L. Berlinghoff, and R. Johnson. 2018. Determining recent subsidence rates for Barataria basin, Louisiana: implications for engineering and design of coastal restoration projects. Final report (August 2018). Prepared for Louisiana Coastal Protection and Restoration Authority by Applied Coastal Research and Engineering, Metairie, Louisiana, in cooperation with CDM Smith, Baton Rouge, Louisiana. https://cims.coastal.louisiana.gov/RecordDetail.aspx?Root=0&sid=21362.

Caffrey, M. A., R. L. Beavers, and C. H. Hoffman. 2018. Sea level rise and storm surge projections for the National Park Service. Natural Resource Report NPS/NRSS/NRR—2018/1648. National Park Service, Fort Collins, Colorado. https://www.nps.gov/subjects/climatechange/sealevelchange.htm/index.htm.

Cahoon, D. R. 2006. A review of major storm impacts on coastal wetland elevations. Estuaries and Coasts 29(6):889–898. http://www.springerlink.com/index/U655147873785482.pdf.

Cahoon, D. R., D. J. Reed, and J. W. Day. 1995. Estimating shallow subsidence in microtidal salt marshes of the southeastern United States: Kaye and Barghoorn revisited. Marine Geology 128(1):1–9.

Carter, L. M., J. W. Jones, L. Berry, V. Burkett, J. F. Murley, S. F. R. P. Council, P. J. Schramm, and D. Wear. 2014. Chapter 17: Southeast and the Caribbean. Pages 396–417 in J. M. Melillo, T. C. Richmond, and G. W. Yohe, editors. Climate change impacts in the united states: the third national climate assessment. US Global Change Research Program, Washington, DC. http://nca2014.globalchange.gov/report/regions/southeast.

Casio Computer Company. 2018. ke!san online calculator (date duration calculator). Casio Computer Co., Ltd., Tokyo, Japan. https://keisan.casio.com/exec/system/1247118517 (accessed 25 April 2019).

Cazenave, A., H. B. Dieng, B. Meyssignac, K. Von Schuckmann, B. Decharme, and E. Berthier. 2014. The rate of sea-level rise. Nature Climate Change 4(5):358–361.

Chamberlain, E. L., T. E. Törnqvist, X. Shen, B. Mauz, and J. Wallinga. 2018. Anatomy of Mississippi Delta growth and its implications for coastal restoration. Science Advances 4(eaar4740):1–9.

Chabreck, R. H. 1970. Marsh zones and vegetative types in the Louisiana coastal marshes. Dissertation, Louisiana State University, Baton Rouge, Louisiana.

Chabreck, R. H., and R. G. Linscombe. 1982. Changes in vegetative types in Louisiana coastal marshes over a ten-year period. Proceedings of the Louisiana Academy of Sciences 45:98–102.

Church, J. A., and N. J. White. 2006. A 20th century acceleration in global sea level rise. Geophysical Research Letters 33, L01602, doi:10.1029/2005GL024826. https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2005GL024826.

Coburn, A., A. D. Griffith, and R. S. Young. 2010. Inventory of coastal engineering projects in coastal national parks. Natural Resource Technical Report NPS/NRPC/GRD/NRTR—2010/373. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2195056.

Coleman, J. M., H. H. Roberts, and G. W. Stone. 1998. Mississippi River Delta: an overview. Journal of Coastal Research 14:698–716.

Conner, W. H., and M. Brody. 1989. Rising water levels and the future of southeastern Louisiana swamp forests. Estuaries 12:318–323.

Conner, W. H., J. W. Day, R. H. Baumann, and J. M. Randall. 1989. Influence of hurricanes on coastal ecosystems along the northern Gulf of Mexico. Wetlands Ecology and Management 1(1):45–56. http://www.springerlink.com/index/NK364085U379XPU4.pdf.

Cooper, R. J., S. B. Cederbaum, and J. J. Gannon. 2005. Natural resource summary for Jean Lafitte National Historical Park and Preserve. Warnell School of Forest Resources, University of Georgia, Athens, Georgia.

Couvillion, B. R., H. Beck, D. Schoolmaster, and M. Fischer. 2017. Land area change in coastal Louisiana 1932 to 2016 (scale 1:265,000). Scientific Investigations Map SIM-3381. US Geological Survey, Wetland and Aquatic Research Center, Lafayette, Louisiana. https://pubs.er.usgs.gov/publication/sim3381.

CPRA (Coastal Protection and Restoration Authority of Louisiana). 2017. Louisiana's comprehensive master plan for a sustainable coast (effective 2 June 2017). CPRA, Baton Rouge, Louisiana. http://coastal.la.gov/our-plan/2017-coastal-master-plan/.

Craig, N. J., R. E. Turner, and J. W. Day Jr. 1979. Land loss in coastal Louisiana (USA). Environmental Management 3:133–144.

Curdts, T. 2011. Shoreline length and water area in the ocean, coastal and Great Lakes parks: updated statistics for shoreline miles and water acres (rev1b). Natural Resource Report NPS/WASO/NRR—2011/464. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/App/Reference/Profile/2180595/.

Day, J. W., D. F. Boesch, E. J. Clairain, G. P. Kemp, S. B. Laska, W. J. Mitsch, K. Orth, H. Mashriqui, D. J. Reed, L. Shabman, C. A. Simenstad, B. J. Streever, R. R. Twilley, C. C. Watson, J. T. Wells, and D. F. Whigham. 2007. Restoration of the Mississippi Delta: lessons from Hurricanes Katrina and Rita. Science 315(5819):1679–1684. http://www.sciencemag.org/cgi/doi/10.1126/science.1137030.

Day, J. W., L. D. Britsch, S. R. Hawes, G. P. Shaffer, D. J. Reed, and D. Cahoon. 2000. Pattern and Process of land loss in the Mississippi Delta: a spatial and temporal analysis of wetland habitat change. Estuaries 23(4):425. http://link.springer.com/10.2307/1353136.

Deepwater Horizon Natural Resource Damage Assessment Trustees. 2016. Deepwater Horizon oil spill final programmatic damage assessment and restoration plan and final programmatic environmental impact statement (February 2016). Lead agency: National Oceanic and Atmospheric Administration, Silver Spring, Maryland. http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan.

Diegel, F. A., J. F. Karlo, D. C. Schuster, and R. C. Shoup. 1995. Cenozoic structural evolution and tectono-stratigraphic framework in the northern Gulf coast continental margin. Pages 109–151 *in* M. P. A. Jackson, D. G. Roberts, and S. Snelson, editors. Salt tectonics: a global perspective. Memoir 65. American Association of Petroleum Geologists, Tulsa, Oklahoma.

Dokka, R. K. 2006. Modernday tectonic subsidence in coastal Louisiana. Geology 34(4):281–284.

Dokka, R. K. 2011. The role of deep processes in late 20th century subsidence of New Orleans and coastal areas of southern Louisiana and Mississippi. Journal of Geophysical Research 116, B06403. doi:10.1029/2010JB008008. https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2010JB008008.

Evans, T. J. 2016. General standards for geologic maps. Section 3.1 *in* M. B. Carpenter and C. M. Keane, compilers. The geoscience handbook 2016. AGI Data Sheets, 5th edition. American Geosciences Institute, Alexandria, Virginia.

Fairbanks, R. G. 1989. A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. Nature 342(6250):637–642. http://www.nature.com/nature/journal/v342/n6250/abs/342637a0.html.

Fasullo, J. T., R. S. Nerem, and B. Hamlington. 2016. Is the detection of accelerated sea level rise imminent? Scientific Reports 6, article 31245. https://www.nature.com/articles/srep31245.

Fisk, H. N. 1938. Geology of the Grant and LaSalle Parishes. Bulletin 10. Louisiana Geological Survey, Baton, Rouge, Louisiana.

Fisk, H. N. 1939. Depositional terrace slopes in Louisiana. Journal of Geomorphology 2(2):181–200.

Fisk, H. N. 1944. Geological investigation of the alluvial valley of the lower Mississippi River. US Army Corps of Engineers, Vicksburg, Mississippi.

Fisk, H. N. 1952. Geological investigation of the Atchafalaya basin and the problem of the Mississippi River diversion. US Army Corps of Engineers, Vicksburg, Mississippi.

Fisk, H. N., and E. McFarlan Jr. 1955. Late Quaternary deltaic deposits of the Mississippi River. Pages 279–302 *in* A. Poldervaart, editor. Crust of the Earth: a symposium. Special Paper 62. Geological Society of America, Boulder, Colorado.

Flocks, J. G., N. F. Ferina, C. Dreher, J. L. Kindinger, D. M. Fitzgerald, and M. A. Kulp. 2006. High-resolution stratigraphy of a Mississippi subdelta-lobe progradation in the Barataria bight, north-central Gulf of Mexico. Journal of Sedimentary Research 76:429–443. doi: 10.2110/jsr.2006.030.

Ford, M. 2014. Chapter 16—USA: Hurricane Katrina, the role of US national parks on the northern Gulf of Mexico and post storm wetland restoration. Pages 141–148 in R. Murti and C. Buyck, editors. Safe havens: protected areas for disaster risk reduction and climate change adaptation. International Union for Conservation of Nature (IUCN), Gland, Switzerland. https://www.iucn.org/sites/dev/files/2014-038.pdf.

Frankson, R., K. Kunkel, and S. Champion. 2017. Louisiana state climate summary. Technical Report NESDIS 149-LA. National Oceanic and Atmospheric Administration, National Centers for Environmental Information, Silver Spring, Maryland. https://statesummaries.ncics.org/la (accessed 12 February 2019).

Frazier, D. E. 1967. Recent deltaic deposits of the Mississippi River: their development and chronology. Gulf Coast Association of Geological Societies Transactions 37:287–315.

Froede, C. R. Jr. 2002. Rhizolith evidence in support of a late Holocene sea-level highstand at least 0.5 m higher than present at Key Biscayne, Florida. Geology 30:203–206.

Gagliano, S. M. 2005a. Effects of natural fault movement on land submergence in coastal Louisiana. Presented paper. 14th Biennial Coastal Zone Conference, New Orleans, Louisiana, 17–21 July 2005.

Gagliano, S. M. 2005b. Effects of geological faults on levee failures in south Louisiana. Testimony of Sherwood M. Gagliano, Ph.D., before the US Senate Committee on Environment & Public Works, 17 November 2005. Washington, DC. https://www.epw.senate.gov/public/_cache/files/0/6/06b95006-cb07-4572-ae98-d6f2e2cb57fb/01AFD79733D77F24A71FEF9DAFCCB056.111705gagliano-testimony.pdf.

Gagliano, S. M. 2007. Environmental section. Submitted to the Unified New Orleans Plan (January 2007). Coastal Environments Inc., Baton Rouge, Louisiana. http://www.coastalenv.com/papers-publications [see file—CEI (2007) Environmental Concerns Geological Hazards].

Gagliano, S. M., E. B. Kemp III, K. M. Wicker, and K. S. Wiltenmuth. 2003a. Active geological faults and land change in southeastern Louisiana. Report to US Army Corps of Engineers, New Orleans District. Contract No. DACW 29-00-C-0034. Coastal Environments Inc., Baton Rouge, Louisiana. https://www.coastalenv.com/newpage835bc770.

Gagliano, S. M., E. B. Kemp III, K. M. Wicker, K. S. Wiltenmuth, and R. W. Sabate. 2003b. Neo-tectonic framework of southeast Louisiana and applications to coastal restoration. Gulf Coast Association of Geological Societies Transactions 53:262–276. http://archives.datapages.com/data/gcags/data/053/053001/0262.htm.

Galloway, W. E., T. L. Whiteaker, and P. Ganey-Curry. 2011. History of Cenozoic North American drainage basin evolution, sediment yield, and accumulation in the Gulf of Mexico basin. Geosphere 7:938–73. https://doi.org/10.1130/GES00647.1.

Goldstein, E. B., and L. J. Moore. 2016. Stability and bistability in a one-dimensional model of coastal foredune height: A 1-D model of coastal foredune height. Journal of Geophysical Research: Earth Surface 121(5):964–977. http://doi.wiley.com/10.1002/2015JF003783.

González, J. L., and T. E. Törnqvist. 2006. Coastal Louisiana in crisis: subsidence or sea level rise? EOS Transactions, American Geophysical Union 87(45):493–498. https://agupubs-onlinelibrary-wiley-com.ezproxy2.library.colostate.edu/loi/23249250/year/2006.

Goodwin, R. C., P. V. Heinrich, W. P. Athens, and S. Hinks. 1991. Overview, inventory and assessment of cultural resources in the Louisiana coastal zone. SFP 25101-90-09. R. Christopher Goodwin and Associates, Inc., New Orleans, Louisiana.

Gosselink, J. G. 1984. The ecology of delta marshes of coastal Louisiana: a community profile. FWS/OBS-84/09. US Fish and Wildlife Service, Washington, DC.

Handley, L. H. 2006. Mapping long-term habitat and shoreline changes at Jean Lafitte National Historic Park and Preserve, Barataria Unit (draft). US Geological Survey, National Wetlands Research Center, Lafayette, Louisiana. https://irma.nps.gov/DataStore/Reference/Profile/2194140.

Hatt, J., T. Prebyl, G. Sundin, L. Worsham, N. Nibbelink, G. Grossman, and M. Mengak. 2015. Natural resource condition assessment for Jean Lafitte National Historical Park and Preserve. Natural Resource Report NPS/JELA/NRR—2015/953. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2222864.

Hatton, R. S., R. D. DeLaune, and W. H. Patrick. 1983. Sedimentation, accretion, and subsidence in marshes of Barataria basin, Louisiana. Limnology and Oceanography 28(3):494–502. http://loesje.m.aslo.net/lo/toc/vol_28/issue_3/0494.pdf.

Heinrich, P. V. 2014. Black Bay 30 × 60 minute geologic quadrangle (scale 1:100,000). 30 × 60 Geologic Quadrangle Series, Black Bay, Louisiana, 29089-E1-TB-100K. Louisiana Geological Survey, Baton Rouge, Louisiana.

Heinrich, P. V. 2018. Underappreciated collateral effects of future sea level rise in the Gulf of Mexico coastal zone. Poster. State of the Coast 2018, 30 May–1 June 1, 2018, New Orleans, Louisiana. https://www.academia.edu/36839499/Underappreciated_Collateral_Effects_of_Future_Sea_Level_Rise_in_the_Gulf_of_Mexico_Coastal_Zone.

Heinrich, P. V., and W. J. Autin. 2000. Baton Rouge 30 × 60 minute geologic quadrangle (scale 1:100,000). 30 × 60 Minute Geologic Quadrangle Series, Baton Rouge, Louisiana, 30091-A1-100K. Louisiana Geological Survey, Baton Rouge, Louisiana.

Heinrich, P. V., R. P. McCulloh, and M. Horn. 2011. New Orleans 30 × 60 minute geologic quadrangle (scale 1:100,000). 30 × 60 Minute Geologic Quadrangle Series, New Orleans, Louisiana, 29090-E1-TM-100K. Louisiana Geological Survey, Baton Rouge, Louisiana.

Heinrich, P. V., R. P. McCulloh, and J. Snead. 2004. Gulfport 30 × 60 minute geologic quadrangle (scale 1:100,000). 30 × 60 Minute Geologic Quadrangle Series, Gulfport, Mississippi/Louisiana, 30089-A1-TM-100K. Louisiana Geological Survey, Baton Rouge, Louisiana.

Heinrich, P. V., J. Snead, and R. P. McCulloh. 2003. Crowley 30 × 60 minute geologic quadrangle (scale 1:100,000). 30 × 60 Geologic Quadrangle Series, Crowley, Louisiana, 30092-A1-TM-100K. Louisiana Geological Survey, Baton Rouge, Louisiana.

Holmes, B. 1986. The Barataria unit of Jean Lafitte National Historical Park. Historic Resources Study. Professional Papers. 5. Southwest Cultural Resources Center, Santa Fe, New Mexico.

Hop, K., A. Strassman, S. Sattler, M. Pyne, J. Teague, R. White, J. Ruhser, E. Hlavacek, and J. Dieck. 2017. National Park Service, Vegetation Mapping Inventory Program, Jean Lafitte National Historical Park and Preserve, Vegetation Mapping Project. Natural Resource Report NPS/GULN/NRR—2017/1528. Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2177230.

Hudson, P. 2005. Natural levees. Entry *in* S. W. Trimble, editor. Encyclopedia of Water Science. CRC Press, Boca Raton, Florida.

Ivins, E. R., R. K. Dokka, and R. G. Bloom. 2007. Post-glacial sediment load and subsidence in coastal Louisiana. Geophysical Research Letters 34, L16303, doi:10.1029/2007GL030003. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2007GL030003.

Jankowski, K. L., T. E. Törnqvist, and A. M. Fernandes. 2017. Vulnerability of Louisiana's coastal wetlands to present-day rates of relative sea-level rise. Nature Communications 8:14,792. http://www.nature.com/doifinder/10.1038/ncomms14792.

Jefferson Parish. 2019. Christmas tree marsh restoration. Online information. Jefferson Parish Coastal Management Department, Harahan, Louisiana. http://www.jeffparish.net/index.aspx?page=321 (accessed 10 April 2019).

Karegar, M. A., T. H. Dixon, and R. Malservisi. 2015. A three-dimensional surface velocity field for the Mississippi Delta: implications for coastal restoration and flood potential: Geology 43:519–522. doi:10.1130/G36598.1.

KellerLynn, K. 2007. Theodore Roosevelt National Park geologic resource evaluation report. Natural Resource Report NPS/NRPC/GRD/NRR—2007/006. National Park Service, Denver, Colorado. http://go.nps.gov/gripubs.

KellerLynn, K. 2010a. Geologic resources inventory scoping summary, Jean Lafitte National Historical Park, Louisiana (25 August 2010). National Park Service, Geologic Resources Division, Lakewood, Colorado. http://go.nps.gov/gripubs.

KellerLynn, K. 2010b. Geologic resources inventory scoping summary, Natchez Trace Parkway, Alabama, Mississippi, Tennessee (4 August 2010). National Park Service, Geologic Resources Division, Lakewood, Colorado. http://go.nps.gov/gripubs.

KellerLynn, K. 2010c. Geologic resources inventory scoping summary, Vicksburg National Military Park, Mississippi and Louisiana (4 August 2010). National Park Service, Geologic Resources Division, Lakewood, Colorado. http://go.nps.gov/gripubs.

Kenworthy, J. P., V. Santucci, and C. C. Visaggi. 2007. Paleontological resource inventory and monitoring, Gulf Coast Inventory & Monitoring Network. Technical Information Center (TIC) number D-750. National Park Service, Geologic Resources Division, Lakewood, Colorado.

Kesel, R. H. 2008. A revised Holocene geochronology for the lower Mississippi valley. Geomorphology 101:78–89.

Kesel, R. H., E. G. Yodis, and D. J. McGraw. 1992. An approximation of the sediment budget of the lower Mississippi River prior to major human modification. Earth Surface Processes and Landforms 17:711–23.

Keucher, G. J. 1994. Geologic framework and consolidation settlement potential of the Lafourche delta, topstratum valley fill: implications for wetland loss in Terrebonne and Lafourche Parishes, Louisiana. Dissertation, Louisiana State University, Baton Rouge, Louisiana.

Kim, W., D. Mohrig, R. Twilley, C. Paola, and G. Parker. 2009. Is it feasible to build new land in the Mississippi River Delta? Eos 90:373–374. doi:10.1029/2009EO420001.

Kious, W. J., and R. I. Tilling. 1996. This dynamic Earth: the story of plate tectonics. US Geological Survey, Washington, DC. https://pubs.usgs.gov/gip/dynamic/dynamic.html.

Kniffen, F. B. 1936. A preliminary report on the mounds and middens of Plaquemines and St. Bernard Parishes. Pages 407–422 *in* R. J. Russell and H. V. Howe, editors. Lower Mississippi River Delta: reports on the geology of Plaquemines and St. Bernard Parishes. Geological Bulletin 8. Department of Conservation, Louisiana Geological Survey, Baton Rouge, Louisiana.

Kolb, C. R., and R. T. Saucier. 1982. Engineering geology of New Orleans. Pages 75–93 *in* R. Legget, editor. Geology under cities. Case Histories in Engineering 5. Geological Society of America, Boulder, Colorado.

Kolb, C. R., and J. R. Van Lopik. 1966. Depositional environments of the Mississippi River deltaic plain, southeastern Louisiana. Pages 17–61 *in* M. L. Shirley and J. A. Ragsdale, editors. Deltas in their geologic frameworks. Houston Geological Society, Houston, Texas.

Kolker, A. S., M. A. Allison, and S. Hameed. 2011. An evaluation of subsidence rates and sea-level variability in the northern Gulf of Mexico. Geophysical Research Letters 38, L21404, doi:10.1029/2011GL049458. https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2011GL049458.

Kosters, E. 1989. Organic-clastic facies relationships and chronostratigraphy of the Barataria interlobe basin, Mississippi delta plain. Journal of Sedimentary Petrology 59(1):98–113.

Kulp, M. 2000. Holocene stratigraphy, history, and subsidence: Mississippi Delta region, north-central Gulf of Mexico. Dissertation. University of Kentucky, Lexington, Kentucky.

Kulp, M., S. Penland, S. J. Williams, C. Jenkins, J. Flocks, and J. Kindinger. 2005. Geologic framework, evolution, and sediment resources for restoration of the Louisiana coastal zone. Journal of Coastal Research, Special Issue 44:56–71. http://www.jstor.org/stable/25737049.

Lentz, E. E., E. R. Thieler, N. G. Plant, S. R. Stippa, R. M. Horton, and D. B. Gesch. 2016. Evaluation of dynamic coastal response to sea-level rise modifies inundation likelihood. Nature Climate Change 6:696–700.

Levin, D. R. 1991. Transgressions and regressions in the Barataria bight region of coastal Louisiana. Gulf Coast Association of Geological Societies Transactions 41:408–431.

Lisiecki, L. E., and M. E. Raymo. 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic ^{18}O records. Paleoceanography 20, PA1003, doi:10.1029/2004PA001071. https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2004PA001071. [See "Ages of MIS boundaries" at http://lorraine-lisiecki.com/stack.html (accessed 4 February 2019)].

Mange, M. A., and E. G. Otvos. 2005. Gulf coastal plain evolution in West Louisiana: heavy mineral provenance and Pleistocene alluvial chronology. Sedimentary Geology 182(1–4):29–57. http://linkinghub.elsevier.com/retrieve/pii/S0037073805002939.

McBride, R. A., M. J. Taylor, and M. R. Byrnes. 2007. Coastal morphodynamics and chenier-plain evolution in southwestern Louisiana, USA: a geomorphic model. Geomorphology 88(3):367–422.

McCulloh, R. P., P. V. Heinrich, and B. Good. 2006. Geology and hurricane-protection strategies in the greater New Orleans area. Public Information Series 11. Louisiana Geological Survey, Baton Rouge, Louisiana. https://www.lsu.edu/lgs/publications/products/public-information-series.php.

McCulloh, R. P., P. V. Heinrich, and J. Snead, with field support from W. J. Autin. 2003. Ponchatoula 30 × 60 minute geologic quadrangle (scale 1:100,000). Geologic Quadrangle Series, Ponchatoula, Louisiana, 30090-A1-TM-100K. Louisiana Geological Survey, Baton Rouge, Louisiana.

Meade, R. H., and J. A. Moody. 2010. Causes for the decline of suspended-sediment discharge in the Mississippi River system, 1940–2007. Hydrological Processes 24:35–49.

Meckel, T. A., U. S. ten Brink, and S. J. Williams. 2006. Current subsidence rates due to compaction of Holocene sediments in southern Louisiana. Geophysical Research Letters 33, L11403, doi:10.1029/2006GL026300. https://www.researchgate.net/publication/33548561_Current_subsidence_rates_due_to_compaction_of_Holocene_sediments_in_southern_Louisiana.

Meckel, T. A., U. S. ten Brink, and S. J. Williams. 2007. Sediment compaction rates and subsidence in deltaic plains, numerical constraints and stratigraphic influences. Basin Research 19:19–31.

Mendelssohn, I. A., M. R. Byrnes, R. T. Kneib, and B. A. Vitto. 2017. Chapter 6: coastal habitats of the Gulf of Mexico. Pages 359–640 *in* C. Ward, editor. Habitats and biota of the Gulf of Mexico: before the Deepwater Horizon oil spill. Springer, New York, New York. https://link.springer.com/chapter/10.1007%2F978-1-4939-3447-8_6.

Middleton, B. A., and M. Jiang. 2013. Use of sediment amendments to rehabilitate sinking coastal swamp forests in Louisiana. Ecological Engineering 54:183–191. http://linkinghub.elsevier.com/retrieve/pii/S0925857413000402.

Monahan, W. B., and N. A. Fisichelli. 2014. Recent climate change exposure of Jean Lafitte National Historical Park and Preserve. Climate Change Resource Brief. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2217701.

Morton, R. A., J. C. Bernier, and J. A. Barras. 2006. Evidence of regional subsidence and associated interior wetland loss induced by hydrocarbon production, Gulf coast region, USA. Environmental Geology 50:261–274.

Morton, R. A., J. G. Paine, and M. D. Blum. 2000. Responses of stable bay-margin and barrier-island systems to Holocene sea-level highstands, western Gulf of Mexico. Journal of Sedimentary Research 70:478–490.

Morton, R. A., G. Tiling, and N. F. Ferina. 2003. Causes of hot-spot wetland loss in the Mississippi delta plain. Environmental Geoscience 10(2):71–80.

National Hurricane Center. 2017. Hurricanes in history. Online information. National Oceanic and Atmospheric Administration, Miami, Florida. http://www.nhc.noaa.gov/outreach/history/ (accessed 10 January 2019).

National Oceanic and Atmospheric Administration. 2017. Tides & currents—products: sea level trends. Mean sea level trend: 8761724 Grand Isle, Louisiana. Online information. https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8761724 (accessed 10 January 2019).

National Park Service (NPS). No date. Civil War Era National Cemeteries: Honoring Those Who Served: Chalmette National Cemetery, Chalmette, Louisiana. Online information. National Park Service, Heritage Travel, Washington, D.C. https://www.nps.gov/nr/travel/national_cemeteries/louisiana/chalmette_national_cemetery.html (accessed 8 April 2019)

National Weather Service. 2001. Tropical Storm Allison, heavy rains and floods, Texas and Louisiana, June 2001. Service assessment (September 2001). National Oceanic and Atmospheric Administration, National Weather Service, Silver Spring, Maryland. https://www.weather.gov/media/publications/assessments/allison.pdf.

National Weather Service. 2004. NWS LIX - Hurricane Ivan post storm report page. Online information. National Oceanic and Atmospheric Administration, National Weather Service, Slidell, Louisiana. http://www.weather.gov/lix/psh_ivan (accessed 10 January 2019).

National Weather Service. 2017a. Hurricane Isaac - August 28, 2012. Online information. National Oceanic and Atmospheric Administration, National Weather Service, Mobile, Alabama. https://www.weather.gov/mob/isaac (accessed 10 January 2019)

National Weather Service. 2017b. Tropical Storm Cindy - June 2017. Online information. National Oceanic and Atmospheric Administration, National Weather Service, Mobile, Alabama. https://www.weather.gov/mob/cindy (accessed 10 January 2019).

Neill, C. F., and M. A. Allison. 2005. Subaqueous deltaic formation on the Atchafalaya shelf, Louisiana. Marine Geology 214(4):411–430. http://linkinghub.elsevier.com/retrieve/pii/S0025322704003160.

Neuendorf, K. K. E., J. P. Mehl Jr., and J. A. Jackson. 2005. Glossary of geology. Fifth edition. American Geological Institute, Alexandria, Virginia.

Nienhuis, J. H., T. E. Törnqvist, K. L. Jankowski, A. M. Fernandes, and M. E. Keogh. 2017. A new subsidence map for coastal Louisiana. GSA Today 27(9):58–59. http://www.geosociety.org/gsatoday/groundwork/G337GW/abstract.htm.

NPS. 1995. Amendment to the general management plan, Jean Lafitte National Historical Park and Preserve. National Park Service, Washington, DC.

NPS. 2008. The Louisiana coastal protection and restoration plan and Jean Lafitte National Historical Park and Preserve, National Park Service: park position statement. Jean Lafitte National Historical Park and Preserve, New Orleans, Louisiana.

NPS. 2009. Canal reclamation at Barataria Preserve, Jean Lafitte National Historical Park and Preserve, Louisiana: environmental assessment. Jean Lafitte National Historical Park and Preserve, New Orleans, Louisiana. https://www.restorethegulf.gov/sites/default/files/FPL_EClib_LA_%20Jean_Lafitte_Canal_Backfilling_FONSI_signed.pdf

NPS. 2012. Administrative history of Jean Lafitte National Historical Park and Preserve. NPS Cultural Resources Division, Atlanta, Georgia.

NPS. 2013. Soil survey geographic (SSURGO) for Jean Lafitte National Historical Park and Preserve, Louisiana. Geodatabase, metadata, and report. National Park Service, Inventory & Monitoring Program, Soil Resource Inventory. https://irma.nps.gov/DataStore/Reference/Profile/1048908.

NPS. 2015. Foundation document, Jean Lafitte National Historical Park and Preserve, Louisiana (May 2015). National Park Service, Washington, DC.

NPS. 2016a. From Acadian to Cajun. Online information. Jean Lafitte National Historical Park and Preserve, New Orleans, Louisiana. https://www.nps.gov/jela/learn/historyculture/from-acadian-to-cajun.htm (accessed 7 February 2019).

NPS. 2016b. Ocean and coastal park jurisdiction handbook (updated 16 November 2016). US Department of the Interior, National Park Service, Natural Resource Stewardship and Science, Lakewood, Colorado. https://docs.google.com/a/nps.USACE. 2018. Mississippi River Commission. Online information. US Army Corps of Engineers, Mississippi Valley Division, Vicksburg, Mississippi. https://www.mvd.usace.army.mil/About/Mississippi-River-Commission-MRC/ (accessed 21 November 2018).

USACE. 2019. Risk reduction plan: background information. Online information. US Army Corps of Engineers, New Orleans District, New Orleans, Louisiana. https://www.mvn.usace.army.mil/Missions/HSDRRS/Risk-Reduction-Plan/ (accessed 10 January 2019).

US Geologic Names Committee. 2010. US Geologic Names Committee remarks on allogroups of Louisiana. Online information [note in the US Geologic Names Lexicon ("Geolex") for Prairie Allogroup]. US Geological Survey, Washington, DC. https://ngmdb.usgs.gov/Geolex/UnitRefs/PrairieRefs_9898.html (accessed 11 February 2019).

Van Asselen, S., E. Stouthamer, and T. W. J. Van Asch. 2009. Effects of peat compaction on delta evolution: a review on processes, responses, measuring and modeling. Earth Science Reviews 92(1–2):35–51.

Van Heerden, I. L., G. P. Kemp, and H. H. Roberts. 1996. The Holocene geology of the central south Louisiana coastal zone. Louisiana State University, Baton Rouge, Louisiana.

Visser, J. M., C. E. Sasser, R. H. Chabreck, and R. G. Linscombe. 1998. Marsh vegetation types of the Mississippi River deltaic plain. Estuaries 21(4):818–828. https://www.researchgate.net/publication/225748565_Marsh_Vegetation_Types_of_the_Mississippi_River_Deltaic_Plain.

Weinstein, R. A., and S. M. Gagliano. 1985. Shifting deltaic coast of the Lafourche Country and its prehistoric settlement. Pages 122–149 *in* P. D. Uzee, editor. The Lafourche country: the people and the land. Center for Louisiana Studies, University of Southwestern Louisiana, Lafayette, Louisiana.

Yeager, K. M., C. A. Brunner, M. A. Kulp, D. Fischer, R. A. Feagin, K. J. Schindler, J. Prouhet, and G. Bera. 2012. Significance of active growth faulting on marsh accretion processes in the lower Pearl River, Louisiana. Geomorphology 153/154:127–143.

Young, R., and L. Norby. 2009. Geological monitoring. Geological Society of America, Boulder, Colorado. http://go.nps.gov/geomonitoring.

Yu, K., S. P. Faulkner, and W. H. Patrick. 2006. Redox potential characterization and soil greenhouse gas concentration across a hydrological gradient in a Gulf coast forest. Chemosphere 62(6):905–914. http://linkinghub.elsevier.com/retrieve/pii/S0045653505007459.

Yuill, B., D. Lavoie, and D. J. Reed. 2009. Understanding subsidence processes in coastal Louisiana. Journal of Coastal Research Special Issue 54:23–36. http://www.bioone.org/doi/abs/10.2112/SI54-012.1.

Additional References

These references, resources, and websites may be of use to resource managers. Refer to Appendix B for laws, regulations, and policies that apply to NPS geologic resources.

Geology of National Park Service Areas

- NPS Geologic Resources Division (Lakewood, Colorado) Energy and Minerals; Active Processes and Hazards; Geologic Heritage: http://go.nps.gov/geology
- NPS Geologic Resources Division Education Website: http://go.nps.gov/geoeducation
- NPS Geologic Resources Inventory: http://go.nps.gov/gri
- NPS Geoscientist-In-the-Parks (GIP) internship and guest scientist program: http://go.nps.gov/gip
- NPS Views (geology-themed modules are available for Geologic Time, Paleontology, Glaciers, Caves and Karst, Coastal Geology, Volcanoes, and a variety of geologic parks): http://go.nps.gov/views

NPS Resource Management Guidance and Documents

- NPS Gulf Coast Inventory & Monitoring Network: https://science.nature.nps.gov/im/units/guln/
- Management Policies 2006 (Chapter 4: Natural resource management): http://www.nps.gov/policy/mp/policies.html
- 1998 National Parks Omnibus Management Act: http://www.gpo.gov/fdsys/pkg/PLAW-105publ391/pdf/PLAW-105publ391.pdf
- NPS-75: Natural Resource Inventory & Monitoring Guideline: http://www.nature.nps.gov/nps75/nps75.pdf
- NPS Natural Resource Management Reference Manual #77: http://www.nature.nps.gov/Rm77/
- Geological Monitoring (2009. R. Young and L. Norby, editors. Geological Society of America, Boulder, Colorado): http://go.nps.gov/geomonitoring
- NPS Technical Information Center (TIC) (Denver, Colorado; repository for technical documents): https://www.nps.gov/dsc/technicalinfocenter.htm

Geological Surveys and Societies

- Louisiana Geological Survey: http://www.lsu.edu/lgs/
- US Geological Survey: http://www.usgs.gov/
- Geological Society of America: http://www.geosociety.org/
- American Geophysical Union: http://sites.agu.org/
- American Geosciences Institute: http://www.americangeosciences.org/
- Association of American State Geologists: http://www.stategeologists.org/

Climate Change Resources

- NPS Climate Change Response Program Resources: http://www.nps.gov/subjects/climatechange/resources.htm
- NPS Coastal Adaptation: https://www.nps.gov/subjects/climatechange/coastaladaptation.htm
- US Global Change Research Program: http://www.globalchange.gov/home
- Intergovernmental Panel on Climate Change: http://www.ipcc.ch/
- USGS Coastal Change Hazards Portal (to view shoreline change, sea level rise projections, and coastal change forecasts): https://marine.usgs.gov/coastalchangehazardsportal/

Louisiana Coastal Restoration Resources

- Coastal Master Plan: http://coastal.la.gov/our-plan/2017-coastal-master-plan/
- Coastal Master Plan project data viewer: https://cims.coastal.louisiana.gov/masterplan/
- Coastal Master Plan, Barataria Sediment Diversion: http://coastal.la.gov/our-work/key-initiatives/diversion-program/
- Restore the Mississippi River Delta: http://mississippiriverdelta.org/
- Coastal Wetlands Planning, Protection and Restoration Act projects: https://www.lacoast.gov/new/Default.aspx
- Louisiana Coastal Area Ecosystem Restoration: http://lca.gov/
- US Army Corps of Engineers (USACE) Louisiana Coastal Area Program: http://www.mvn.usace.army.mil/Missions/Environmental/Louisiana-Coastal-Area/
- USACE Louisiana Coastal Protection and Restoration Study: http://www.mvn.usace.army.mil/Missions/Environmental/LaCPR/
- USACE Coastal Systems Portfolio Initiative: http://navigation.usace.army.mil/CSPI/Default.aspx
- Louisiana Coastal Protection and Restoration Educational Resources: http://coastal.la.gov/resources/educational-resources/
- Louisiana Department of Natural Resources: http://www.dnr.louisiana.gov

- National Oceanic and Atmospheric Administration (NOAA) data related to environmental injury, including Deepwater Horizon: https://www.diver.orr.noaa.gov/ and https://www.diver.orr.noaa.gov/deepwater-horizon-nrda-data
- NOAA Environmental Response Management Application (ERMA) online mapping tool that integrates both static and real-time data, including Environmental Sensitivity Index (ESI) maps: https://response.restoration.noaa.gov/maps-and-spatial-data/environmental-response-management-application-erma

Louisiana Coastal Data

- Coastwide Reference Monitoring System (CRMS) datasets: https://www.lacoast.gov/crms_viewer2/Default.aspx#
- The closest CRMS hydrologic monitoring site is #0234 (BAFS-SM-02H), in fresh marsh east of Barataria Preserve. A closer site, CRMS #0188, began collecting data in 2017.
- SONRISNG (interactive maps and GIS downloads), Louisiana Department of Natural Resource (e.g., oil and gas, mineral resources, coastal management, coastal protection and restoration, water wells, surface water, and boundaries): http://sonris-www.dnr.state.la.us/gis/agsweb/IE/JSViewer/index.html?TemplateID=181
- FEMA National Flood Hazard Layer: http://fema.maps.arcgis.com/home/item.html?id=cbe088e7c8704464aa0fc34eb99e7f30
- NOAA Sea Level Rise and Coastal Flooding Impact Viewer data download: https://coast.noaa.gov/slrdata/

Subsidence Rates

- Coastwide Reference Monitoring System (CRMS) datasets: https://www.lacoast.gov/crms_viewer2/Default.aspx#

US Geological Survey Reference Tools

- National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html
- US Geologic Names Lexicon (Geolex; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/search
- Geographic Names Information System (GNIS; official listing of place names and geographic features): http://gnis.usgs.gov/
- GeoPDFs (download PDFs of any topographic map in the United States): http://store.usgs.gov (click on "Map Locator")
- Publications Warehouse (many publications available online): http://pubs.er.usgs.gov
- Tapestry of Time and Terrain (descriptions of physiographic provinces): http://pubs.usgs.gov/imap/i2720/

Appendix A: Scoping Participants

The following people attended the GRI scoping meeting, held on 15 April 2010, or the follow-up conference call, held on 28 September 2017. Discussions during these meetings supplied a foundation for this GRI report. The scoping summary document is available on the GRI publications website: http://go.nps.gov/gripubs.

2010 Scoping Meeting Participants

Name	Affiliation	Position
Kelly Altenhofen	Jean Lafitte National Historical Park and Preserve	Biological Science Technician
Carol Clark	Jean Lafitte National Historical Park and Preserve	Superintendent
Tim Connors	NPS Geologic Resources Division	Geologist
Mark Ford	NPS Southeast Regional Office	Wetland Specialist
Paul Heinrich	Louisiana Geological Survey	Research Associate/Geologist
Katie KellerLynn	Colorado State University	Research Associate/Geologist
Richard McCulloh	Louisiana Geological Survey	Research Associate/Geologist
David Muth	Jean Lafitte National Historical Park and Preserve	Chief of Resources Management
Lisa Norby	NPS Geologic Resources Division	Geologist
Dusty Pate	Jean Lafitte National Historical Park and Preserve	Natural Resource Program Manager
Martha Segura	NPS Gulf Coast Inventory & Monitoring Network	Network Coordinator

2017 Conference Call Participants

Name	Affiliation	Position
Rebecca Beavers	NPS Geologic Resources Division	Coastal Geologist
Jeff Bracewell	NPS Gulf Coast Inventory & Monitoring Network	GIS Specialist
Mark Ford	NPS Southeast Regional Office	Wetlands Ecologist
Guy Hughes	Jean Lafitte National Historical Park and Preserve	Chief of Resource Management
Jason Kenworthy	NPS Geologic Resources Division	Geologist/GRI Reports Coordinator
Dusty Pate	Jean Lafitte National Historical Park and Preserve	Natural Resource Manager
Courtney Schupp	NPS Geologic Resources Division	Coastal Geologist/GRI Report Writer
Julie Whitbeck	Jean Lafitte National Historical Park and Preserve	Ecologist
Linda York	NPS Southeast Regional Office	Coastal Geologist

Appendix B: Geologic Resource Laws, Regulations, and Policies

The NPS Geologic Resources Division developed this table to summarize laws, regulations, and policies that specifically apply to NPS minerals and geologic resources. The table does not include laws of general application (e.g., Endangered Species Act, Clean Water Act, Wilderness Act, National Environmental Policy Act, or National Historic Preservation Act). The table does include the NPS Organic Act when it serves as the main authority for protection of a particular resource or when other, more specific laws are not available. Information is current as of December 2018. Contact the NPS Geologic Resources Division for detailed guidance

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Caves and Karst Systems	**Federal Cave Resources Protection Act of 1988, 16 USC §§ 4301 – 4309** requires Interior/Agriculture to identify "significant caves" on Federal lands, regulate/restrict use of those caves as appropriate, and include significant caves in land management planning efforts. Imposes civil and criminal penalties for harming a cave or cave resources. Authorizes Secretaries to withhold information about specific location of a significant cave from a Freedom of Information Act (FOIA) requester. **National Parks Omnibus Management Act of 1998, 54 USC § 100701** protects the confidentiality of the nature and specific location of cave and karst resources. **Lechuguilla Cave Protection Act of 1993, Public Law 103-169** created a cave protection zone (CPZ) around Lechuguilla Cave in Carlsbad Caverns National Park. Within the CPZ, access and the removal of cave resources may be limited or prohibited; existing leases may be cancelled with appropriate compensation; and lands are withdrawn from mineral entry.	**36 CFR § 2.1** prohibits possessing/destroying/disturbing…cave resources…in park units. **43 CFR Part 37** states that all NPS caves are "significant" and sets forth procedures for determining/releasing confidential information about specific cave locations to a FOIA requester.	**Section 4.8.1.2** requires NPS to maintain karst integrity, minimize impacts. **Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity. **Section 4.8.2.2** requires NPS to protect caves, allow new development in or on caves if it will not impact cave environment, and to remove existing developments if they impair caves. **Section 6.3.11.2** explains how to manage caves in/adjacent to wilderness.
Paleontology	**National Parks Omnibus Management Act of 1998, 54 USC § 100701** protects the confidentiality of the nature and specific location of paleontological resources and objects. **Paleontological Resources Preservation Act of 2009, 16 USC § 470aaa et seq.** provides for the management and protection of paleontological resources on federal lands.	**36 CFR § 2.1(a)(1)(iii)** prohibits destroying, injuring, defacing, removing, digging or disturbing paleontological specimens or parts thereof. **Prohibition in 36 CFR § 13.35** applies even in Alaska parks, where the surface collection of other geologic resources is permitted. **43 CFR Part 49** (in development) will contain the DOI regulations implementing the Paleontological Resources Preservation Act.	**Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity. **Section 4.8.2.1** emphasizes Inventory and Monitoring, encourages scientific research, directs parks to maintain confidentiality of paleontological information, and allows parks to buy fossils only in accordance with certain criteria.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Recreational Collection of Rocks Minerals	**NPS Organic Act, 54 USC. § 100101 et seq.** directs the NPS to conserve all resources in parks (which includes rock and mineral resources) unless otherwise authorized by law. **Exception: 16 USC. § 445c (c)** Pipestone National Monument enabling statute. Authorizes American Indian collection of catlinite (red pipestone).	**36 C.F.R. § 2.1** prohibits possessing, destroying, disturbing mineral resources…in park units. **Exception: 36 C.F.R. § 7.91** allows limited gold panning in Whiskeytown. **Exception: 36 C.F.R. § 13.35** allows some surface collection of rocks and minerals in some Alaska parks (not Klondike Gold Rush, Sitka, Denali, Glacier Bay, and Katmai) by non-disturbing methods (e.g., no pickaxes), which can be stopped by superintendent if collection causes significant adverse effects on park resources and visitor enjoyment.	**Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.
Geothermal	**Geothermal Steam Act of 1970, 30 USC. § 1001 et seq. as amended in 1988**, states ● No geothermal leasing is allowed in parks. ● "Significant" thermal features exist in 16 park units (the features listed by the NPS at **52 Fed. Reg. 28793-28800** (August 3, 1987), plus the thermal features in Crater Lake, Big Bend, and Lake Mead). ● NPS is required to monitor those features. ● Based on scientific evidence, Secretary of Interior must protect significant NPS thermal features from leasing effects. **Geothermal Steam Act Amendments of 1988, Public Law 100--443** prohibits geothermal leasing in the Island Park known geothermal resource area near Yellowstone and outside 16 designated NPS units if subsequent geothermal development would significantly adversely affect identified thermal features.	None applicable.	**Section 4.8.2.3** requires NPS to ● Preserve/maintain integrity of all thermal resources in parks. ● Work closely with outside agencies. ● Monitor significant thermal features.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Mining Claims (Locatable Minerals)	**Mining in the Parks Act of 1976, 54 USC § 100731 et seq.** authorizes NPS to regulate all activities resulting from exercise of mineral rights, on patented and unpatented mining claims in all areas of the System, in order to preserve and manage those areas. **General Mining Law of 1872, 30 USC § 21 et seq.** allows US citizens to locate mining claims on Federal lands. Imposes administrative and economic validity requirements for "unpatented" claims (the right to extract Federally-owned locatable minerals). Imposes additional requirements for the processing of "patenting" claims (claimant owns surface and subsurface). Use of patented mining claims may be limited in Wild and Scenic Rivers and OLYM, GLBA, CORO, ORPI, and DEVA. **Surface Uses Resources Act of 1955, 30 USC § 612** restricts surface use of unpatented mining claims to mineral activities.	**36 CFR § 5.14** prohibits prospecting, mining, and the location of mining claims under the general mining laws in park areas except as authorized by law. **36 CFR Part 6** regulates solid waste disposal sites in park units. **36 CFR Part 9, Subpart A** requires the owners/operators of mining claims to demonstrate bona fide title to mining claim; submit a plan of operations to NPS describing where, when, and how; prepare/ submit a reclamation plan; and submit a bond to cover reclamation and potential liability. **43 CFR Part 36** governs access to mining claims located in, or adjacent to, National Park System units in Alaska.	**Section 6.4.9** requires NPS to seek to remove or extinguish valid mining claims in wilderness through authorized processes, including purchasing valid rights. Where rights are left outstanding, NPS policy is to manage mineral-related activities in NPS wilderness in accordance with the regulations at **36 CFR Parts 6 and 9A**. **Section 8.7.1** prohibits location of new mining claims in parks; requires validity examination prior to operations on unpatented claims; and confines operations to claim boundaries.
Nonfederal Oil and Gas	**NPS Organic Act, 54 USC § 100751 et seq.** authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights). Individual Park Enabling Statutes: • **16 USC § 230a** (Jean Lafitte NHP & Pres.) • **16 USC § 450kk** (Fort Union NM), • **16 USC § 459d-3** (Padre Island NS), • **16 USC § 459h-3** (Gulf Islands NS), • **16 USC § 460ee** (Big South Fork NRRA), • **16 USC § 460cc-2(i)** (Gateway NRA), • **16 USC § 460m** (Ozark NSR), • **16 USC § 698c** (Big Thicket N Pres.), • **16 USC § 698f** (Big Cypress N Pres.)	**36 CFR Part 6** regulates solid waste disposal sites in park units. **36 CFR Part 9, Subpart B** requires the owners/operators of nonfederally owned oil and gas rights outside of Alaska to • demonstrate bona fide title to mineral rights; • submit an Operations Permit Application to NPS describing where, when, how they intend to conduct operations; • prepare/submit a reclamation plan; and • submit a bond to cover reclamation and potential liability. **43 CFR Part 36** governs access to nonfederal oil and gas rights located in, or adjacent to, National Park System units in Alaska.	**Section 8.7.3** requires operators to comply with 9B regulations.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Federal Mineral Leasing (Oil, Gas, and Solid Minerals)	**The Mineral Leasing Act, 30 USC § 181 et seq., and the Mineral Leasing Act for Acquired Lands, 30 USC § 351 et seq.** do not authorize the BLM to lease federally owned minerals in NPS units. **Combined Hydrocarbon Leasing Act, 30 USC §181**, allowed owners of oil and gas leases or placer oil claims in Special Tar Sand Areas (STSA) to convert those leases or claims to combined hydrocarbon leases, and allowed for competitive tar sands leasing. This act did not modify the general prohibition on leasing in park units but did allow for lease conversion in GLCA, which is the only park unit that contains a STSA. **Exceptions: Glen Canyon NRA (16 USC § 460dd et seq.), Lake Mead NRA (16 USC § 460n et seq.), and Whiskeytown-Shasta-Trinity NRA (16 USC § 460q et seq.)** authorizes the BLM to issue federal mineral leases in these units provided that the BLM obtains NPS consent. Such consent must be predicated on an NPS finding of no significant adverse effect on park resources and/or administration. American Indian Lands Within NPS Boundaries Under the **Indian Allottee Leasing Act of 1909, 25 USC §396, and the Indian Leasing Act of 1938, 25 USC §396a, §398 and §399, and Indian Mineral Development Act of 1982, 25 USCS §§2101-2108**, all minerals on American Indian trust lands within NPS units are subject to leasing. **Federal Coal Leasing Amendments Act of 1975, 30 USC § 201** prohibits coal leasing in National Park System units.	**36 CFR § 5.14** states prospecting, mining, and…leasing under the mineral leasing laws [is] prohibited in park areas except as authorized by law. **BLM regulations at 43 CFR Parts 3100, 3400, and 3500** govern Federal mineral leasing. **43 CFR Part 3160** governs onshore oil and gas operations, which are overseen by the BLM. Regulations re: Native American Lands within NPS Units: • **25 CFR Part 211** governs leasing of tribal lands for mineral development. • **25 CFR Part 212** governs leasing of allotted lands for mineral development. • **25 CFR Part 216** governs surface exploration, mining, and reclamation of lands during mineral development. • **25 CFR Part 224** governs tribal energy resource agreements. • **25 CFR Part 225** governs mineral agreements for the development of Indian-owned minerals entered into pursuant to the **Indian Mineral Development Act of 1982, Pub. L. No. 97-382, 96 Stat. 1938** (codified at **25 USC §§ 2101-2108**). • **30 CFR §§ 1202.100-1202.101** governs royalties on oil produced from Indian leases. • **30 CFR §§ 1202.550-1202.558** governs royalties on gas production from Indian leases. • **30 CFR §§ 1206.50-1206.62 and §§ 1206.170-1206.176** governs product valuation for mineral resources produced from Indian oil and gas leases. • **30 CFR § 1206.450** governs the valuation coal from Indian Tribal and Allotted leases. • **43 CFR Part 3160** governs onshore oil and gas operations, which are overseen by the BLM.	**Section 8.7.2** states that all NPS units are closed to new federal mineral leasing except Glen Canyon, Lake Mead and Whiskeytown-Shasta-Trinity NRAs.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Nonfederal minerals other than oil and gas	**NPS Organic Act, 54 USC §§ 100101 and 100751**	NPS regulations at **36 CFR Parts 1, 5, and 6** require the owners/operators of other types of mineral rights to obtain a special use permit from the NPS as a **§ 5.3** business operation, and **§ 5.7 – Construction of buildings or other facilities**, and to comply with the solid waste regulations at **Part 6**.	**Section 8.7.3** states that operators exercising rights in a park unit must comply with **36 CFR Parts 1 and 5**.
Coal	**Surface Mining Control and Reclamation Act of 1977, 30 USC § 1201 et. seq.** prohibits surface coal mining operations on any lands within the boundaries of a NPS unit, subject to valid existing rights.	**SMCRA Regulations at 30 CFR Chapter VII** govern surface mining operations on Federal lands and Indian lands by requiring permits, bonding, insurance, reclamation, and employee protection. **Part 7** of the regulations states that National Park System lands are unsuitable for surface mining.	None applicable.
Uranium	**Atomic Energy Act of 1954** Allows Secretary of Energy to issue leases or permits for uranium on BLM lands; may issue leases or permits in NPS areas only if president declares a national emergency.	None applicable.	None applicable.
Common Variety Mineral Materials (Sand, Gravel, Pumice, etc.)	**Materials Act of 1947, 30 USC § 601** does not authorize the NPS to dispose of mineral materials outside of park units. **Reclamation Act of 1939, 43 USC §387**, authorizes removal of common variety mineral materials from federal lands in federal reclamation projects. This act is cited in the enabling statutes for Glen Canyon and Whiskeytown National Recreation Areas, which provide that the Secretary of the Interior may permit the removal of federally owned nonleasable minerals such as sand, gravel, and building materials from the NRAs under appropriate regulations. Because regulations have not yet been promulgated, the National Park Service may not permit removal of these materials from these National Recreation Areas. **16 USC §90c-1(b)** authorizes sand, rock and gravel to be available for sale to the residents of Stehekin from the non-wilderness portion of Lake Chelan National Recreation Area, for local use as long as the sale and disposal does not have significant adverse effects on the administration of the national recreation area.	None applicable.	**Section 9.1.3.3** clarifies that only the NPS or its agent can extract park-owned common variety minerals (e.g., sand and gravel), and: ● only for park administrative uses; ● after compliance with NEPA and other federal, state, and local laws, and a finding of non-impairment; ● after finding the use is park's most reasonable alternative based on environment and economics; ● parks should use existing pits and create new pits only in accordance with park-wide borrow management plan; ● spoil areas must comply with Part 6 standards; and ● NPS must evaluate use of external quarries. Any deviation from this policy requires a written waiver from the Secretary, Assistant Secretary, or Director.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Coastal Features and Processes	**NPS Organic Act, 54 USC § 100751 et. seq.** authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights). **Coastal Zone Management Act, 16 USC § 1451 et. seq**. requires Federal agencies to prepare a consistency determination for every Federal agency activity in or outside of the coastal zone that affects land or water use of the coastal zone. **Clean Water Act, 33 USC § 1342/ Rivers and Harbors Act, 33 USC 403** require that dredge and fill actions comply with a Corps of Engineers Section 404 permit. **Executive Order 13089** (coral reefs) (1998) calls for reduction of impacts to coral reefs. **Executive Order 13158** (marine protected areas) (2000) requires every federal agency, to the extent permitted by law and the maximum extent practicable, to avoid harming marine protected areas. *See also "Climate Change"*	**36 CFR § 1.2(a)(3)** applies NPS regulations to activities occurring within waters subject to the jurisdiction of the US located within the boundaries of a unit, including navigable water and areas within their ordinary reach, below the mean high water mark (or OHW line) without regard to ownership of submerged lands, tidelands, or lowlands. **36 CFR § 5.7** requires NPS authorization prior to constructing a building or other structure (including boat docks) upon, across, over, through, or under any park area. *See also "Climate Change"*	**Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks unless directed otherwise by Congress. **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety. **Section 4.8.1** requires NPS to allow natural geologic processes to proceed unimpeded. NPS can intervene in these processes only when required by Congress, when necessary for saving human lives, or when there is no other feasible way to protect other natural resources/ park facilities/historic properties. **Section 4.8.1.1** requires NPS to: ● Allow natural processes to continue without interference, ● Investigate alternatives for mitigating the effects of human alterations of natural processes and restoring natural conditions, ● Study impacts of cultural resource protection proposals on natural resources, ● Use the most effective and natural-looking erosion control methods available, and avoid new developments in areas subject to natural shoreline processes unless certain factors are present. *See also "Climate Change"*

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Climate Change	**Secretarial Order 3289** (Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources) (2009) requires DOI bureaus and offices to incorporate climate change impacts into long-range planning; and establishes DOI regional climate change response centers and Landscape Conservation Cooperatives to better integrate science and management to address climate change and other landscape scale issues. **Executive Order 13693** (Planning for Federal Sustainability in the Next Decade) (2015) established to maintain Federal leadership in sustainability and greenhouse gas emission reductions.	*No applicable regulations, although the following NPS guidance should be considered:* **Coastal Adaptation Strategies Handbook (Beavers et al. 2016)** provides strategies and decision-making frameworks to support adaptation of natural and cultural resources to climate change. **Climate Change Facility Adaptation Planning and Implementation Framework**: The NPS Sustainable Operations and Climate Change Branch is developing a plan to incorporate vulnerability to climate change (Beavers et al. 2016b). **NPS Climate Change Response Strategy** (2010) describes goals and objectives to guide NPS actions under four integrated components: science, adaptation, mitigation, and communication. **Policy Memo 12-02** (Applying National Park Service Management Policies in the Context of Climate Change) (2012) applies considerations of climate change to the impairment prohibition and to maintaining "natural conditions". **Policy Memo 14-02** (Climate Change and Stewardship of Cultural Resources) (2014) provides guidance and direction regarding the stewardship of cultural resources in relation to climate change. **Policy Memo 15-01** (Climate Change and Natural Hazards for Facilities) (2015) provides guidance on the design of facilities to incorporate impacts of climate change adaptation and natural hazards when making decisions in national parks. *Continued in 2006 Management Policies column*	**Section 4.1** requires NPS to investigate the possibility to restore natural ecosystem functioning that has been disrupted by past or ongoing human activities. This would include climate change, as put forth by Beavers et al. (2016). *NPS guidance, continued:* **DOI Manual Part 523, Chapter 1** establishes policy and provides guidance for addressing climate change impacts upon the Department's mission, programs, operations, and personnel. **Revisiting Leopold: Resource Stewardship in the National Parks** (2012) will guide US National Park natural and cultural resource management into a second century of continuous change, including climate change. **Climate Change Action Plan** (2012) articulates a set of high-priority no-regrets actions the NPS will undertake over the next few years **Green Parks Plan** (2013) is a long-term strategic plan for sustainable management of NPS operations.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Upland and Fluvial Processes	**Rivers and Harbors Appropriation Act of 1899, 33 USC § 403** prohibits the construction of any obstruction on the waters of the United States not authorized by congress or approved by the USACE. **Clean Water Act 33 USC § 1342** requires a permit from the USACE prior to any discharge of dredged or fill material into navigable waters (waters of the US [including streams]). **Executive Order 11988** requires federal agencies to avoid adverse impacts to floodplains. (see also **D.O. 77-2**) **Executive Order 11990** requires plans for potentially affected wetlands (including riparian wetlands). (see also **D.O. 77-1**)	None applicable. *2006 Management Policies, continued:* **Section 4.6.6** directs the NPS to manage watersheds as complete hydrologic systems and minimize human-caused disturbance to the natural upland processes that deliver water, sediment, and woody debris to streams. **Section 4.8.1** directs the NPS to allow natural geologic processes to proceed unimpeded. Geologic processes…include…erosion and sedimentation…processes. **Section 4.8.2** directs the NPS to protect geologic features from the unacceptable impacts of human activity while allowing natural processes to continue.	**Section 4.1** requires NPS to manage natural resources to preserve fundamental physical and biological processes, as well as individual species, features, and plant and animal communities; maintain all components and processes of naturally evolving park ecosystems. **Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks, unless directed otherwise by Congress. **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety. **Section 4.6.4** directs the NPS to (1) manage for the preservation of floodplain values; [and] (2) minimize potentially hazardous conditions associated with flooding. *continued in Regulations column*

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Soils	**Soil and Water Resources Conservation Act, 16 USC §§ 2011–2009** provides for the collection and analysis of soil and related resource data and the appraisal of the status, condition, and trends for these resources. **Farmland Protection Policy Act, 7 USC § 4201 et. seq.** requires NPS to identify and take into account the adverse effects of Federal programs on the preservation of farmland; consider alternative actions, and assure that such Federal programs are compatible with State, unit of local government, and private programs and policies to protect farmland. NPS actions are subject to the FPPA if they may irreversibly convert farmland (directly or indirectly) to nonagricultural use and are completed by a Federal agency or with assistance from a Federal agency. Applicable projects require coordination with the Department of Agriculture's Natural Resources Conservation Service (NRCS).	**7 CFR Parts 610 and 611** are the US Department of Agriculture regulations for the Natural Resources Conservation Service. **Part 610** governs the NRCS technical assistance program, soil erosion predictions, and the conservation of private grazing land. **Part 611** governs soil surveys and cartographic operations. The NRCS works with the NPS through cooperative arrangements.	**Section 4.8.2.4** requires NPS to ● prevent unnatural erosion, removal, and contamination; ● conduct soil surveys; ● minimize unavoidable excavation; and ● develop/follow written prescriptions (instructions).

NPS 467/165264, September 2019

National Park Service
U.S. Department of the Interior

Natural Resources Stewardship and Science
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

https://www.nps.gov/nature/index.htm