Coastal Protection and Restoration Authority of Louisiana

2019 Operations, Maintenance, and Monitoring Report

for

Delta Management at Fort St. Philip (BS-11)

State Project Number BS-11
Priority Project List 10

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Plaquemines Parish

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Preface

The Delta Management at Fort St. Philip (BS-11) project was funded through the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) on the 10th Priority Project List with the United States Fish and Wildlife Service (USFWS) as the federal sponsor. The 2019 Operations, Maintenance, & Monitoring (OM&M) report for BS-11 is the 2nd in a series of reports to summarize monitoring and O&M activities conducted during the life of the project. This report includes monitoring data and annual maintenance inspections available through 2018. Additional documents pertaining to the BS-11 project may be accessed on the Coastal Protection and Restoration Authority (CPRA) website at https://cims.coastal.louisiana.gov/outreach/Project-View.aspx?projID=BS-0011 or on the CWPPRA website at https://www.lacoast.gov/new/-Projects/Info.aspx?num=bs-11 .

I. Introduction

The Delta Management at Fort St. Philip (BS-11) project is located at the southern end of the Breton Sound Basin, which is a remnant of the St. Bernard Delta, an abandoned Mississippi River delta lobe (Figure 1). It is located within two separate areas across the Mississippi River from Fort Jackson at River Mile 19.5 AHP in Plaquemines Parish, LA. The western-most area, denoted as 'Subarea 1' is north of Fort St. Philip in Bay Denesse (Figure 2). Subarea 1 contains 856 acres with 19,600 linear feet of terraces and three dredged crevasses. 'Subarea 2' is located near Little Coquille Bay approximately 4.5 miles east of Subarea 1 (Figure 3), and consists of 490 acres with three dredged crevasses.

Subsidence and sediment deprivation are natural characteristics of abandoned deltas (Neill and Deegan 1986, Coleman and Gagliano 1964, Kolb and Van Lopik 1966, Coleman 1988, Wells and Coleman 1987, Penland et al. 1990). These characteristics may be significantly accelerated by anthropogenic activities such as leveeing. Historically, the Breton Sound Basin received fresh water and sediment inputs from the Mississippi River – during flood events – and its distributaries – through crevasses formed by scouring channels through the bank (Baumann et al. 1984, Cahoon 1991, Penland et al. 1990, Coleman 1988).

Crevasse formation along the lower Mississippi River and its distributaries is the major process that supplies sediment, fresh water, and nutrients to surrounding marsh during high river stages. Once a crevasse is formed, sediment will accrete near the mouth of the crevasse forming a 'splay' within the receiving bay (Boyer et al. 1997). This newly formed "splay" provides the substrate for rapid colonization of emergent vegetation, which in turn stabilizes the sediment and increases the rate of accretion (White 1993). Over time, the splay will grow as the crevasse channel undergoes a series of bifurcations, eventually forming a 'sub-delta'. The main crevasse channel loses efficiency for sediment delivery as it begins to fill with sediment. In an attempt to recreate this marsh-building process, artificial crevasses have been utilized as a marsh-management tool in the Mississippi River delta in recent decades (Kelley 1996, Boyer et al. 1997, Marin 1996, Louisiana Department of Natural Resources [LDNR] 1993, Trepagnier 1994, Gossman and Gisclair 2018, Gossman 2018). This process is recognized as a successful and cost-effective way to combat land loss.

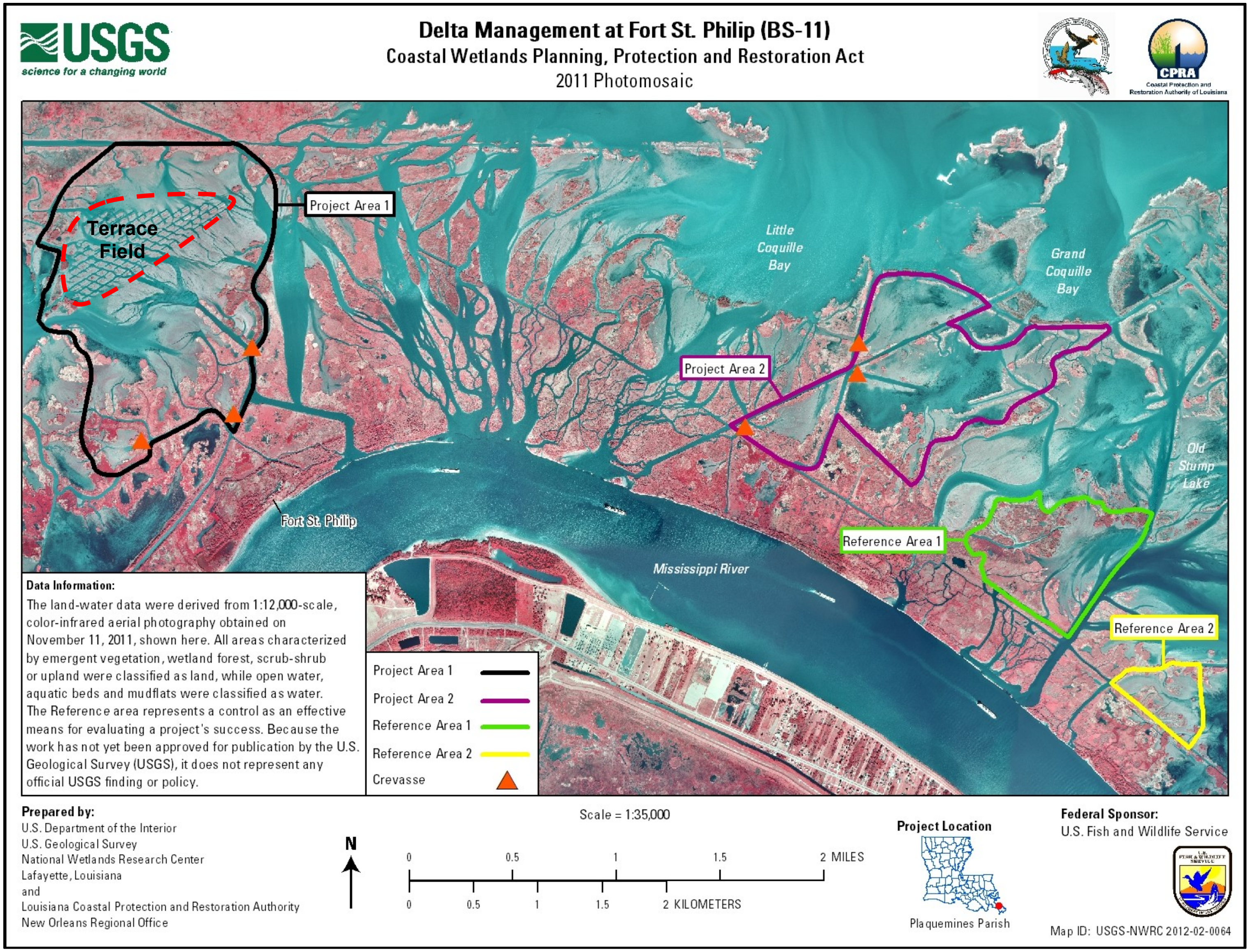


Figure 1. Delta Management at Fort St. Philip (BS-11) project and reference areas.

Marsh terracing is a restoration technique used to build marsh and reduce erosion rates. This technique uses existing bottom sediments to create a pattern of terraces or ridges that maximize the intertidal edge and minimize wave fetch (Rozas and Minello 2001). The terraces can then be planted or seeded with marsh vegetation. The main goal of terrace-field construction is to increase sedimentation, marsh-edge habitat, and marsh productivity. Terraces have been shown to reduce erosion rates in adjacent marshes and to provide habitat for fishery species. Habitat value also increases proportionally within the newly created marsh in the terrace field (Rozas and Minello 2001). In 1990, the state successfully used marsh terracing at the Sabine National Wildlife Refuge, Louisiana (LDNR 1999). Since that time, marsh terracing has been utilized in several CWPPRA-funded projects, including the Little Vermilion Bay Sediment Trapping (TV-12), Pecan Island Terracing (ME-14), and Four-Mile Canal Terracing and Sediment Trapping (TV-18) projects (Wood and Aucoin 2016, Miller and Aucoin 2011, Thibodeax and Guidry 2009). The BS-11 project is the first CWPPRA project to combine marsh terracing with an artificial crevasse feature.

Marshes surrounding the BS-11 project area have experienced a rapid transition from nearly unbroken marsh in 1956 to a highly fragmented marsh by 1990 (Roy 2003). In the American Bay mapping unit, in which the BS-11 project area is contained, more than 12% of the total marsh acreage was lost between 1932 and 1974. Primary contributors to this land loss included dredging, wind/wave erosion, and subsidence (Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority [LCWCRTF and WCRA] 1999). In 1949 and 1968, the marshes surrounding this area were classified as brackish adjacent to the river and saline near Breton Sound (LCWCRTF and WCRA 1999). During a 1973 flood event, a natural crevasse formed on the eastern bank of the Mississippi River causing intermediate marsh to establish between Area 1 and 2 by 1978 (Chabreck and Linscombe 1978; Suir et al. 2014). By 1988, a band of fresh and intermediate marsh had formed adjacent to the river, with the remainder of the area classified as brackish and saline (Chabreck and Linscombe 1988); however, there was an overall net loss of land in the years following the 1973 crevasse formation due to physical scouring of the diverted water combined with regional subsidence and episodic storm events (Suir et al. 2014).

In 1997 the entire area was classified as fresh and intermediate marsh, with the two project subareas being entirely intermediate marsh (Chabreck and Linscombe 1997). The marshes within the project areas support a diverse assemblage of vegetative species representing a broad salinity gradient due to the influences of both the Mississippi River and Breton Sound. Species present in the project area at the time of project development included elephant-ear (*Colocasia esculenta*), common reed (*Phragmites australis*), bulltongue arrowhead (*Sagittaria lancifolia*), delta arrowhead (*Sagittaria platyphylla*), alligatorweed (*Alternanthera philoxeroides*), common rush (*Juncus effusus*), needlegrass rush (*Juncus roemerianus*), smartweed (*Polygonum* sp.), Walter's millet (*Echinochloa walteri*), saltmeadow cordgrass (*Spartina patens*), smooth cordgrass (*Spartina alterniflora*), Olney's threesquare (*Schoenoplectus americanus*), common threesquare (*Schoenoplectus pungens*), saltmarsh bulrush (*Schoenoplectus maritimus*), torpedo grass (*Panicum repens*), giant cutgrass (*Zizaniopsis miliacea*), hairypod cowpea (*Vigna luteola*), cattail (*Typha* sp.), and poisonbean (*Sesbania drummondii*) (Roy 2003). Submerged and floating aquatic species in the project area included spike watermilfoil (*Myriophyllum spicatum*), southern waternymph

(*Najas guadalupensis*), sago pondweed (*Stuckenia pectinatus*), curly pondweed (*Potamogeton crispus*), and water stargrass (*Heteranthera dubia*) (Roy 2003).

Project Goals

The following goals and strategies for the Delta Management at Fort St. Philip project were provided by the U.S. Fish and Wildlife Service in the Environmental Assessment (Roy 2003) and the Ecological Review (Banks 2001).

Project goals are as follows:

1) By the end of the 20 year project life, create 244 additional acres (1-km^2) of emergent marsh through the construction of crevasses. It should be noted that 174 acres (0.7-km^2) of emergent marsh are projected to accrete naturally without the proposed project, thus a net gain of 418 acres (1.7-km^2) is expected within the project area by the end of the 20 year project life.

2) Create 25-acres (0.1-km^2) of emergent marsh through terrace construction. Terrace building will directly account for 16.5 acres (0.07-km^2) of emergent marsh, and the projected expansion of the vegetated terraces over the 20 year project life will account for the remaining 8.5 acres (0.03-km^2).

Project Strategies:

1) Reintroduction of alluvial sediments through six constructed crevasses.

2) Marsh creation and sediment trapping through the construction of earthen terraces with vegetative plantings.

This project aims to utilize the land-building potential of crevasses and wave reducing characteristics of terrace mounds to halt the extensive loss of marsh in the area. The objective is to enhance natural marsh growth by diverting fresh, sediment-laden water through the dredged crevasses into shallow, open-water receiving areas. The earthen terraces constructed in Subarea 1 are designed to reduce the fetch distance for wind-induced waves while also trapping sediment, thereby promoting the marsh-building processes.

Project Features

The Delta Management at Fort St. Philip project features 19,600 linear feet of terraces and six (6) artificial crevasses. Construction of the project was completed in November 2006 for a total construction cost of $1,015,533.80 (ABMB Engineers 2007).

A. Terraces – *Subarea 1 (Figure 2)*.

- A total of 98 terraces were constructed, each 200 ft in length, with a 50-ft separation between the ends of each terrace.
- Each terrace was built with a crown width of 10 ft, tapering at a slope of 1 vertical to 6 horizontal to a base width of 52 ft.
- Terraces were built to an initial elevation of +3.5 ft (NAVD 88), with a target settled elevation of +3.0 ft (NAVD 88).
- The aggregate length of constructed terraces was 19,600 linear ft.
- The minimum distance to the existing shoreline was 50 ft and minimum pipeline clearance was 50 ft. Within these constraints, the locations of individual terraces were left to the discretion of the construction manager. In order to maintain the minimum clearance from the existing pipelines, three of the terraces were decreased in length by a total of 100 ft.

B. Crevasse 1A – *Subarea 1 (Figure 2)*. 2000 ft long x 75 ft base width x -8.0 ft (NAVD 88). Marsh elevation was assumed to be +1.5 ft (NAVD 88). The crevasse, dredged from the center of the channel, passes through a reference point defined by the pre-construction shoreline (X = 3,875,963.63 ft, Y = 322,516.09 ft NAD 83), and extends along a quadrant bearing of N47^{o}W. Dredge material was placed between 25-175 ft on either side of the crevasse to a maximum elevation of +5.0 ft (NAVD 88).

C. Crevasse 1B – *Subarea 1 (Figure 2)*. 400 ft long x 75 ft base width x -6.0 ft (NAVD 88). Marsh elevation was assumed to be +1.5 ft (NAVD 88). The crevasse, dredged from the center of the channel, passes through a reference point defined by the pre-construction shoreline (X = 3,875,557.544 ft., Y = 320,705.6253 ft NAD 83), and extends along a quadrant bearing of N22^{o}W. Dredge material was placed between 25-175 ft on either side of the crevasse to a maximum elevation of +5.0 ft (NAVD 88).

D. Crevasse 1C – *Subarea 1 (Figure 2)*. 700 ft long x 75 ft base width x -6.0 ft (NAVD 88). Marsh elevation was assumed to be +1.5 ft (NAVD 88). The crevasse, dredged from the center of the channel, passes through a reference point defined by the pre-construction shoreline (X = 3,873,382.42 ft, Y = 320,246.83 ft NAD 83), and extends along a quadrant bearing of S77oW. Dredge material was placed between 25-175 ft on either side of the crevasse to a maximum elevation of +5.0 ft (NAVD 88).

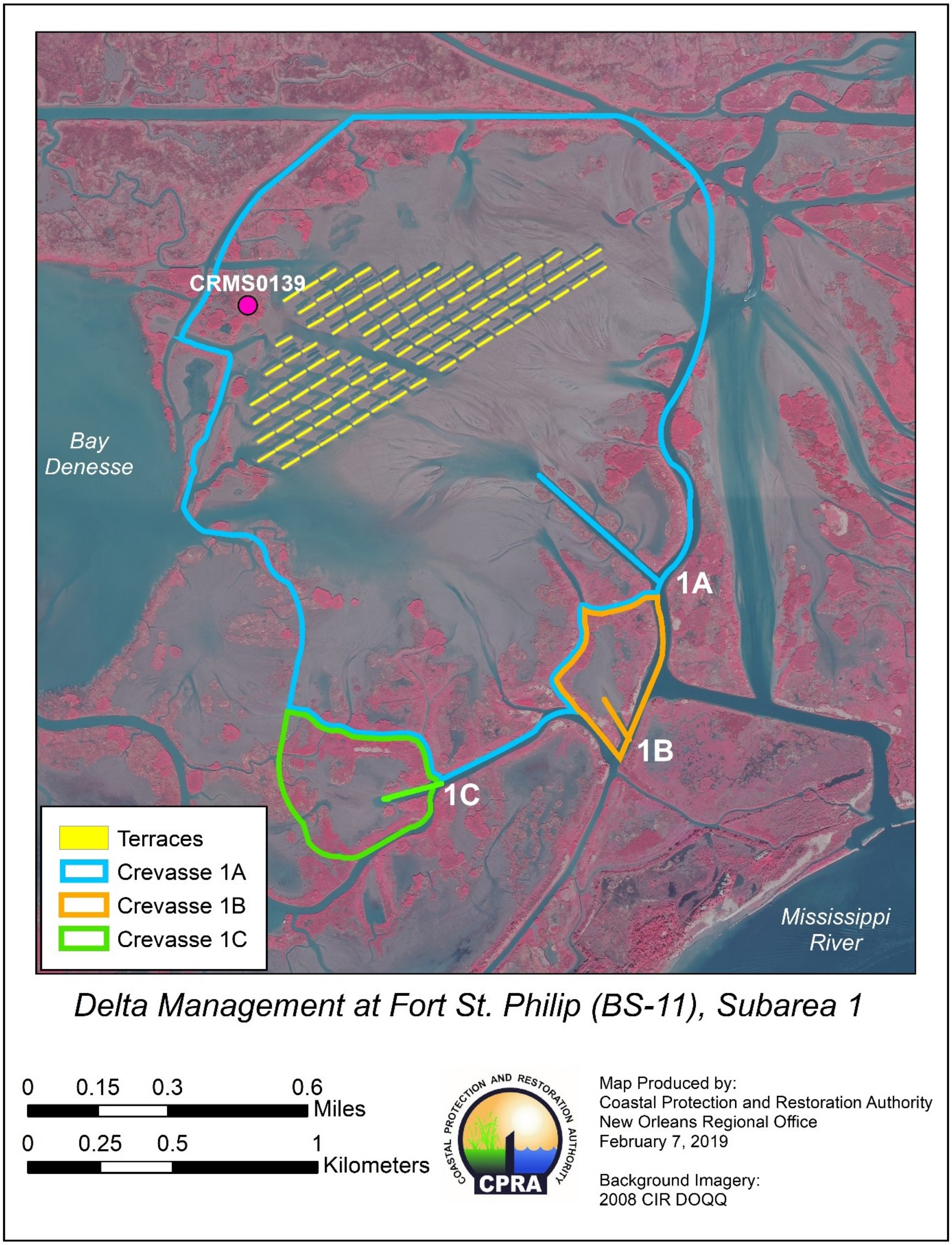


Figure 2. Project features within Subarea 1 of the Delta Management at Fort St. Philip (BS-11) project.

E. **Crevasse Alt. 2A –** *Subarea 2 (Figure 3)*. 732 ft long x 75 ft base width x -8.0 ft (NAVD 88). Crevasse 'Alt 2A' replaced the proposed Crevasse '2A' located further north along the pipeline canal. Marsh elevation was assumed to be +1.5 ft (NAVD 88). The crevasse, dredged from the center of the channel, passes through a reference point defined by the pre-construction shoreline (X = 3,891,269.92 ft, Y = 322,243.99 ft NAD 83), and extends along a quadrant bearing of N50ºE. Dredge material was placed between 25-175 ft on either side of the crevasse.

F. **Crevasse 2B –** *Subarea 2 (Figure 3)*. 500 ft long x 75 ft base width x -6.0 ft (NAVD 88). Marsh elevation was assumed to be +1.5 ft (NAVD 88). The crevasse, dredged from the center of the channel, passes through a reference point defined by the pre-construction shoreline (X = 3,888,519.61 ft, Y = 320,569.13 ft NAD 83), and extends along a quadrant bearing of S69ºE. Dredge material was placed between 25-175 ft on either side of the crevasse to a maximum elevation of +5.0 ft NAVD 88.

G. **Crevasse 2C –** *Subarea 2 (Figure 3)*. 2000 ft long x 75 ft base width x -6.0 ft (NAVD 88). Marsh elevation was assumed to be +1.5 ft (NAVD 88). The crevasse, dredged from the center of the channel, passes through a reference point defined by the pre-construction shoreline (X = 3,891,138.38 ft, Y = 321,807.44 ft NAD 83), and extends along a quadrant bearing of S77ºE. Dredge material was placed between 25-175 ft on either side of the crevasse to a maximum elevation of +5.0 ft (NAVD 88).

The CPRA and USFWS inspect all crevasses annually to ensure continued sediment transport to the receiving bays. Due to shallow water depths (1.5 to 2.0-ft) and reduced fetch, significant erosion of the terraces was not expected to occur. Terraces are not subject to maintenance or rehabilitation under the Cost Sharing Agreement or permits; therefore, no maintenance of the terraces was proposed.

In November 2006, approximately 18,000 vegetative plugs of smooth cordgrass (*Spartina alterniflora* 'Vermilion') were planted along the edges of the newly constructed terraces and 4,900 4-inch containers of seashore paspalum (*Paspalum vaginatum* 'Brazoria') were planted along the upper edge of the terraces. Vegetative plantings on the terraces were contracted separately from the construction contract and are not subject to maintenance or rehabilitation by CPRA or USFWS.

All crevasses except 1B were constructed at a 60-degree angle from the parent pass using a barge-mounted, bucket dredge. Crevasse 1B was constructed at a 120-degree angle from the parent pass. Dredge material from crevasse construction was placed into adjacent disposal areas up to a height of +5.0 ft (NAVD88).

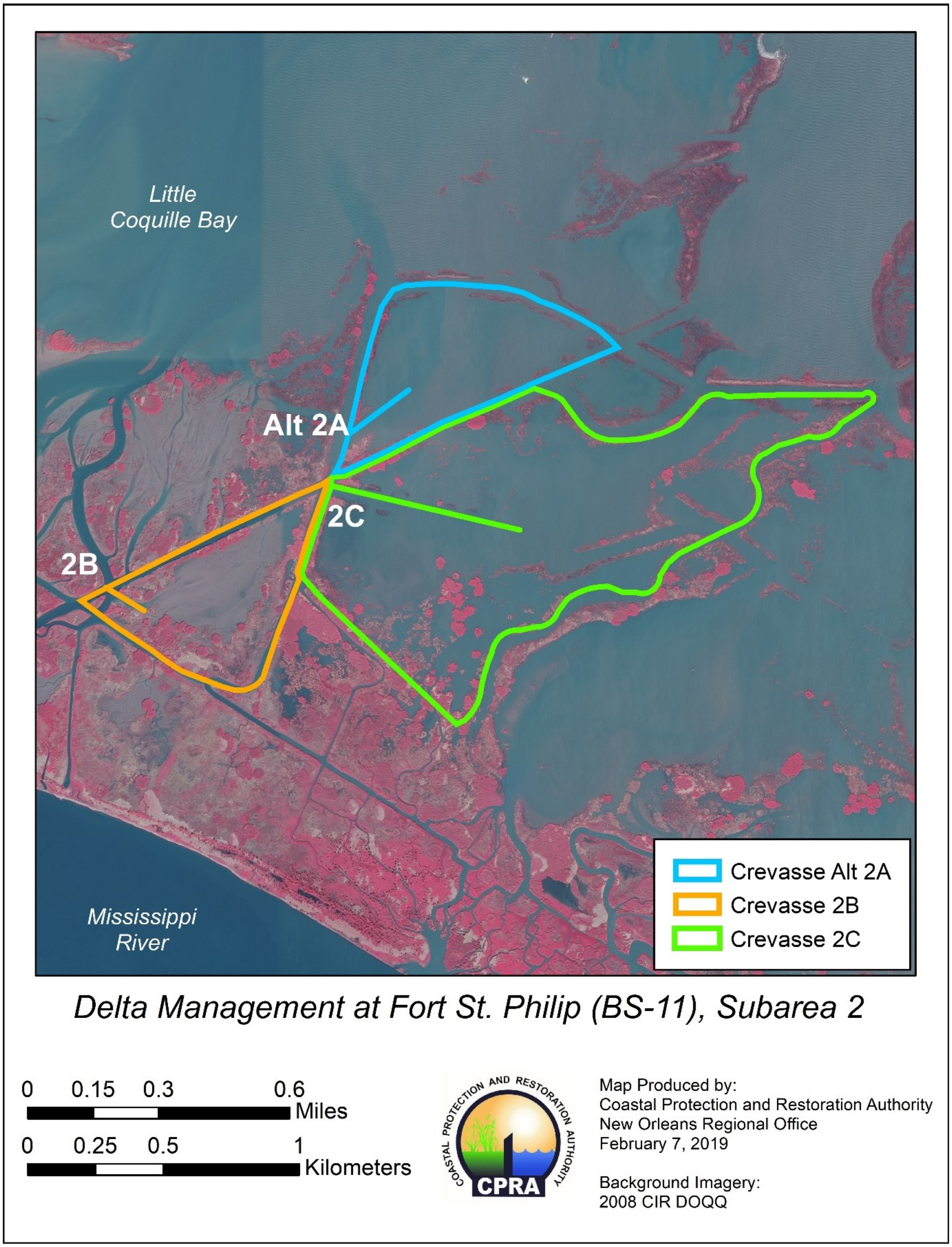


Figure 3. Project features within Subarea 2 of the Delta Management at Fort St. Philip (BS-11) project.

II. Maintenance Activity

a. Project Feature Inspection Procedures

The purpose of the annual inspection of the Delta Management at Fort St. Philip Project (BS-11) is to conduct a visual inspection of the constructed project features and identify any deficiencies. The CPRA assesses the urgency of any necessary repairs and provides a detailed cost estimate for the engineering, design, supervision, inspection, and construction contingencies (O&M Plan: LDNR 2007). Any recommended corrective actions are detailed in the annual inspection report. The annual inspection report also contains a summary of project maintenance and an estimated projected budget (Appendix A) for operation, maintenance, and rehabilitation for the upcoming three (3) years.

Due to issues with access, an on-site inspection of the Delta Management at Fort St. Philip Project (BS-11) was not held in 2018. Instead it was agreed by CPRA and USFWS that observations would be made by viewing aerial imagery. This imagery was acquired by Gulf Coast Aerial Mapping (GCAM) on October 11, 2018 (Appendix B).

b. Inspection Results

i. **Terraces**: As viewed from aerial imagery provided by GCAM, the terrace field appears to be intact and vegetation densely covers each terrace.

ii. **Crevasse 1A:** This crevasse appears to be funneling river water directly into the Bay Denesse terrace field.

iii. **Crevasse 1B:** This crevasse has infilled. The channel outfall shows colonization of emergent vegetation.

iv. **Crevasse 1C:** The crevasse remains intact. Dense growth of emergent vegetation was observed just beyond the outfall, and healthy marsh grass rings the entire perimeter of this site.

v. **Crevasse Alt 2A:** The crevasse remains intact, channel banks are well-vegetated, and significant emergent vegetation was observed in the receiving area.

vi. **Crevasse 2B:** The crevasse remains intact. Dense growth of emergent vegetation was observed in the receiving bay.

vii. **Crevasse 2C:** The crevasse appears to have begun infilling. The receiving area appears to have large areas of emergent vegetation near the crevasse outfall.

c. Maintenance Recommendations

i. Immediate/ Emergency Repairs

There are no immediate or emergency repairs needed at this time.

ii. Programmatic/ Routine Repairs

There are no programmatic or routine repairs needed at this time.

d. Maintenance History

The original access route over the USACE Olga Revetment along the east bank of the Mississippi River was deemed no longer practical due to shoal conditions identified in a 2014 survey. Alternative access routes from the shallow bays to the north would require flotation channel dredging and the acquisition of oyster leases impacted by those routes. There is no funding in the project budget for oyster lease acquisition. Based on the estimated cost of the Year 5 maintenance event (which exceeded the current O&M budget) and the anticipated costs and delays associated with landrights and oyster lease acquisitions, the project team decided to forego crevasse maintenance and not request an O&M budget increase to conduct this work.

III. Operation Activity

Operations are not required for this project.

III. Monitoring Activity

a. Monitoring Goals

Monitoring strategies for the Delta Management at Fort St. Philip project address both the sediment diversion and the sediment trapping features of this project. They focus on evaluating project effects on land/water ratios, bathymetry/topography, and emergent vegetation. Analysis of land/water ratios in the project and reference areas will be used to determine the effects of the constructed crevasses and terraces on the acreage of subaerial land. Periodic elevation surveys of the crevasse receiving bays and of the terrace field will be performed to monitor project effects on vertical accretion of sediment. Surveys of emergent vegetation within the crevasse receiving bays and terrace field will determine if the project is effectively creating marsh substrate for colonizing vegetation.

The specific measurable goals established to evaluate the effectiveness of the project are:

- Determine the effects of the project on land/water ratios in the project area.
- Determine the changes in the elevation within the crevasse receiving bays and the terrace field as a result of the creation of sub-aerial land.
- Determine the changes in emergent vegetation within the crevasse receiving bays and the terrace field.

b. Monitoring Elements

The following monitoring elements will provide the information necessary to evaluate the specific goals listed above:

Land/Water Analysis

Color-infrared aerial photography (1:12,000 scale) was obtained of the BS-11 project and reference areas in 2002 (pre-construction), 2006 (as-built), and 2011 (Year 5). The acquired photography was geo-rectified, photo-interpreted, and analyzed by the USGS Wetland and Aquatic Research Center to determine land/water ratios using standard operating procedures documented in Steyer et al. (1995, revised 2000) (Appendix C1-C9). All areas characterized by emergent vegetation, wetland forest, scrub-shrub, or upland were classified as land, while open water, aquatic beds, and non-vegetated mudflats were classified as water. Photography will be obtained again in years 2021 (Year 15) and 2026 (Year 20).

Land/water analyses of the Fort St. Philip region were also conducted by Costanza and Frank-Gilchrist (2019) on 1-meter resolution, 4-band digital orthophoto quarter quadrangles (DOQQs) collected in years 2008, 2013, and 2017. Land classification categories were determined to be consistent with previous BS-11 analyses. These analyses were clipped to the BS-11 project areas for quantification of land acreage in those years (Appendix C10-C15). The extent of the analysis included all areas except for Reference Area 2.

Elevation

Topographic and bathymetric surveys were conducted within the project area in 2002 (design), 2006 (as-built), 2011 (year +5), and 2016 (year +10) to determine changes in sediment elevation, and will be conducted a final time in 2021 (year +15). Transect lines were established within the dredged crevasse channels to verify as-built specifications and to determine the need for maintenance dredging at years 5 and 15. Transect lines were established within the terrace field and receiving bays to document changes in elevation as it relates to the creation of sub-aerial land. Two reference monuments, "HYD-1" (Subarea 1) and "HYD-2" (Subarea 2), were established in 2002 prior to construction and were utilized for all four survey events. The reference monument elevations were held to the same value relative to the Geoid99 model for all four surveys; however, the 2016 survey provided an adjustment value for each Subarea for adjustment to the current geoid model, Geoid12A (Subarea 1: -1.262 ft, Subarea 2: -1.233 ft). All previous surveys (2002, 2006, and 2011) were then adjusted to the current Geoid12A model by the same adjustment factor so that relative changes between survey years would be maintained.

Each survey dataset was re-projected horizontally and vertically to the UTM NAD83 coordinate system and the NAVD88 vertical datum in meters using Corpscon® software. The re-projected data were imported into ESRI ArcMap® 10.5.1 software for surface interpolation. Digital Elevation Models (DEMs) of elevation surfaces were created from the point data sets using the Spatial Analyst>Interpolation>Natural Neighbor tool with a 1.0 m^2 (10.8 ft^2) cell size. The DEMs were then clipped to polygons covering the shared spatial extent for the different survey years to estimate elevation and volume changes within each analysis area, and the spatial distribution of elevations were mapped in one foot (0.31 m) elevation classes (Appendix D). DEMs of elevation change within the receiving bays were created by subtracting the corresponding DEMs using the Spatial Analyst>Math>Minus tool (Appendix E). Volume changes within the channels and receiving bays were calculated in cubic meters (m^3) using the 3D Analyst>Raster Surface>Cut/Fill function within ESRI ArcMap®.

Crevasse Channels: Six crevasse channels were surveyed in 2002 (pre-construction), 2006 (as-built), 2011 (year 5), and 2016 (year 10). In 2002, proposed channel 2B was surveyed in a different location than was constructed, so comparisons cannot be made with that dataset. Survey points at each cross-section within the dredged crevasse channels were taken every 20 ft along evenly spaced lines, perpendicular to the crevasse centerline (Figure 4, Crevasse 1A).

Receiving Bays: Due to limitations of the monitoring budget, all six receiving bays were not included in every survey event. All receiving bays except 1B and 1C were surveyed in 2002, only receiving bays 1A and Alt 2A were surveyed in 2011, and all six receiving bays were surveyed in 2016. No receiving bays were surveyed in 2006. Within the receiving bays, three transect lines spaced 500 ft apart were established perpendicular to each crevasse centerline (Figure 4, Crevasse 1A). Elevations were recorded every 250 ft or at any significant change in elevation.

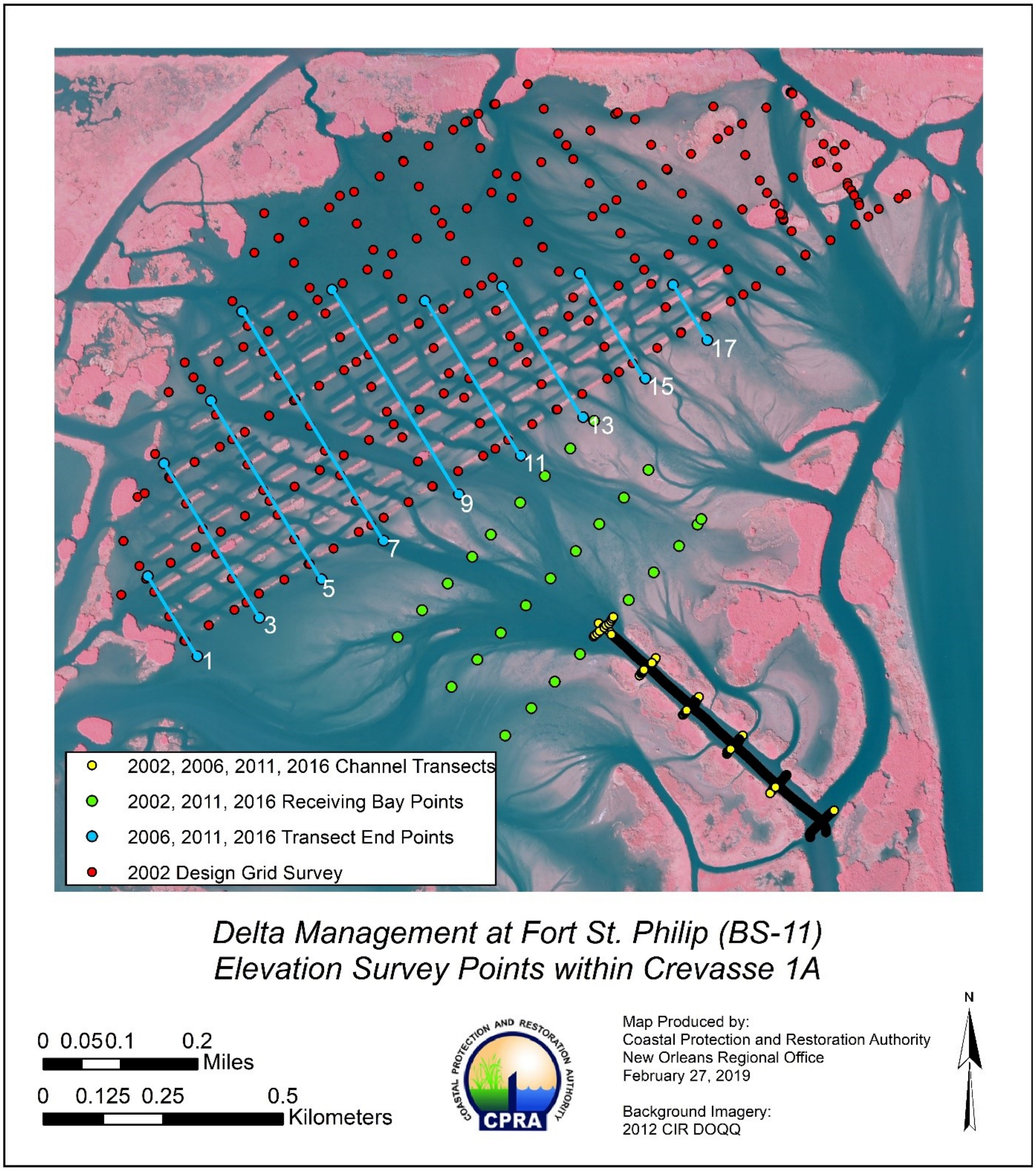


Figure 4. Layout of elevation survey points in Crevasse 1A of the Delta Management at Fort St. Philip (BS-11) project.

Terrace Field: The terrace field was surveyed in 2002, 2006, 2011, and 2016 (Figure 4). In 2002, a grid of points was surveyed within the area of the proposed terrace field. Grid lines were spaced 500-ft (152.4-m) apart, and elevations were recorded at points every 100-ft (30.5-m) along each grid line. In 2006 (as-built), elevations were surveyed along 18 transects spaced 250 ft apart, running perpendicular to the terraces. Elevations were recorded approximately every 20 ft along the transect lines. Due to monitoring budget limitations, a subset of the 2006 transects was surveyed in 2011 and 2016. A total of 9 transects spaced 500 ft apart were surveyed, and elevations were recorded at 50-ft intervals as well as at the crown of each intercepted terrace. A 54-acre area located immediately to the northeast of the terrace field was also surveyed in 2002, 2011, and 2016. Digital Elevation Models (DEM's) were generated for the terrace field using data collected in 2002, 2011, and 2016 (Appendix D1) and volumetric comparisons were made among these years. A DEM was not generated from the 2006 dataset due to anomalies within the dataset. Due to the irregular surface of the terrace field, volumetric comparisons between survey years are considered to be highly approximated. As a means of comparison, approximations of sediment volume within the terrace field were also made using the average end area method along the survey transects.

Vegetation

Species composition, percent cover, and relative abundance were evaluated within the terrace field at 18 plots (4-m^2) in 2007 (year 1), 2011 (year 5), and 2016 (year 10) using a modified Braun-Blanquet sampling method (Mueller-Dombois and Ellenberg 1974) (Figure 5). Receiving bays at crevasses 1A and Alt 2A were chosen for vegetation sampling at years 5, 10, and 15; however, sufficient vegetative growth did not occur until year 10 for plots to be established. In year 10 (2016), nine plots were established in the receiving bay of crevasse 1A and five plots were established in crevasse Alt 2A (Figures 5 and 6) along the topo/bathy elevation transects where vegetative growth was present. Vegetation surveys will be conducted again within the terrace field and crevasses 1A and Alt 2A in 2021 (Year 15).

Emergent marsh vegetation has also been sampled annually at CRMS0139 since 2007. Ten 2-m x 2-m sampling plots were randomly located along a 288-m transect and were sampled using the same method described above (Figure 5).

CRMS Supplemental

Additional data was collected at CRMS0139 which provides supporting or contextual information for this project. Data types collected at CRMS sites include hydrologic, emergent vegetation, physical soil characteristics, discrete porewater salinity, marsh surface elevation change, vertical accretion, and land:water analysis of 1 km^2 area encompassing the station (Folse et al. 2008, revised 2018).

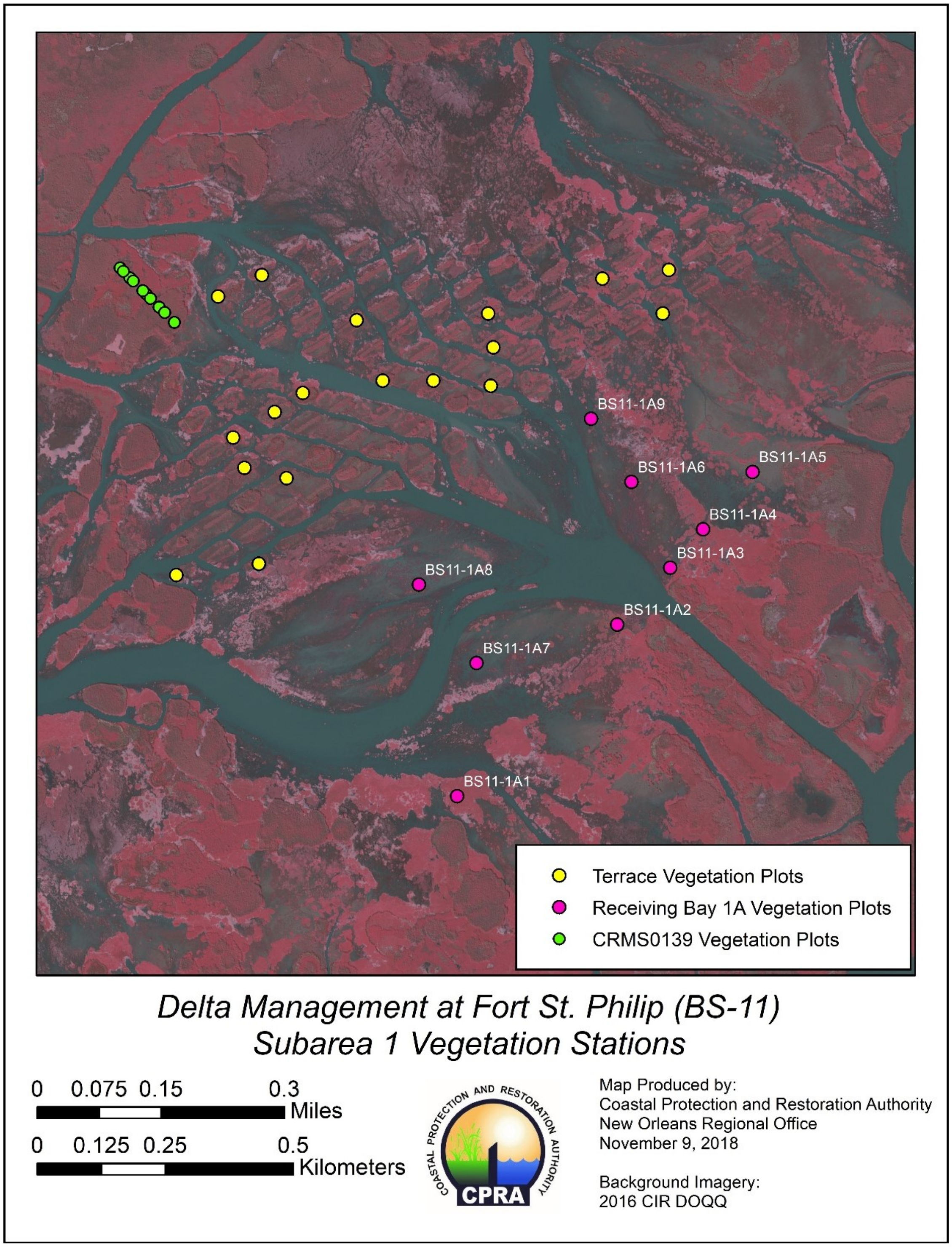


Figure 5. Vegetation stations within Subarea 1 of the Delta Management at Fort St. Philip (BS-11) project.

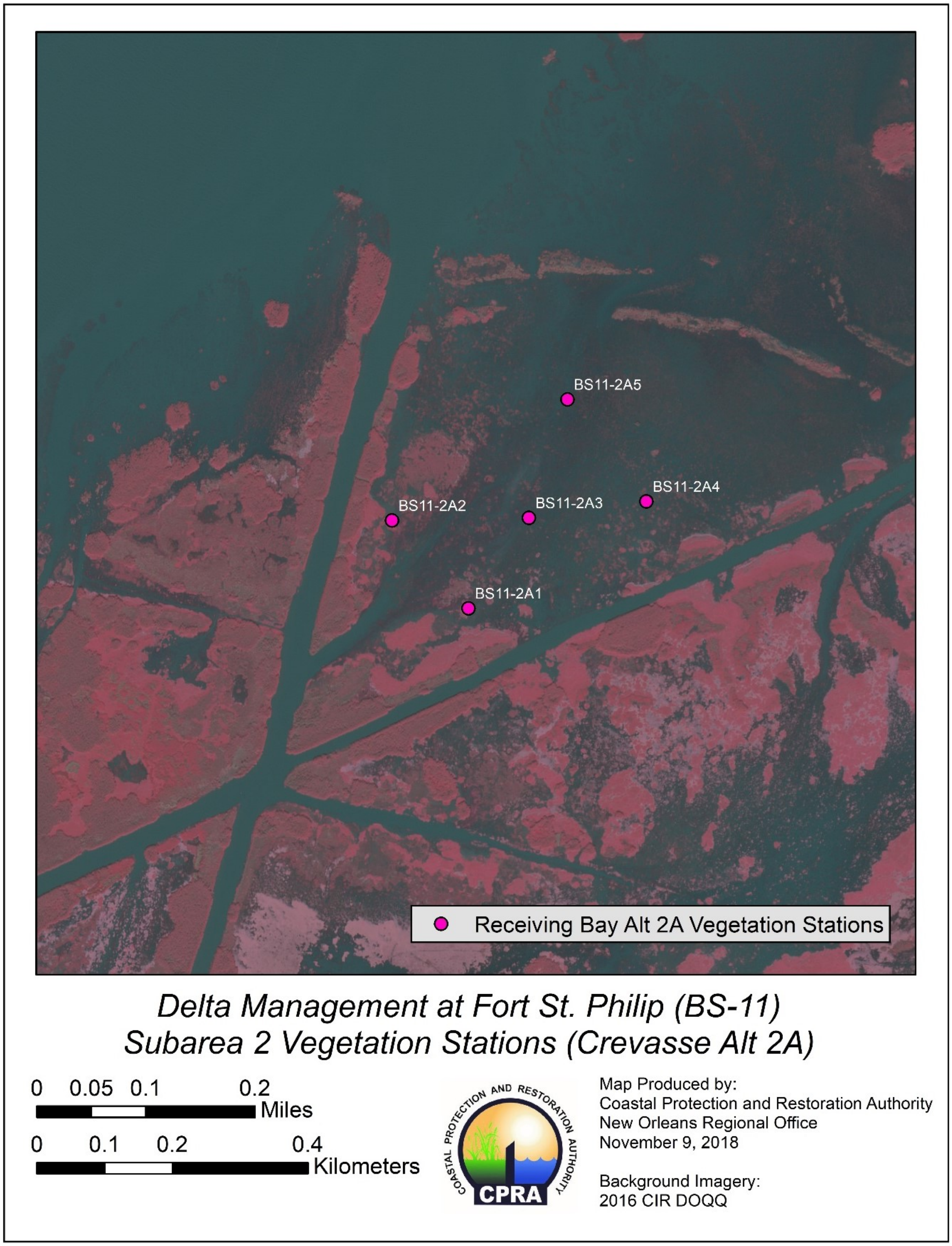


Figure 6. Vegetation stations within Subarea 2 of the Delta Management at Fort St. Philip (BS-11) project.

c. Preliminary Monitoring Results and Discussion

Elevation

Crevasse Channels: Between June and August 2006, approximately 94,066 CY of dredged material was removed from the six crevasse channels and placed into adjacent designated disposal areas (ABMB Engineers 2007). Volumes removed from the individual channels ranged from 9,569 CY at Crevasse 1B to 30,870 CY at Crevasse 1A (Table 1) with construction volumes removed being estimated from the as-built survey data using the average end-area method. Volume loss from 2002 to 2006 estimated from the DEMs (Appendix D) was higher than the volume removed as reported during construction for all six crevasses (Table 1). This is due in part to different methods of calculation, but may also indicate that additional volume losses occurred during the pre-construction period within the proposed channels ranging from 611 CY at Crevasse 1B to 15,891 CY at Crevasse 1A (Table 1).

Table 1. Channel statistics and volume removed for six dredged crevasses within the BS-11 project area. Estimated volume loss between 2002 and 2006 is compared to volumes removed in 2006 as calculated during construction.

Crevasse Channel	Length (ft)	Width (ft)	Depth (ft)	Angle	Volume Removed during Construction (2006) (CY)	Volume Loss (2002-2006) (CY)	Difference between Volume Removed during Construction and Volume Loss (2002-2006) (CY)
1A	2000	75	-8	60	-30,870	-46,761	-15,891
1B	400	75	-6	120	-9,569	-10,180	-611
1C	700	75	-6	60	-10,356	-14,662	-4,306
Alt 2A	732	75	-8	60	-13,760	-16,647	-2,887
2B	500	75	-6	60	-9,793	no data	no data
2C	2000	75	-6	60	-19,719	-26,505	-6,786

All of the crevasse channels except Channel 1A showed a net gain in material at ten years following construction (2006-2016) (Figures 7, 8, and Appendix D). Channels 1C and 2C showed the greatest amount of infilling with +104% and +101% of the lost volume replaced in the post-construction period. Channels 1B, Alt 2A, and 2B have infilled by +85%, +45%, and +14%, respectively. Channel 1A, alternatively, showed a net loss of sediment in the post-construction period of 19,677 CY, which is equivalent to 42% of the original volume lost. Magnitude of infilling was generally higher within the channels during the first five years (2006-2011) than from years 5 to 10 (2011-2016). Additionally, sediment loss within

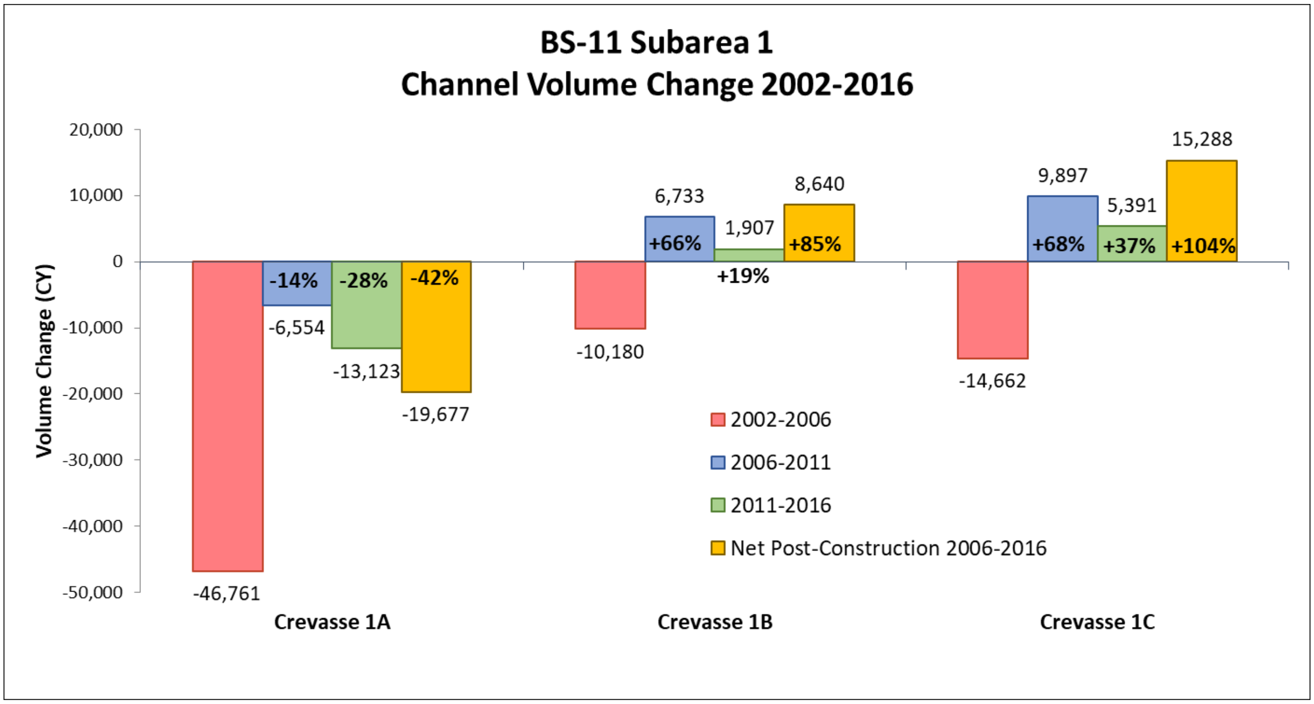


Figure 7. Volume change (CY) within the three dredged Subarea 1 channels (1A, 1B, and 1C) from 2002 (pre-construction) to 2016 (Year 10).

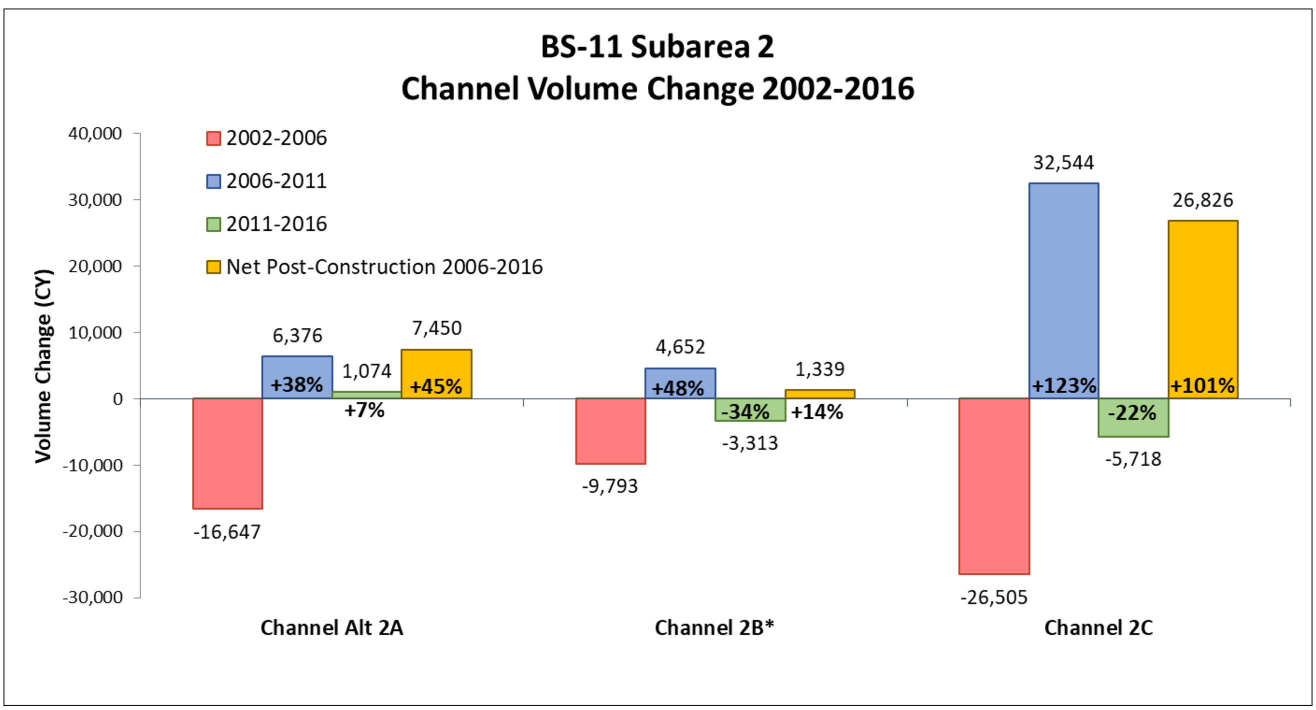


Figure 8. Volume change (CY) within the three dredged Subarea 2 channels (Alt 2A, 2B, and 2C) from 2002 (pre-construction) to 2016 (Year 10).

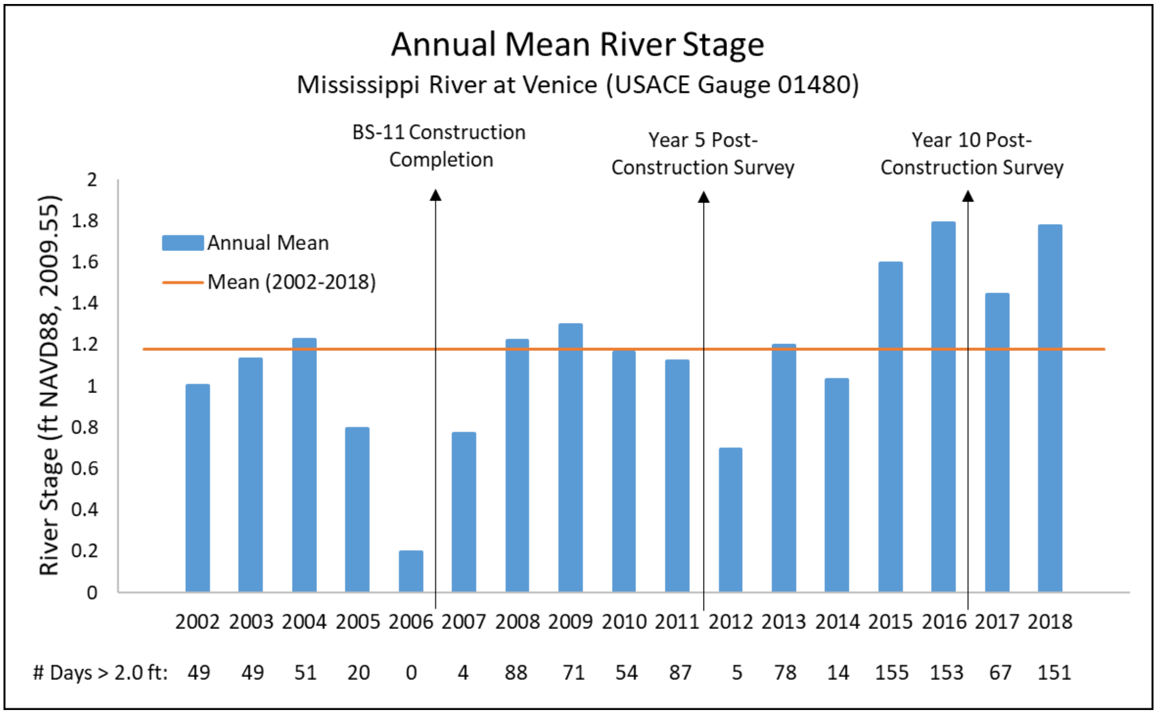


Figure 9. Annual mean Mississippi River stage (ft NAVD88, 2009.55) from 2002 to 2018 measured at USACE Gauge 01480 near Venice, LA.

Channel 1A doubled during years 5 to 10 and Channels 2B and 2C also showed a loss of sediment during this period. Data from the USACE Gauge 01480 in the Mississippi River near Venice, LA indicated that annual mean river stage (ft NAVD88, 2009.55) in 2015 and 2016 was the highest since the project was designed and constructed (Figure 9). During those two years, which immediately preceded the October 2016 (Year 10) survey, mean daily river stage was above 2.0 ft (80^{th} percentile) for 155 and 153 days, while in earlier years the number of days at that level was 88 or less. Above average river stage in 2015 and 2016 would presumably lead to increased flows through the crevasse channels thereby increasing scour and decreasing infilling within the channels observed at the Year 10 survey. The two years following the Year 10 survey (2017 and 2018) also showed a higher than average annual mean river stage, with a mean daily river stage above 2.0 ft for 151 days in 2018.

Following the Year 5 survey, it was recommended that re-dredging of some crevasse channels (1C, Alt 2A, 2B, and 2C) was warranted to enhance conveyance of sediment into the receiving bays. Re-dredging of crevasse channel 1B was determined to be cost-prohibitive since there were only 15 acres of open water remaining. Following an assessment of access and landrights issues, it was determined that re-dredging of the Subarea 2 channels was also cost-prohibitive and beyond the scope of the approved O&M budget. Although this anticipated maintenance event did not occur, the scouring and loss of sediment observed within Channels 2B and 2C following the high river event is a positive sign that sufficient flow is continuing to convey sediment through the channels and into the receiving bays. Inspection trips in 2015 and 2016 noted strong water flows present in all six channels.

Receiving Bays: Receiving Bays 1A and Alt 2A showed a loss of sediment volume by Year 5 compared to pre-construction conditions; however, significant sediment gains were observed between Year 5 and 10 (Figure 10) (Appendix E1 and E2). Receiving Bay 1A showed a loss of -1,685 CY of material from 2002 (pre-construction) to 2011 (Year 5), which is partly attributable to scouring and extension of the crevasse channel into the receiving bay (Appendix D1). Receiving Bay Alt 2A showed a smaller loss of -523 CY of sediment from 2002 (pre-construction) to 2011 (Year 5); however, between Year 5 and Year 10 there was a gain of +10,162 CY within Receiving Bay 1A and +8,387 CY within Receiving Bay Alt 2A. Although survey data was not collected within Receiving Bays 2B and 2C in 2011, comparisons of survey data between 2002 and 2016 showed a gain of +5,332 CY in Receiving Bay 2B and +36,346 CY in Receiving Bay 2C from pre-construction to Year 10 of the project (Appendix E3). Due to the varying size of receiving bays, comparisons were made between receiving bays based on volume change per acre of each receiving bay analysis area (Table 2). This indicates that Receiving Bay 2B gained the most sediment volume per acre (1,238 CY/ac) by Year 10. It should be noted that for all receiving bays analyzed, the volume gained is limited to the extent of the survey data and should not be considered the total volume gained within the full extent of the receiving bay. Volume change per acre for Receiving Bay 1A (186 CY/ac) is underestimated because a significant portion of the sediment load is being carried beyond the analysis area and into the terrace field as discussed in the next section. When considering volumetric gains estimated within all analysis areas of the Crevasse 1A receiving bay (Appendix D1), the volume change per acre is 1,134 CY/ac.

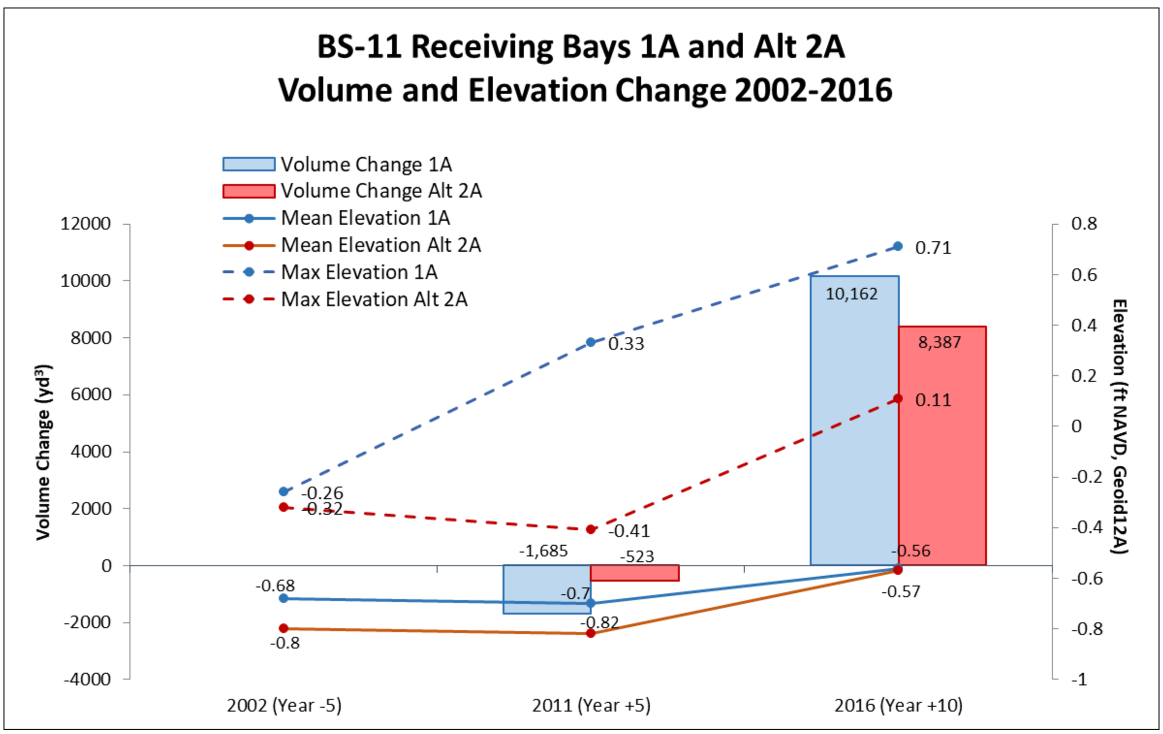


Figure 10. Volume and elevation changes within BS-11 Receiving Bays 1A and Alt 2A from 2002 to 2016.

Table 2. Volume gain (CY) and volume gain per acre (CY/ac) within four BS-11 receiving bays between 2002 (pre-construction) and 2016 (Year 10).

Receiving Bay	2002-2016 Volume Gain (CY)	Receiving Bay Area of Analysis (ac)	2002-2016 Volume Gain per acre (CY/ac)
1A	8,477	45.7	186
1A including terraces	230,406	203.3	1,134
2A	7,864	21.2	371
2B	5,332	4.3	1,238
2C	36,346	46.1	788

Vegetative colonization of crevasse splays can not occur until sufficient elevation gain within the receiving bays is achieved. As sediments become subaerial, vegetative colonization of crevasse splays has been shown to occur quickly followed by a high rate of below-ground production which further stabilizes the loose sediments (Cahoon et al. 2011). Hourly water level (ft NAVD) measured continuously at CRMS0139 (Figure 2) from June 2007 to present was analyzed to determine elevations at which percent inundation levels are conducive to marsh productivity and growth. Productivity of fresh to intermediate marshes has been estimated to be 80% or greater at inundation ranges between 10% and 90% (Visser et al. 2004). Therefore, the 90% inundation level was chosen as an elevation benchmark for the vertical accretion within the receiving bays as the minimum elevation at which optimized productivity is reached. Water level data from CRMS0139 showed that the 90% inundation level is -0.39 ft with a 90%-10% inundation range of -0.39 to 1.42 ft (ft NAVD, Geoid12A) (Figure 11). Mean low water (MLW) and mean high water (MHW) were determined to be -0.11 and 1.12 ft. For reference, the average marsh elevation at CRMS0139 was determined in 2014 to be 0.44 ft; therefore, the existing marsh at CRMS0139 is flooded 50-60% of the time.

Mean elevations within receiving bays 1A, Alt 2A, 2B, and 2C were below the 90% inundation level before construction, and ranged from -1.29 ft (2C) to -0.47 ft (2B) (Figure 12A). By 2016 (Year 10), Receiving Bay 2B showed the greatest elevation increase of 0.77 ft to a mean elevation of 0.30 ft, which is between the 60-70% inundation level. Receiving Bays 1B and 1C showed even higher mean elevations in 2016 of 1.39 ft and 0.74 ft; however, these elevations could not be compared to pre-construction conditions since survey data was only collected in 2016. Mean elevation also increased, but to a lesser degree, within receiving bays 1A, Alt 2A, and 2C between 2002 and 2016, with observed increases in elevation of 0.12 ft, 0.23 ft, and 0.49 ft, respectively. Receiving Bays 1A and Alt 2A, which were the only receiving bays surveyed at post-construction Year 5 (2011), showed no significant change in elevation at that time (Figure 10). This indicates that the observed gain in elevation at Year 10 occurred between Years 5 and 10 post-construction, which coincides with the period of higher than normal river stage (Figure 9). Maximum

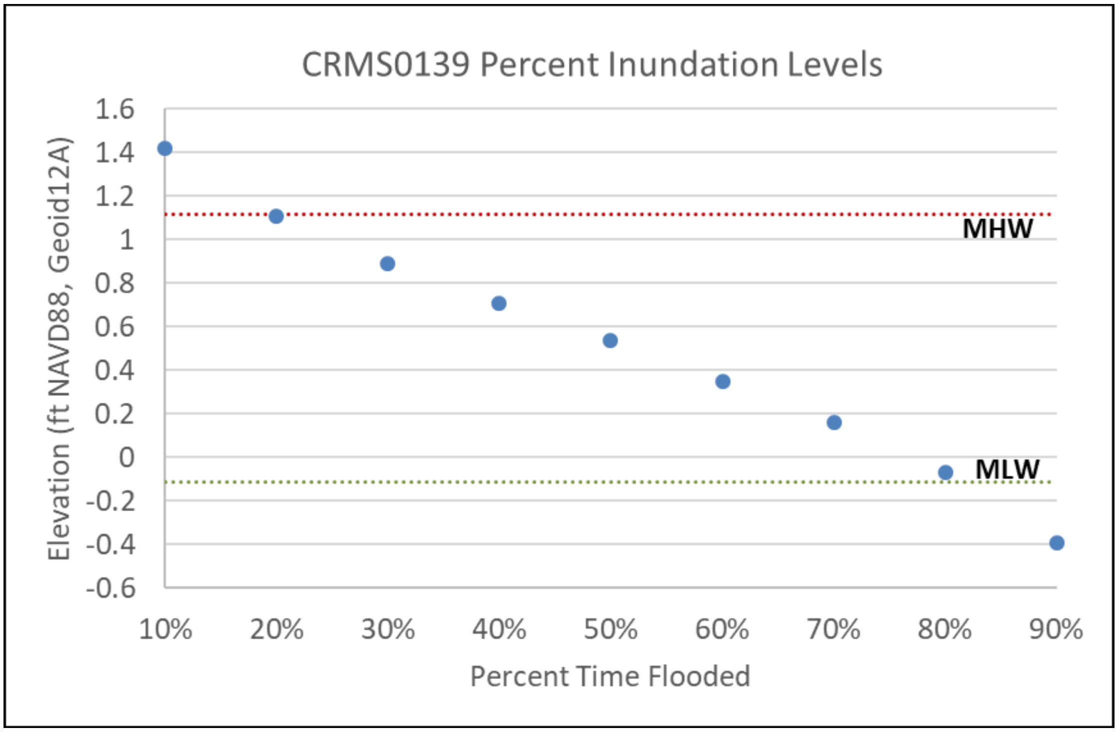


Figure 11. Percent inundation levels calculated from hourly continuous data collected at CRMS0139 from June 2008 to December 2018.

elevations observed in the pre-construction period ranged from 0.11 ft (Alt 2A) to 1.80 ft (2C) and increased by an average of 1.2 ft by Year 10 (Figure 12B).

Gains in surface elevation must outpace rates of relative sea level rise (RSLR) for persistent land gain to occur. The rate of RSLR in the vicinity of the BS-11 project has been estimated to range from 0.78 to 0.87 cm/yr (adapted from Jankowski et al. 2017). Expressed in terms of elevation change per year from 2002 to 2016, mean elevation gains observed within Receiving Bays 1A, Alt 2A, 2B, and 2C were +0.24, +0.50, +1.68, and +1.07 cm/yr; however, localized gains were as large as +3.55, +2.02, +3.90, and +7.53 cm/yr, respectively. While the mean surface elevation gains were less than the estimated RSLR within the analysis areas of Receiving Bays 1A and Alt 2A, it should be noted that the analysis areas do not capture the entire receiving bay. The surface elevation change rate measured from 2008 to 2018 at CRMS0139, which is located at the opposite end of Receiving Bay 1A from the crevasse channel, is estimated to be +1.17 cm/yr. This gain indicates that a significant portion of the sediment load is travelling beyond the Receiving Bay 1A analysis area and terrace field. The short-term accretion rate of +3.57 cm/yr (2016-2018) measured at CRMS0139 was greater than the long-term accretion rate of +1.78 cm/yr (2008-2018), indicating increased deposition in the recent timeframe.

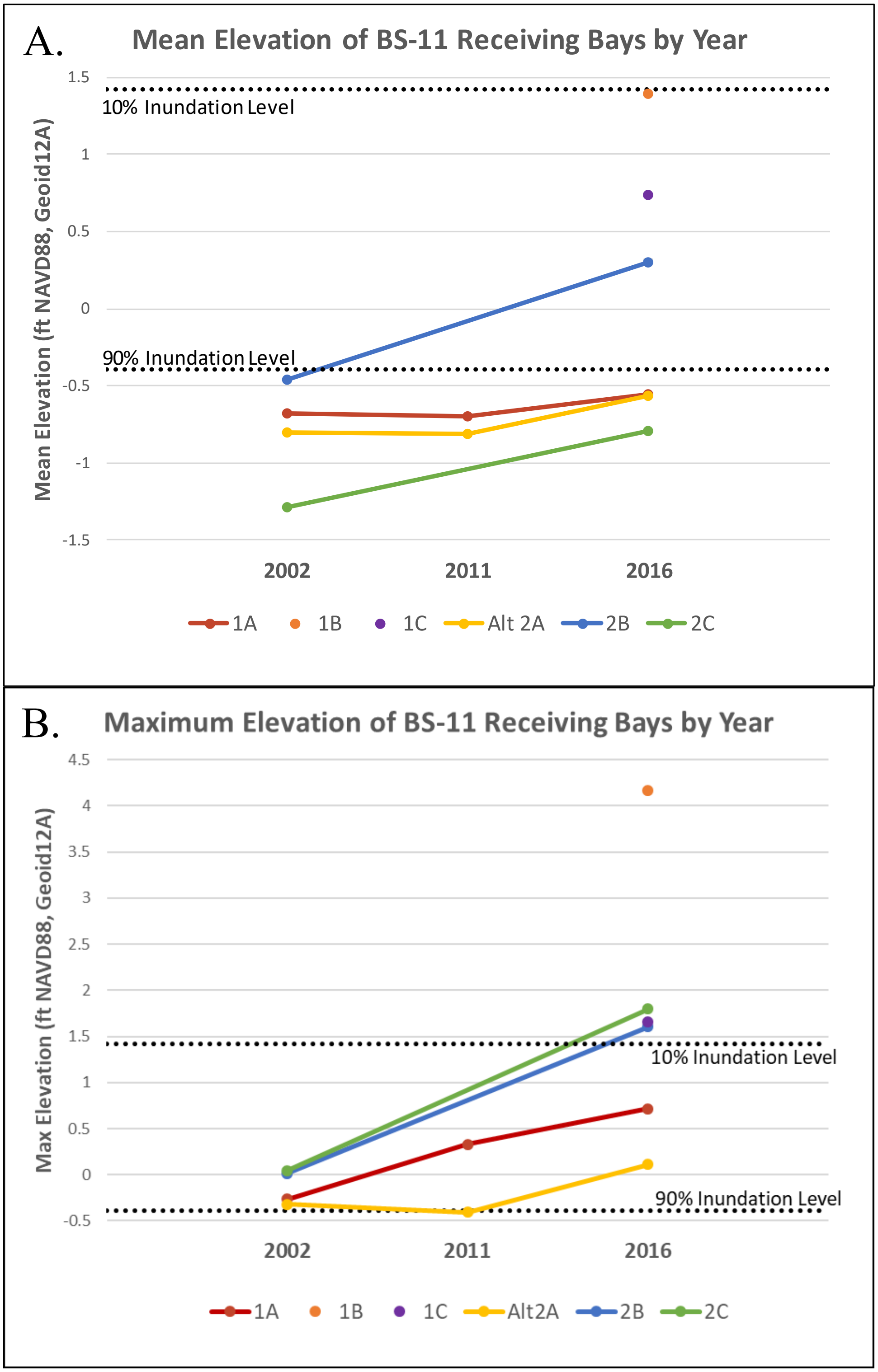


Figure 12. Mean (A) and maximum (B) elevation of BS-11 receiving bays in 2002, 2011, and 2016.

Inundation regimes calculated from CRMS0139 were applied to the DEMs of the receiving bays where possible (Appendix E) to determine the percentage of total area within four inundation classes over time. Inundation levels were classified as <10% (> 1.4 ft), 10-50% (0.5 to 1.4 ft), 50-90% (-0.4 to 0.5 ft) and >90% (< -0.4 ft). In Subarea 1, the majority of the Receiving Bay 1A analysis area (83%) was flooded more than 90% of the time in the preconstruction period (Figure 13A). By Year 5, there was little change with 78% of the area still flooded more than 90% of the time. By Year 10, however, 63% of the analysis area was flooded only 50-90% of the time. Receiving bay data for 1B and 1C are only available for Year 10 (2016) which shows that 100% of the areas analyzed were at the optimum elevation for marsh productivity or higher by that time. Receiving Bay 1B, the smallest of the receiving bays, is now at a higher elevation with less time flooded than the other five crevasses, as well as the marsh at CRMS0139 (Figure 13B). The 2016 analysis showed that 48% of the area is flooded less than 10% of the time and the remaining 52% is within the 10-50% flooding range. Within Receiving Bay 1C, 75% of the analysis area is flooded 10-50% of the time and 25% is flooded 50-90% of the time indicating that the entire area analyzed was within the optimum range for marsh productivity by Year 10.

In Subarea 2, Receiving Bay 2B performed better than Alt 2A and 2C in relation to the creation of emergent land, although all three areas are showing a progression towards less time flooded. The analysis of Receiving Bay 2B showed that 88% of the area analyzed was flooded more than 90% of the time before construction in 2002; however by Year 10, 98% of the area was within the optimum flooding range (10-90% time flooded). Receiving Bays Alt 2A and 2C were both flooded more than 90% of the time before project construction (2002) and this was still the case in Receiving Bay Alt 2A by Year 5. By Year 10, however, 18% of Receiving Bay Alt 2A and 14% of Receiving Bay 2C were within the 50-90% flooding range.

A study of the morphological evolution of the West Bay Sediment Diversion, another man-made crevasse located downriver from the BS-11 project, indicated that erosional processes may dominate during the first five years following crevasse formation as initial scour occurs and channel morphology reaches a steady state (Yuill et al. 2016). The depositional period during which splay formation occurs may not be fully reached until Year 10. Similarly, the BS-11 results appear to indicate that there was a temporal lag following crevasse formation before significant deposition was observed. An additional factor influencing sediment deposition between Years 5 and 10 would be the higher than average annual river stage observed in years 2015-2018, which would have served to increase velocities and flush the infilled crevasse channels, thereby improving conveyance into the receiving bays.

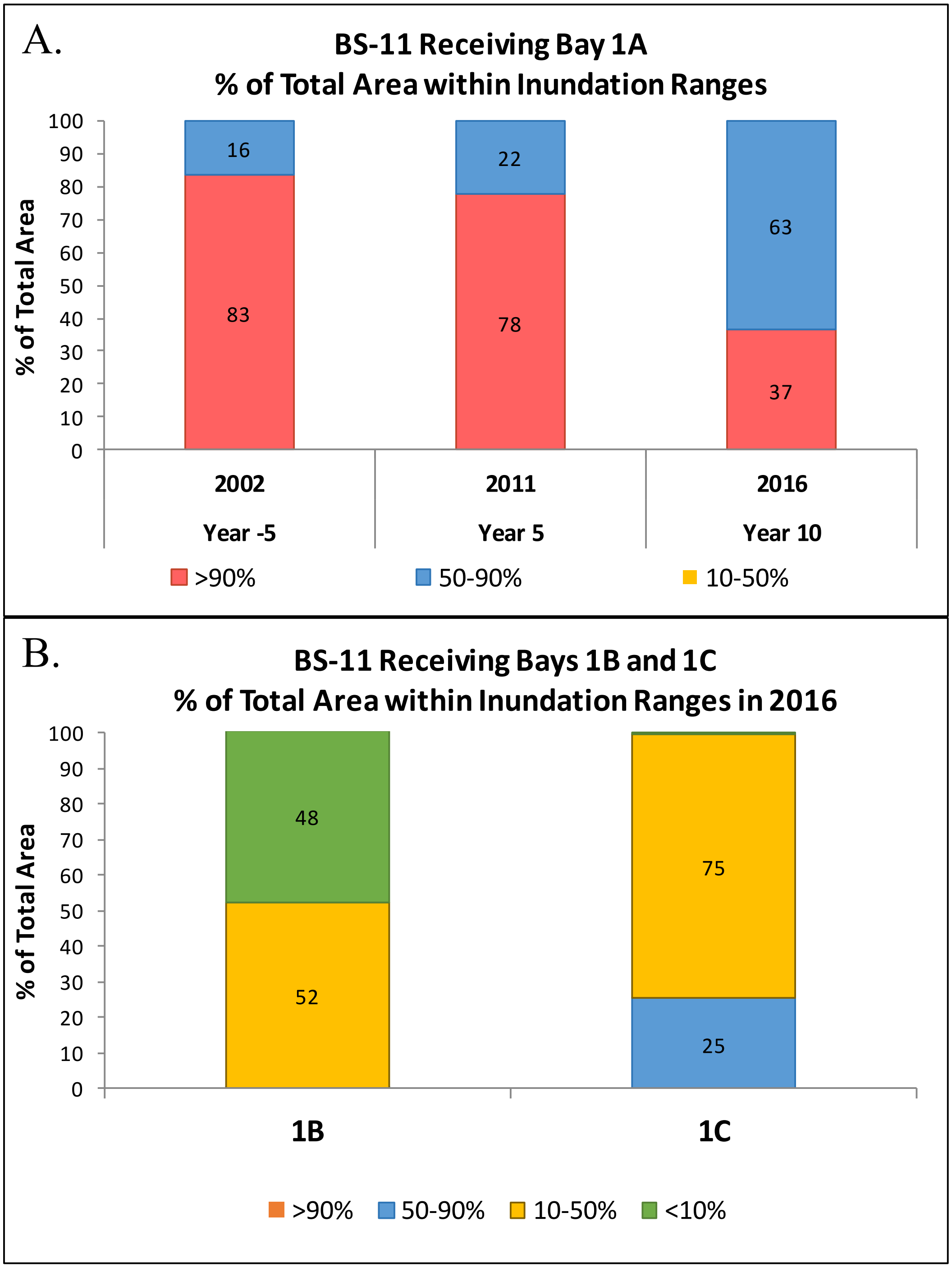


Figure 13. Percent of total area within defined inundation classes within BS-11 Receiving Bay 1A in 2002, 2011, and 2016 (A), and within Receiving Bays 1B and 1C in 2016 (B).

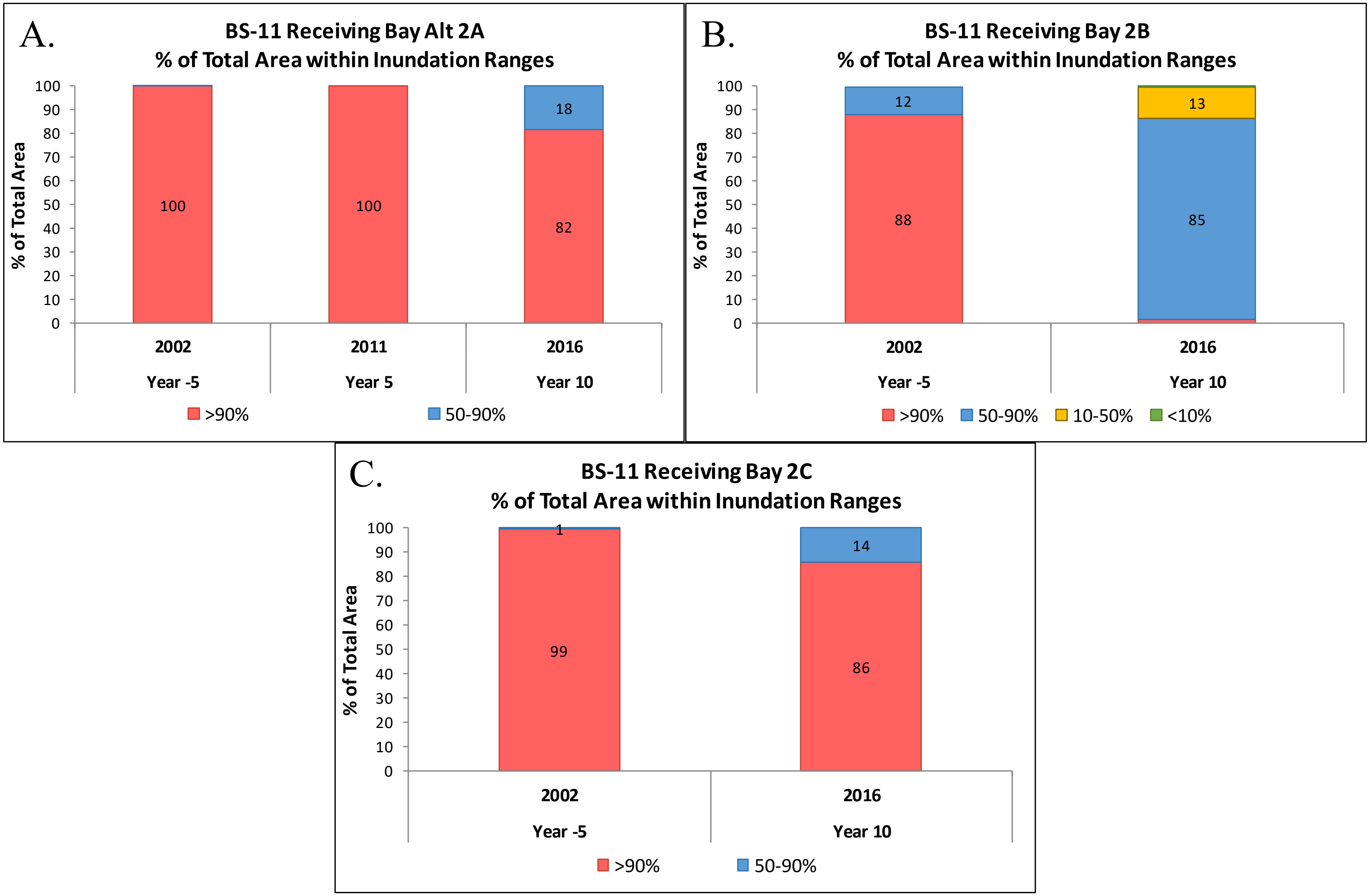


Figure 14. Percent of total area within defined inundation classes within BS-11 Receiving Bay Alt 2A in 2002, 2011, and 2016 (A), within Receiving Bay 2B in 2002 and 2016 (B), and within Receiving Bay 2C in 2002 and 2016 (C).

Terraces: Comparison of the 2011 and 2016 survey transects to the 2006 as-built transects revealed discrepancies in the 2006 dataset. The 2006 survey reflects crown elevations even where transects crossed directly between two adjacent terraces, whereas the 2011 survey accurately reflects a low elevation in these locations (Figure 15). Terrace elevation loss is therefore exaggerated upon comparison of the as-built survey with the later datasets. Presumably, survey points were taken at terrace peaks where necessary in 2006 to indicate as-built specifications, and then snapped to the transect line during post-processing. Unfortunately, unmanipulated datasets from 2006 could not be obtained from the surveyor. As a result, comparisons between pre-construction conditions (2002) and Years 5 (2011) and 10 (2016) are considered to be the most valid.

Volumetric changes within the terrace field due are considered to be highly estimated due to the irregular surface between the survey transects. Compared to pre-construction conditions (2002), interpolated results showed a gain of approximately +20,876 CY by Year 5 (2011) followed by a much larger volume gain of +159,435 CY between Years 5 and 10 for a net volume gain of +180,311 CY (Figure 16) (Appendix D1 and E1). Rough approximations of sediment volume using the average end area method along the survey transects show a similar total volume gain of +176,803 CY from 2002 to 2016. Due to construction using in situ material, much of the sediment gain in the first five years following construction served to replace sediment within the adjacent borrow areas leading to modest volume gains during this period, while the significant gain observed between Years 5 and 10 was enhanced further by the higher river stage.

The 2011 and 2016 profiles of the terrace field transects indicate a progressive infilling of the borrow channels in the post-construction period (Figure 17). The 2011 profiles indicate initial erosion/subsidence of the terraces, but by 2016 there was an increase in mean height of the terrace crowns. Survey points taken at the terrace crowns show the terraces subsiding about one foot on average from 2006 to 2011 and then increasing by an average of 0.13 ft from 2011 to 2016 with an estimated mean crown height of +0.94 ft in 2016. Mean elevation of the interpolated terrace field surface showed little change by Year 5 (+0.13 ft), but increased by approximately 1 foot from 2011 to 2016, with the mean elevation at Year 5 (-1.17 ft) increasing to -0.21 ft by Year 10. Therefore, the estimated mean elevation of the terrace field at Year 10 is now above the 90% inundation level of -0.39 ft. The maximum elevation within the terrace field also increased from -0.47 ft before construction to +1.81 ft by Year 10.

A 55-acre area to the northeast of the terrace field was also surveyed and analyzed for changes in mean elevation and volume in 2002, 2011, and 2016 (Appendix D1). This area showed a small loss of elevation (-0.20 ft) and volume (-17,689 CY) by Year 5, but gains of +0.66 ft in elevation and +59,307 CY of sediment volume between Years 5 and 10 (Appendix E1). Net volume gains estimated within Crevasse 1A by Year 10 within the Receiving Bay 1A analysis area (+8,477 CY), the terrace field (+180,311 CY), and northeast of the terrace field (+41,618 CY) provide a total sediment volume gain of +230,406 CY within Crevasse 1A by Year 10 (Appendix E1 and Table 2).

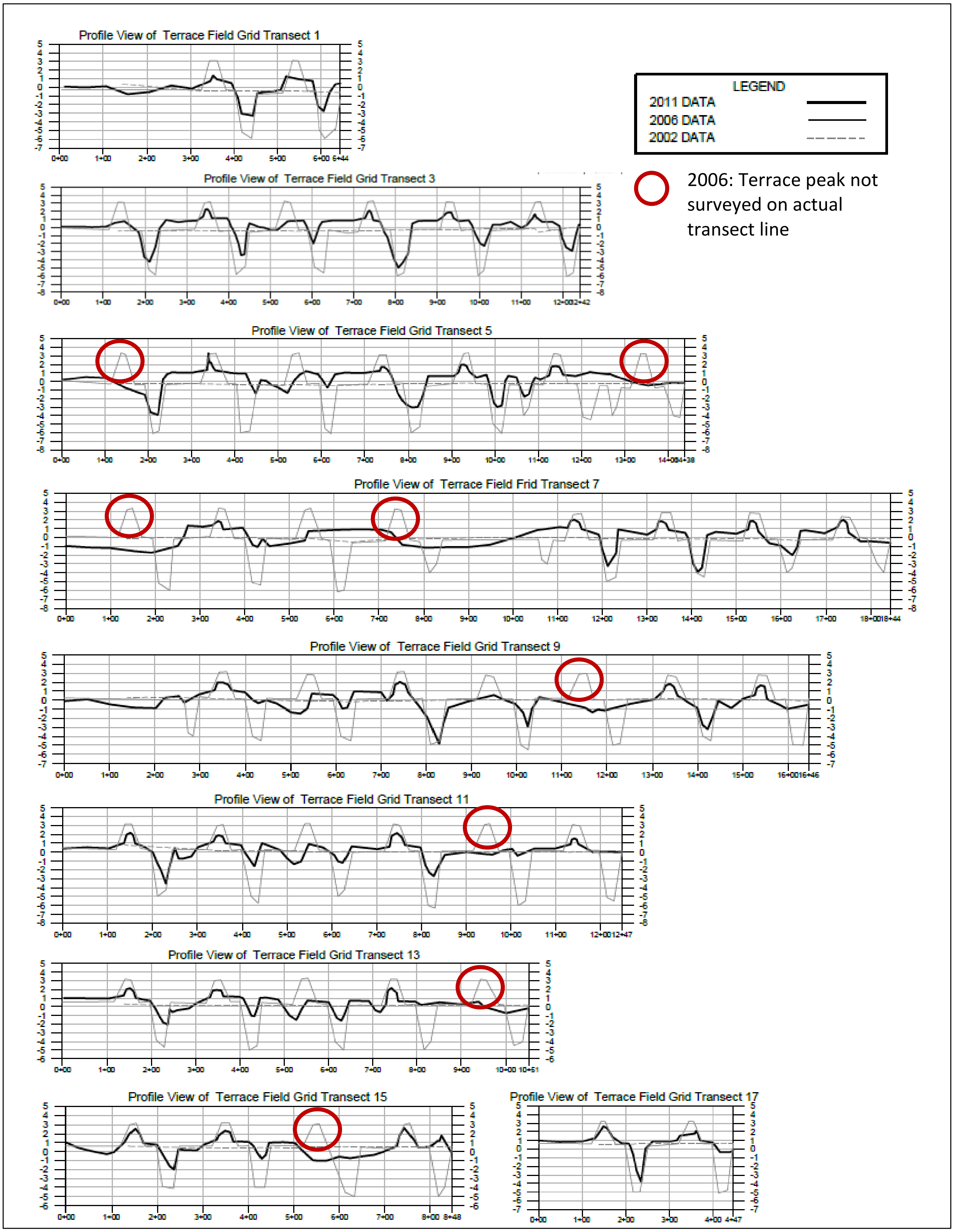


Figure 15. Profile view of surveyed transects within the terrace field of the Delta Management at Fort St. Philip project in 2002, 2006, and 2011.

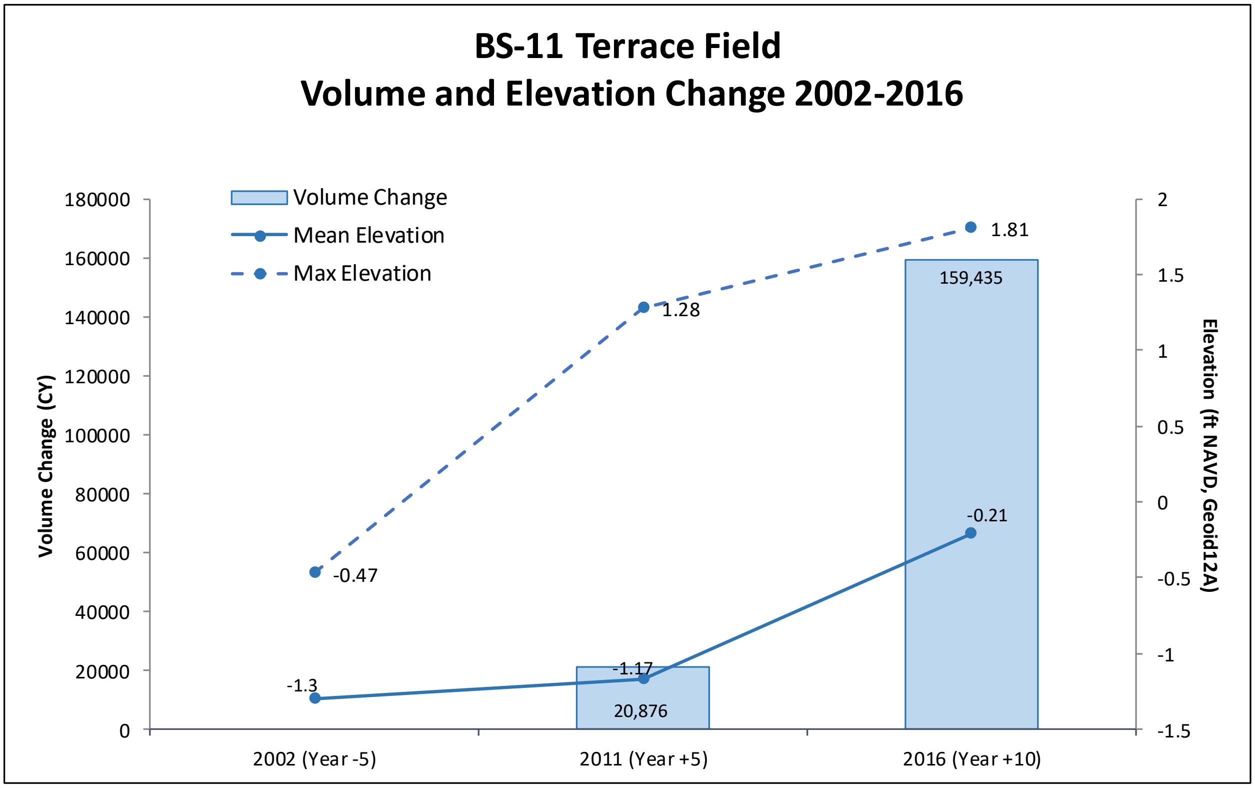


Figure 16. Estimated volume and elevation changes within the BS-11 terrace field from 2002 to 2016.

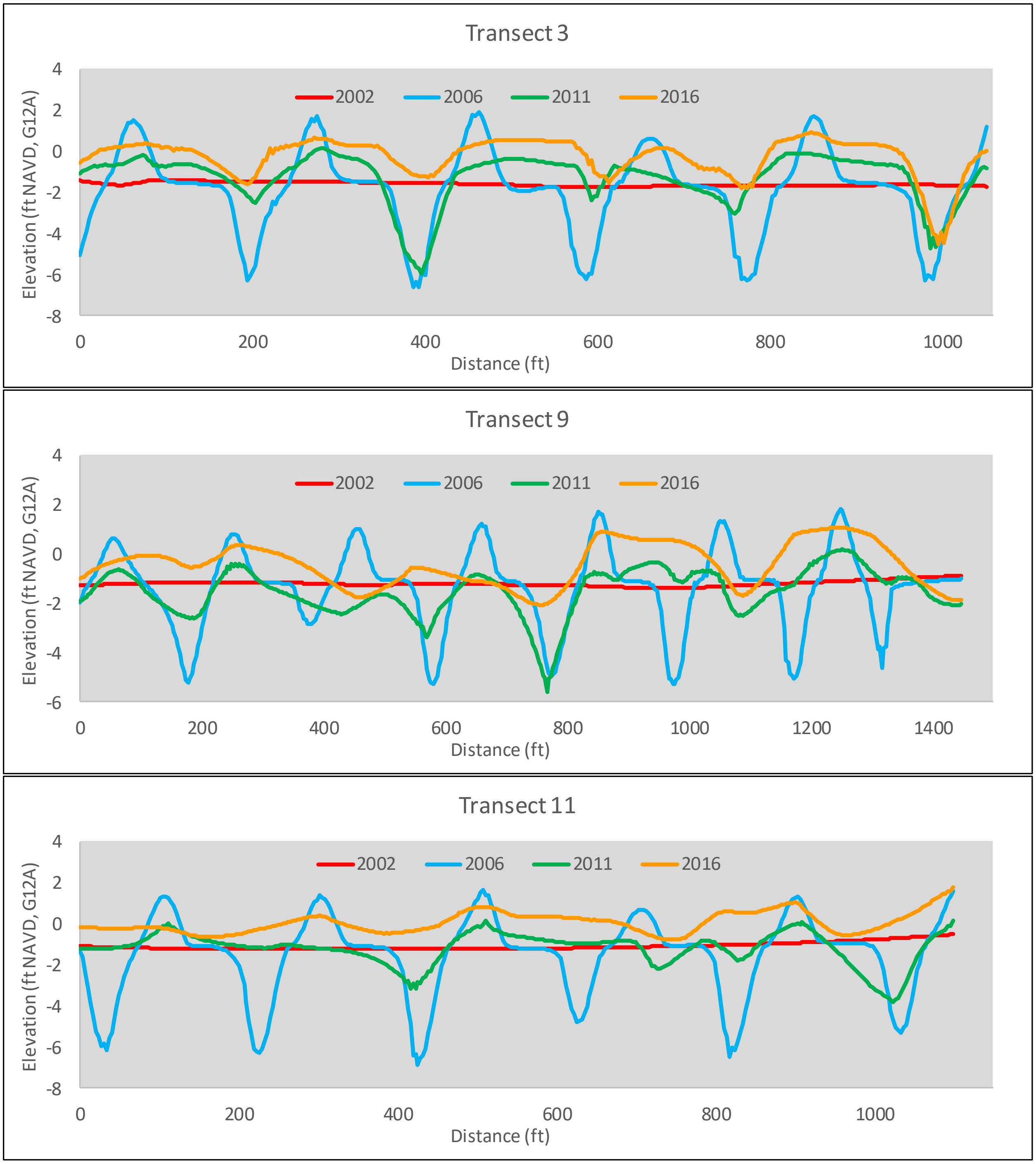


Figure 17. Elevation profiles (ft NAVD88, Geoid12A) along three transects within the terrace field of the Delta Management at Fort St. Philip project in 2002, 2006, 2011, and 2016. Refer to Figure 4 for transect locations.

Land/Water Analyses

One of the specific goals of the Delta Management at Fort St. Philip project was to create an additional 244 acres of emergent marsh through splay growth within the constructed crevasses and 25 acres of emergent marsh through terrace construction for a total of 269 additional acres gained by Year 20 of the project life. Some land gain was expected to occur naturally within the project area, with the Wetland Value Assessment [WVA (USFWS 2000)] assuming a natural growth rate of 1.8 ac/yr in Subarea 1 and 0.5 ac/yr in Subarea 2. Multiple regression analyses were performed before project construction to determine the relationship between several crevasse parameters and the growth rate of emergent marsh in the project area (Banks 2001). Crevasse parameters used to predict growth rates included parent channel order, parent channel width, crevasse cross-sectional area, crevasse age, and receiving bay area. Total predicted net gain over the project life included estimated splay growth due to crevasse construction, estimated natural land gain, direct gains due to terrace construction, and expansion of marsh growth within the terrace field due to accumulated sediment (USFWS 2000). Total net gain predicted by Year 20 of the project life was 268 ac in Subarea 1 and 175 ac in Subarea 2 for a total net gain of 443 ac expected within the project area by Year 20 (Roy 2003). As indicated in the project goals, 269 ac (61%) of this gain was predicted to be attributable to the BS-11 project.

To evaluate land changes within the project and reference areas, land/water analyses were conducted on 1:12,000 scale, color-infrared aerial photography collected in 2002 (pre-construction), 2006 (as-built), and 2011 (Year 5) (Appendix C1-C9). All areas characterized by emergent vegetation, wetland forest, scrub-shrub, or upland were classified as land, while open water, aquatic beds, and mudflats were classified as water. In addition to the analyses conducted for the BS-11 project, two recent studies (Suir et al. 2014; Costanza and Frank-Gilchrist 2019) have assessed changes in land acreage within the broader Fort St. Philip region over time. Suir et al. 2014 conducted an historical analysis of landscape changes within the Fort St. Philip area from 1956 to 2008. This study concluded that the breaching of the east bank of the Mississippi River near Fort St. Philip in 1973 was initially a land-loss accelerant resulting from the physical removal of marsh areas due to scouring from crevasse channels. These direct losses combined with regional losses due to subsidence and episodic events (storms, frontal passages, etc.) led to a 58% reduction of the land area from 1956 to 2008; however, the most recent time period analyzed, 1998 to 2008, was the only period which reflected a net land gain (18%). To further investigate recent land gains within the Fort St. Philip area, Costanza and Frank-Gilchrist (2019) analyzed 1-meter resolution data from 2008, 2013, and 2017 utilizing similar techniques and analysis area as the Suir et al. (2014) study. Results from this study showed a significant land gain of 1,134 acres from 2008 to 2017 in the Fort St. Philip region. To determine gains within the BS-11 project, land-water datasets from the Costanza and Frank-Gilcrist study were acquired and clipped to the BS-11 project boundaries (Appendix C10-C15). The only BS-11 boundary not captured in the Costanza and Frank-Gilchrist analysis area was Reference Area 2.

A summary of land acreage and percentage land by crevasse for each analysis year is shown in Table 3, and land changes during each period of analysis are summarized in Table 4.

Results show that land gains were minimal by Year 5 post-construction (2011) but increased dramatically between Year 5 and Year 11 (2011 to 2017). The project area gained 75 acres of land (6%) from 2002 to 2006, due in part to direct land creation through terrace construction and spoil deposition along the crevasse channels. Only 15 more acres of land (1%) were gained within the project area from 2006 to 2011 (Years 1 to 5) for a net gain of 90 acres from 2002 to 2011. Reference Area 1 gained more land from 2006 to 2011 than any of the project receiving bays. The Jurjevich Canal, which runs along its eastern side of Reference Area 1, appears to be supplying significant sediment input to this area. Percent of acreage gained in Reference Area 2 from 2006 to 2011 was also greater than five of the six receiving bays. The reference areas are located slightly downriver from the project areas and flow from the river travels a shorter, more direct route to the reference areas. There are no pre-construction elevation surveys of the reference areas to compare whether the receiving areas were shallower than the project receiving areas at the beginning of the analysis period.

Significant land gains were observed within all six crevasses between Years 5 and 11 (2011 to 2017), which is consistent with increased sedimentation observed through the elevation surveys. The project area gained 125 acres from 2011 to 2013 and 328 acres from 2013 to 2017 for a total gain of 453 acres of land (+34%) during this period. Despite significant infilling observed within the crevasse channel (Figure 8), Crevasse 2C experienced the greatest percent change of 46% with an increase of 139 acres from 2011 to 2017. It is possible that the Crevasse 2C receiving basin is also receiving sediment input at multiple openings along its eastern boundary. Crevasses 1B and 1C, which are the smallest of the six crevasses, showed land gains from 2011-2013 but no further land gains from 2013-2017; however, these two crevasses now contain 77% and 78% land in 2017, respectively, with significant infilling of the crevasse channels by 2016. Therefore, further land gains within these crevasses may be self-limiting.

The rate of land gain for all crevasses combined from 2011-2013 was 63 ac/yr and increased to 82 ac/yr from 2013-2017. While Crevasse 1A showed the same gain rate for both of these periods (~40 ac/yr), all three of the Subarea 2 crevasses showed an increase in the land gain rate from 2013-2017. Reference Area 1, which receives significant riverine input, showed proportional land gains to the project areas with a gain of 92 acres (+40%) from 2002-2017. Overall rate of land gain for each crevasse was highly correlated (r^2=0.9913) with the size of its receiving basin and the land gain observed within Reference Area 1 was proportional to the other BS-11 crevasses (Figure 18).

The total land acreage within the project area by 2017 was 797 acres (59%) and the overall land gain in the project area from 2002 to 2017 was 543 acres (+40%) with 332 acres gained in Subarea 1 and 211 acres gained in Subarea 2. This land gain observed by Year 11 surpasses the Year 20 project goal of 268 acres in Subarea 1 and 175 acres in Subarea 2 by 64 acres in Subarea 1 and 36 acres in Subarea 2. The overall rate of land gain observed in the project area from 2002 to 2017 was 36 ac/yr. Percentage land within the individual crevasse receiving bays in 2017 ranged from 45% within Crevasse Alt 2A to 78% within Crevasse 1C. From 2002 to 2017, Subarea 1 receiving bays increased from 18% to 57% land and Subarea 2 receiving bays increased from 21% to 64% land, which is already

Table 3. Summary of land acreage and % land within the BS-11 project and reference areas from 2002 to 2017.

		2002 Pre-Construction		2006 As Built		2008* Year +2		2011 Year +5		2013* Year +7		2017* Year +11	
Crevasse	Total Acreage	Land (acres)	% Land	Land (acres)	% Land	Land (acres)	% Land	Land (acres)	% Land	Land (acres)	% Land	Land (acres)	% Land
1A	775	125	16%	175	23%	180	23%	183	24%	264	34%	422	54%
1B	31	13	42%	15	48%	15	48%	16	52%	24	77%	24	77%
1C	50	15	30%	23	46%	23	46%	29	58%	38	76%	39	78%
Total Sub-Area 1	856	153	18%	213	25%	218	25%	228	27%	326	38%	485	57%
Alt 2A	98	10	10%	12	12%	6	6%	9	9%	12	12%	44	45%
2B	87	25	29%	36	41%	45	52%	38	44%	44	51%	60	69%
2C	305	66	22%	68	22%	58	19%	69	23%	87	29%	208	68%
Total Sub-Area 2	490	101	21%	116	24%	109	22%	116	24%	143	29%	312	64%
TOTAL Project	**1346**	**254**	**19%**	**329**	**24%**	**327**	**24%**	**344**	**26%**	**469**	**35%**	**797**	**59%**
Reference 1	228	64	28%	76	33%	85	37%	105	46%	119	52%	156	68%
Reference 2	67	12	18%	15	22%	n/a	n/a	19	28%	n/a	n/a	n/a	n/a

*Source: Costanza and Frank-Gilchrist 2019

Table 4. Summary of land change (acres), % land change, and gain/loss rates (ac/yr) observed within the BS-11 project and reference areas from 2002 to 2017.

	2002-2006			2006-2011			2011-2013			2013-2017			2002-2017		
Crevasse	Land Change (acres)	% Change	Gain/Loss Rate (ac/yr)	Land Change (acres)	% Change	Gain/Loss Rate (ac/yr)	Land Change (acres)	% Change	Gain/Loss Rate (ac/yr)	Land Change (acres)	% Change	Gain/Loss Rate (ac/yr)	**Land Change (acres)**	**% Change**	**Gain/Loss Rate (ac/yr)**
1A	50	6%	13	8	1%	2	81	10%	41	158	20%	40	**297**	**38%**	**20**
1B	2	6%	1	1	3%	<1	8	26%	4	0	0%	0	**11**	**35%**	**1**
1C	8	16%	2	6	12%	1	9	18%	5	1	2%	<1	**24**	**48%**	**2**
Alt 2A	2	2%	1	-3	-3%	-1	3	3%	2	32	33%	8	**34**	**35%**	**2**
2B	11	13%	3	2	2%	<1	6	7%	3	16	18%	4	**35**	**40%**	**2**
2C	2	<1%	1	1	<1%	<1	18	6%	9	121	40%	30	**142**	**47%**	**9**
TOTAL	**75**	**6%**	**19**	**15**	**1%**	**3**	**125**	**9%**	**63**	**328**	**24%**	**82**	**543**	**40%**	**36**
Reference 1	12	5%	3	29	13%	6	14	6%	7	37	16%	9	**92**	**40%**	**6**
Reference 2	3	4%	1	4	6%	1	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**	**n/a**	**n/a**

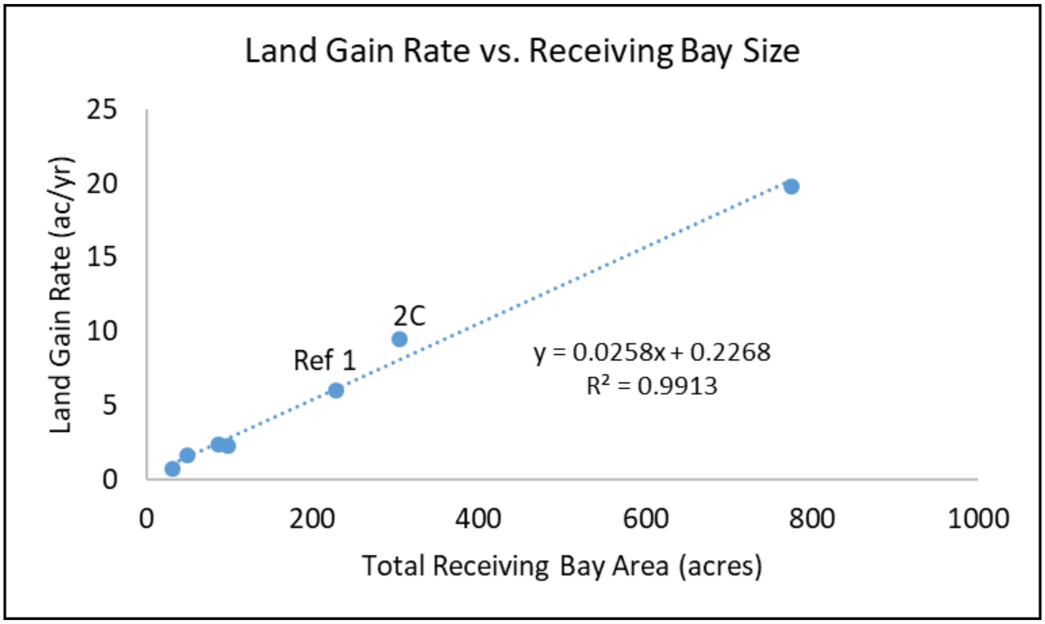


Figure 18. Observed rate of land gain (acres/year) from 2002 to 2017 vs. total receiving bay area (acres) for the crevasses within the BS-11 project and reference areas.

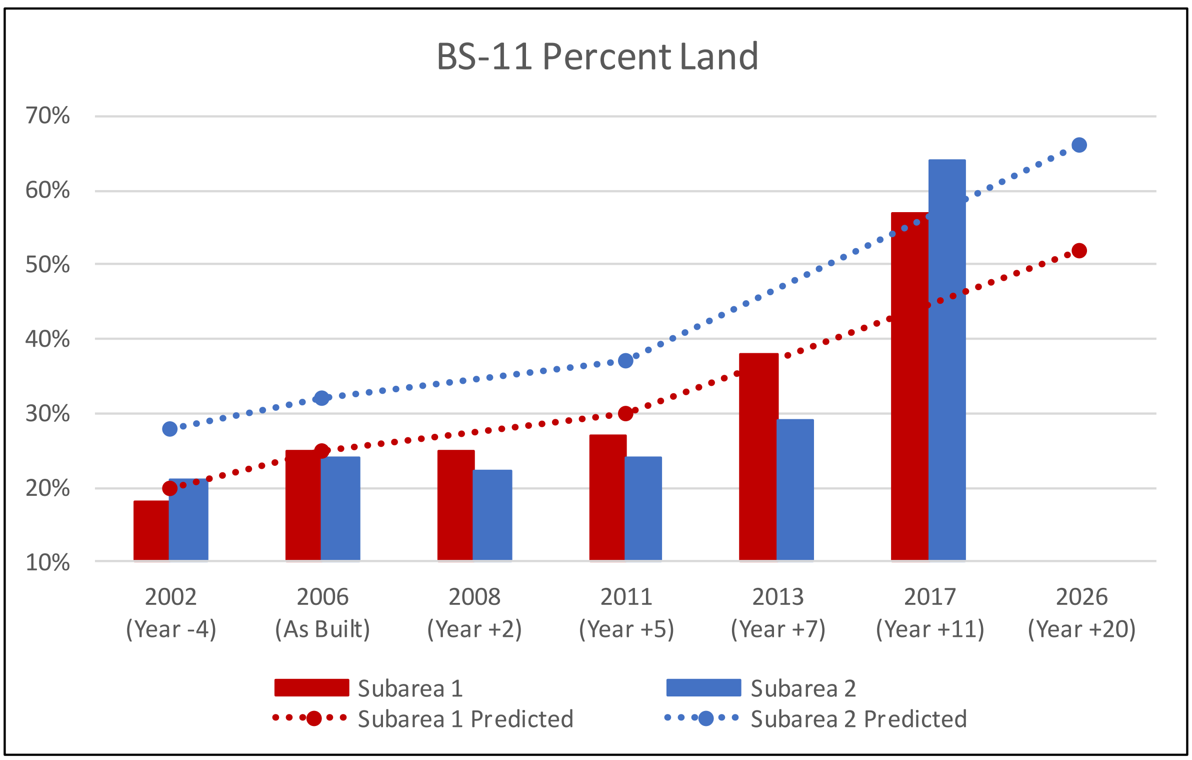


Figure 19. Observed vs. predicted percentage of land within Subareas 1 and 2 of the Delta Management at Fort St. Philip (BS-11) project over time.

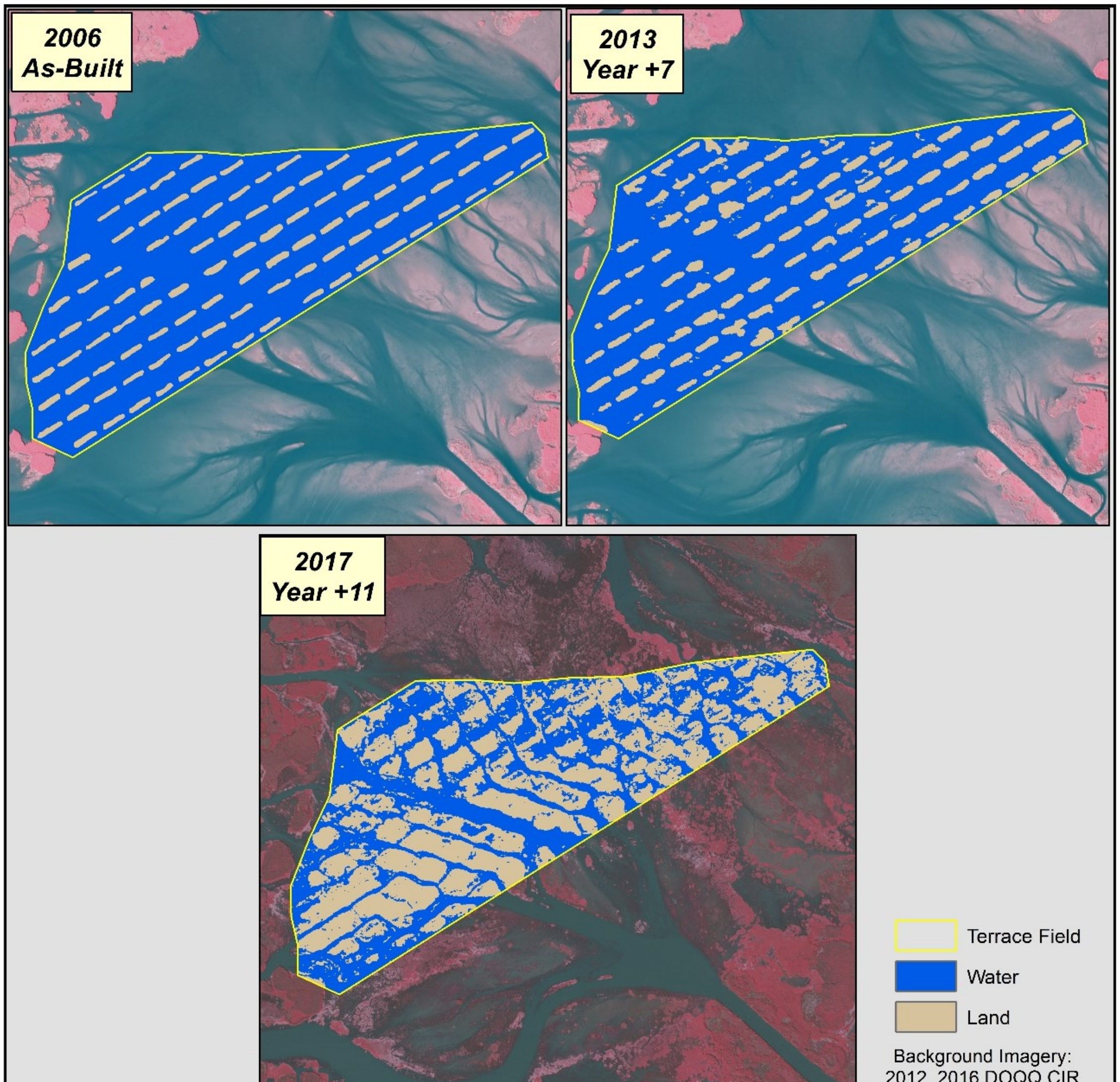
achieving project predictions for Year 20 (Figure 19). Land gain within the terrace field is also surpassing project predictions. There were 16.5 acres of direct land creation expected through terrace construction with an additional 8.5 acres of land accumulation within the terrace field over the 20-year project life. Analyses show 18 acres of land following construction in 2006 and an additional gain of 45 acres by 2017 for a total gain of 63 acres within the terrace field (Figure 20). This equates to a land gain rate within the terrace field of approximately 4.1 acres/yr following terrace construction.

It appears that much of the sedimentation in Years 1 to 5 served to decrease depths within the open water receiving areas with subaerial land formation occurring primarily between Years 5 and 11. Higher than average river stage from 2015 to 2017 (Figure 9) likely provided favorable conditions for land building in the Fort St. Philip area, although land gains had already begun to increase within the crevasses by 2013 as sediment accumulation reached subaerial levels. In addition to enhanced sediment load, greater flows through the channels served to scour and self-maintain the crevasse channels despite the absence of a maintence event at Year 5. Another artificial crevasse project, the Delta-Wide Crevasses (MR-09) project, also showed large land gains from 2012 to 2016 with 20 out of 22 crevasses gaining land during this period (Gossman and Gisclair 2018).

Vegetation

Vegetation surveys within the terrace field were conducted in Year 1 (2007), Year 5 (2011), and Year 15 (2016) within 18 4-m^2 plots (Figure 5). The mean percent coverage of vegetation on the constructed terraces increased significantly during the first growing season to 86% in 2007, and has remained steady at approximately 86% at Years 5 and 10 (Figure 21); however, notable changes in species composition and cover have occurred over the ten years following construction. The greatest number of species was observed in 2007 (28 species), which included several species associated with disturbance, such as various *Cyperus* (flatsedge) species, that were not observed in later years (Table 5). Dominant species in 2007 included the planted species, *Spartina alterniflora* and *Paspalum vaginatum*, as well as *Echinochloa walterii, Vigna luteola,* and *Polygonum spp.* (Figure 20). The planting schematic remained evident in 2007 with thick growth of *Spartina alterniflora* around the terrace edges; however, the planted *P. vaginatum* appeared to be becoming displaced on many of the terraces, particularly by *E. walterii*.

The total number of species observed decreased from 28 in 2007 to 16 in 2011 (Year 5) (Table 5). The dominant species in 2011 were *S. alterniflora* and *P. puncatum* (Figure 21), with *S. alterniflora* found in or near every plot sampled. A large decrease in percent cover of *E. walterii,* as well as the artificially planted species, *P. vaginatum*, was observed in 2011. Alternatively, an increase in the percent coverage of *Polygonum spp., V. luteola*, *Schoenoplectus americanus,* and *Sagittaria platyphylla* was observed in 2011. Newly recruited species by Year 5 include *Colocasia esculenta, Panicum repens, Bolboschoenus robustus,* and *Schoenoplectus tabernaemontani*.



Delta Management at Fort St. Philip (BS-11), Terrace Field
2006, 2013, and 2017 Land/Water Classification

Class	2002	2006	2013	2017
Land (acres)	0	18	24	63
Water (acres)	118	100	94	55
% Land	0%	15%	20%	53%

500 250 0 500 Meters
0 0.125 0.25 0.5 Miles

Figure 20. Land/water classification within the terrace field of the Delta Management at Fort St. Philip (BS-11) project in 2006, 2013, and 2017.

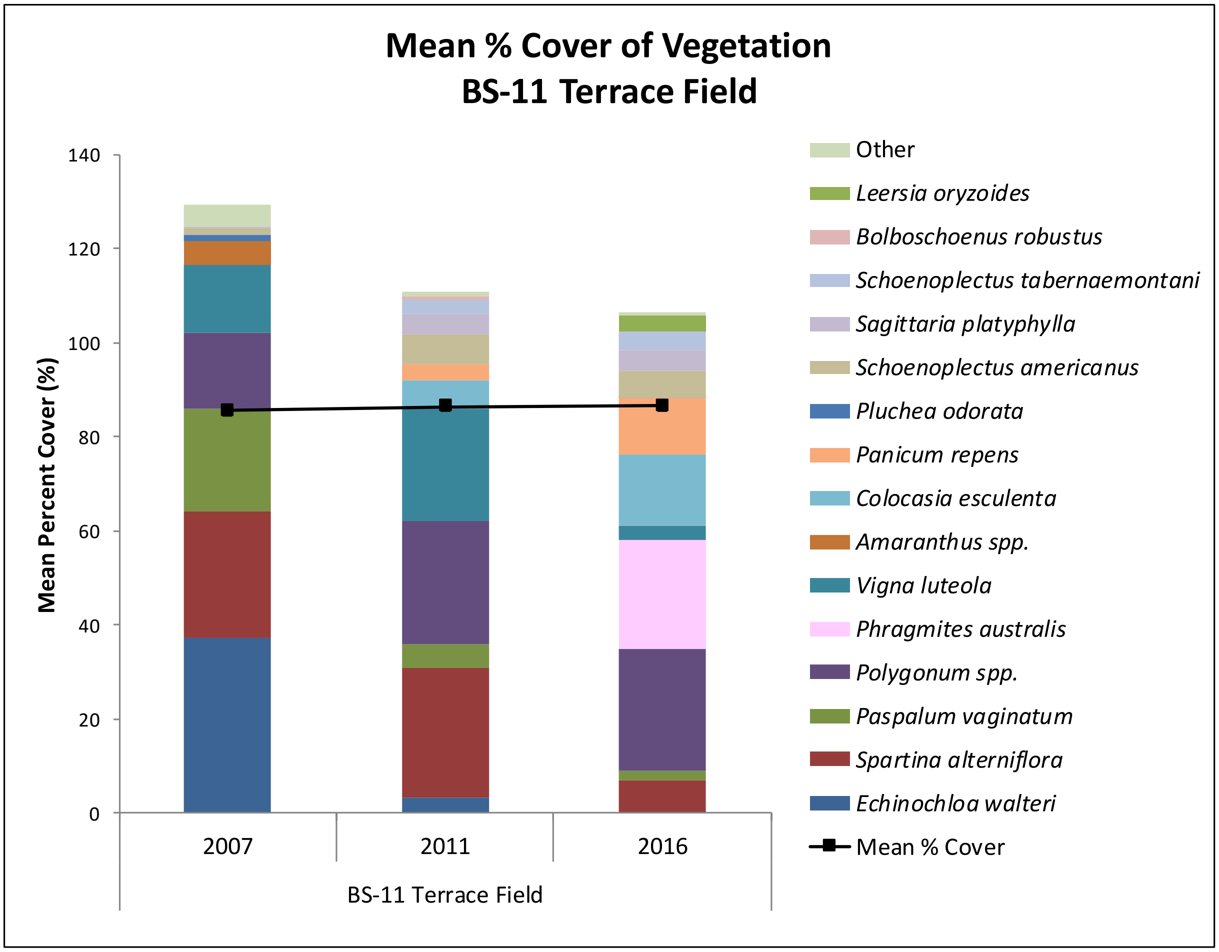


Figure 21. Mean percent cover of emergent vegetation species within the BS-11 terrace field in 2007, 2011, and 2016.

Table 5. Percent occurrence of emergent vegetation species observed within the BS-11 terrace field plots (or within 15-ft of plots*) in 2007, 2011, and 2016.

		% Occurrence of Plots (n=18)		
Scientific Name	**Common Name**	**2007**	**2011**	**2016**
Alternanthera philoxeroides	alligatorweed	6	22	22
Amaranthus spp	pigweed	56		*
Ammannia latifolia	pink redstem	*		
Bolboschoenus robustus	sturdy bulrush		22	6
Colocasia esculenta	coco yam		50	67
Cuscuta indecora	bigseed alfalfa dodder	6		
Cyperus spp	flatsedge	*		
Cyperus difformis	variable flatsedge	6		
Cyperus odoratus	fragrant flatsedge	11		
Cyperus oxylepis	sharpscale flatsedge	6		
Cyperus pseudovegetus	marsh flatsedge	6		
Cyperus strigosus	strawcolored flatsedge	6		
Echinochloa walteri	coast cockspur grass	89	50	*
Eclipta prostrata	false daisy	11		
Ipomoea sagittata	saltmarsh morning-glory			6
Kosteletzkya virginica	Virginia saltmarsh mallow	6		
Leersia oryzoides	rice cutgrass			28
Ludwigia grandiflora	Uruguayan primrose-willow	*		
Panicum repens	torpedo grass		33	56
Paspalum vaginatum	seashore paspalum	61	61	39
Phragmites australis	common reed			22
Pluchea odorata	sweetscent	11		6
Polygonum spp	knotweed	56	83	61
Sagittaria lancifolia	bulltongue arrowhead	6		
Sagittaria platyphylla	delta arrowhead	17	83	67
Schoenoplectus americanus	chairmaker's bulrush	28	67	56
Schoenoplectus californicus	California bulrush	22	6	
Schoenoplectus tabernaemontani	softstem bulrush		67	56
Sesbania drummondii	poisonbean	*	*	
Spartina alterniflora	smooth cordgrass	83	89	72
Spartina patens	saltmeadow cordgrass	*		
Strophostyles helvola	trailing fuzzybean	6		
Symphyotrichum tenuifolium	perennial saltmarsh aster		6	11
Typha spp	cattail	6	17	6
Vigna luteola	hairypod cowpea	78	50	56
Xanthium strumarium	rough cocklebur	*		
TOTAL # of SPECIES		**28**	**16**	**19**
		*Species found within 15-ft of plot		

By 2016 (Year 10), there was a further decrease in the planted species, *P. vaginatum* and *S. alterniflora*, which is no longer dominant. The dominant species in 2016 were *Polygonum spp.* and *P. australis*; however, *P. australis* was observed growing in dense, monotypic stands. In the four plots where it was observed, the mean percent cover of *P. australis* was 95-100%. In other plots, the typical community was a diverse deltaic mix dominated by *Polygonum spp.*, *C. esculenta*, and *P. repens,* with other species including *S. americanus*, *S. tabernaemontani*, and *S. platyphylla*. *Leersia oryzoides*, which was not previously observed within the terrace field plots, was found in 29% of the plots in 2016. The total number of species increased slightly from 16 in 2011 to 19 in 2016. Overall, the terraces remain well vegetated at ten years following construction and the species composition has transitioned from a post-disturbance community at Year 1 to a community indicative of a stable, deltaic marsh by Year 10. Although some terraces have subsided, vegetative cover now extends onto sediment deposited between the terrace rows.

Vegetation was also sampled annually at CRMS0139 from 2007 to 2018 at ten 4-m^2 plots (Figure 5). The vegetation community at CRMS0139 may be considered a natural reference marsh for comparison with the vegetation on the constructed terraces, although survey data indicate that there are differences in elevation between the two areas. The average marsh elevation at CRMS0139 (0.44 ft NAVD88, Geoid12A) is approximately 0.5 ft lower than the estimated mean elevation of the terrace crowns in 2016 (0.94 ft NAVD88, Geoid12A); therefore, frequency of inundation is expected to be higher at CRMS0139. Mean percent cover of vegetation at CRMS0139 has remained generally stable at 90-94% in most sample years, with temporary drops in vegetative coverage observed in 2007, 2008, and 2013 (Figure 22). Over the 12 year sample period, the percent coverage of *P. australis* has remained relatively stable, whereas the relative abundance of other dominant species have shifted over time. Percent coverage of *C. esculenta* has shown an increasing trend since 2013, while the percent coverage of *P. repens*, *S. alterniflora,* and *A. philoxeroides* have decreased over time. Dominant species in the most recent sample year (2018) were *C. esculenta* and *Polygonum spp*, with other commonly occurring species including *P. australis*, *V. luteola*, and *S. platyphylla*. A comparison of the percent composition of species between the terrace field and CRMS0139 over time indicates that the terrace field community was increasingly similar to CRMS0139 by 2016 (Figure 23). One difference observed in 2016 was a higher percentage of *Polygonum spp*. within the terrace field, although a 33% increase in *Polygonum* was later observed at CRMS0139 in 2018. With the exception of *S. patens* and *A. philoxeroides*, most species observed at CRMS0139 are now also present within the terrace field and the relative abundance of species in the terrace field is becoming more similar to the natural surrounding marsh.

Due to vegetative colonization observed within Receiving Bays 1A and Alt 2A by Year 10 (2016), nine sample plots were established in Receiving Bay 1A and five sample plots were established in Receiving Bay Alt 2A along the topo/bathy elevation transects where vegetative growth was present (Figures 5 and 6). The elevation of each established plot (ft NAVD88, Geoid12A) was then approximated from the 2016 elevation transect data. In Receiving Bay 1A, *Sagittaria platyphylla* was the dominant species in 7 of the 9 plots, with percent coverage ranging from 3 to 95% (Figure 24A). Of the remaining two plots, one was dominated by *Zizaniopsis miliacea* at 85% cover and one was dominated by *Colocasia esculenta* at 5% cover. The only other species observed was *A. philoxeroides* within one sample plot. The sediment elevation of all plots was above the 90% inundation level (-0.39 ft) in 2016. The mean elevation of the plots in 2016 was 0.31 ft NAVD88 and ranged from 0.01 to 0.75 ft. The was no apparent correlation between percent coverage of vegetation and sediment elevation (R^2=0.005) in Receiving Bay 1A, which may be due in part to the highly dynamic nature of the Crevasse 1A splay (Figure 5). In Receiving Bay Alt 2A, the only species observed within the 5 sample plots was *S. platyphylla* with percent coverage ranging from 3 to 95% (Figure 24B). There was a significant correlation between elevation and percent cover (R^2=0.9772) in Receiving Bay Alt 2A with the lowest percent coverage of vegetation observed within the lowest elevation plots. Three of the plots were below the 90% inundation level with elevations ranging from -0.74 to -0.46 ft and showed percent coverages ranging from 3 to 15%, whereas a percent coverage of 90-95% was observed within the two plots above the 90% inundation level with elevations of 0.13 and 0.25 ft. Vegetation will be surveyed within the receiving bays and terrace field again at Year 15 (2021) and will continue to be sampled annually at CRMS0139.

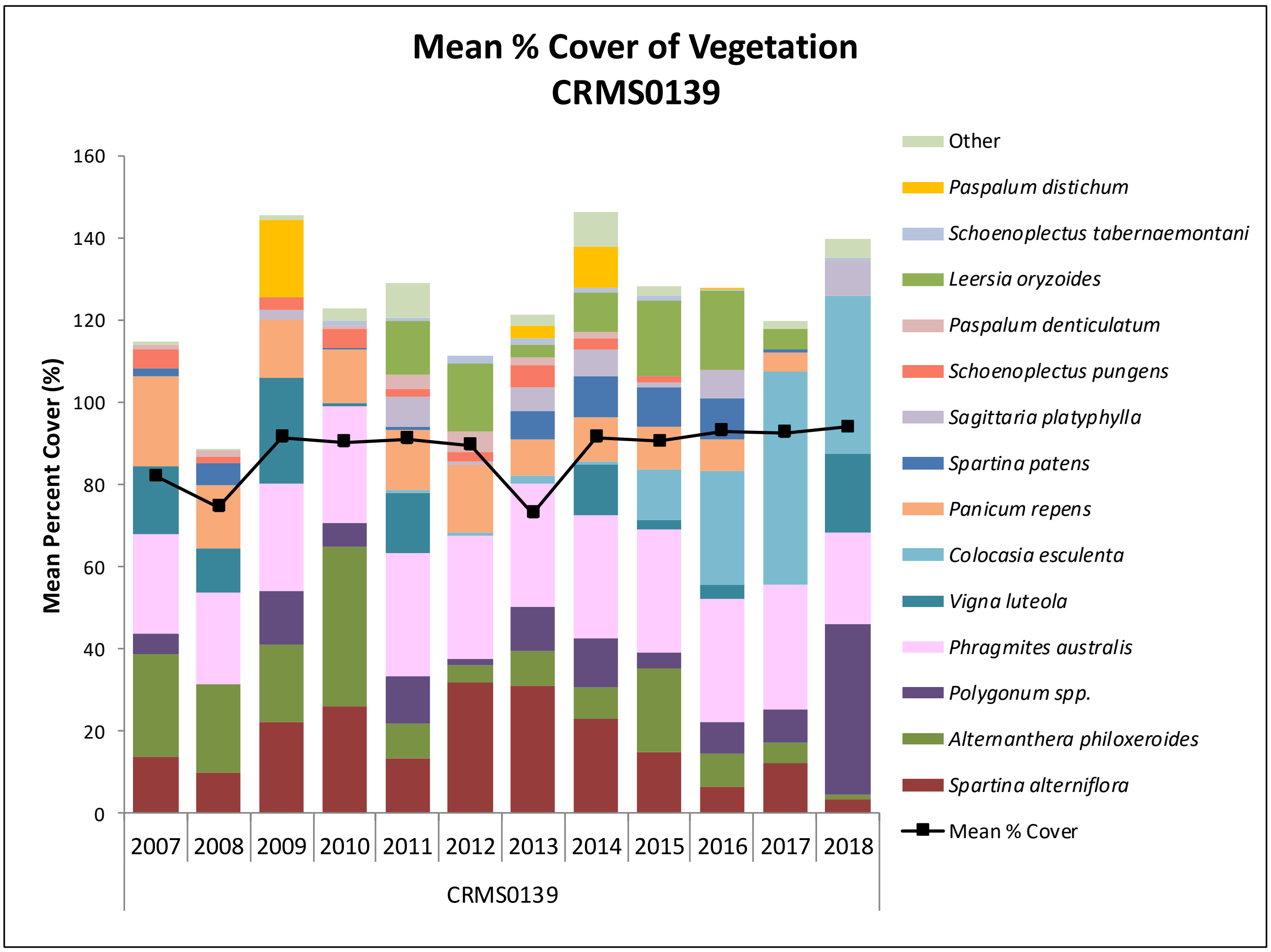


Figure 22. Mean percent cover of emergent vegetation species at CRMS0139 from 2007 to 2016.

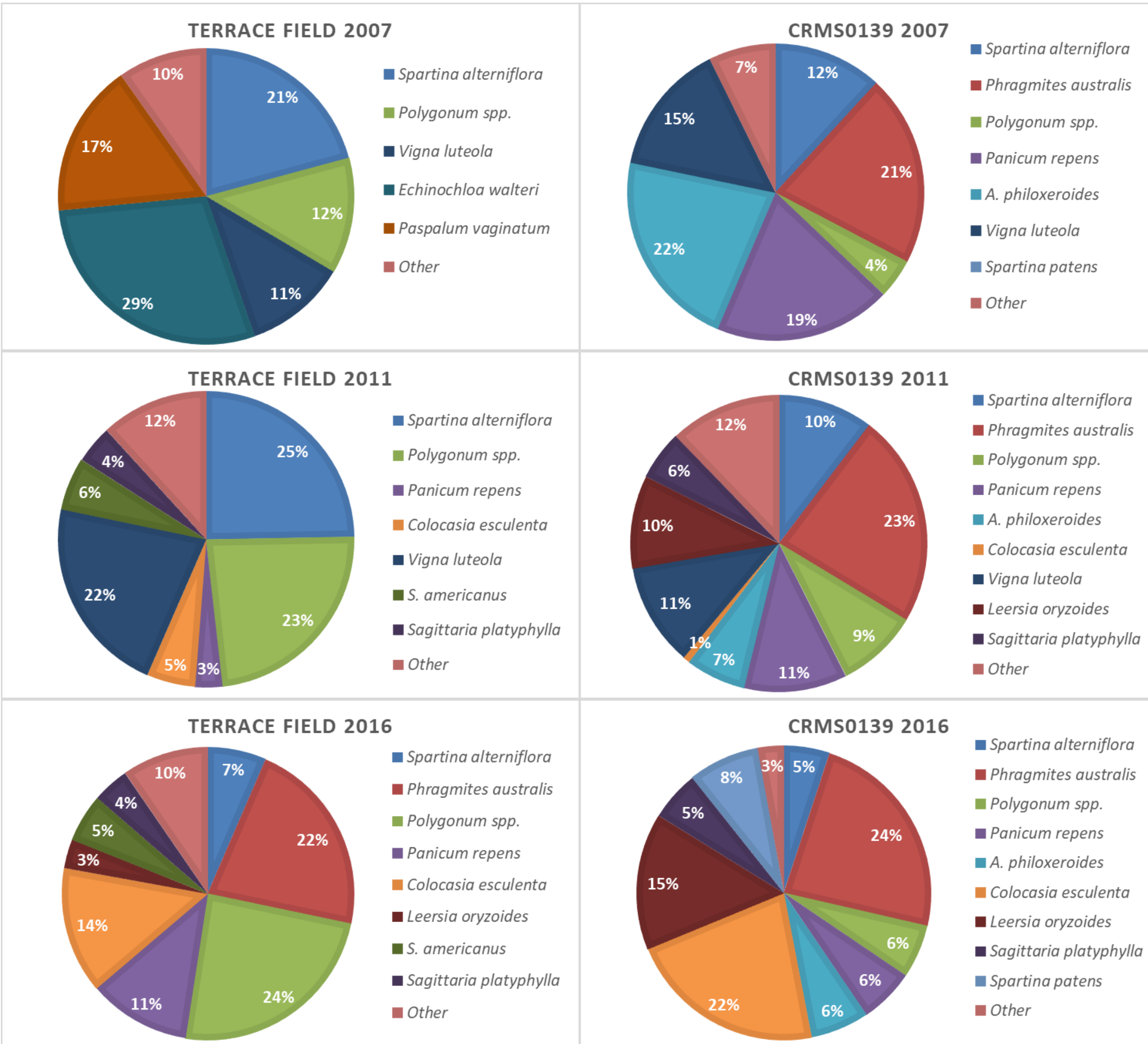


Figure 23. Percent composition of emergent vegetation species observed within the terrace field and at CRMS0139 in 2007, 2011, and 2016.

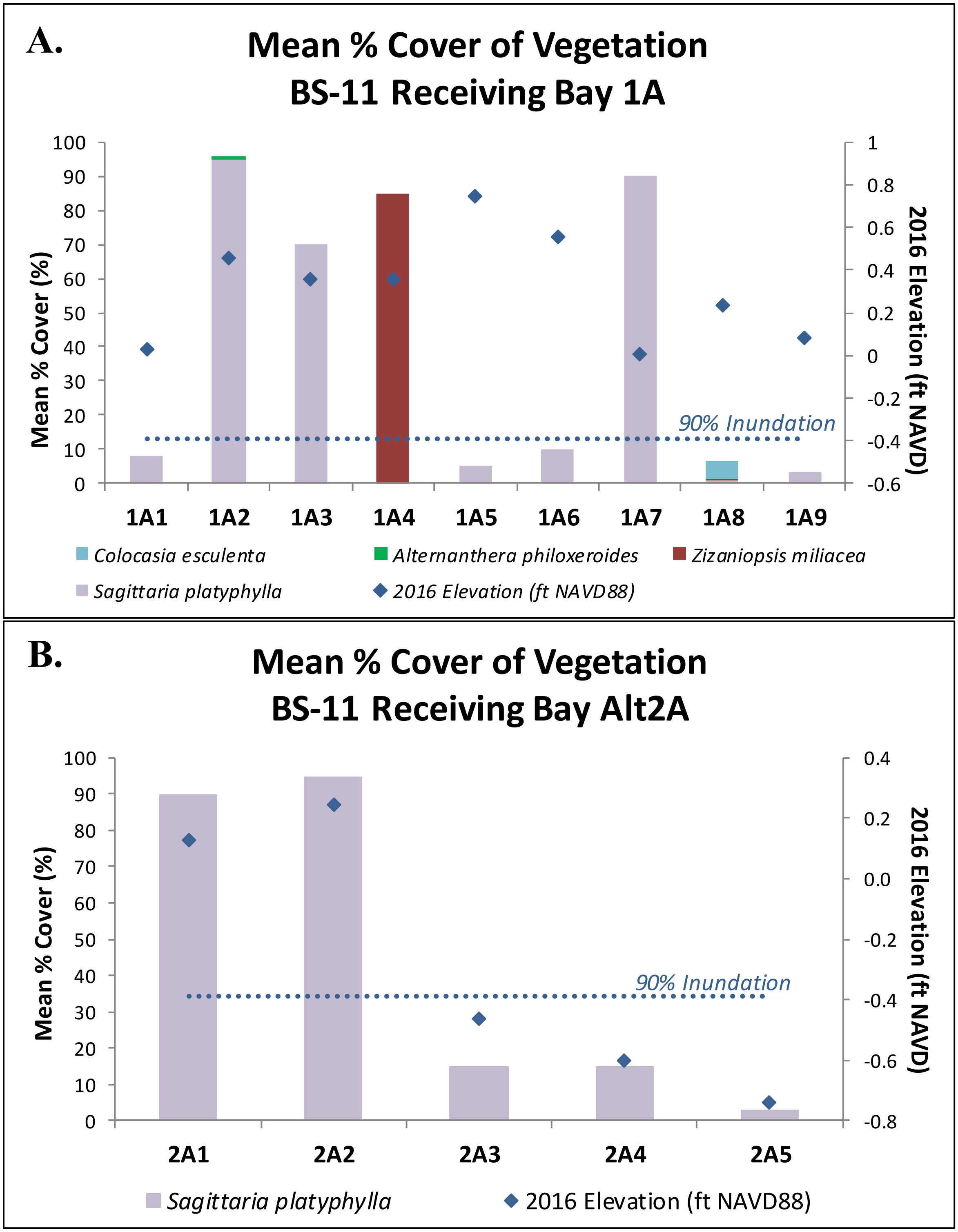


Figure 24. Mean percent cover (%) of vegetation and surface elevation (ft NAVD88) at sample plots established within Receiving Bay 1A (A) and Receiving Bay Alt 2A (B) in 2016.

V. Conclusions

a. Project Effectiveness

At 12 years following construction, the Delta Management at Fort St. Philip project appears to be surpassing project predictions of land acreage within the crevasse receiving bays. Although significant land gains did not begin to occur until five years following construction, a total of 543 acres were gained within the project area since 2002 with 453 of those acres (83%) being gained between Years 5 and 11. This surpasses the Year 20 predicted net land gain of 443 acres by 100 acres. An estimated 174 acres of land gain were predicted to occur naturally without project construction; therefore, there was an observed additional gain of 369 acres that are attributable to the BS-11 project. All crevasses performed well with percent increase in total land area ranging from 35% (1B, Alt 2A) to 48% (1C) from 2002 to 2017. The rate of land gain for all crevasses combined from 2002 to 2017 was 36 acres/year with gain rate per crevasse being highly correlated with receiving bay size. Above average annual river stage from 2015 to 2018 (measured at USACE Gauge 01480 near Venice, LA) most likely enhanced the performance of the project through increased sedimentation and scouring of the crevasse channels.

Elevation surveys within analyzed receiving bays also showed gains in sediment volume and surface elevation between Years 5 and 10 post-construction, although there was an initial loss in volume between Years 1 and 5 as splay formation and scour occurred. Estimated net volume gains from 2002 to 2016 were 230,406 CY in Receiving Bay 1A (1,134 CY/ac), 7,864 CY in Receiving Bay Alt 2A (371 CY/ac), 5,332 CY in Receiving Bay 2B (1,238 CY/ac), and 36,347 CY in Receiving Bay 2C (788 CY/ac) for a total volume gain of 279,948 CY within those four receiving bays. Mean surface elevation gains within the receiving bays from 2002 to 2016 ranged from +0.24 to +1.68 cm/yr, and the surface elevation change rate measured from 2008 to 2018 at CRMS0139 (Receiving Bay 1A) was estimated to be +1.17 cm/yr.

The terrace field appears to be successfully trapping sediment within Receiving Bay 1A as intended based on land gain and estimated increases in sediment volume. By 2017, there were 63 acres of land created within the terrace field, surpassing the project goal of 25 acres by Year 20. The land gain rate within the terrace field following construction was approximately 4.1 acres/year. There was a sediment gain within the terrace field of approximately +20,876 CY by Year 5 (2011) followed by a much larger volume gain of +159,435 CY between Years 5 and 10 for a net volume gain of +180,311 CY. Due to construction using in situ material, much of the sediment gain in the first five years following construction served to replace sediment within the adjacent borrow areas leading to modest volume gains initially, while the significant gain observed between Years 5 and 10 was enhanced further by the higher river stage.

As surface elevation increased, all six receiving bays showed a progression toward the optimum flooding range for marsh productivity (10 to 90% inundation) by Year 10. This was reflected by an increase in vegetative colonization of the newly formed crevasse splays by 2016. *Sagittaria platyphylla* (delta arrowhead) was generally the first species to establish as surface elevation became subaerial. Within the terrace field, the percent composition of vegetative species has become increasingly similar to the natural surrounding marsh at CRMS0139 from 2007 to 2016.

b. Recommended Improvements

There are no recommended improvements at this time. Although some of the crevasse channels have infilled, re-dredging has been determined to be cost-prohibitive and all receiving bays are exhibiting sufficient land gains.

c. Lessons Learned

- Predicting land gains for artificial crevasse projects can be challenging due to the complex combination of factors influencing splay growth rates. Crevasse parameters used to predict growth rates during BS-11 project design included parent channel order, parent channel width, crevasse age, crevasse cross-sectional area and receiving bay area. Additional parameters significantly affecting splay growth such as receiving bay depth, sediment load of the water column, flow velocity, river stage, and distance from main river channel were unavailable for the design growth analysis. The land growth observed within the BS-11 crevasses was less than predicted by Year 5 and greater than predicted by Year 11. This observation is consistent with other crevasse studies which have demonstrated that land growth within new crevasse splays is not linear (Cahoon et al. 2011) and may demonstrate a time lag where depositional processes must overcome the erosional processes that initiate following crevasse formation (Yuill et al. 2016, Kolker et al. 2012). Higher than normal river stage most likely contributed to increased gains observed by Year 11, which can not be predicted during project design. Land growth, however, was already occurring before the high river years as indicated by land/water analyses of imagery collected in 2013.

- Performance evaluation of artificial crevasse projects may be premature at Year 5 due to the time lag in subaerial land creation. For future crevasse projects, the scheduling of expensive maintenance events at Year 5 based on project performance should be carefully considered. Maintenance dredging of the BS-11 crevasses was scheduled to occur at Year 5 in response to channel infilling and slow land growth in the receiving basins, but was cancelled due to equipment access issues. Despite the lack of maintenance dredging, land growth has exceeded project predictions by Year 11. The high river events appear to have contributed to 'self-maintenance' of the crevasse channels through increased flow velocities.

- This is the first CWPPRA project to combine marsh terracing with an artificial crevasse feature, and monitoring results have indicated that this is a successful technique. Once an open water pond, the BS-11 terrace field now contains 63 acres of vegetated land at 11 years following construction, which is 38 more acres than had been predicted at Year 20. Sediment loss during construction due to excavation of the borrow channel offset much of the sediment gains from Years 1 to 5, with subaerial land creation occurring primarily after Year 5.

- Monitoring budgets often rely on pre-construction or as-built elevation surveys funded through design or construction. Layout and methodology of as-built surveys may need to be modified when they are to provide vital baseline data for comparison with future surveys. For accurate monitoring post-construction, baseline surveys must acknowledge long-term monitoring goals. Communication between monitoring and construction managers is vital when planning elevation surveys with shared goals.

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Appendix A
(Three Year O&M Budget Projection)

Delta Management at Fort St. Phillip (BS-11)

Federal Sponsor: USFWS

Construction Completed : November 20, 2006

Current Approved O&M Budget June 2011	Year - 0 FY07	Year - 1 FY08	Year -2 FY09	Year -3 FY10	Year -4 FY11	*Year -5 FY12*	*Year -6 FY13*	*Year -7 FY14*	Year -8 FY15	Year -9 FY16	Year -10 FY17	Year -11 FY18	Year -12 FY19	Year -13 FY20	Year -14 FY21	Year -15 FY22	Year -16 FY23	Year - 17 FY24	Year -18 FY25	Year -19 FY26	OCPR Project Estimate Project Life Budget	CWPPRA Allocated Money Currently Funded (Sum YR 0 to YR 19)
State O&M	$4,500	$4,617	$4,737	$4,860	$209,909	$5,116	$5,249	$5,386	$5,526	$245,546	$5,817	$5,968	$6,123	$6,038	$6,216	$6,453	$6,785	$6,962	$7,143	$7,328	$560,279	$560,279
Corps Admin																					$20,039	$20,039
Federal S&A																					$0	$0
Total																					$580,318	$580,318

Projected O&M Expenditures	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	Remaining Project Life	*Current 3 year Request (FY12, 13, 14)*
Maintenance Inspection														$6,038	$6,216	$6,453					$18,707	$0
General Maintenance																					$0	$0
Structure Operation																					$0	$0
Federal S&A																					$0	$0
State S&A																					$0	$0
E&D																					$0	$0
Surveys																					$0	$0
Construction																					$0	$0
Construction Oversight																					$0	$0
Total									$0	$0	$0	$0	$0	$6,038	$6,216	$6,453	$0	$0	$0	$0	$18,707	$0

Total O&M Expenditures from COE Report (Inception to present)	$4,197.62	From 5/23/11
State O&M Expenditures not submitted for in-kind credit	$0	
Federal Sponsor MIPRs (if applicable) (REQUESTED MONEY)		
Total Estimated O&M Expenditures (as of May 2011)	**$4,197.62**	

Current O&M Budget less COE Admin *(State O&M Currently Funded + Fed S&A Currently Funded)*	$560,279	
Remaining Available O&M Budget *(Current O&M - Total Est. O&M Expenditures)*	$556,081	
Incremental Funding Request Amount FY12-FY14	**$ (556,081.40)**	Unexpended

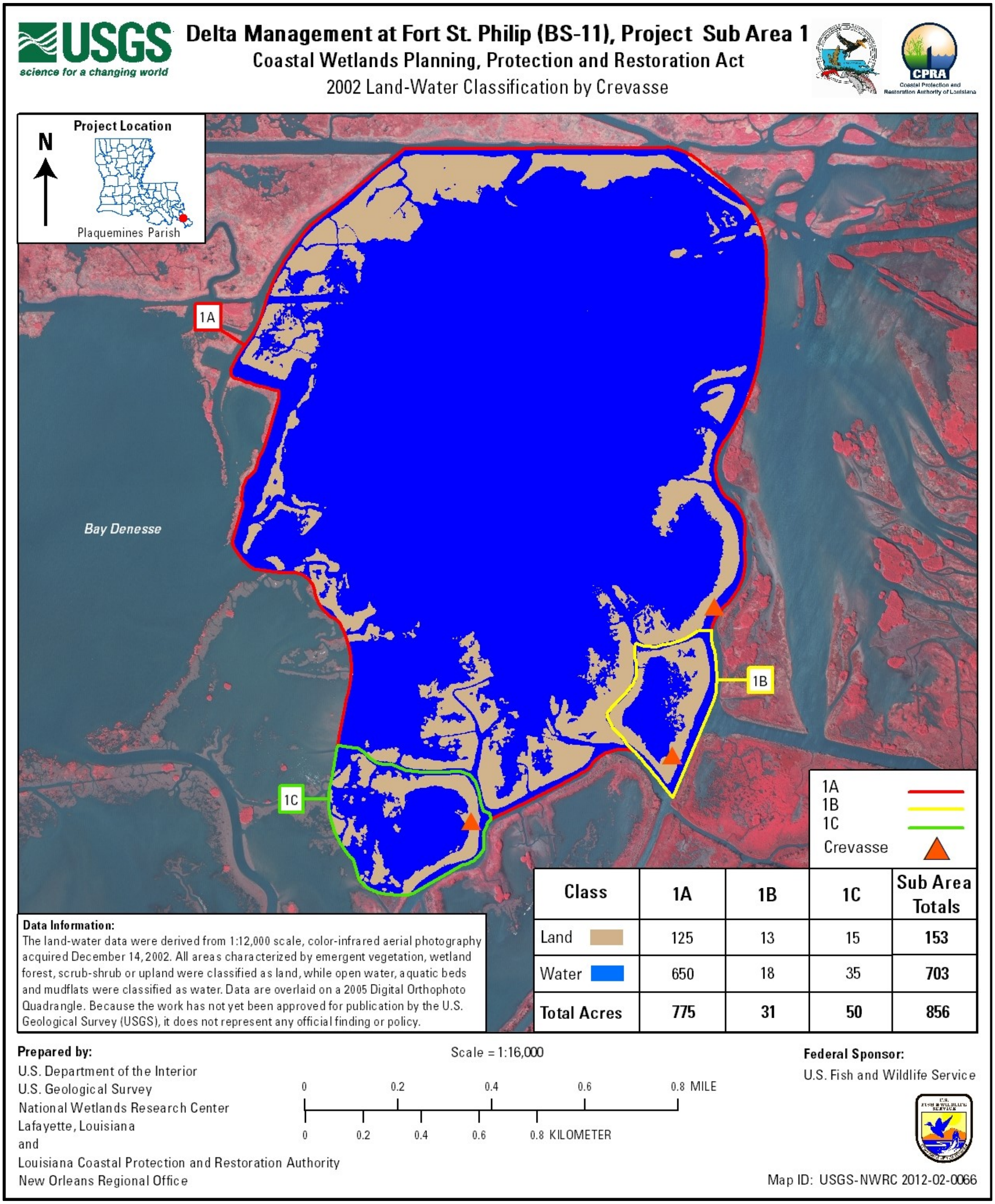
Current Project Life Budget less COE Admin *(State O&M Porject Life Budget + Fed S&A Project Life Budget)*	$560,279
Total Projected Project Life Budget *(Remaining Project Life + Total Estimated O&M Expenditures)*	$22,905
Project Life Budget Request Amount	**-$537,374**

Appendix B
(Inspection Photographs)

Appendix B-1. Aerial imagery of the BS-11 project area (Subarea 1) collected on October 11, 2018.

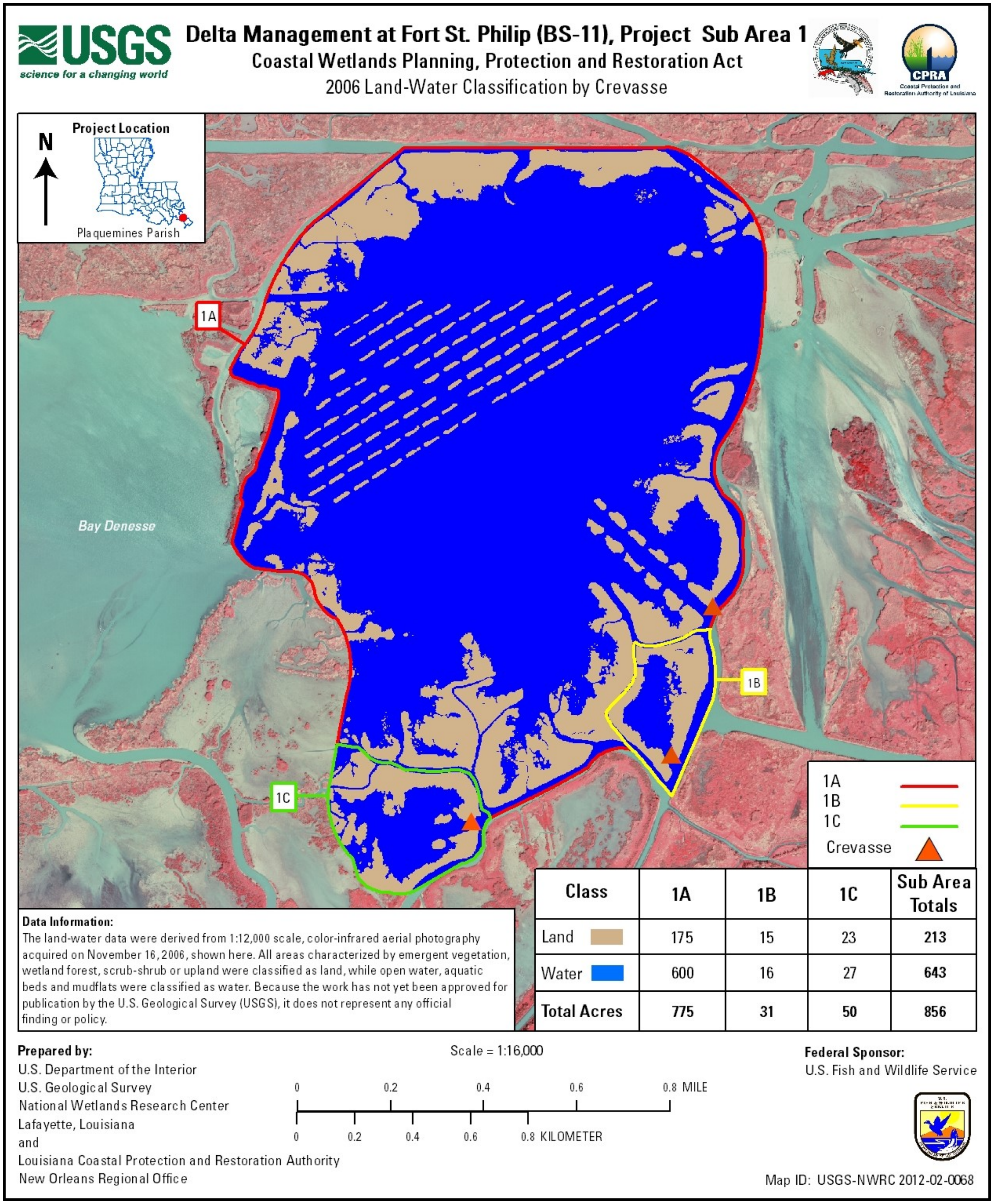
Appendix B-2. Aerial imagery of the BS-11 project area (Subarea 2) collected on October 11, 2018.

Appendix C
(Land-Water Analyses)



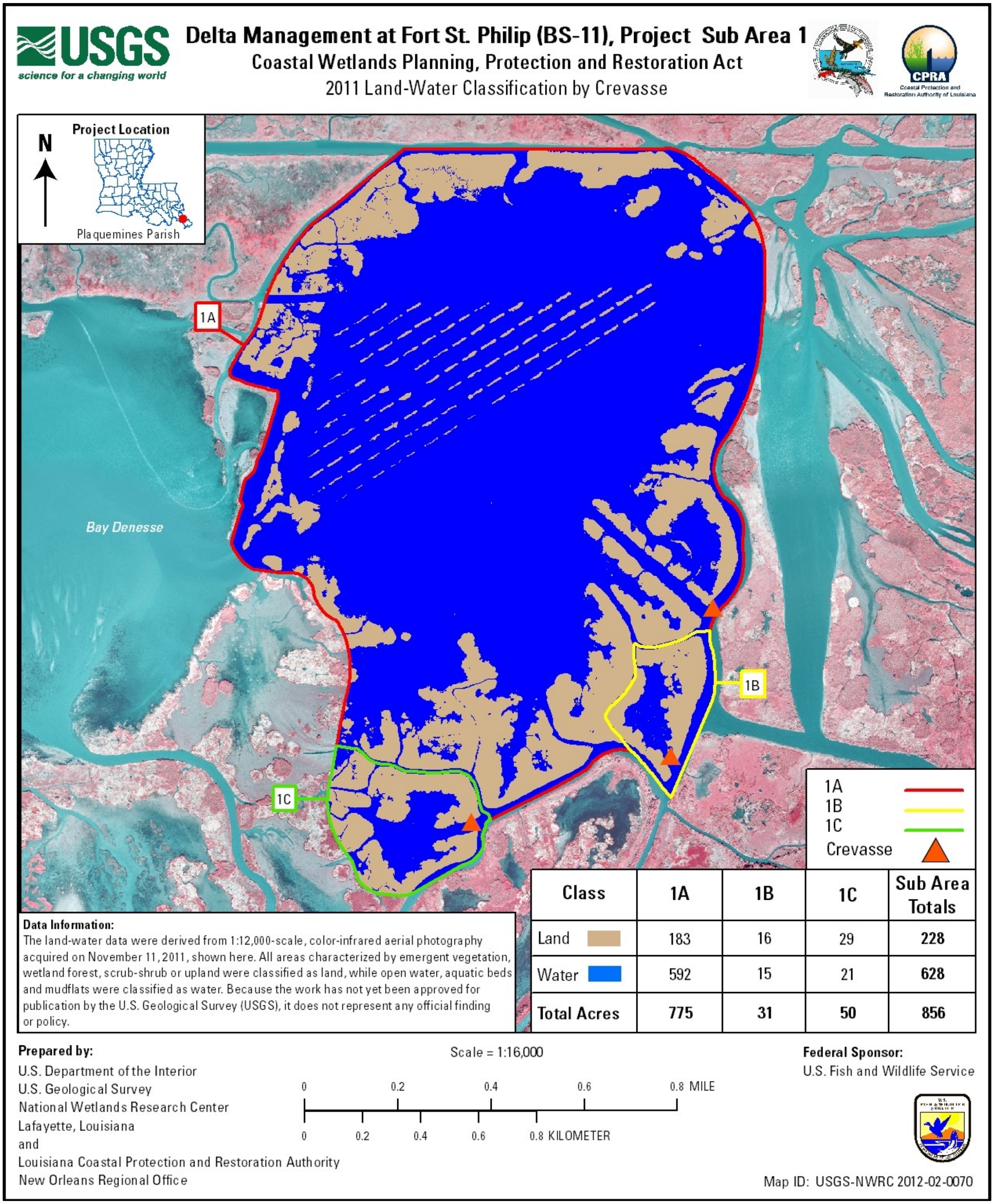
Class	1A	1B	1C	Sub Area Totals
Land	125	13	15	**153**
Water	650	18	35	**703**
Total Acres	**775**	**31**	**50**	**856**

Appendix C1. 2002 land-water analysis for Crevasses 1A, 1B, and 1C of the Delta Management at Fort St. Philip (BS-11) project.



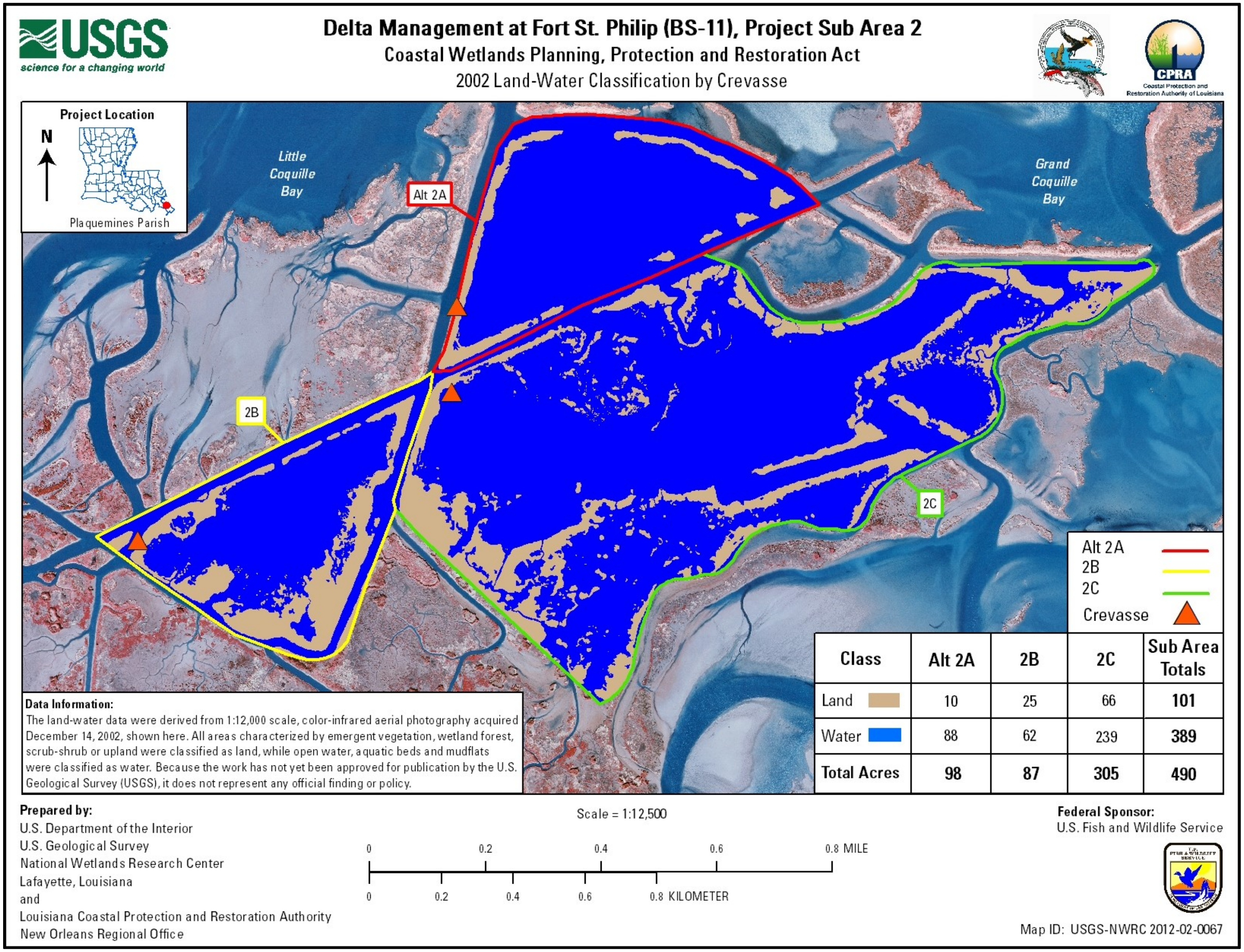
Class	1A	1B	1C	Sub Area Totals
Land	175	15	23	213
Water	600	16	27	643
Total Acres	775	31	50	856

Appendix C2. 2006 land-water analysis for Crevasses 1A, 1B, and 1C of the Delta Management at Fort St. Philip (BS-11) project.



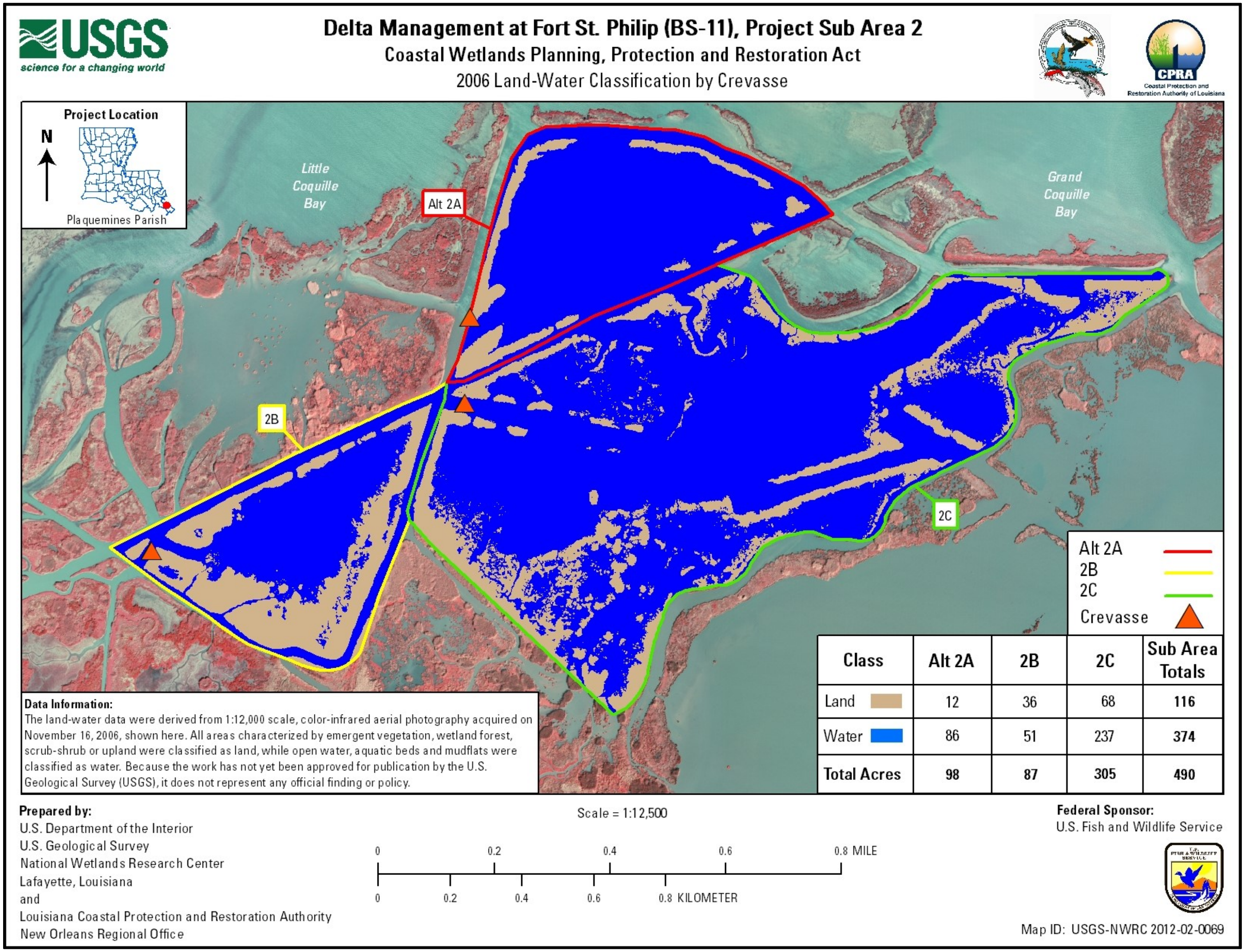
Class	1A	1B	1C	Sub Area Totals
Land	183	16	29	228
Water	592	15	21	628
Total Acres	775	31	50	856

Appendix C3. 2011 land-water analysis for Crevasses 1A, 1B, and 1C of the Delta Management at Fort St. Philip (BS-11) project.



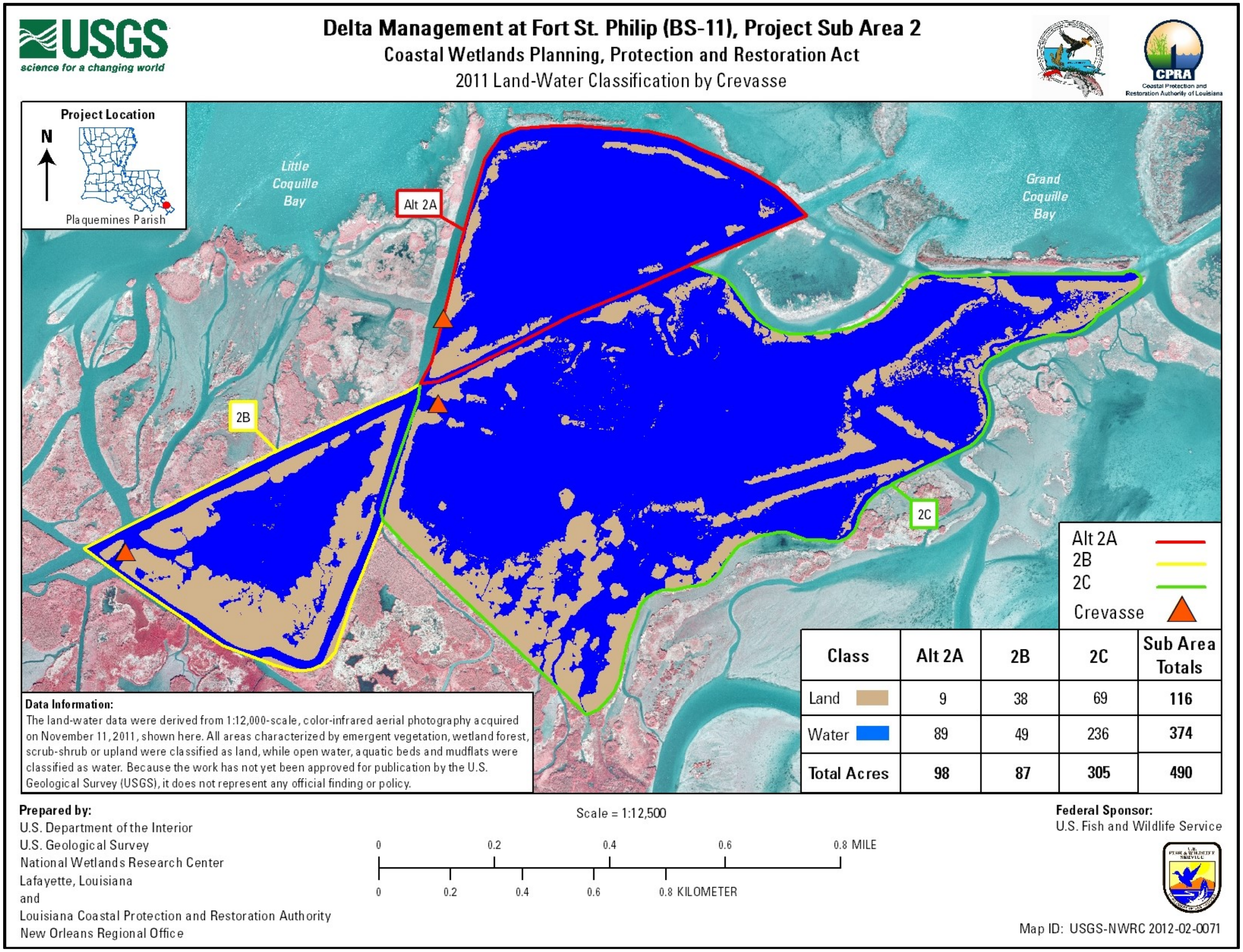
Class	Alt 2A	2B	2C	Sub Area Totals
Land	10	25	66	101
Water	88	62	239	389
Total Acres	98	87	305	490

Appendix C4. 2002 land-water analysis for Crevasses Alt 2A, 2B, and 2C of the Delta Management at Fort St. Philip (BS-11) project.



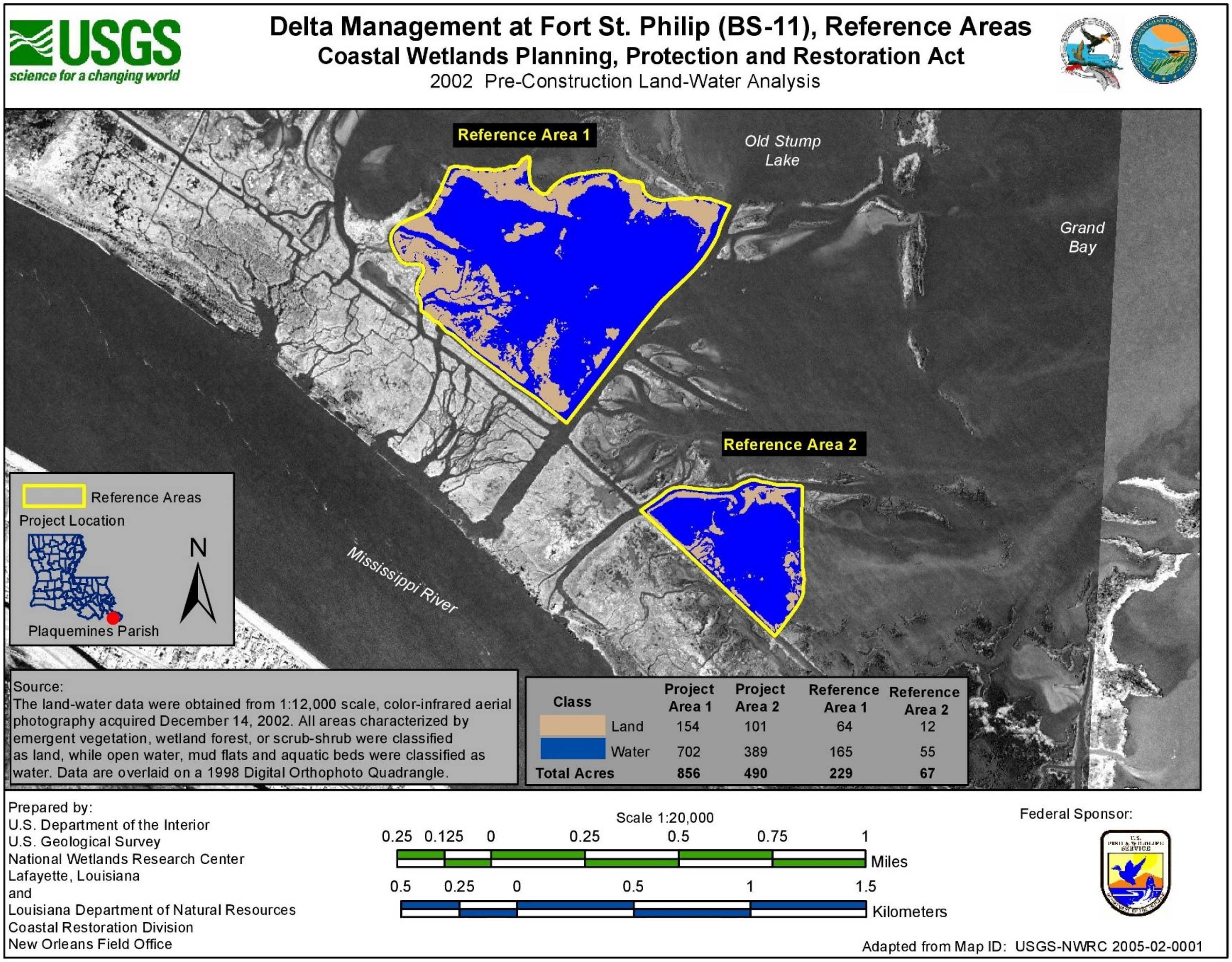
Class	Alt 2A	2B	2C	Sub Area Totals
Land	12	36	68	116
Water	86	51	237	374
Total Acres	98	87	305	490

Appendix C5. 2006 land-water analysis for Crevasses Alt 2A, 2B, and 2C of the Delta Management at Fort St. Philip (BS-11) project.

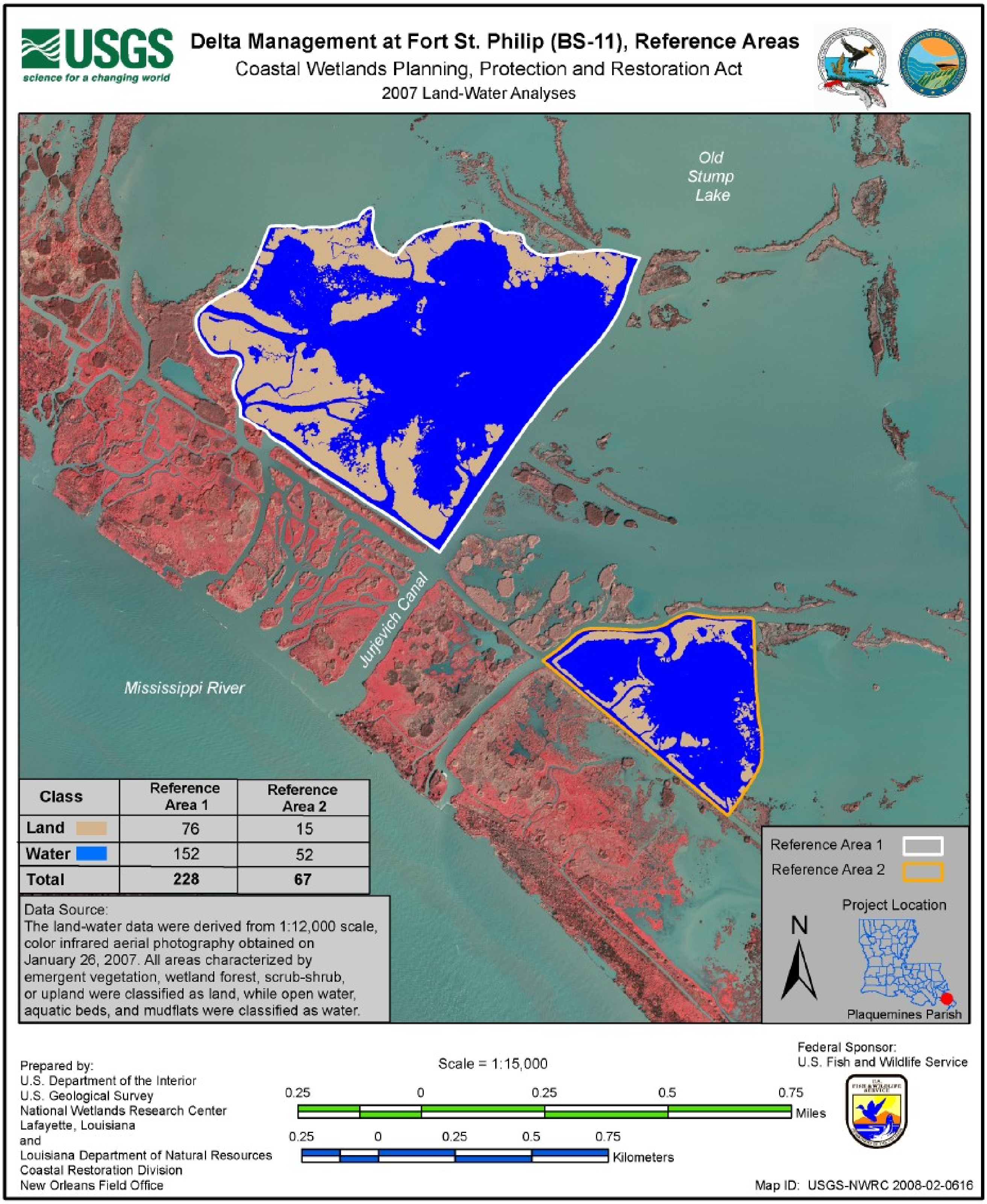


Class	Alt 2A	2B	2C	Sub Area Totals
Land	9	38	69	116
Water	89	49	236	374
Total Acres	98	87	305	490

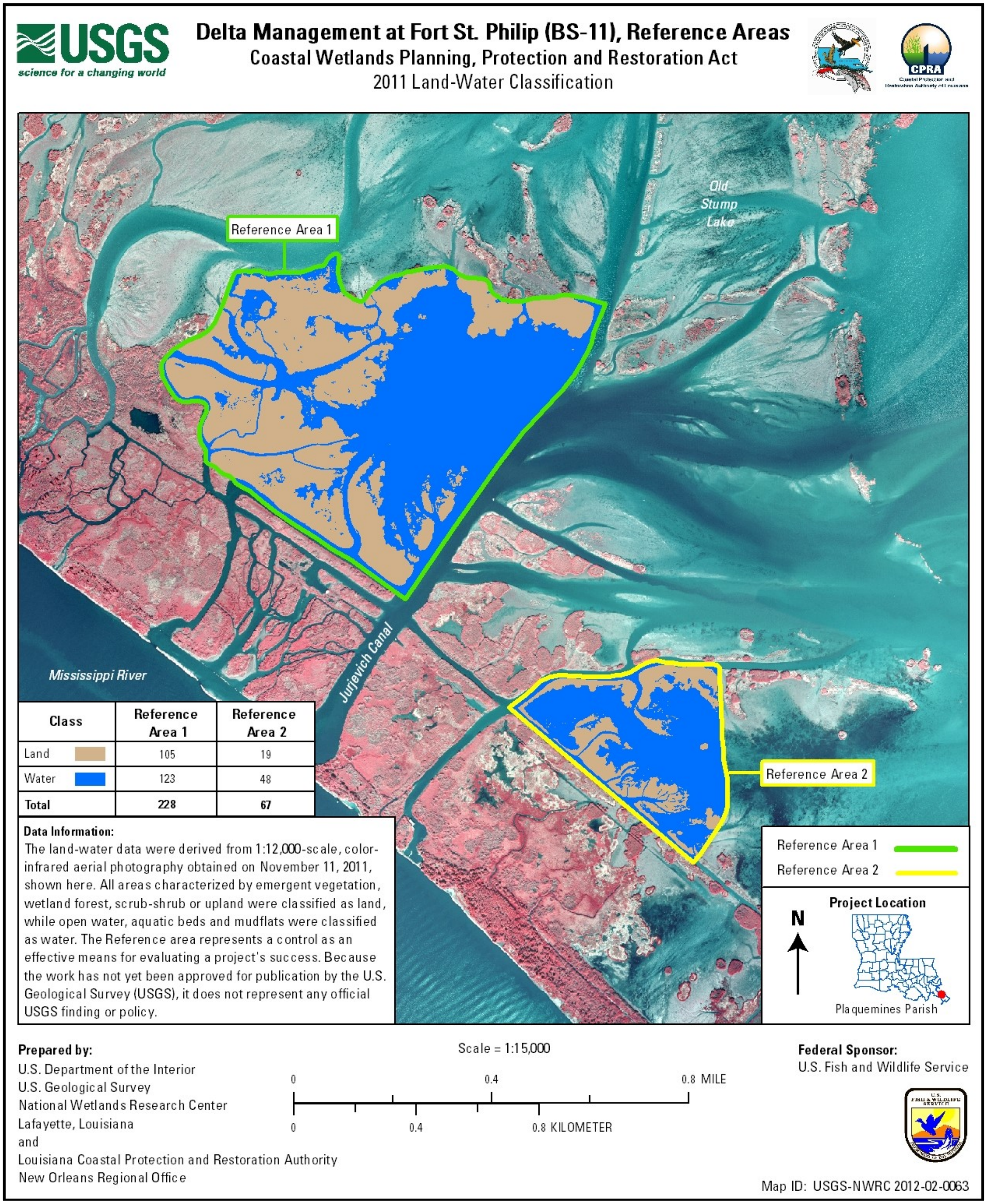
Appendix C6. 2011 land-water analysis for Crevasses Alt 2A, 2B, and 2C of the Delta Management at Fort St. Philip (BS-11) project.



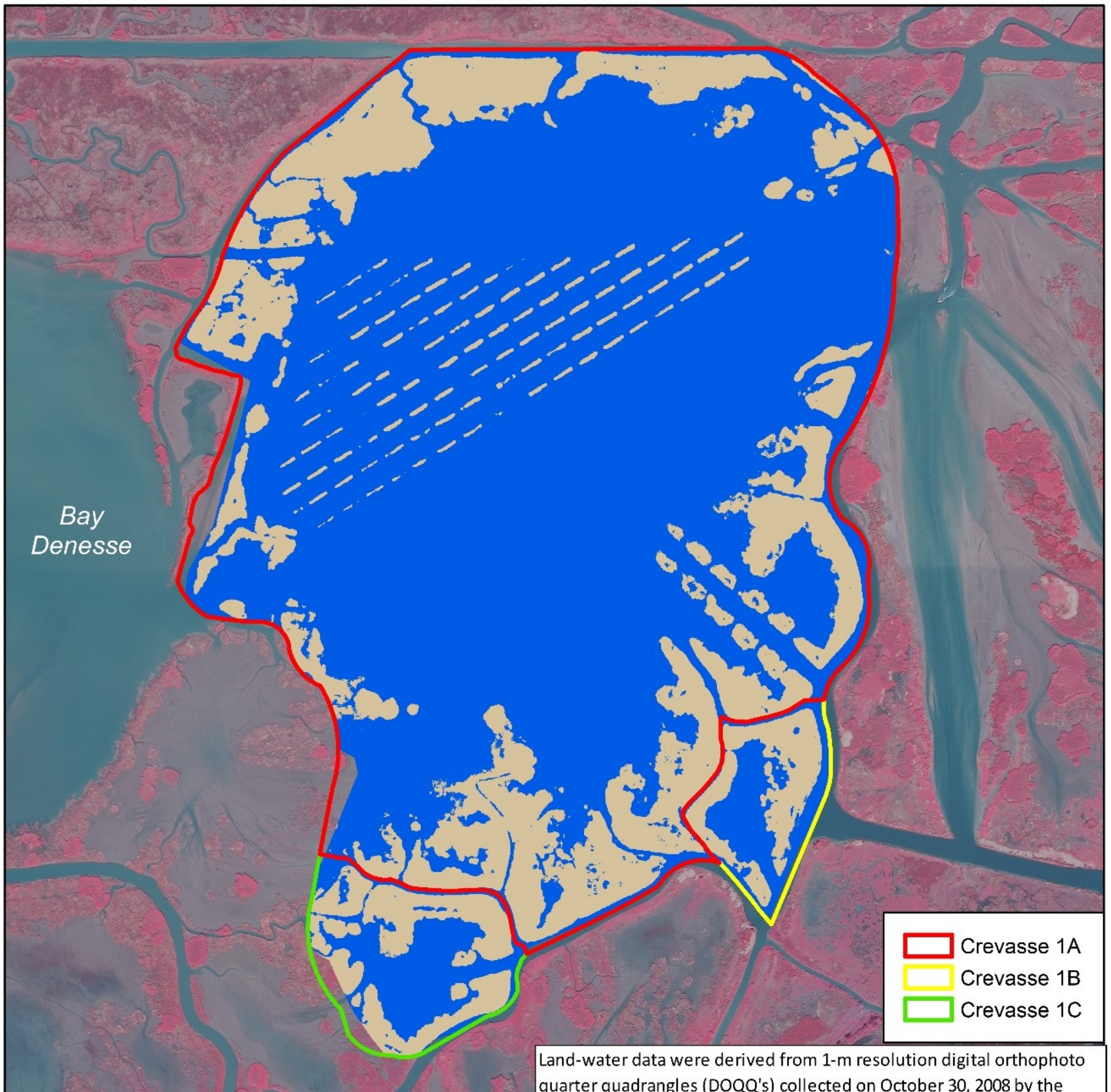
Appendix C7. 2002 land-water analysis for Reference Area 1 and 2 of the Delta Management at Fort St. Philip (BS-11) project.



Appendix C8. 2007 land-water analysis for Reference Areas 1 and 2 of the Delta Management at Fort St. Philip (BS-11) project.



Appendix C9. 2011 land-water analysis for Reference Areas 1 and 2 of the Delta Management at Fort St. Philip (BS-11) project.



Class	1A	1B	1C	Sub Area Totals
Land	180	15	23	**218**
Water	593	16	23	**632**
Total Acres	**773**	**31**	**46**	**850**

Land-water data were derived from 1-m resolution digital orthophoto quarter quadrangles (DOQQ's) collected on October 30, 2008 by the USGS National Wetlands Research Center for CWPPRA (CRMS). Uplands, emergent vegetation, wetland forest, and scrub-shrub were classified as land, while open water, floating or submerged aquatics, and non-vegetated mudflats were classified as water. Land-water analysis of a larger dataset was conducted by Costanza and Frank-Gilchrist (2019) and clipped to BS-11 project areas by the CPRA.

Delta Management at Fort St. Philip (BS-11), Subarea 1
2008 Land-Water Classification (Costanza and Frank-Gilchrist 2019)

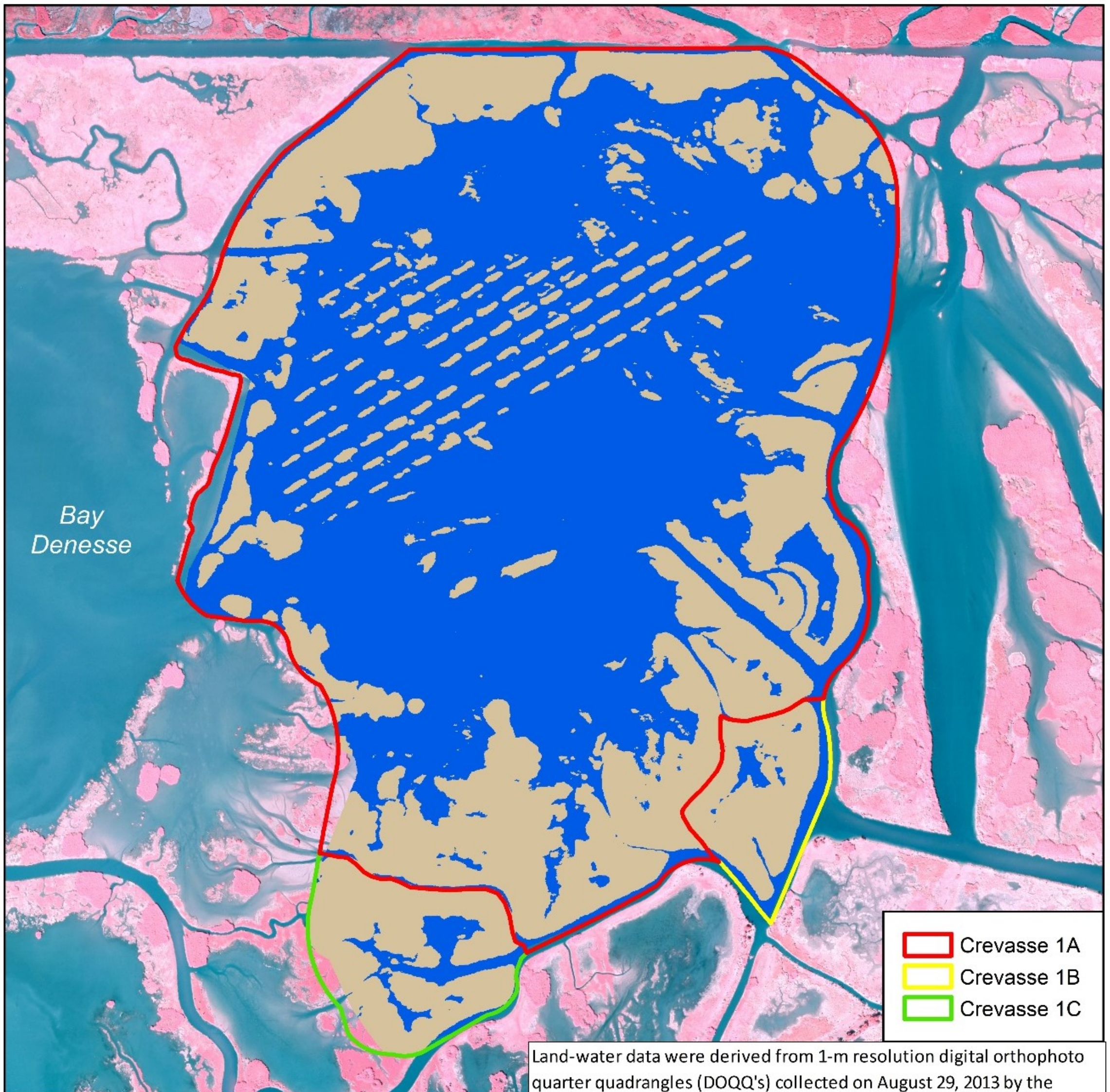
0 0.125 0.25 0.5 Miles

0 0.2 0.4 0.8 Kilometers

Map Produced by:
Coastal Protection and Restoration Authority
New Orleans Regional Office
August 8, 2019

Background Imagery:
2008 CIR DOQQ

Appendix C10. 2008 land-water analysis for Subarea 1 of the Delta Management at Fort St. Philip (BS-11) project conducted by Costanza and Frank-Gilchrist (2019).



Class	1A	1B	1C	Sub Area Totals
Land	264	24	38	**326**
Water	510	7	9	**526**
Total Acres	**774**	**31**	**47**	**852**

Land-water data were derived from 1-m resolution digital orthophoto quarter quadrangles (DOQQ's) collected on August 29, 2013 by the National Agriculture Imagery Program (NAIP), USDA. Uplands, emergent vegetation, wetland forest, and scrub-shrub were classified as land, while open water, floating or submerged aquatics, and non-vegetated mudflats were classified as water. Land-water analysis of a larger dataset was conducted by Costanza and Frank-Gilchrist (2019) and clipped to BS-11 project areas by the CPRA.

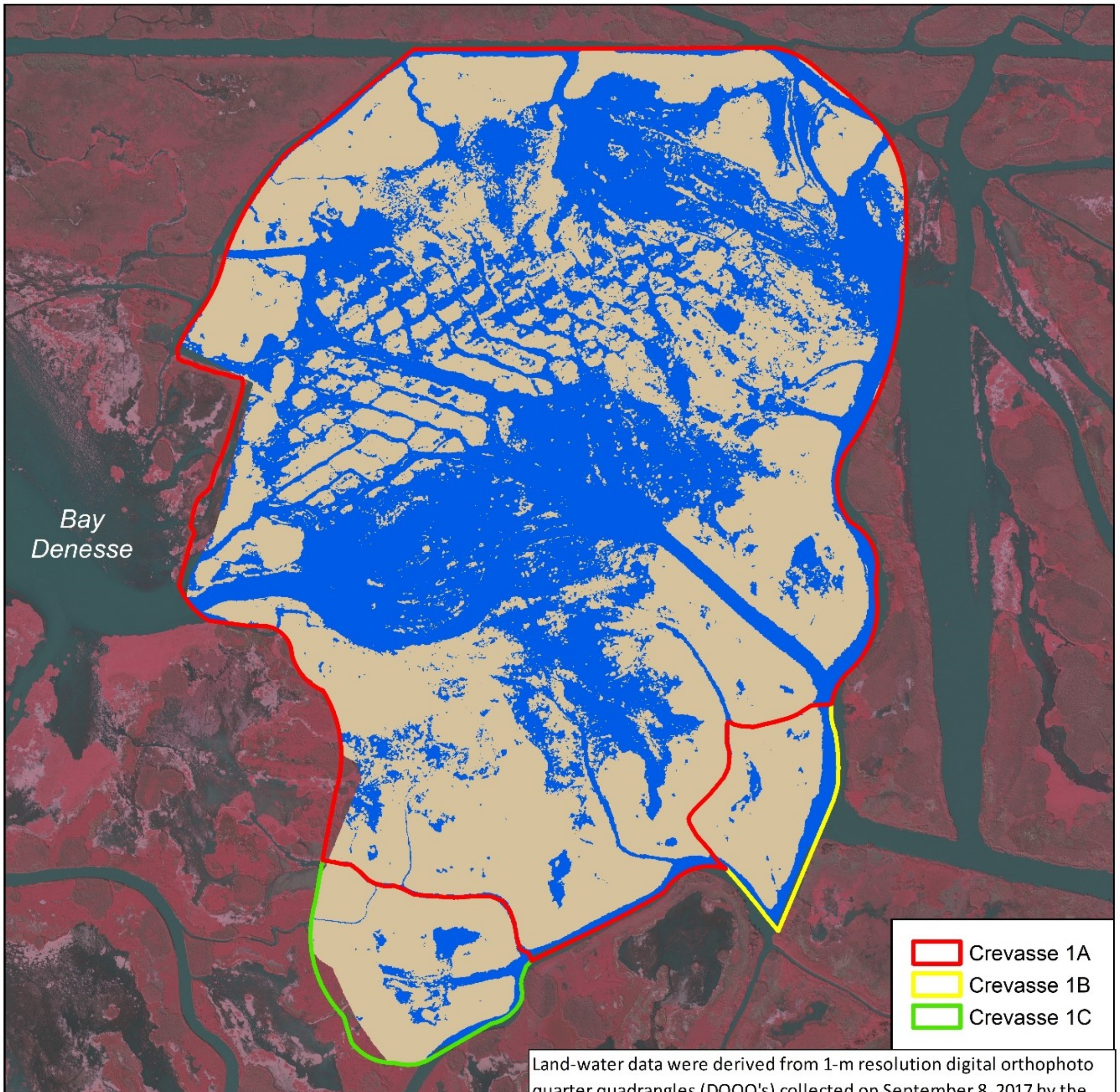
Delta Management at Fort St. Philip (BS-11), Subarea 1
2013 Land-Water Classification (Costanza and Frank-Gilchrist 2019)

0 0.125 0.25 0.5 Miles
0 0.2 0.4 0.8 Kilometers

Map Produced by:
Coastal Protection and Restoration Authority
New Orleans Regional Office
August 8, 2019

Background Imagery:
2012 CIR DOQQ

Appendix C11. 2013 land-water analysis for Subarea 1 of the Delta Management at Fort St. Philip (BS-11) project conducted by Costanza and Frank-Gilchrist (2019).



Class	1A	1B	1C	Sub Area Totals
Land	422	24	39	**485**
Water	351	7	7	**365**
Total Acres	**773**	**31**	**46**	**850**

Land-water data were derived from 1-m resolution digital orthophoto quarter quadrangles (DOQQ's) collected on September 8, 2017 by the National Agriculture Imagery Program (NAIP), USDA. Uplands, emergent vegetation, wetland forest, and scrub-shrub were classified as land, while open water, floating or submerged aquatics, and non-vegetated mudflats were classified as water. Land-water analysis of a larger dataset was conducted by Costanza and Frank-Gilchrist (2019) and clipped to BS-11 project areas by the CPRA.

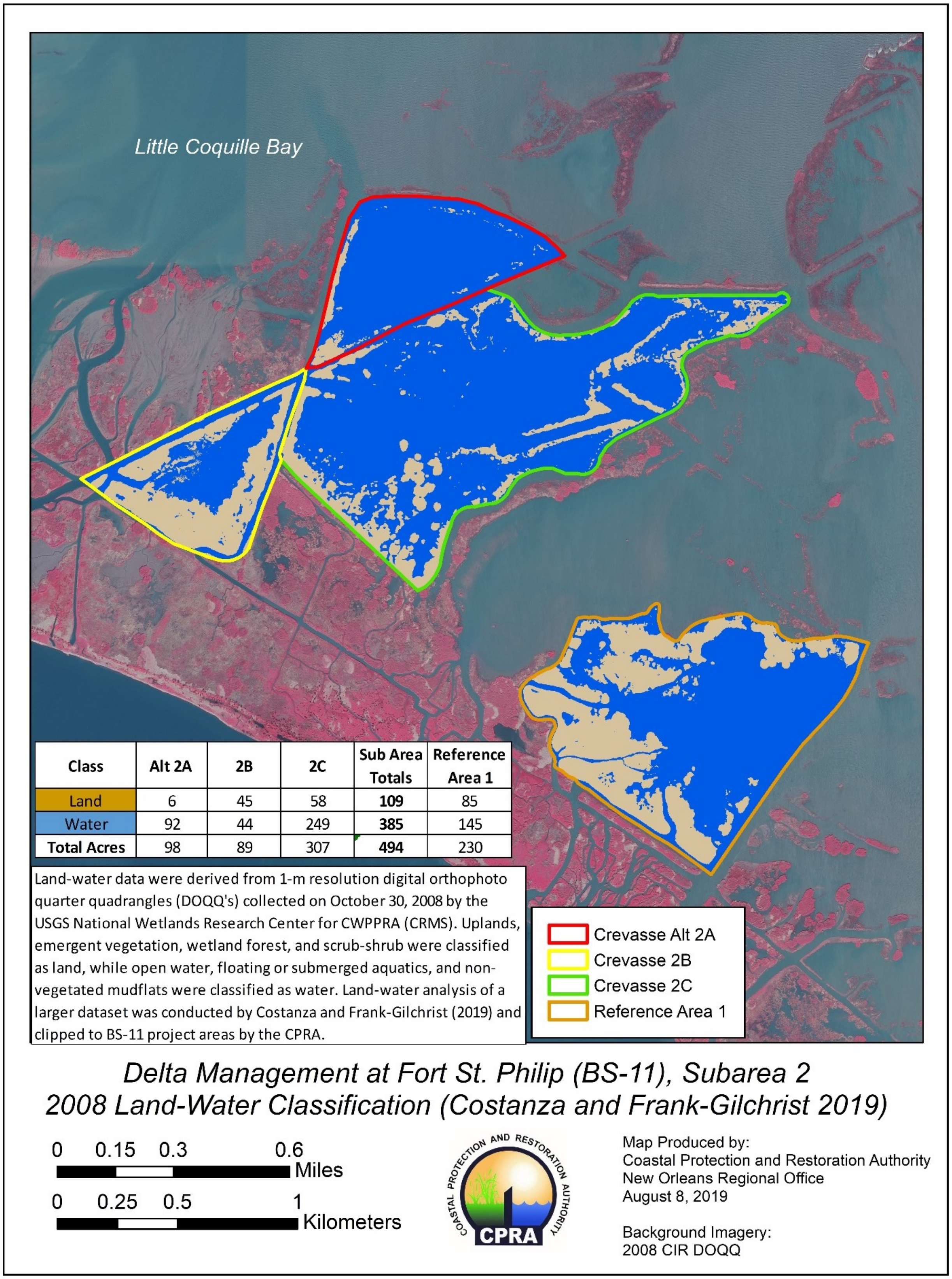
Delta Management at Fort St. Philip (BS-11), Subarea 1
2017 Land-Water Classification (Costanza and Frank-Gilchrist 2019)

0 0.125 0.25 0.5 Miles
0 0.2 0.4 0.8 Kilometers

Map Produced by:
Coastal Protection and Restoration Authority
New Orleans Regional Office
August 1, 2019

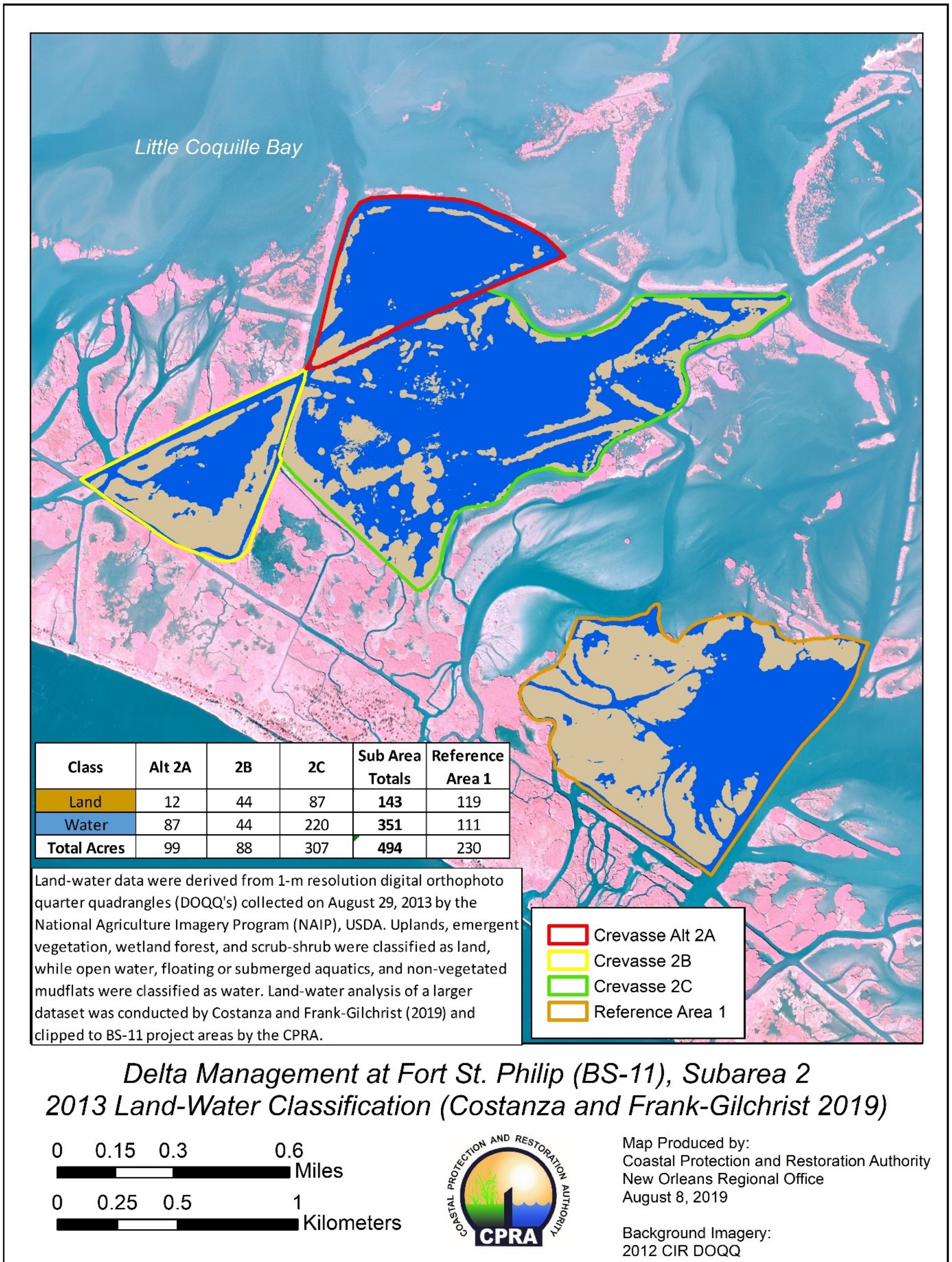
Background Imagery:
2016 CIR DOQQ

Appendix C12. 2017 land-water analysis for Subarea 1 of the Delta Management at Fort St. Philip (BS-11) project conducted by Costanza and Frank-Gilchrist (2019).



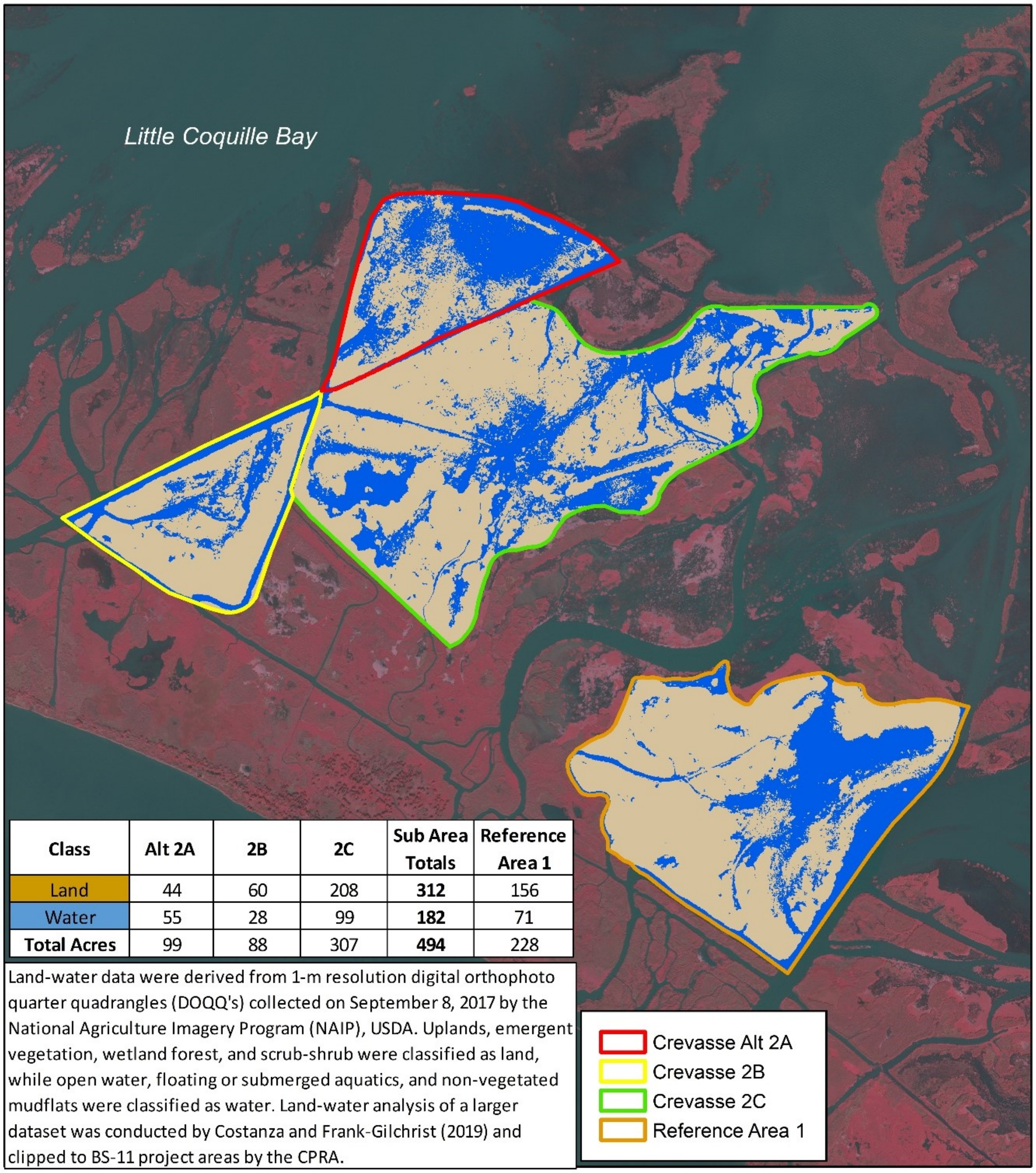
Class	Alt 2A	2B	2C	Sub Area Totals	Reference Area 1
Land	6	45	58	**109**	85
Water	92	44	249	**385**	145
Total Acres	98	89	307	**494**	230

Appendix C13. 2008 land-water analysis for Subarea 2 of the Delta Management at Fort St. Philip (BS-11) project conducted by Costanza and Frank-Gilchrist (2019).



Class	Alt 2A	2B	2C	Sub Area Totals	Reference Area 1
Land	12	44	87	**143**	119
Water	87	44	220	**351**	111
Total Acres	99	88	307	**494**	230

Appendix C14. 2013 land-water analysis for Subarea 2 of the Delta Management at Fort St. Philip (BS-11) project conducted by Costanza and Frank-Gilchrist (2019).



Class	Alt 2A	2B	2C	Sub Area Totals	Reference Area 1
Land	44	60	208	**312**	156
Water	55	28	99	**182**	71
Total Acres	99	88	307	**494**	228

Land-water data were derived from 1-m resolution digital orthophoto quarter quadrangles (DOQQ's) collected on September 8, 2017 by the National Agriculture Imagery Program (NAIP), USDA. Uplands, emergent vegetation, wetland forest, and scrub-shrub were classified as land, while open water, floating or submerged aquatics, and non-vegetated mudflats were classified as water. Land-water analysis of a larger dataset was conducted by Costanza and Frank-Gilchrist (2019) and clipped to BS-11 project areas by the CPRA.

Delta Management at Fort St. Philip (BS-11), Subarea 2
2017 Land-Water Classification (Costanza and Frank-Gilchrist 2019)

0 0.15 0.3 0.6 Miles

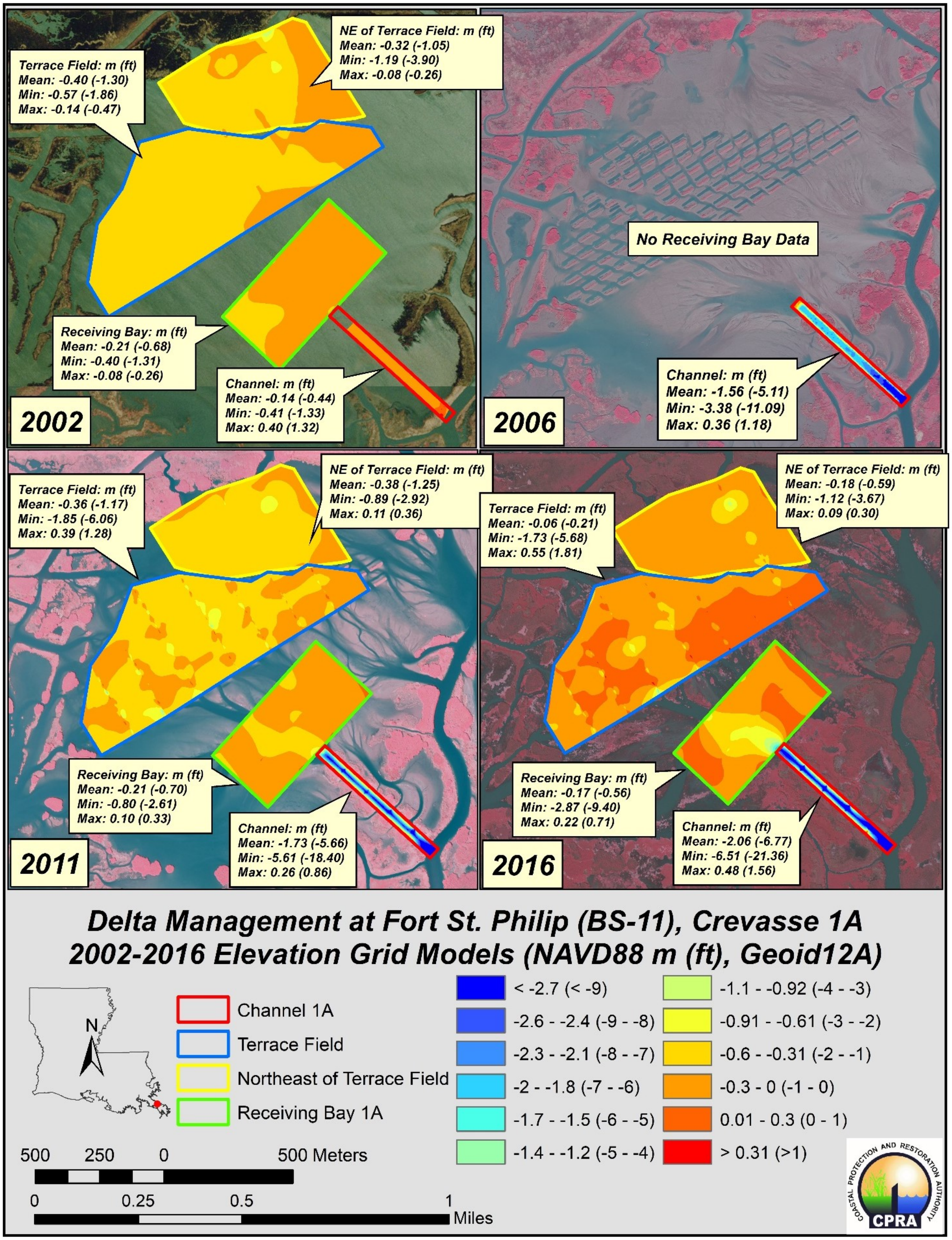
0 0.25 0.5 1 Kilometers

Map Produced by:
Coastal Protection and Restoration Authority
New Orleans Regional Office
August 1, 2019

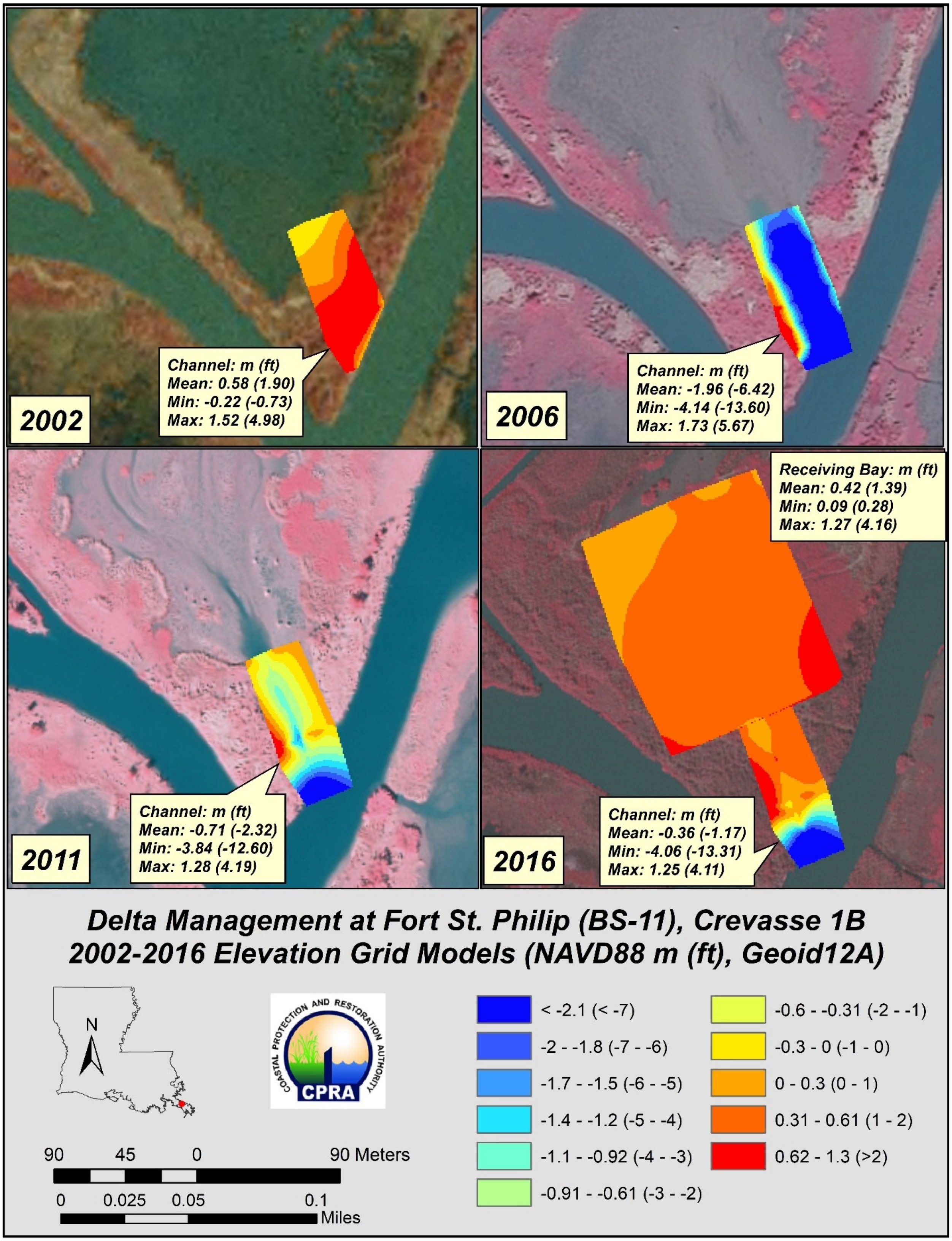
Background Imagery:
2016 CIR DOQQ

Appendix C15. 2017 land-water analysis for Subarea 2 and Reference Area 1 of the Delta Management at Fort St. Philip (BS-11) project conducted by Costanza and Frank-Gilchrist (2019).

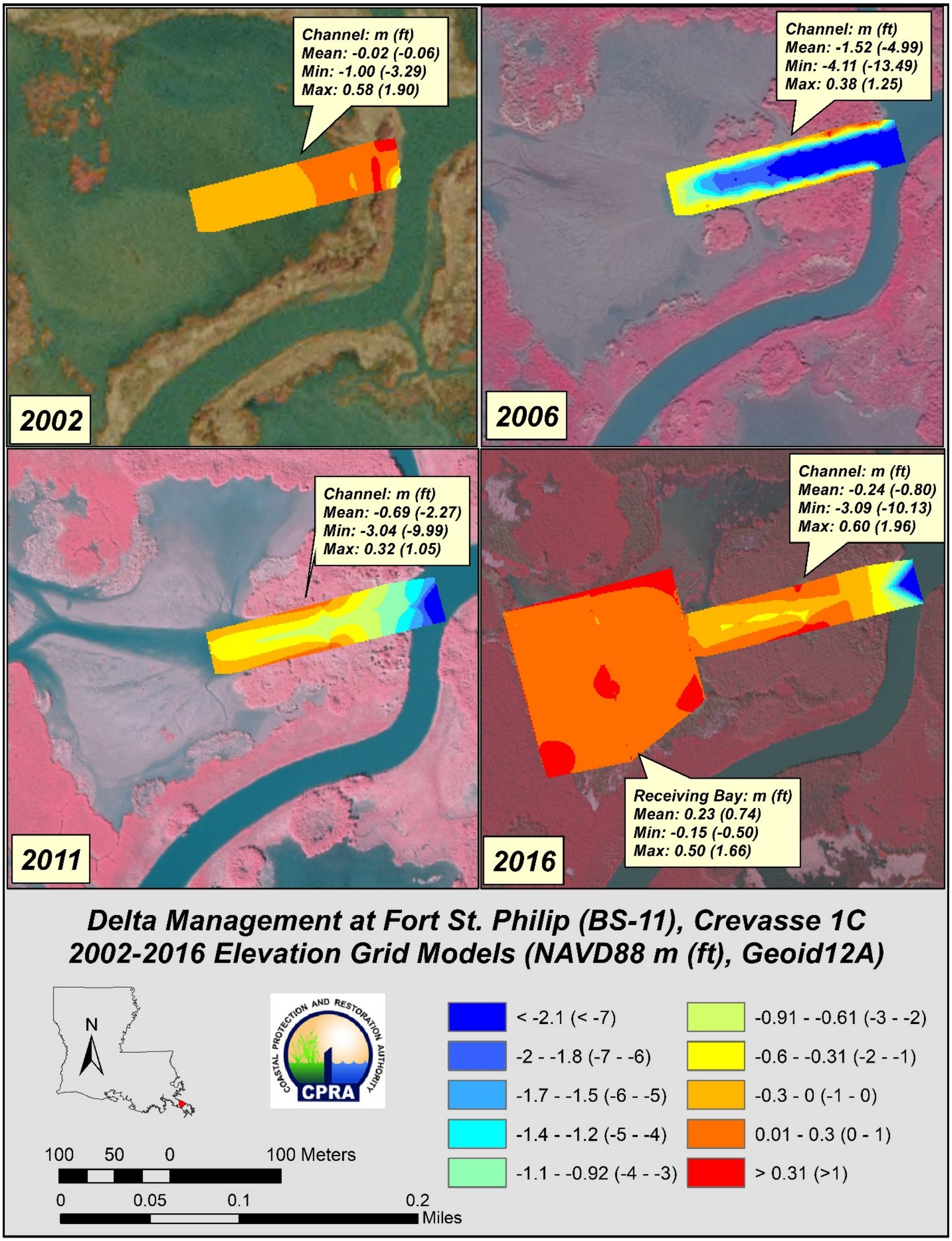
Appendix D
(Digital Elevation Models)



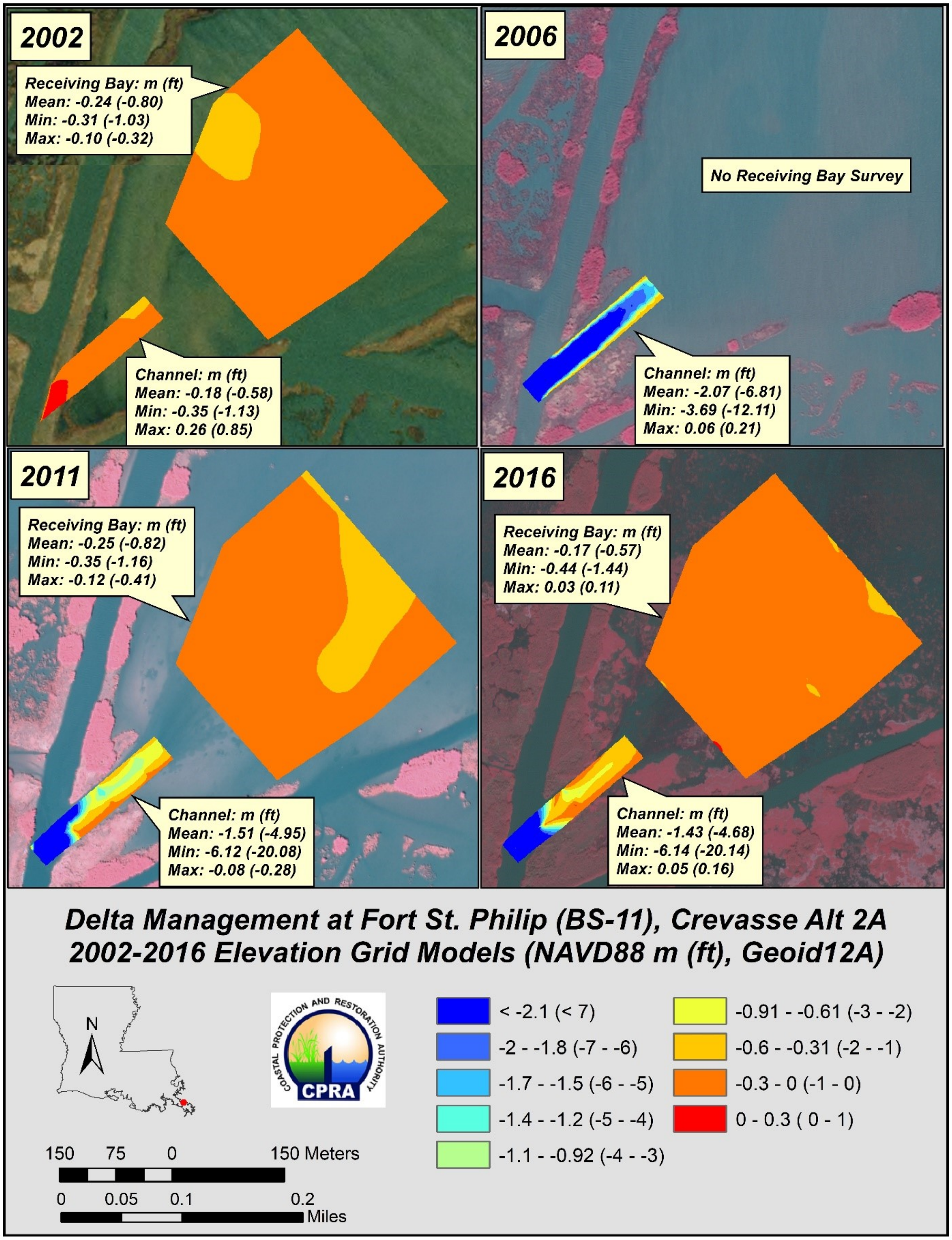
Appendix D1. 2002-2016 digital elevation models for Crevasse 1A of the Delta Management at Fort St. Philip (BS-11) project.



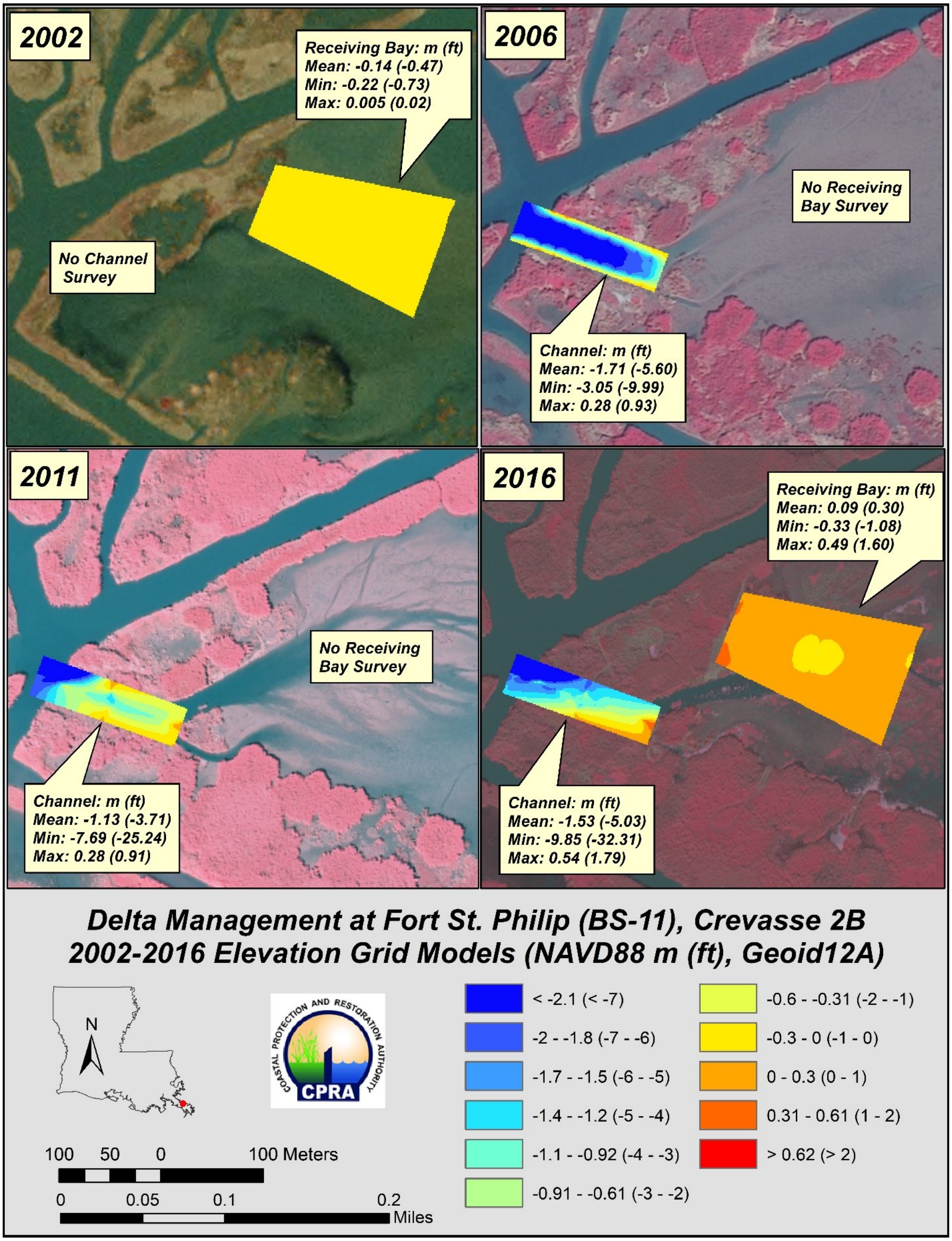
Appendix D2. 2002-2016 digital elevation models for Crevasse 1B of the Delta Management at Fort St. Philip (BS-11) project.



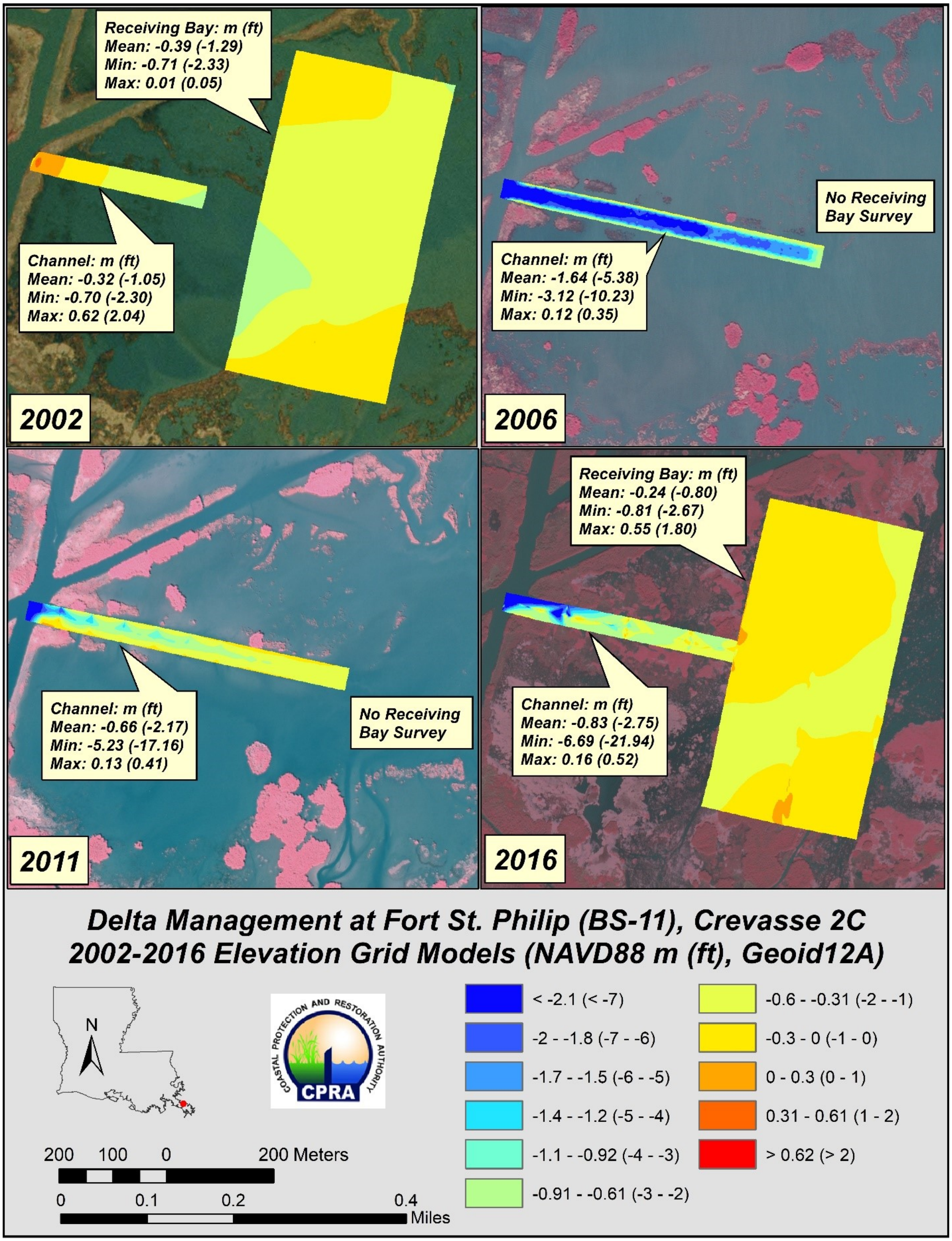
Appendix D3. 2002-2016 digital elevation models for Crevasse 1C of the Delta Management at Fort St. Philip (BS-11) project.



Appendix D4. 2002-2016 digital elevation models for Crevasse Alt 2A of the Delta Management at Fort St. Philip (BS-11) project.

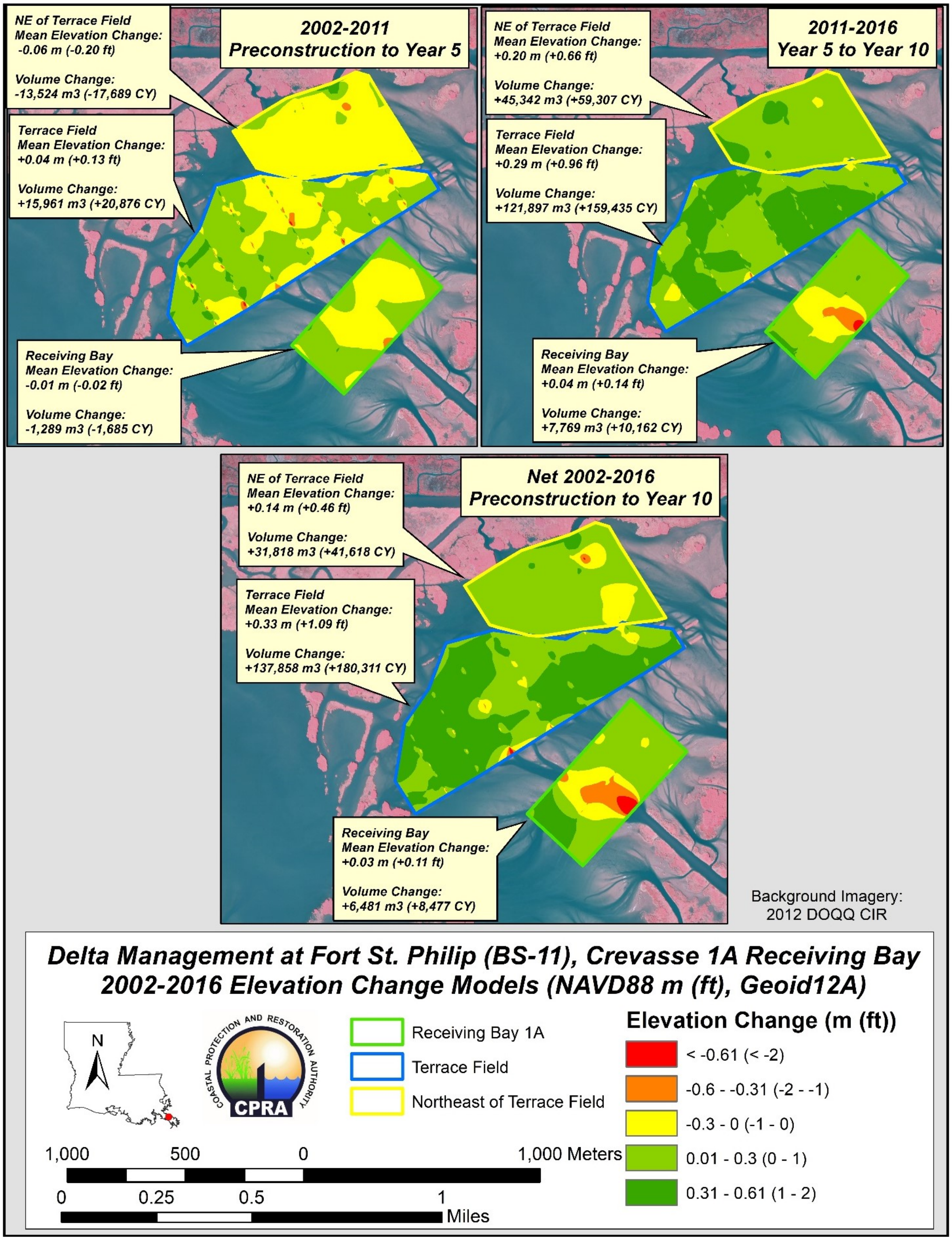


Appendix D5. 2002-2016 digital elevation models for Crevasse 2B of the Delta Management at Fort St. Philip (BS-11) project.

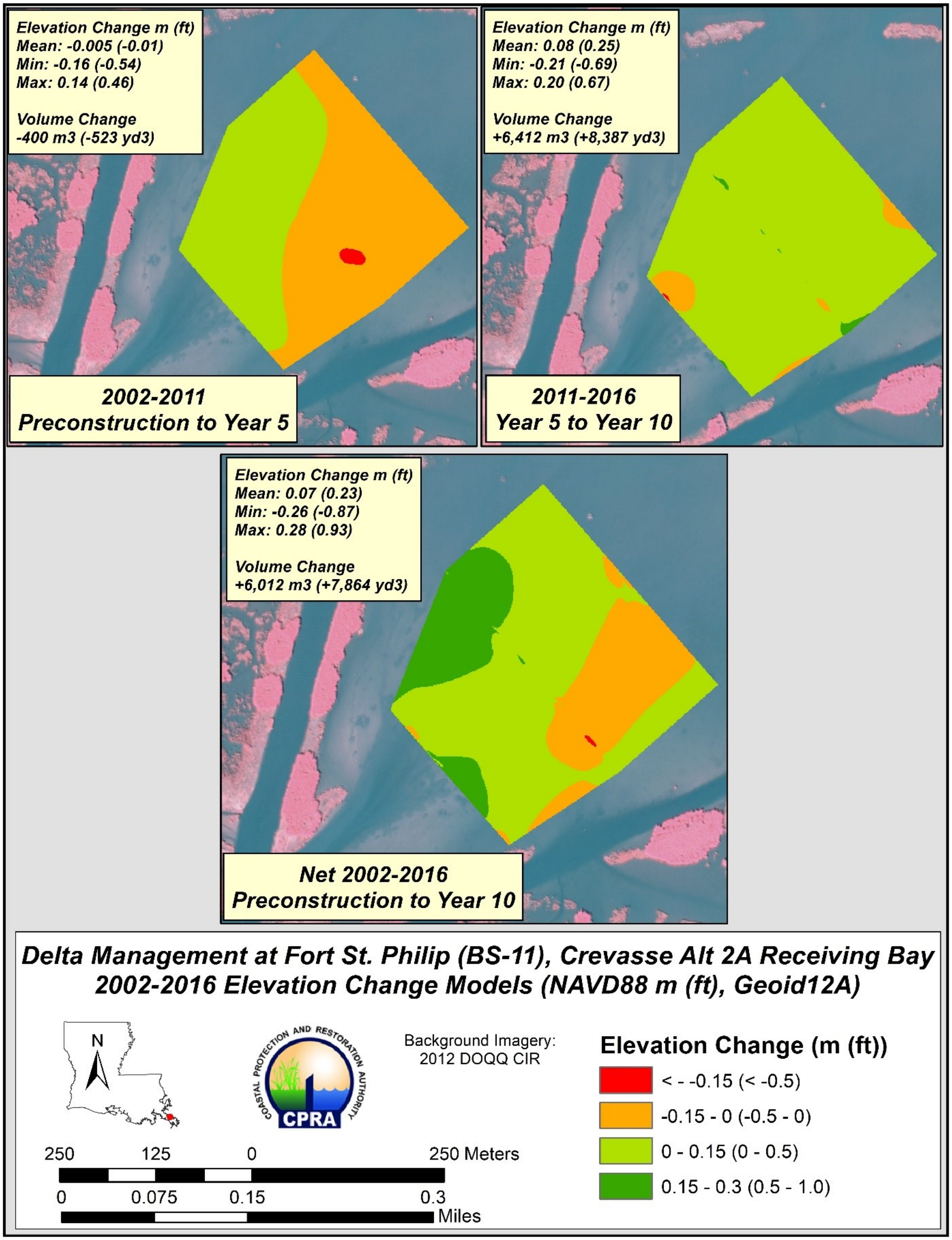


Appendix D6. 2002-2016 digital elevation models for Crevasse 2C of the Delta Management at Fort St. Philip (BS-11) project.

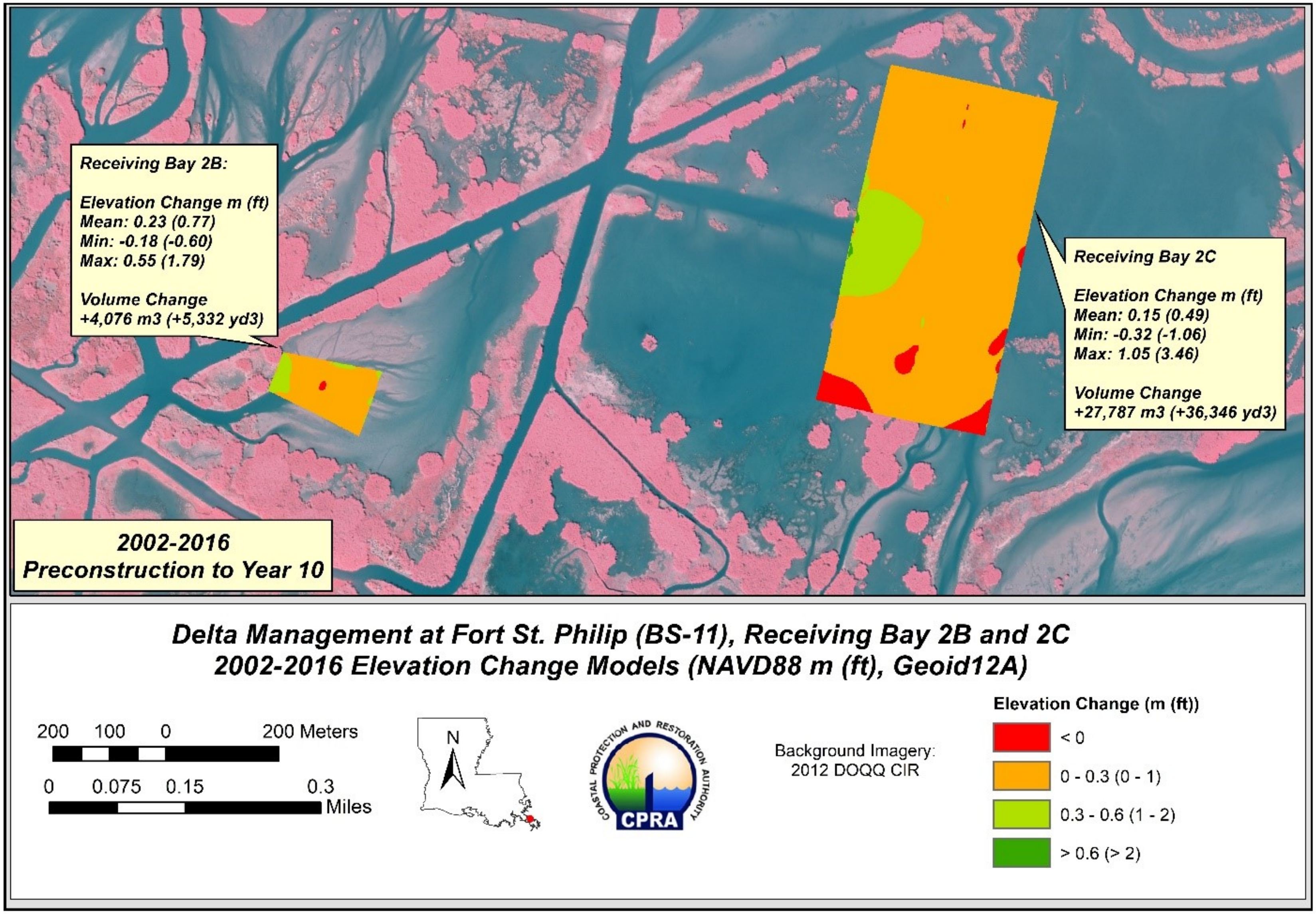
Appendix E
(Elevation Change Models)



Appendix E1. 2002-2016 elevation change models for Crevasse 1A of the Delta Management at Fort St. Philip (BS-11) project.



Appendix E2. 2002-2016 elevation change models for Crevasse Alt 2A of the Delta Management at Fort St. Philip (BS-11) project.



Appendix E3. 2002-2016 elevation change models for Crevasses 2B and 2C of the Delta Management at Fort St. Philip (BS-11) project.