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Pictorial Account and Landscape Evolution of the Crevasses near Fort St. Philip, Louisiana

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and Potamology Program

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Pictorial Account and Landscape Evolution of the Crevasses near Fort St. Philip, Louisiana

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Final report

Abstract

Quantifying the effects of active natural and constructed crevasses is critical to the planning and success of future ecosystem restoration activities. This document provides a historical overview of landscape changes within the vicinity of the natural crevasses near Fort St. Philip, Louisiana. A significant event influencing landscape change within the Fort St. Philip study area was the breaching of the eastern levee of the Mississippi River. Initially, the river water that was diverted through these crevasse channels physically removed significant marsh areas within the study area. These initial direct impacts were succeeded by several decades of larger regional loss patterns driven by subsidence and other episodic events (e.g, hurricanes and floods), and recent localized land gains. These increases in land area are potentially the long-term results of the Fort St. Philip crevasses, and the short-term impacts of delta management activities. However, for the majority of the 1956-2008 period of analysis, the crevassing of the eastern bank of the Mississippi River levee was a loss accelerant in the Fort St. Philip area.

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Quantifying the effects of active natural and constructed crevasses is critical to the planning and success of future ecosystem restoration activities. However, program stakeholders often lack the comprehensive assessments and tools necessary to quantify those short- and long-term effects. Therefore, this document has been prepared to provide a historical overview of landscape changes within the vicinity of the natural crevasses near Fort St. Philip, Louisiana.

This study utilized aerial photography, satellite imagery, and existing and newly generated land and water classifications to: (1) identify the time at which the Fort St. Philip crevasses were formed; (2) provide a pictorial account of the evolution of the Fort St. Philip crevasses and impacted wetlands; (3) evaluate land-water ratios and landscape change within the study area; (4) detect change relative to reference wetland areas; and (5) develop descriptive figures and summary statistics. These assessments, which cover decadal or greater time periods, include historical and modern landscape analyses that are based on previous methodologies developed by this study's principal investigators.

A significant event influencing landscape change within the Fort St. Philip study area during the study period was the breaching of the eastern levee of the Mississippi River and subsequent development of the Fort St. Philip crevasse channels. Initially, the river water that was diverted through these crevasse channels physically removed significant marsh areas within the study area. These initial direct impacts were succeeded by several decades of larger regional loss patterns driven by subsidence and other episodic events (e.g, hurricanes and floods), and recent localized land gains. These increases in land area are potentially the long-term results of the Fort St. Philip crevasses, and the short-term impacts of the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) BS-11 delta management activities. However, for the majority of the 1956-2008 period of analysis, the crevassing of the eastern bank of the Mississippi River levee was a loss accelerant in the Fort St. Philip area.

Preface

The research documented in this report was conducted as part of the Mississippi River Geomorphology and Potamology (MRG&P) Program. The MRG&P is part of the Mississippi River and Tributaries Program and is managed by the US Army Corps of Engineers (USACE) Mississippi Valley Division (MVD) and Districts. The MRG&P Program Manager was Freddie Pinkard and the Technical Leader was Dr. Barbara Kleiss.

The MVD Commander was BG Peter A. DeLuca. The MVD Director of Programs was Edward Belk.

Providing Mississippi River engineering direction and policy advice was the Mississippi River Commission. The Commission members were BG DeLuca, USACE; the Honorable Sam E. Angel; the Honorable R. D. James; the Honorable Norma Jean Mattei, Ph.D.; RDML Gerd F. Glang, National Oceanic and Atmospheric Administration; BG Margaret W. Burcham, USACE; and BG John S. Kem, USACE.

The US Army Engineer Research and Development Center (ERDC) conducted this research supporting the MRG&P under the purview of the Environmental Laboratory (EL), Vicksburg, Mississippi.

This report was prepared by Glenn Suir, Environmental Systems Branch (EE-C), ERDC-EL; Bill Jones, U.S. Geological Survey, National Wetlands Research Center; Adrienne Garber, Five Rivers Services, LLC, National Wetlands Research Center; and John Barras, U.S. Geological Survey, St. Petersburg Coastal and Marine Science Center–Baton Rouge Colocation Office. The report was prepared under the general supervision of Mark Graves, Chief, EE-C; Dr. Edmond J. Russo, Jr., P.E., Chief, Ecosystem Evaluation and Engineering Division, EL; Dr. Jack Davis, Deputy Director, EL; and Dr. Beth Fleming, Director, EL.

COL Jeffrey R. Eckstein was Commander of ERDC. Dr. Jeffery P. Holland was the ERDC Director.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
miles (U.S. statute)	1,609.347	meters
square miles	2.589998 E+06	square meters

1 Introduction

1.1 Background

Crevassing of the Mississippi River has significantly contributed to delta lobe formation adjacent to the river. Crevasses, which occur as large breaches or breaks in river levees, promote infilling of shallow inter-distributary ponds with sediment-laden river water, ultimately resulting in vegetated deltaic splays (Rodrigue 2003). From 1773 to 1927, the total number of Mississippi River crevasses (principally in Louisiana) reported in the literature was 1,062 (Davis 2000). During that same period, as many as 20 natural crevasse splays were active in the modern Mississippi River Delta, accounting for more than 80% of its subaerial land (Davis 2000). However, human alterations to the Mississippi River system (e.g. channel training and flood protection measures) have eliminated the majority of crevasses above river mile 42 (corresponds to the southern terminus of the east bank flood protection levee, Figure 1), thereby reducing the supply of nutrient- and sediment-rich water that is vital for the subsistence of deltaic wetlands (National Research Council 2006).

For the last half-century, Louisiana's coastal wetlands have experienced rapid degradation (Suir et al. 2013). However, with past successes of delta progradation through natural crevassing, artificial crevasse cuts and freshwater diversions could be viable engineering techniques for utilizing nutrient- and sediment-laden water for marsh management and ecosystem restoration. With numerous artificial crevasses and freshwater diversions currently constructed or proposed, quantifying the long-term landscape changes and trends that are associated with active crevasses is critical to the planning and success of future projects.

1.2 Purpose

The primary goals of this study were to identify and quantify recent and historical land change trends from the mid-1950s through 2008 for the area surrounding the active Mississippi River levee breach near Fort St. Philip, Louisiana, and to compare the magnitude and sequencing of those changes to reference areas along the eastern bank of the Mississippi River (Breton Sound Basin).

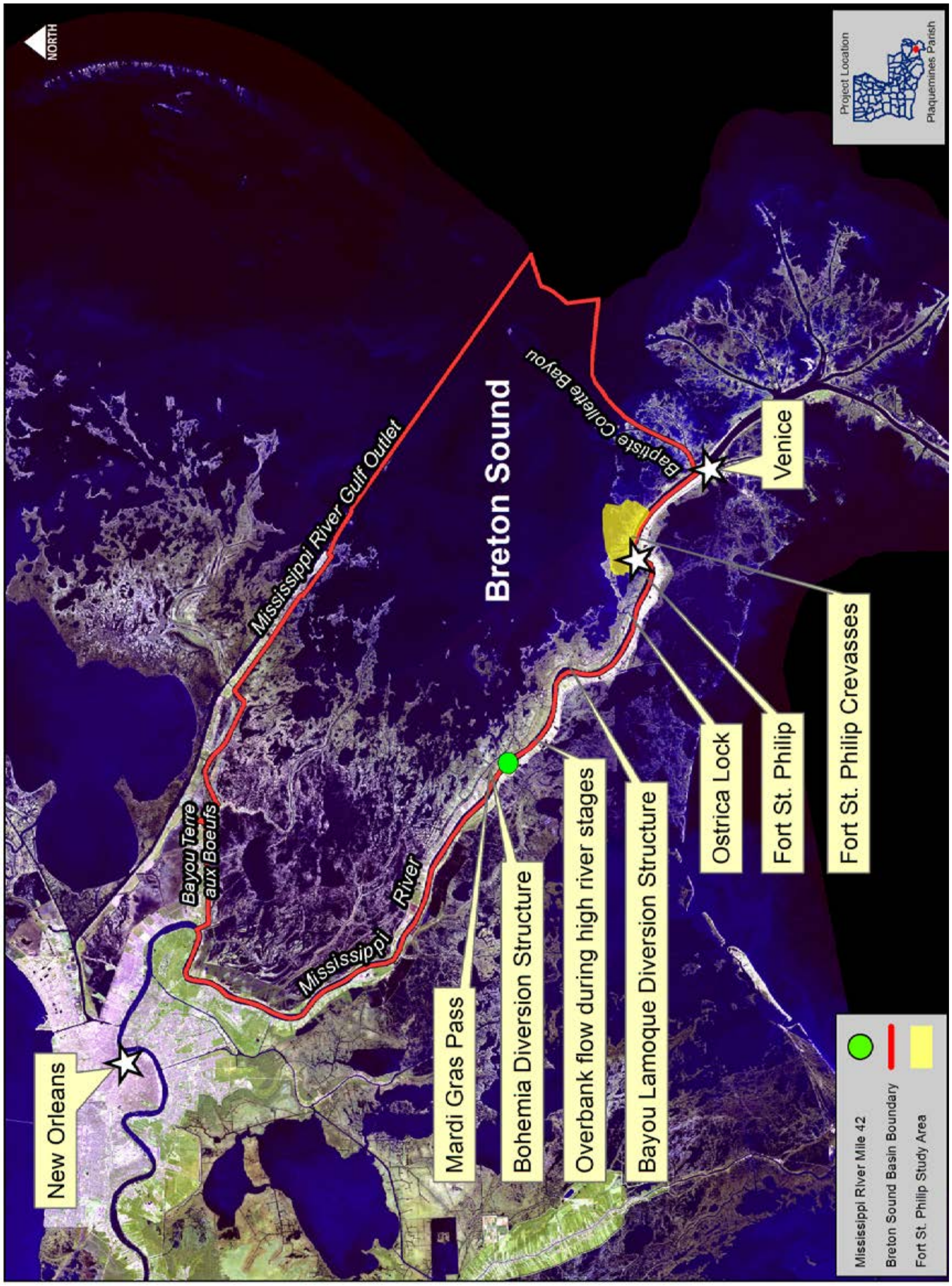


Figure 1. Fort St. Philip Crevasses study location map.

To achieve these goals, the authors proposed that geospatial data be acquired, processed, and/or generated in order to: (1) identify the event(s) and timing at which the Mississippi River levee was breached, resulting in the Fort St. Philip crevasses; (2) provide a pictorial account of the evolution of the Fort St. Philip crevasses; (3) analyze changes in project area wetland landscapes over time using land and water classifications; (4) analyze changes to compare the project area to reference area landscapes; and (5) develop descriptive figures and summary statistics.

1.3 Project area

The 7,391-acre study site is located in southeastern Breton Sound Basin, which extends from the Mississippi River east to the Mississippi River Gulf Outlet, and south from Bayou Terre aux Boeufs to Baptiste Collette Bayou (Figure 1). The 983-mi^2 basin, a remnant of the St. Bernard Delta, also contains several abandoned distributary channels including Bayou La Loutre, River aux Chenes, and Bayou Lamoque (US Fish and Wildlife Service (USFWS) 2003). In addition to these channels, flows also escape the river through several natural and man-made openings in the bank (Figure 1). The study area is generally impacted by riverine overbank flooding/crevassing, tidal and metrological conditions, and rapid subsidence. This study will focus on the openings (crevasses) and the area of influence located near Fort St. Philip.

Assessing the short- and long-term landscape changes that have occurred pre- and post-crevassing, and comparing those changes to reference areas, provides valuable information related to natural crevasse formation and evolution. Also, at 100,000 ft^3/sec (measured during high river stage), the flow through these crevasse channels provides an analog by which to assess landscape-level impacts from large freshwater diversions.

2 Methods

Three primary tasks were associated with this study. Those tasks were: (1) data acquisition and processing, (2) landscape analyses within the study area using high-resolution photography and imagery, and (3) comparison of project and reference area landscapes using moderate-resolution imagery. These assessments consisted of historical and modern landscape analyses based on methodologies and data developed for prior coastal trend studies (Barras 2009, Barras et al. 2008, Louisiana Department of Natural Resources (LDNR) 1995, Saltus et al. 2012, Suir et al. 2011).

2.1 Data acquisition and processing

Decadal or greater periods of analyses were proposed for this study. However, those periods were ultimately based on the time of crevasse formation, available aerial photography and classified imagery, and time requirements for performing additional land and water classifications. Higher resolution (<1:65,000 scale) historical and recent aerial photography and digital imagery were acquired for the years 1956, 1970, 1973,[1] 1974,[1] 1978, 1989,[1] 1998, and 2008 (Table 1). Though the 1998 and 2008 data exist in geo-rectified and mosaicked digital formats, the 1956, 1970, 1973, 1974, 1978, and 1989 data were only available in un-rectified Tagged Image File (TIF) format. Therefore, all un-rectified frames were rectified using the 2008 digital imagery as the control, and subset to the study area boundary.

The land change assessments (both high- and moderate-resolution) discussed within this report were calculated using land and water data sets and methods developed for prior coastal land area change assessments (Barras 2006, 2009; Barras et al. 1994, 2003, 2008; Cahoon and Groat 1990; Saltus et al. 2012; US Geological Survey (USGS) 1980, 1988a, 1988b, 2009), as well as land and water data sets created as part of this study (1970 and 1998). Existing and newly created land and water data sets were derived from multiple source data. Existing data sources include Landsat

[1] These photographs were converted to a digital format by the US Geological Survey, Earth Resources Observation and Science (EROS) Center using charge-coupled device (CCD) capture rather than a flatbed scanner and are considered medium-resolution data. However, compared to moderate-resolution Landsat imagery, and for simplifying assessment tasks, these photos will be considered high-resolution data for this study.

Thematic Mapper (TM) satellite imagery obtained from the USGS Center for Earth Resources Observation and Science (moderate-resolution data from 1988, 2001, and 2008; Table 1). Those land and water data sets that were modified from photo-interpreted National Wetlands Inventory (NWI) habitat data consist of high-resolution data from 1956, 1978, 1988, and 2008 (Table 1). Additionally, the land and water data sets that were derived specifically for this study consist of photo-interpreted, high-resolution panchromatic and color infrared (CIR) aerial photography from 1970 and 1998, respectively (Table 1). Since these data were processed by various analysts and classified using differing methods, measures were taken to ensure compatibility between data sets (see below).

Table 1. Status of available photography, imagery, and classified land and water data within the Fort St. Philip study area.

Assessment	Date	Data Type	Data Source	Scale	Process/Application
Fort St. Philip Project Area Higher Resolution (1-m resampled)	24 March 1956	Panchromatic Photography	Army Map Service	1:24,000	Aggregated NWI Habitat
	8 March 1970[1]	Panchromatic Photography	U.S. Geological Survey	1:54,800	Land and Water Delineation
	11 April 1973	Panchromatic Photography[3]	NASA - AMES	1:127,000	Visual Interpretation
	17 October 1974	Panchromatic Photography[3]	NASA - JSC	1:119,000	Visual Interpretation
	15 October 1978	CIR Photography[4]	NASA - AMES	1:65,000	Aggregated NWI Habitat
	1 January 1988	CIR Photography[4]	NASA	1:65,000	Aggregated NWI Habitat
	30 October 1989[2]	CIR Photography[4]	U.S. Geological Survey - NAPP	1:40,000	Visual Interpretation
	4 February 1998[1]	DOQQ[4]	La. Oil Spill Coordinator's Office	1:40,000	Land and Water Delineation
	30 October 2008	Digital Imagery[4]	U.S. Geological Survey	-	Aggregated NWI Habitat
Breton Reference Area Moderate Resolution (25-m resampled)	24 March 1956	Panchromatic Photography	Army Map Service	1:20,000	Previously Aggregated and Resampled NWI
	15 October 1978	CIR Photography	NASA - AMES	1:65,000	Previously Aggregated and Resampled NWI
	28 January 1988	Landsat 5 Imagery	NASA	-	Land and Water Delineation
	30 October 2001	Landsat 5 Imagery	NASA	-	Land and Water Delineation
	1 October 2008	Landsat 5 Imagery	NASA	-	Land and Water Delineation

[1] 1970 and 1998 land and water data were delineated as part of this study.

[2] 1989 photography provides higher quality data than those used in 1988 NWI classification.

[3] Used for assessing sequencing of levee breach.

[4] The color infrared photography used in this report's figures are displayed in grayscale for ease of comparison.

2.2 High-resolution data

The higher resolution land and water data that were used in this study were derived from photography obtained in 1956 (1:24K), 1970 (1:58.4K), 1978 (1:65K), and 1988 (1:65K, magnified to 1:24k for zoom transfer); from 1998 color infrared (CIR) photography (1:40K/1 m); and from 2008 (1-m) CIR digital imagery (Table 1). As a precursor, it should be noted that methods used to derive these land and water data varied considerably. Land and water data for the years 1956, 1978, and 1988 were derived from existing NWI habitat data developed for prior coastal characterization studies (Wicker 1980, 1981; USGS 1988b; Barras et al. 1994; Fuller et al. 1995). These habitat data were classified using a standard NWI classification scheme (Cowardin et al. 1979). The NWI habitat scheme was adapted to identify specific Louisiana wetland habitats using code modifiers (Wicker 1980). To compare changes in land and water area, the classified habitat data were aggregated into land and water categories using a standard classification scheme. Land features represent uplands, emergent vegetation, wetland forest, or scrub-shrub; and water features represent any open water, floating or submerged aquatics, and non-vegetated mud flat. For tidally-influenced landscapes, as with the Fort St. Philip study area, delineating land and water feature boundaries from NWI habitat data is often difficult. For this project, the delineation was set between habitat classes with “Regularly Flooded” and “Irregularly Flooded” water regimes. These tidally-influenced regimes are based on intermediate, brackish, and saline modifiers. Regularly Flooded features represent areas that alternately flood and expose the land surface at least once daily; Irregularly Flooded features are those where water floods the land surface less often than daily.

The 1970 and 1998 land and water data were derived from unrectified panchromatic photography and ortho-rectified CIR aerial photography, respectively. The 1970 photos were scanned into a digital format and geo-rectified to a Universal Transverse Mercator (UTM) coordinate system. Manual land and water classifications were performed using an on-screen interactive "heads-up" technique that utilizes photo radiance, contrast, texture, and pattern recognition by which land and water features were delineated directly into a digital GIS (Suir et al. 2011).

The 2008 habitat data were derived from 1-m digital imagery captured with the ZI Digital Mapping Camera. As part of ongoing efforts by the USGS to map Louisiana’s coastal habitats, the 2008 imagery was classified using the established NWI habitat classification scheme. The classified habitat data were then aggregated into land and water categories.

Due to evolving classification and rectification techniques, it was essential to evaluate inconsistencies in the registration, scale, and mapping unit size of source and classified data. The earlier habitat data sets were transformed to match the 1998 and 2008 data. This was achieved by either re-registering the historic line-work to 2008 control points, or by rasterizing the historical land and water line-work and geo-referencing to the 2008 imagery. Co-registering the data provides greater confidence in the results. Additionally, classification accuracies of those land and water data that were aggregated from existing NWI data were also assessed. Any misclassified land or water features were corrected using the “heads-up” method described above.

2.3 Moderate-resolution data

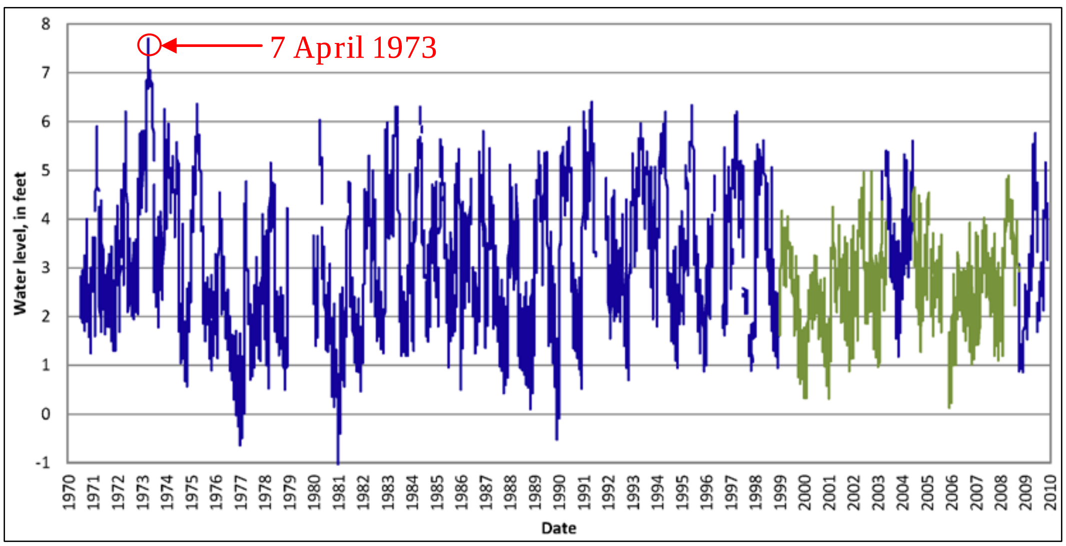
The moderate-resolution data used in this study consist of existing Landsat 5 Thematic Mapper (TM) satellite imagery from 1988, 2001, and 2008, previously resampled to 25 m (Barras 2009; Barras et al. 2008; Saltus et al. 2012, Table 1); and aggregated 1956 and 1978 habitat data (Wicker 1980, 1981) that were rasterized and resampled to match TM spatial resolution (Cahoon and Groat 1990). All of the TM data that were used in this study were classified using a standard classification methodology to ensure repeatability and consistency, as well as to minimize classification interpretation subjectivity (Barras et al. 2003). These methods consisted of radiometric correction, edge enhancement, and band 5-level slicing of the TM data. Final resampling and noise filtering were performed on all data that were used in the moderate-resolution assessments (Braud and Feng 1998, Suir et al. 2011).

3 Results

3.1 Aerial photography

Examining historical and modern aerial photography, acquired from 1956 through 2008, provides a means of identifying and empirically documenting the landscape changes that have occurred within the Fort St. Philip study area. Previous reports have theorized that marsh loss in this area has been the result of subsidence, wind and wave erosion, and the scouring of organic marsh soils when river water was introduced through the natural crevasses near Fort St. Philip (USFWS 2003). Though the specific time of breaching near Fort St. Philip has never been documented, it has been assumed that these crevasses were created during the major Mississippi River flood of 1973 (USFWS 2003). Figures 2 and 3 correlate bounding aerial photography and historical river stage with the sequencing of the Mississippi River levee breach. The 7 April 1973 flood stage peak (+7.7 ft) at the Empire gage (Figure 2) corresponds to the pre-, active-, and post-breach sequence that is illustrated in Figure 3.

Figure 2. Daily Mississippi River stage data (water level, in feet) at Empire gage (blue) and Venice gage (green), Louisiana. Flood stage peak identified with red circle.



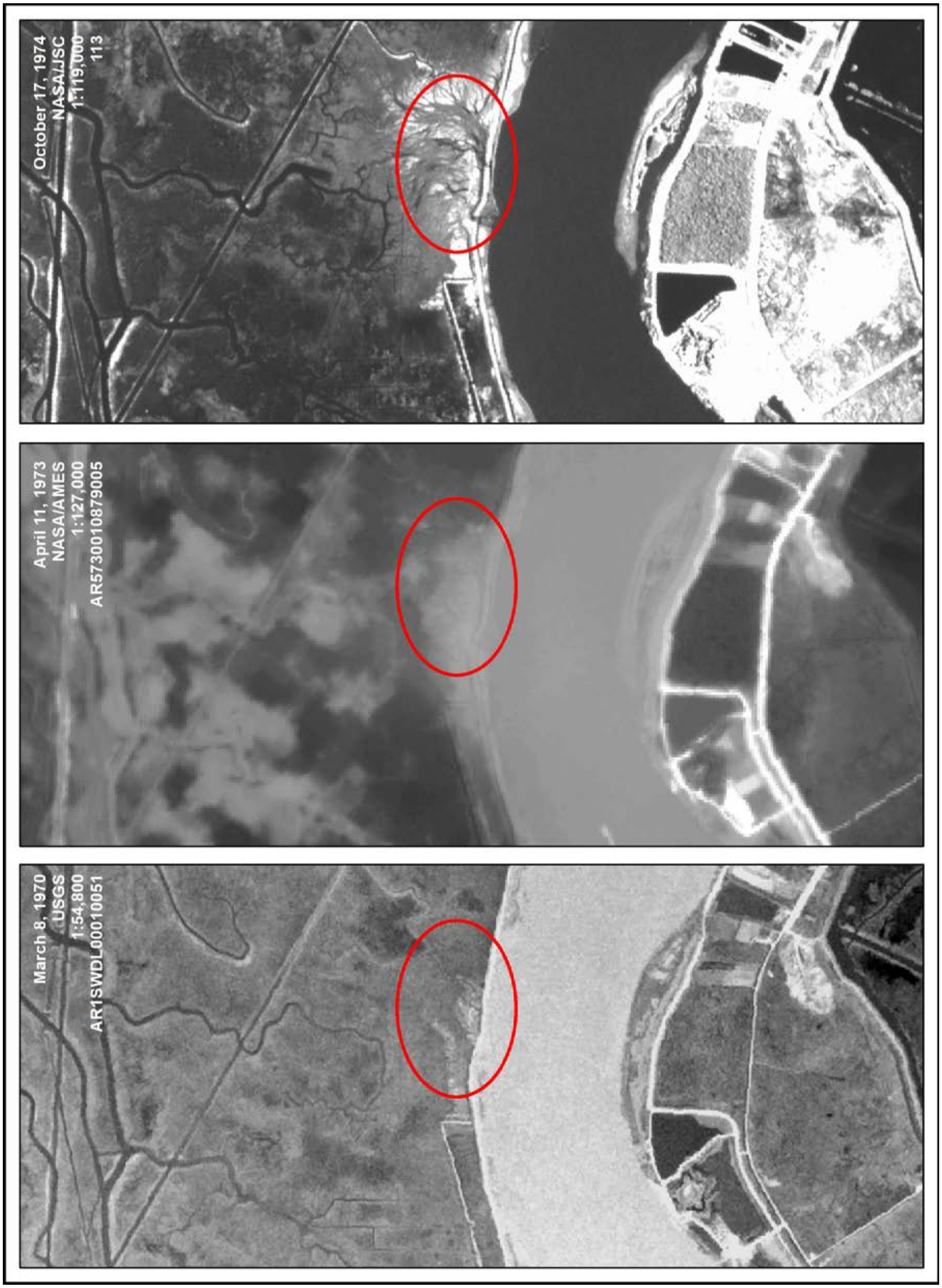


Figure 3. Aerial photography showing pre- (left pane), active- (middle pane), and post-breaching (right pane) of the Mississippi River levee near Fort St. Philip, Louisiana in 1970, 1973 (moderate-resolution photography experiencing Moiré effect), and 1974, respectively. Breach site identified with red ovals.

Figures 4-10 present a pictorial account of the Fort St. Philip study area and provide further evidence that the crevasses were a result of the 1973 flood (Figure 6). These figures, which consist of photography from 1956, 1970, 1978, 1989, 1998, and 2008 (and the 2011 photomosaic map from the Delta Management at Fort St. Philip Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) project), allow for visual interpretation and comparison of landscape feature extent and change. Notable landscape feature changes within the Fort St. Philip study area are provided in Table 2 and identified in Figures 3-10.

3.2 Landscape area and change – High-resolution analyses

Existing and newly classified land and water data provide visual and computational aids for assessing wetland area and change. Figures 11, 12, 14, 16, 18, and 20 illustrate the land and water area, and landscape configuration for the years 1956, 1970, 1978, 1988, 1998, and 2008. Figures 13, 15, 17, 19, and 21 depict land and water changes for sequential periods of analysis.

Figure 11 shows a 1956 landscape that consisted of 5,012 acres of relatively solid marsh, and 2,379 acres of water, comprised primarily of the Mississippi River, Little Coquille Bay, natural bayous, and minimal oil and gas access canals. By 1970 (Figure 12), the study area consisted of 4,377 and 3,014 acres of land and water, respectively. This amounts to 635 acres of net land loss between 1956 and 1970 (Table 3). The net change between 1956 and 1970 was calculated by subtracting the total area of land loss (832 acres) from the total area of land gains (197 acres). These moderate land losses (compared to subsequent time periods) were the primary results of bay-side shoreline erosion (likely accelerated by Hurricanes Betsy and Camille), direct impacts by access canals, and potentially the results of minor under-classification of water features in the 1956 data (Figure 13; loss depicted in red). The gains (depicted in green) during this period were primarily due to the armoring of the east bank of the river.

By 1978, the Fort St. Philip study area consisted of 2,760 and 4,631 acres of land and water, respectively (Figure 14). The 1,617 acres of net loss (1,932 acres of loss and 315 acres of gain) are possibly due to the combined effects of marsh scouring, as a result of the newly formed crevasses (7.7 ft river stage on 7 April 1973, Empire gage; Table 3 and Figures 2 and 15) and subsidence (Gagliano 1999). Subsequent major flooding events (i.e. 6.36 ft river stage on 14 April 1975, Empire gage) may have exacerbated the initial scouring. The nominal land gains during this period are presumably due to infilling and depositional processes as a result of sediment-rich river water being diverted through the crevasse channels.

Figure 4. Fort St. Philip study area - 1956 high-resolution photomosaic map.

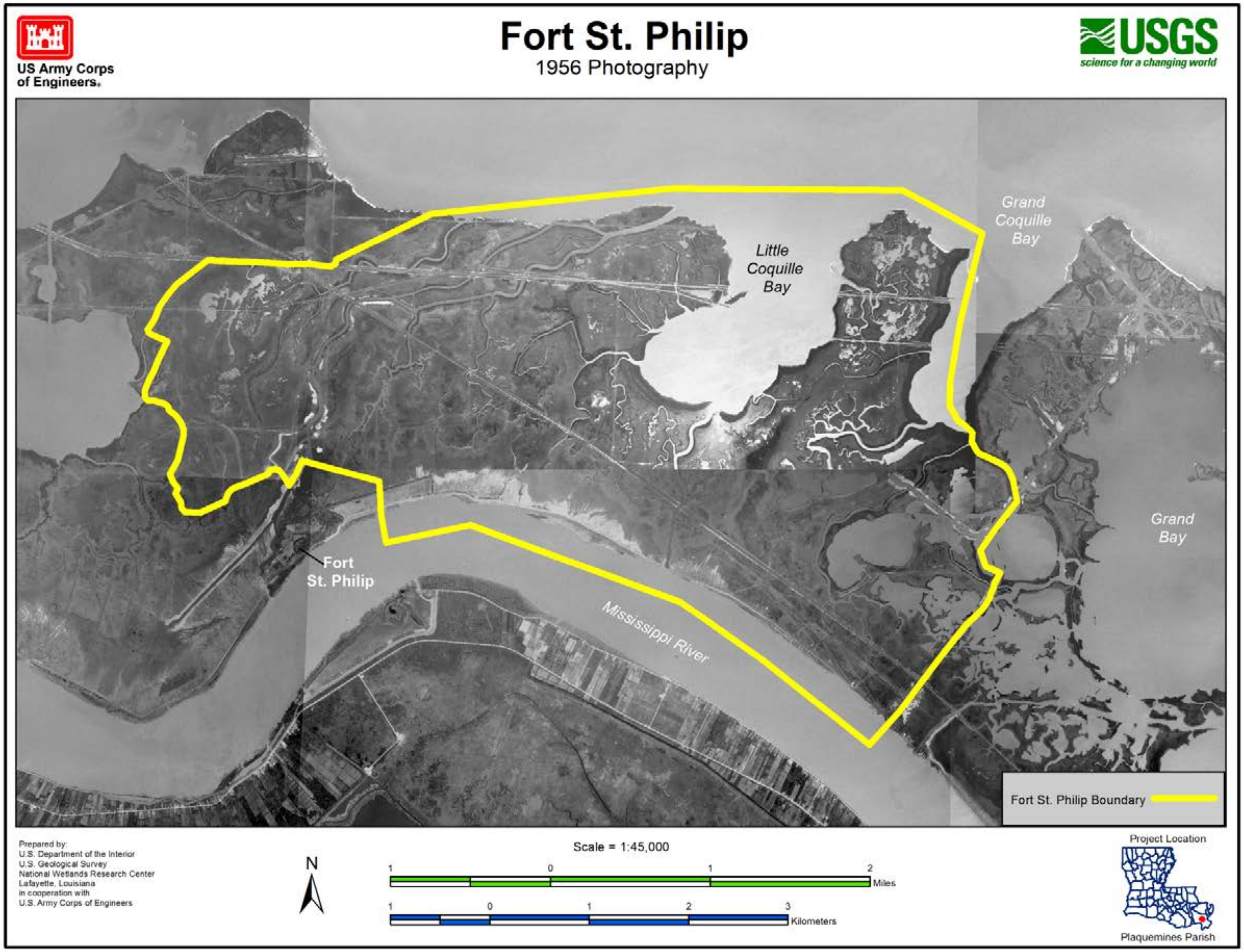


Figure 5. Fort St. Philip study area with access canals (#1) - 1970 high-resolution photomosaic map (Table 2).

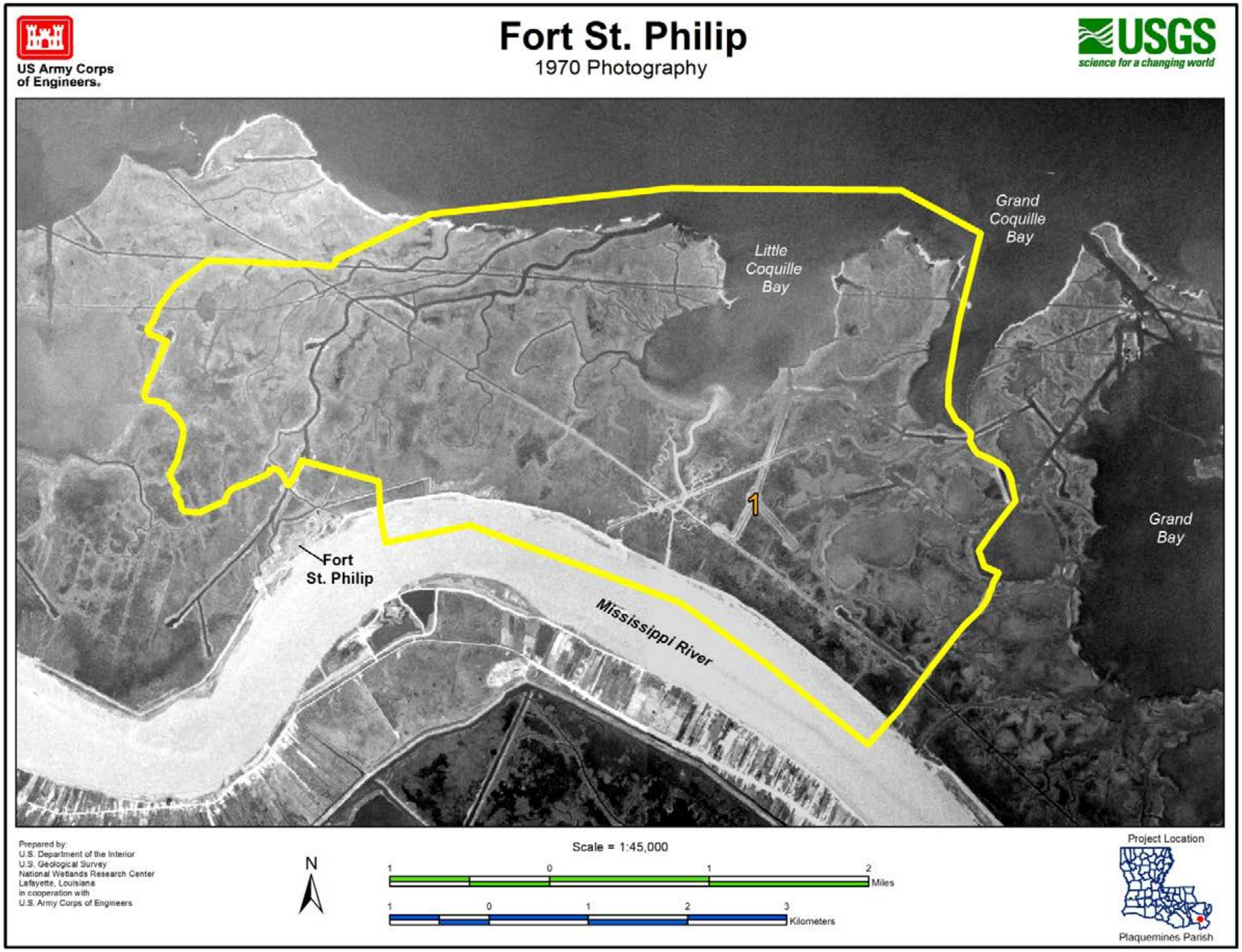


Figure 6. Fort St. Philip study area with crevasse locations (#2), areas with major land-to-water conversion (#3), and formation of crevasse channels (#4) - 1978 high-resolution photomosaic map (Table 2).

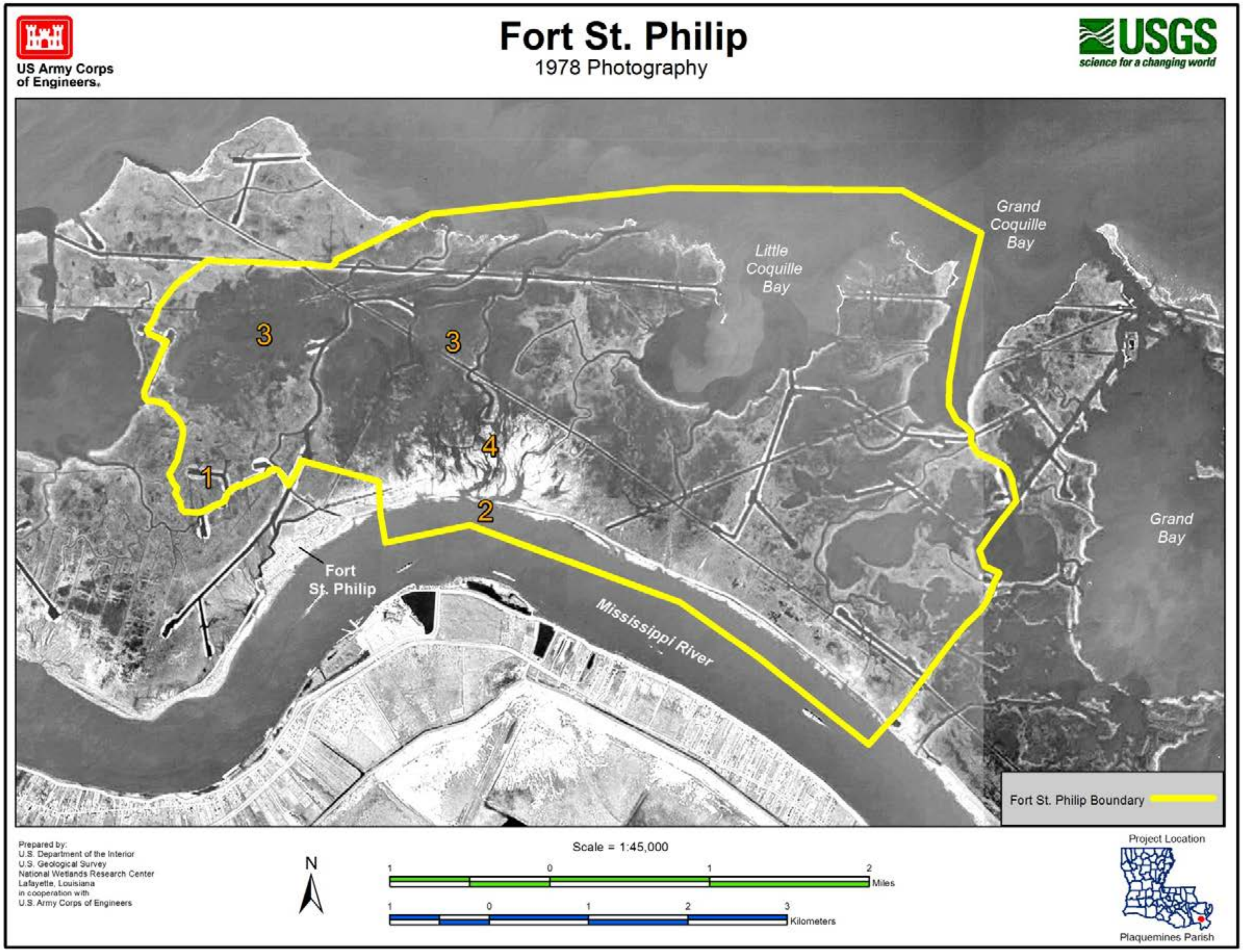


Figure 7. Fort St. Philip study area with areas of land-to-water conversion (#3), crevasse channel development (#4), and large impoundment area (#5) - 1989 high-resolution photomosaic map (Table 2).

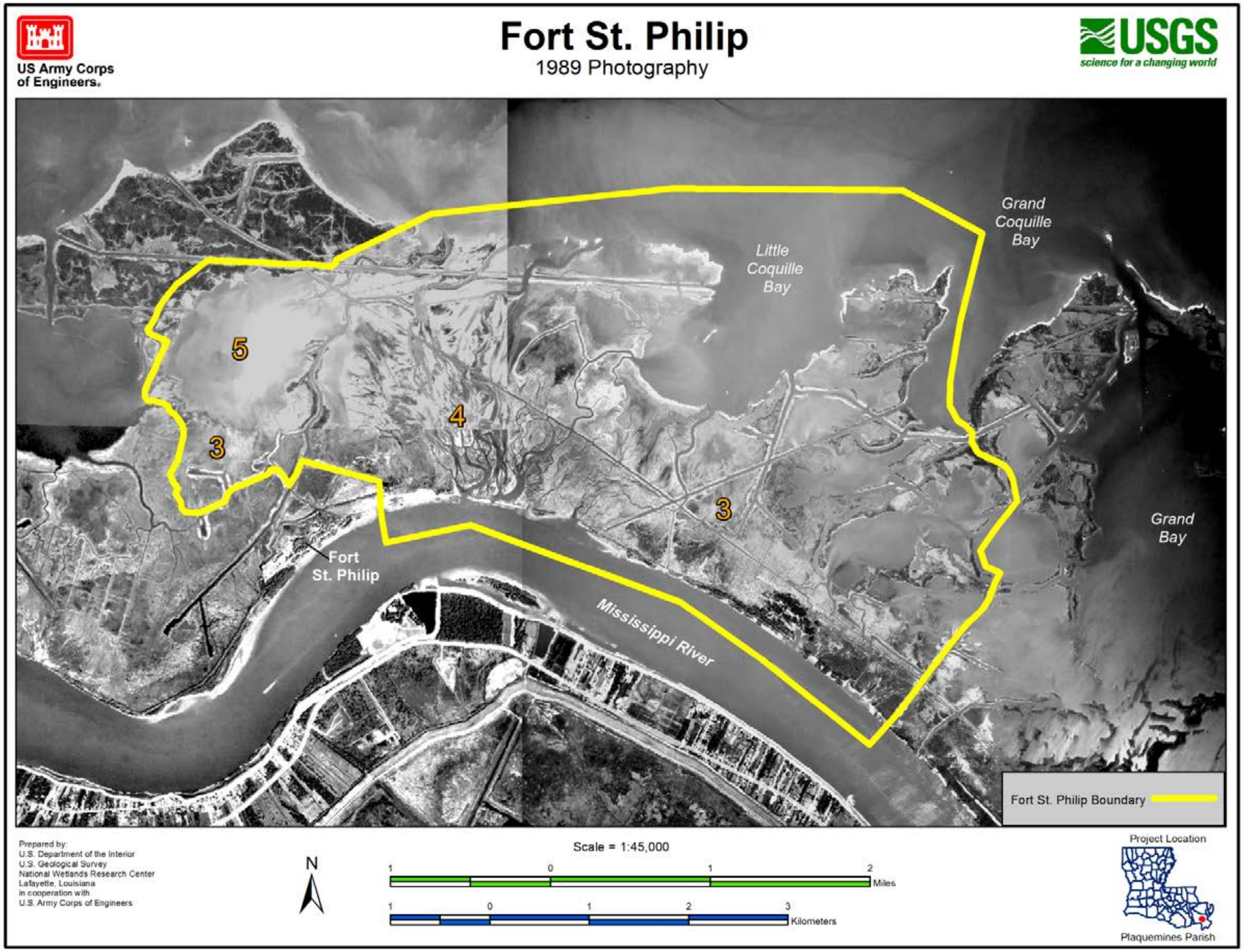


Figure 8. Fort St. Philip study area with areas of land-to-water conversion (#3), crevasse channel development (#4), and large impoundment area (#5) - 1998 high-resolution photomosaic map (Table 2).

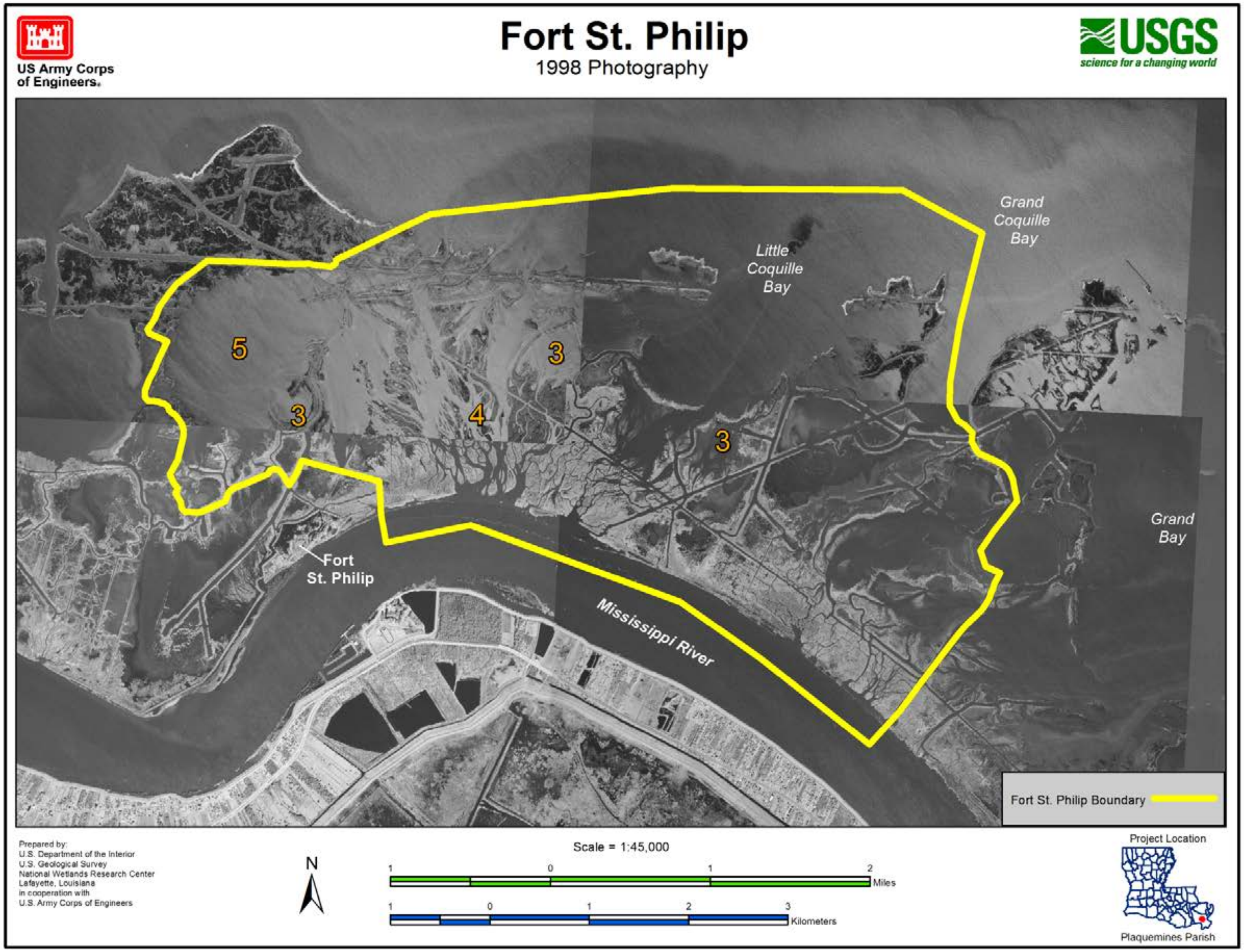


Figure 9. Fort St. Philip study area constructed CWPPRA BS-11 project terraces (#6) - 2008 high-resolution photomosaic map (Table 2).

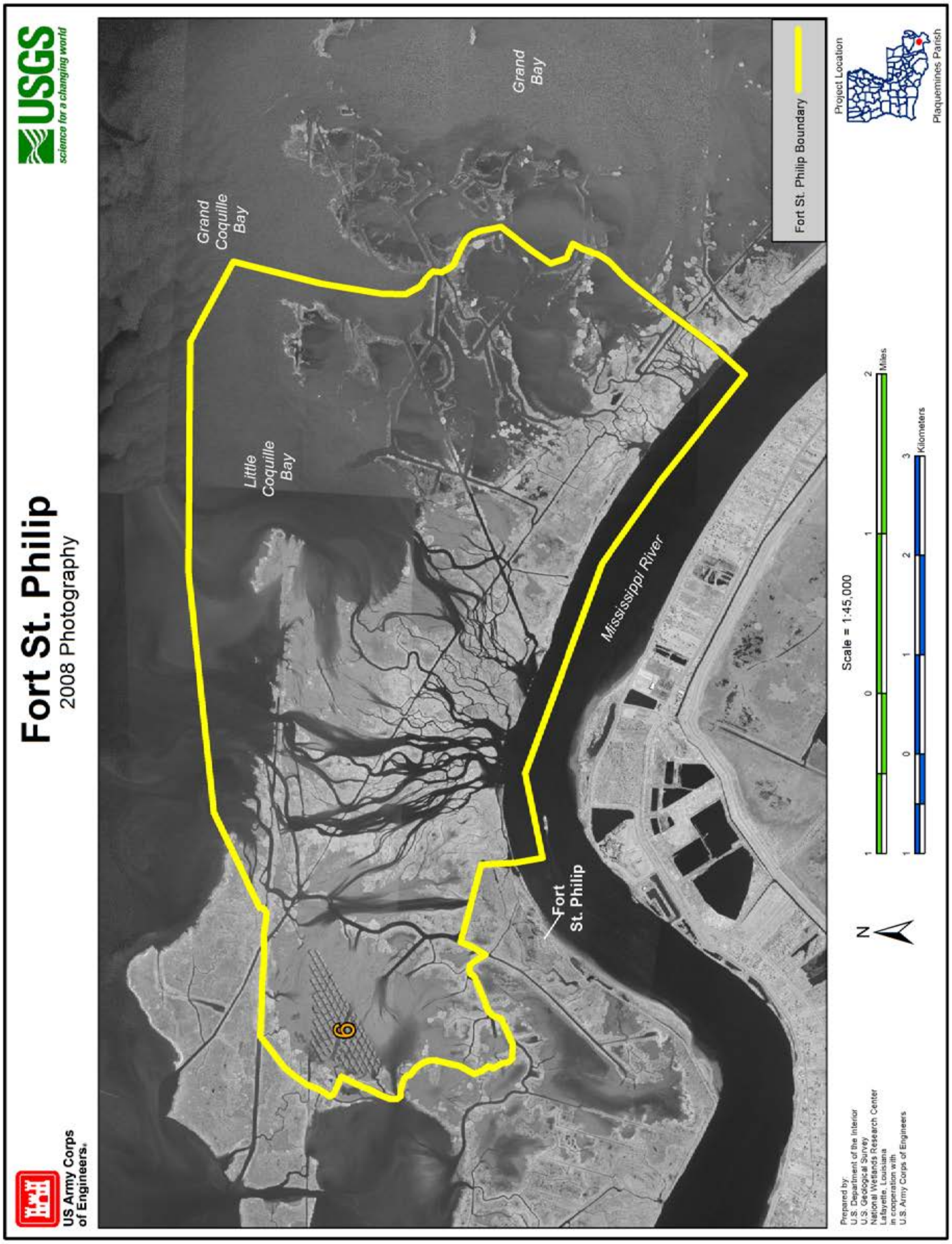


Figure 10. Delta Management at Fort St. Philip project area - 2011 high-resolution photomosaic map (USFWS 2013b).

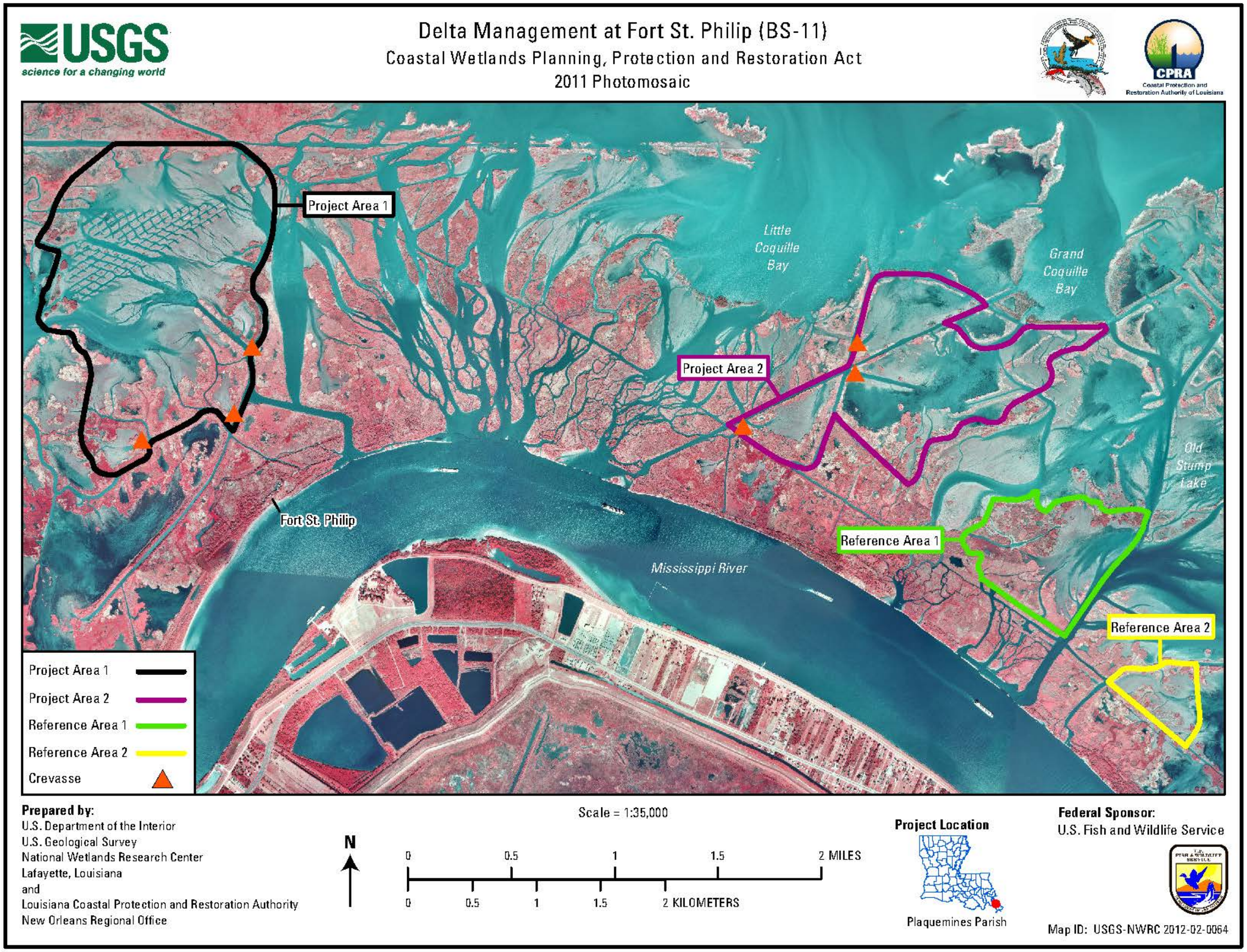


Table 2. Dominant landscape feature changes identified using visual observation of high-resolution aerial photography and digital imagery. Corresponding feature numbers are represented in Figures 5-10 for location identification.

No.	Features	Period	Reference
1	Construction of oil and gas access canals	1956-1978	Figures 5 & 6
2	Breaching of the Mississippi River bank	1970-1978	Figures 3, 5 & 6
3	Major conversion of land to water	1978-1998	Figures 6, 7 & 8
4	Formation of crevasse channels	1978-2008	Figures 6, 7 & 8
5	Development of large impoundment feature	1978-2008	Figures 7 & 8
6	Construction of CWPPRA BS-11 project terraces[1]	1998-2008	Figures 9 & 10

[1] CWPPRA's Delta Management at Fort St. Philip (BS-11) Sediment and Nutrient Trapping, and Outfall Management project (USFWS 2013a).

There were 2,444 acres of land and 4,947 acres of water within the study area in 1988 (Figure 16). This amounts to a net loss of 316 acres of land between 1978 and 1988 (Table 3). Though this net loss is significantly reduced from the previous period of analysis, the localized land losses (1,054) and gains (738) remained relatively high. Figure 17 shows the formation of additional crevasse channels, which resulted in increased sediment deposition on mud flats and substrate, and potentially in direct localized scouring and flooding (during high river flow). Additionally, since the study area contains broad shallow flats, localized changes are partially due to seasonality and fluctuations in river stage, tides, and winds, as well as recurring aquatic vegetation.

Land loss continued through 1998, when the study area accounted for 1,780 acres of land and 5,611 acres of water (Figure 18). Though this period experienced loss (1,080 acres) similar to the previous period, there were significantly fewer gains from 1988 to 1998 (Figure 19). The losses experienced during this period appear to have occurred along the fringe of marsh and wetland landforms, and are consistent with subsidence, and wind- and wave-induced erosion.

The 1998 to 2008 time frame is the only period of analysis that experienced net land gains. By 2008, the study area contained 2,102 acres of land, a net land gain of 322 acres (Figure 22 and Table 3). These gains are presumably the effects of the crevasses (gains are in close proximity to crevasse channels) and the results of the CWPPRA BS-11 restoration project. The BS-11 project authorized the construction of terraces in the large impounded area to the west, and artificial crevasse cuts into two BS-11 Project Areas (both of which are within the Fort St. Philip study area; Figure 10). Areas that did experience erosion during this period were primarily along the fringe marsh near Little Coquille Bay and are therefore assumed losses due to wind and wave energy (Figure 21).

Figure 11. Fort St. Philip study area - 1956 high-resolution land-water classification map.

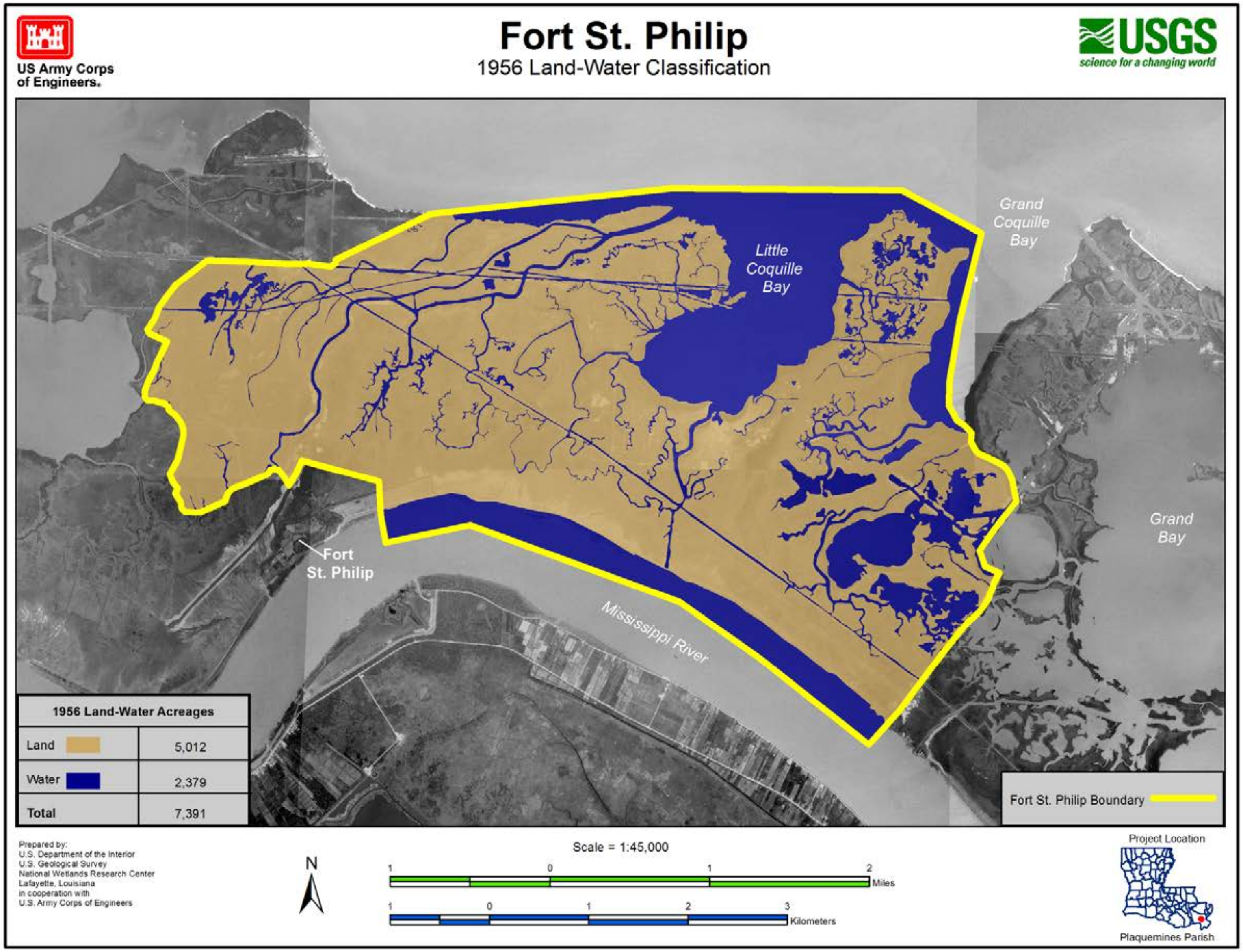


Figure 12. Fort St. Philip study area - 1970 high-resolution land-water classification map.

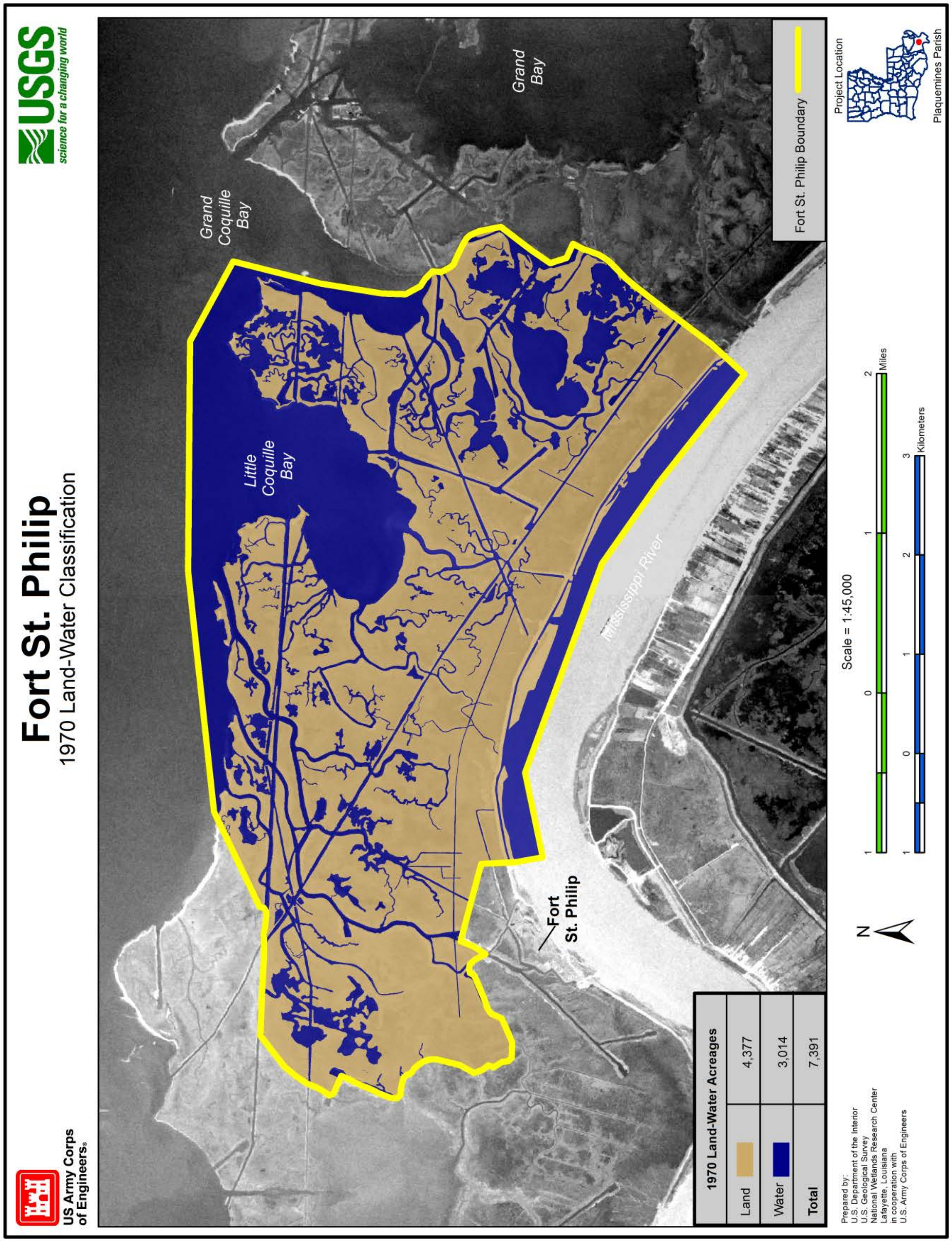


Figure 13. Fort St. Philip study area - 1956-1970 high-resolution land change analysis map.

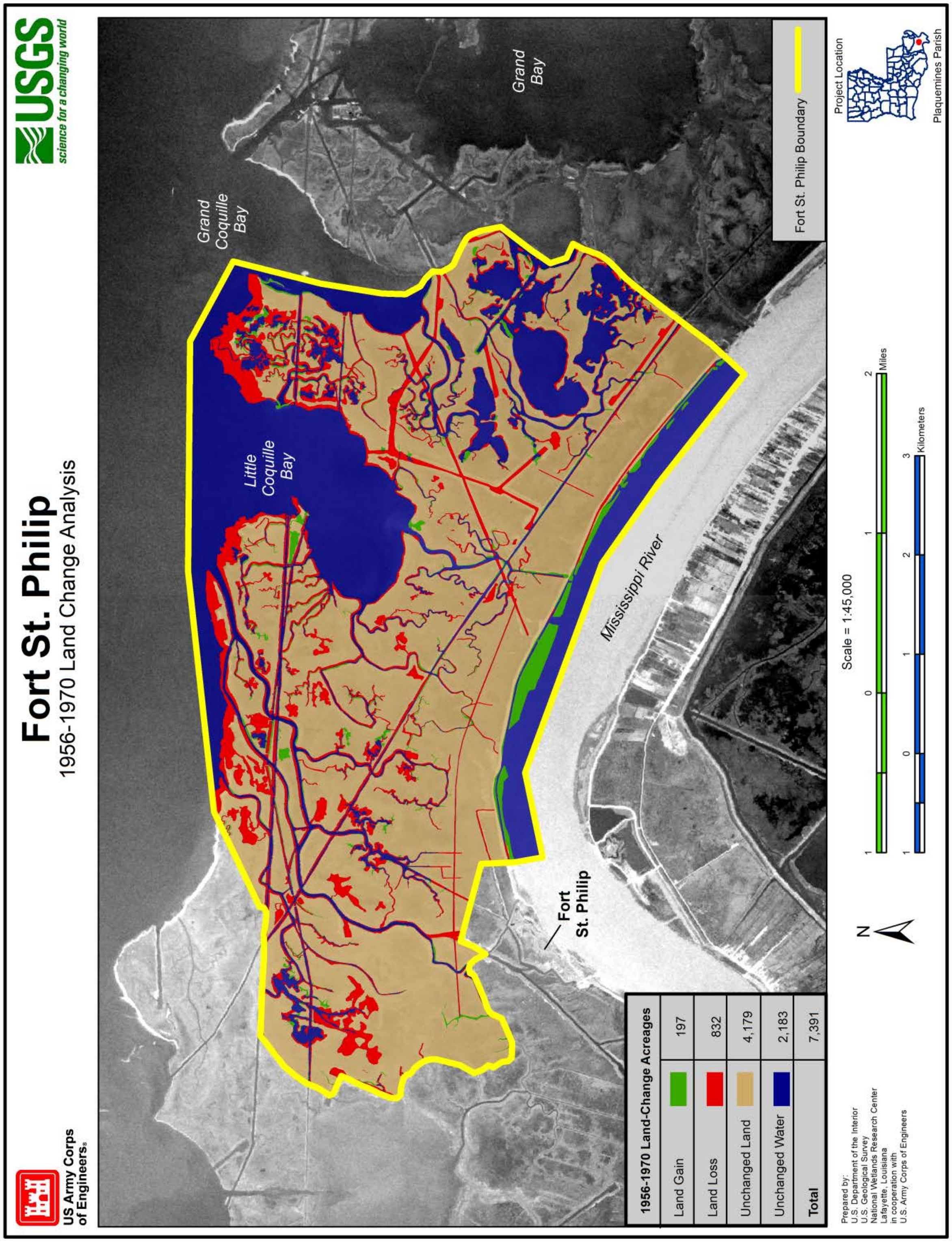


Figure 14. Fort St. Philip study area - 1978 high-resolution land-water classification map.

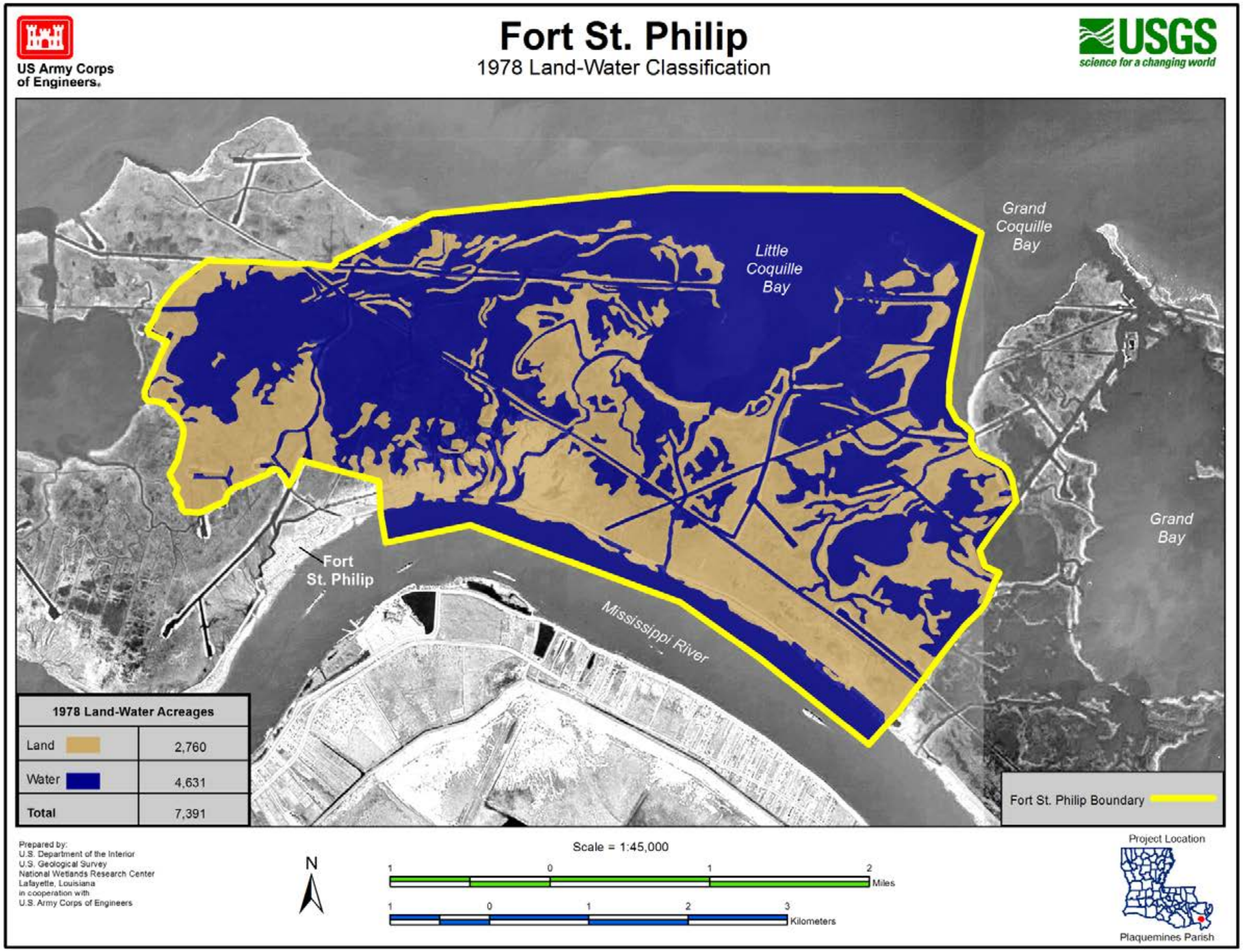


Figure 15. Fort St. Philip study area - 1970-1978 high-resolution land change analysis map.

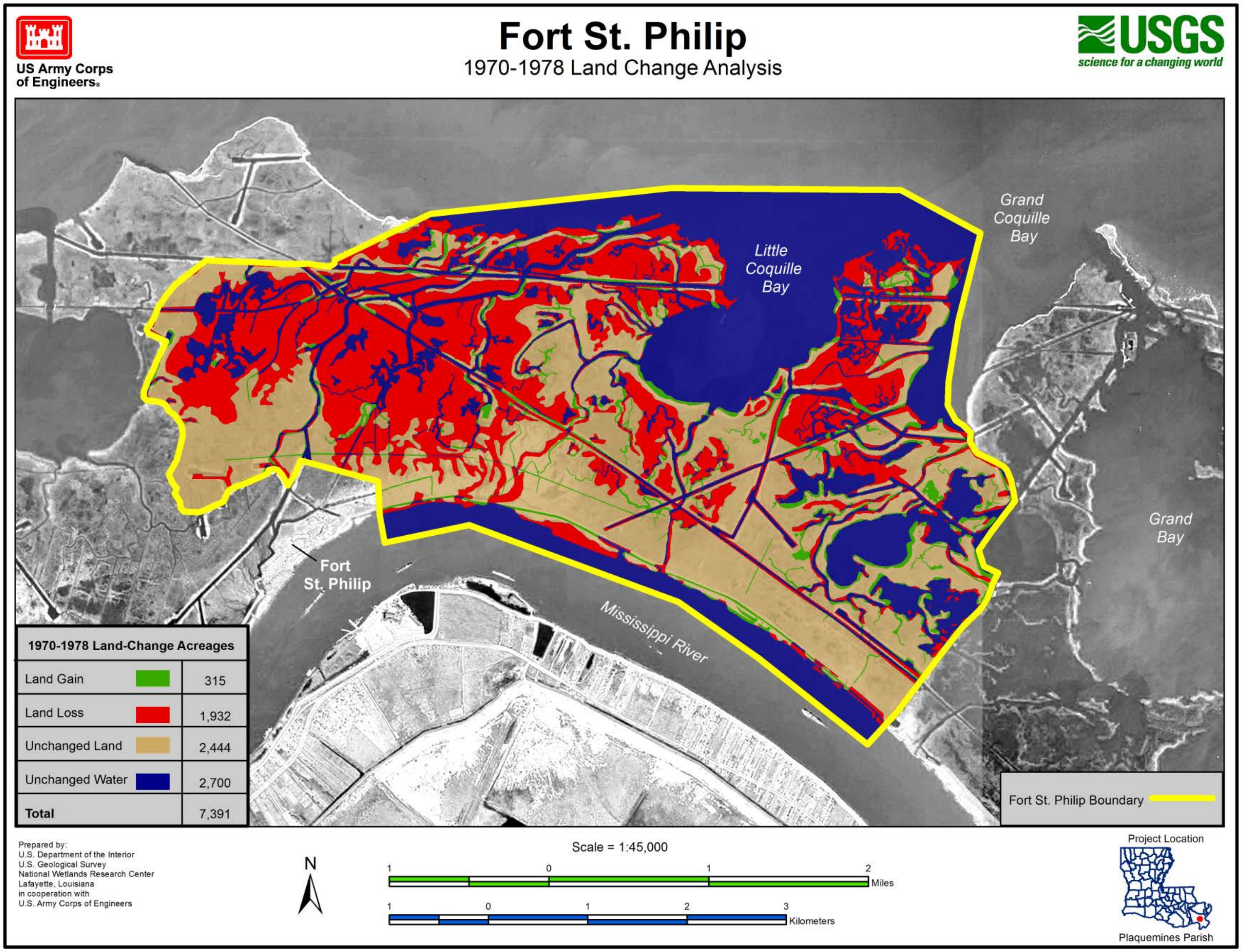


Figure 16. Fort St. Philip study area - 1988 high-resolution land-water classification map.

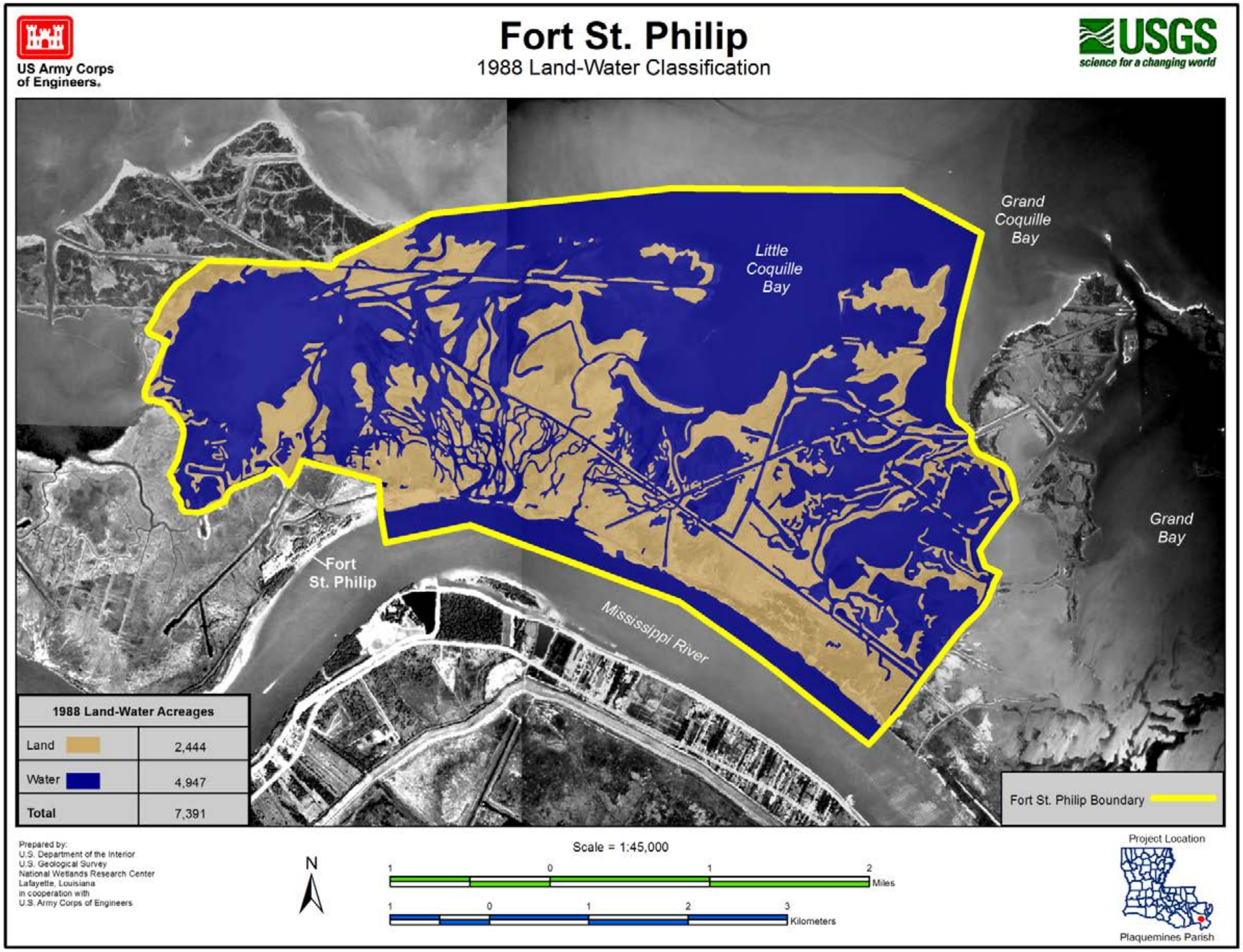


Figure 17. Fort St. Philip study area - 1978-1988 high-resolution land change analysis map.

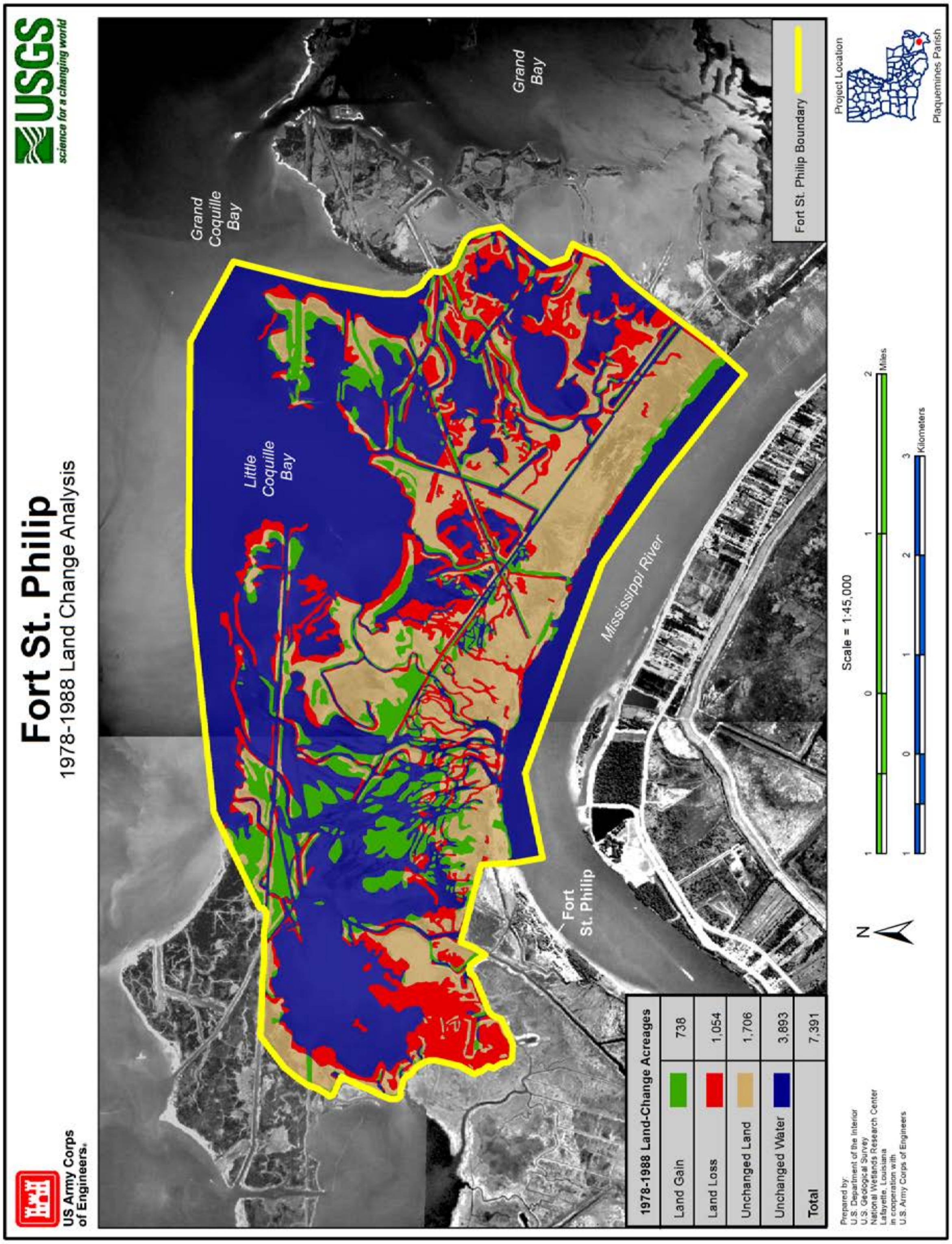


Figure 18. Fort St. Philip study area - 1998 high-resolution land-water classification map.

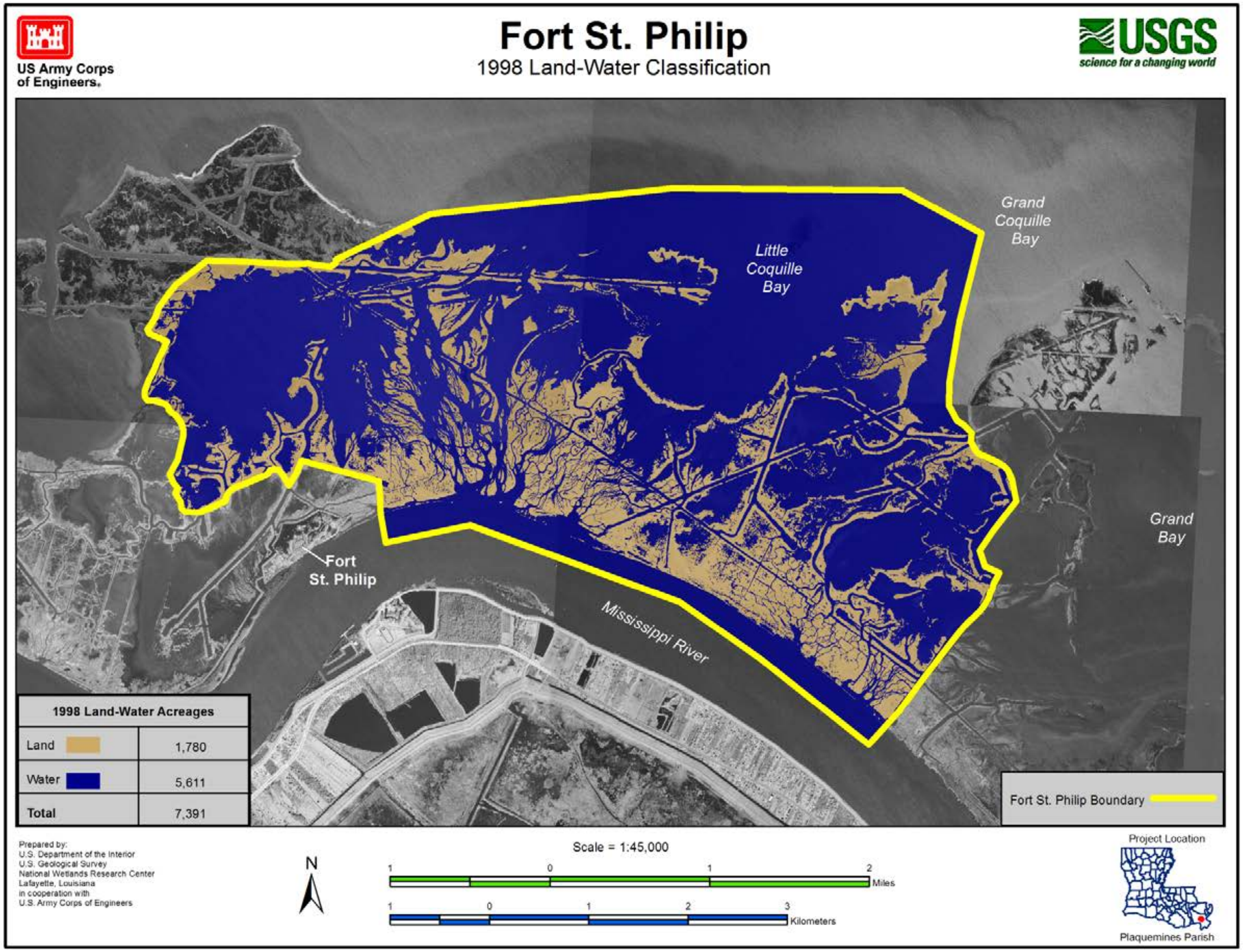


Figure 19. Fort St. Philip study area - 1988-1998 high-resolution land change analysis map.

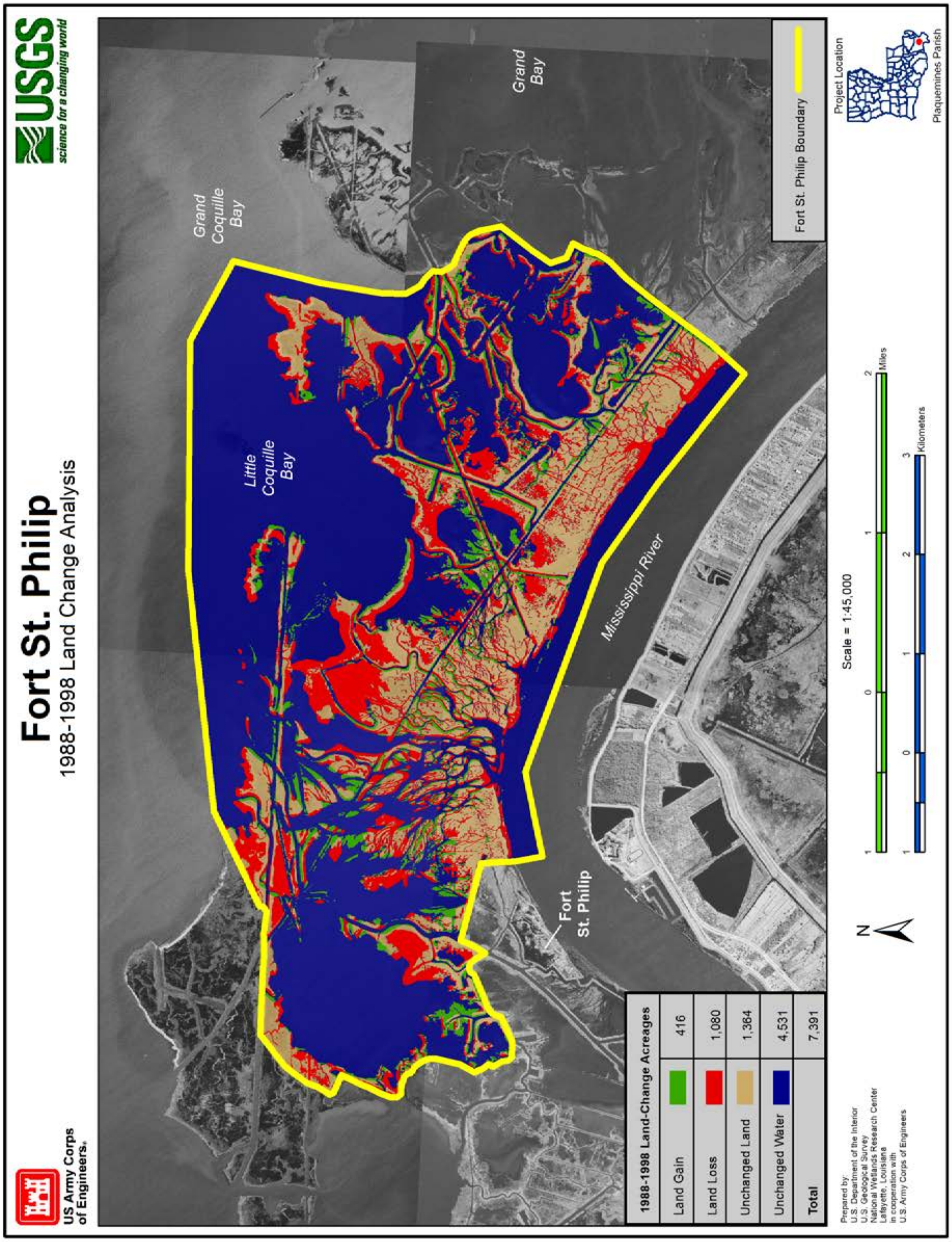


Figure 20. Fort St. Philip study area - 2008 high-resolution land-water classification map.

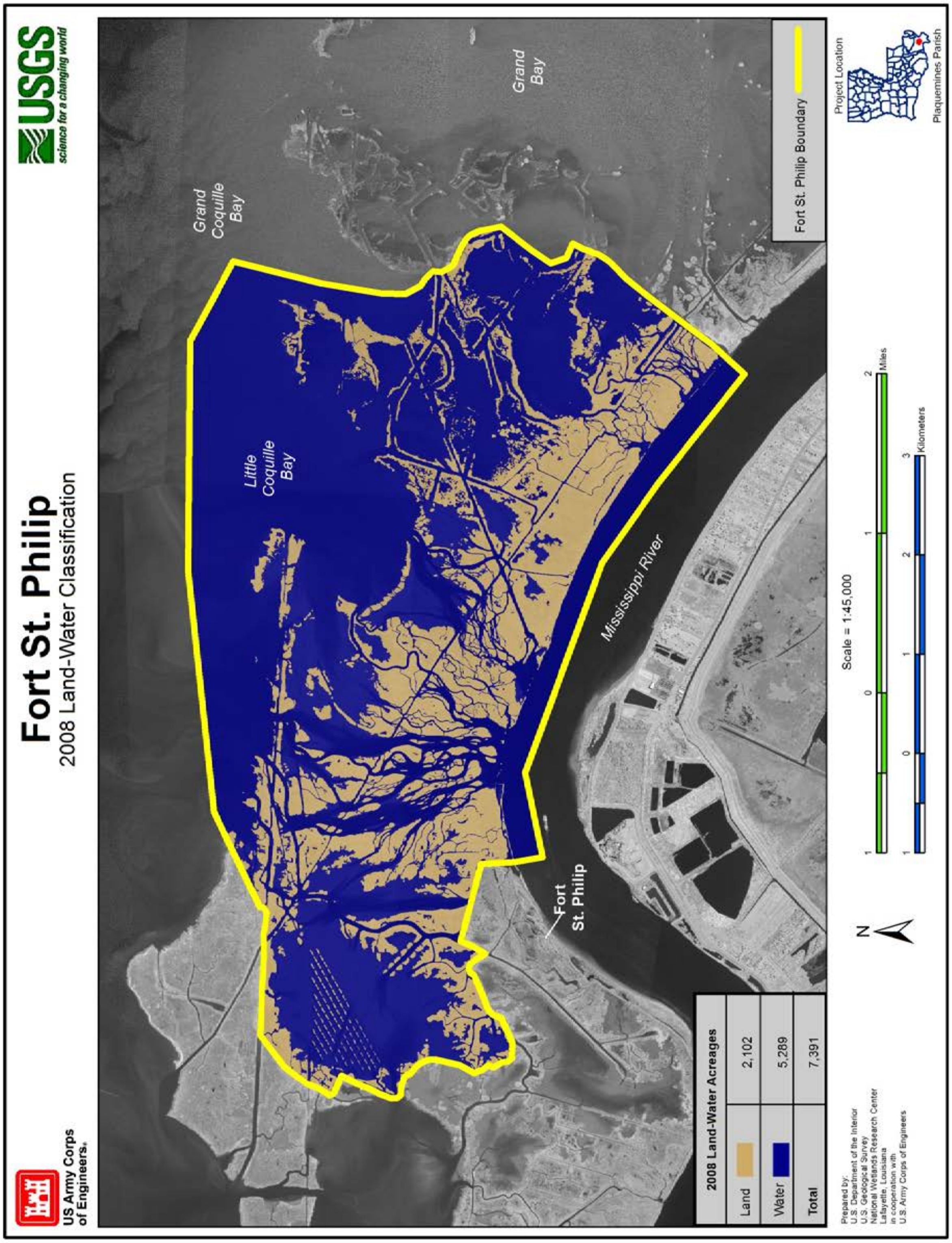


Figure 21. Fort St. Philip study area - 1998-2008 high-resolution land change analysis map.

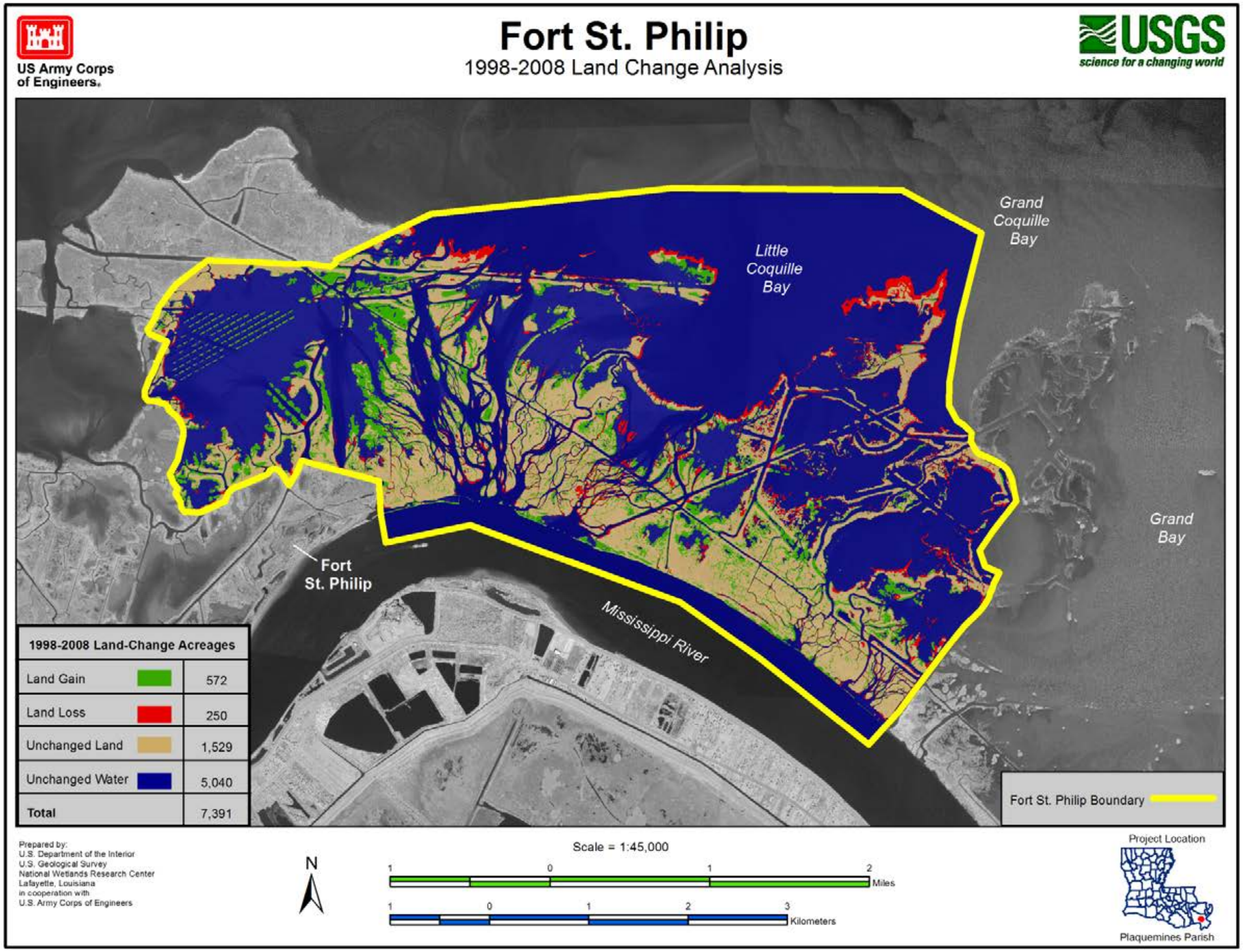


Table 3. Summary of Fort St. Philip study area acreages, and percentages of area change, for select time periods - from high-resolution analyses. The color-ramp illustrates the type and magnitude of land change, where the darkest red represents the loss maxima and darkest green represents gain maxima.

Period of Analysis	Years	Land Area (initial)	Land Area (ending)	Area Change	Area Change[1] (within period)	Area Change[2]
		Acres			Percentage	
1956 to 1970	14	5,012	4,377	-635	-13%	-13%
1970 to 1978	8	4,377	2,760	-1,617	-37%	-32%
1978 to 1988	10	2,760	2,444	-316	-11%	-6%
1988 to 1998	10	2,444	1,780	-664	-27%	-13%
1998 to 2008	10	1,780	2,102	322	18%	6%
1956 to 2008	52	5,012	2,102	-2,910	-58%	-58%

[1] Land change percentage is based on initial land area of the period of analysis.

[2] Land change percentage is based on the 1956 land area.

The CWPPRA BS-11 restoration project provides useful ancillary information. The BS-11 project area experienced extensive loss of emergent wetlands from 1974 to 1990 (USFWS 2003). Data from the U.S. Army Corps of Engineers (Britsch and Dunbar 1993) indicate that the loss rates during that period were 4.1%/year for Project Area 1 and 1.6%/year for Project Area 2 (USFWS 2003, Figure 10). From 2002 to 2011, the amount of subaerial land within BS-11 Project Area 1 (artificial crevasse cuts and terraces) increased from 153 to 228 acres, while the land in Project Area 2 (artificial crevasse cuts) increased from 101 to 116 acres (Hymel and Breaux 2012, Figure 10). Visual comparisons between the photomosaics in Figure 9 (2008) and Figure 10 (2011) show large areas of sediment plumes and accretion in Project Areas 1 and 2. These features suggest that the sediments that are being transported through the natural Fort St. Philip crevasses (and possibly through other channelized cuts) are also being conveyed through the interior artificial crevasse cuts, and ultimately deposited within the BS-11 Project Areas.

Net land area changes for the Fort St. Philip study area are summarized in Table 3. This table contains the initial and ending acreages for each of the five sequential periods, and the overall period of analysis (1956 to 2008). The table also contains the percentage of land area change for each period, based both on that period's initial land acreage and on the 1956 acreage. Color-ramping was assigned to the percentage of land change columns to classify the type (loss or gain) and magnitude of change. The time periods with the greatest land loss are represented with dark reds, and those with the greatest land gains are represented with dark greens. The 1956-1970 period, which contained a number of major episodic events (e.g Hurricanes

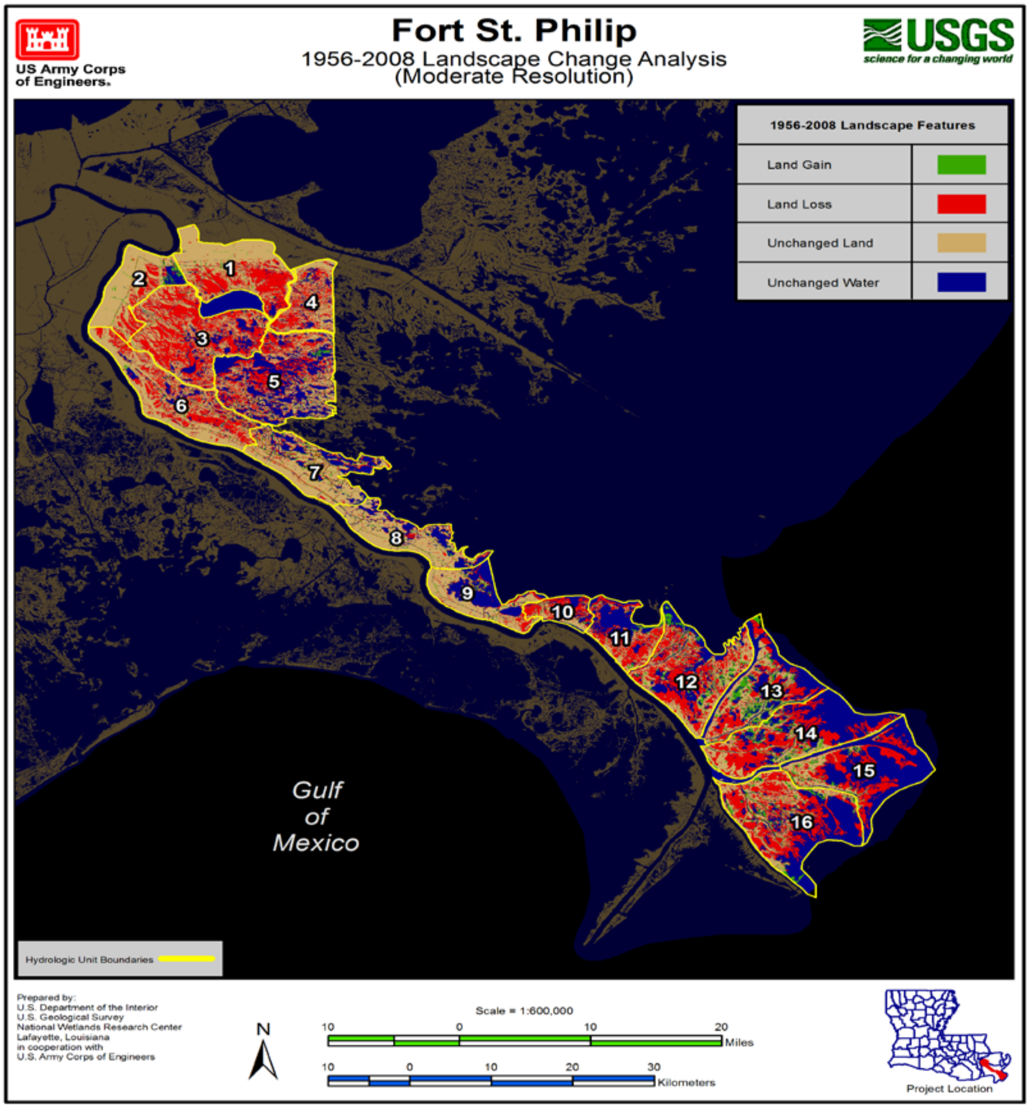
Betsy and Camille), accounted for 13% loss of land. Of the 58% of total land loss that occurred between 1956 and 2008, 32% occurred between 1970 and 1978. This period encompassed the major Mississippi River flood of 1973. Compared to the 1970-1978 time period, the 1978-1998 period experienced significantly reduced rates of loss. The 1978-1988 loss rates were similar to those experienced prior to 1970, while the 1988-1998 rates were higher, possibly as a result of additional floods (6.4-ft river stage on 23 May 1991, 6.33-ft river stage on 17 June 1995, and 6.2-ft river stage on 5 April 1997 at the Empire gage). The final period (1998-2008) was the only period with observed net land gain; an 18% increase in 1998 land acreages, and a 6% increase in 1956 land acreages.

3.3 Landscape area and change – Moderate-resolution analyses

Landscape area change analyses, utilizing moderate-resolution imagery, were performed as a means of comparing the sequence and magnitude of land change within the Fort St. Philip study area with reference areas along the eastern bank of the Mississippi River. Reference and study area boundaries (zones) were established by adjusting (simplifying) 12-digit hydrologic unit boundaries (Figure 22). The total reference area was 658 mi^2 (excluding the Fort St. Philip study area). The Fort St. Philip study area boundary coincides with zone 10, while the other zones constitute the reference areas. Zonal statistics were calculated for each zone using moderate resolution (25-m) land and water imagery that was generated using resampled 1956 and 1978 NWI data, and classified 1988, 2001, and 2008 Landsat 5 TM imagery (Barras et al. 2008). Figure 22 is an example of the land change analysis that was performed for all sequential periods within, and including, the 1956 to 2008 end points. The land change image in Figure 22 shows significant land loss in the northwestern zones (1-6; predominantly hurricane impacts; Barras et al. 2010; Barras 2006, 2009) and southeastern zones (subsidence and wind/wave impacts in zones 10-16; and significant hurricane impacts in 13-16; Barras 2006, 2007), and sparse land loss within the central zones (7-9; with minor regional scale impacts from Hurricane Katrina in zone 7). Gains that have resulted from ecosystem restoration activities are also identifiable in Figure 22, specifically the CWPPRA MR-09 Delta Wide Crevasses project, which is in the bounds of zones 12, 13, 14, and 15.

Land area summaries by zone and date are included in Table 4. This table also includes percentages of land change by periods of analysis, which like Table 3, are color-ramped to illustrate the type and magnitude of land change. The time periods and zones with the greatest land loss are

Figure 22. Fort St. Philip study and reference area zonal boundaries and the 1956-2008 moderate-resolution land change analysis map.



represented with dark reds, and those with the greatest land gains are represented with dark greens. In 1956, zone 10 accounted for 5,228 acres of land (calculated using moderate-resolution data). By 2008, only 2,520 acres remained – a loss of 2,708 acres (51.8%, Table 4). The majority of that loss (46.7%) occurred during the period when the crevassing occurred near Fort St. Philip. Compared to zone 10, most of the reference zones experienced more gradual landscape changes over time, with the exceptions of zones 12, 13, and 14. However, those zones received significant restoration benefits from the MR-09 project (see land gains between 1998 and 2001). A more detailed investigation with finer temporal resolution, linked to known episodic events, would provide more confidence in landscape analyses using moderate-resolution data.

Table 4. Summary of Fort St. Philip study area zonal statistics, and percentages of area change, for select time periods - from moderate-resolution analyses. The color-ramp illustrates the type and magnitude of land change, where the darkest red represents the loss maxima and the darkest green represents gain maxima.

Zone	Land Area (acres)					Land Change (percentage)				
	1956	1978	1988	2001	2008	1956-1978	1978-1988[1]	1988-2001[1]	2001-2008[1]	1956-2008
1	26,201	23,602	24,082	23,333	17,833	-9.9%	1.8%	-2.9%	-21.0%	-31.9%
2	16,787	13,418	13,404	13,900	14,418	-20.1%	-0.1%	3.0%	3.1%	-14.1%
3	33,339	28,894	28,506	28,075	15,541	-13.3%	-1.2%	-1.3%	-37.6%	-53.4%
4	12,779	9,845	10,613	9,916	8,285	-23.0%	6.0%	-5.5%	-12.8%	-35.2%
5	23,573	20,857	20,457	19,343	13,962	-11.5%	-1.7%	-4.7%	-22.8%	-40.8%
6	27,336	23,812	23,827	23,328	19,220	-12.9%	0.1%	-1.8%	-15.0%	-29.7%
7	17,207	15,900	16,246	16,104	16,035	-7.6%	2.0%	-0.8%	-0.4%	-6.8%
8	14,181	13,487	13,379	13,267	13,427	-4.9%	-0.8%	-0.8%	1.1%	-5.3%
9	10,907	9,952	9,887	9,468	9,581	-8.8%	-0.6%	-3.8%	1.0%	-12.2%
10	5,228	2,787	2,467	2,505	2,520	-46.7%	-6.1%	0.7%	0.3%	-51.8%
11	8,718	6,848	5,559	4,311	4,144	-21.5%	-14.8%	-14.3%	-1.9%	-52.5%
12	23,476	13,166	9,783	12,123	13,001	-43.9%	-14.4%	10.0%	3.7%	-44.6%
13	14,510	9,863	9,941	11,967	10,294	-32.0%	0.5%	14.0%	-11.5%	-29.1%
14	19,216	11,287	10,948	11,815	8,920	-41.3%	-1.8%	4.5%	-15.1%	-53.6%
15	13,147	8,827	7,700	7,370	4,862	-32.9%	-8.6%	-2.5%	-19.1%	-63.0%
16	24,752	15,894	15,167	18,025	12,591	-35.8%	-2.9%	11.5%	-22.0%	-49.1%

[1] Land change percentage is based on 1956 land area.

4 Conclusions

This study identified and quantified land changes within the Fort St. Philip study area, and compared those changes to reference areas along the eastern bank of the lower Mississippi River. The assessments performed as part of this study were based on aerial photography and satellite imagery, as well as representative land and water data for the years 1956, 1970, 1978, 1988/89, 1998, 2001, and 2008. It should be noted that inconsistencies in area and percentage of change between the higher and moderate-resolution analyses are largely due to the reduction in precision with increasing grain (pixel) size.

A significant event influencing landscape change within the Fort St. Philip study area during the study period was the breaching of the eastern levee of the Mississippi River and subsequent development of the Fort St. Philip crevasse channels. Initially, the river water that was diverted through these crevasse channels physically removed significant marsh areas within the study area. These initial direct impacts were succeeded by several decades of larger regional loss patterns driven by subsidence (Gagliano 1999) and other episodic events (e.g, hurricanes and floods; Barras 2009), and recent localized land gains. These increases in land area are potentially the long-term results of the Fort St. Philip crevasses, and the short-term impacts of the CWPPRA BS-11 delta management activities. However, for the majority of the 1956-2008 period of analysis, the crevassing of the eastern bank of the Mississippi River levee was a loss accelerant in the Fort St. Philip area.

The decadal comparison periods used in this study provide useful long-term trends, but they can potentially obscure short-term land and water variation. Additionally, variations in tidal and river regimes at the time of geospatial data acquisition may exacerbate or minimize actual loss trends. These can be considerable limitations, since Breton Sound contains multiple complex environmental conditions that may confound trend trajectories. Embedded within the decadal comparison periods are landscape changes that are typically caused by episodic events (e.g. hurricanes or major floods) that are super-imposed over subsidence-induced loss or losses caused by other processes (e.g. sea level rise, frontal passages, tidal variations, sediment deficiencies, etc.).

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14. ABSTRACT
Quantifying the effects of active natural and constructed crevasses is critical to the planning and success of future ecosystem restoration activities. This document provides a historical overview of landscape changes within the vicinity of the natural crevasses near Fort St. Philip, Louisiana. A significant event influencing landscape change within the Fort St. Philip study area was the breaching of the eastern levee of the Mississippi River. Initially, the river water that was diverted through these crevasse channels physically removed significant marsh areas within the study area. These initial direct impacts were succeeded by several decades of larger regional loss patterns driven by subsidence and other episodic events (e.g, hurricanes and floods), and recent localized land gains. These increases in land area are potentially the long-term results of the Fort St. Philip crevasses, and the short-term impacts of delta management activities. However, for the majority of the 1956-2008 period of analysis, the crevassing of the eastern bank of the Mississippi River levee was a loss accelerant in the Fort St. Philip area.

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