State of Louisiana

Coastal Protection and Restoration Authority of Louisiana (CPRA)

2022 Operations, Maintenance, and Monitoring Report

for

Black Bayou Hydrologic Restoration

State Project Number CS-27
Priority Project List 6

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Calcasieu and Cameron Parishes

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For
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Preface

The Black Bayou Hydrologic Restoration (CS-27) project was funded through the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) on the 6th Priority Project List with the National Marine Fisheries Service (NMFS) as the federal sponsor and the Coastal Protection and Restoration Authority (CPRA). The 2022 OM&M Report format combines the Operations and Maintenance annual project inspection information with the Monitoring data and analyses for the project. This report includes monitoring data collected through December 2021, and annual Maintenance Inspections through 2022.

The 2022 report is the 7th and final report in a series of OM&M reports. For additional information on lessons learned, recommendations, and project effectiveness please refer to the previous OM&M reports from 2004, 2005, 2008, 2012, 2015, and 2018 on the CPRA web site (http://lacoast.gov/new/Projects/Info.aspx?num=CS-27).

I. Introduction

The Black Bayou Hydrologic Restoration Project (CS-27) is located in northwest Cameron and southwest Calcasieu Parishes. The project is bordered to the north by the Gulf Intracoastal Waterway (GIWW), to the south by Black Bayou, to the east by Gum Cove Ridge, and to the west by the Sabine River (Figure 1). Total project area is approximately 27,948 acres (11,310 ha) and was originally comprised of approximately 16,247 acres (6,574 ha) of intermediate and brackish marsh and 11,700 acres (4,735 ha) of open water. The marshes in the project area are dominated in large part by monocultures of *Spartina patens* (saltmeadow cordgrass), with a cohort of subordinate species consisting of *Phragmites australis* (Roseau cane), *Panicum dichotomiflorum* (fall panicum), *Typha sp.* (cattail), *Cladium jamaicense* (sawgrass), *Schoenoplectus californicus* (California bulrush), *Bolboschoenus robustus* (sturdy bulrush), and *Juncus roemerianus* (black needlerush).

Historically, the Black Bayou area was in the northern watershed of Sabine Basin collecting sheet flow from the surrounding uplands. Black Bayou provided a freshwater head which ran southwest from the uplands near Vinton to the northern rim of Sabine Lake. Beginning in the late 1800s, significant hydrologic changes in the Calcasieu/Sabine basin began affecting water level fluctuation and water circulation patterns in the project area. This has inhibited the freshwater head from flowing north to south and has diverted it to a bidirectional east and west flow via the Gulf Intracoastal Waterway (GIWW) (LCWCRTF 2002). Modifications to Calcasieu Pass such as the removal of the Calcasieu Pass oyster reef (1876) and maintenance of a deep (40 ft) and wide (400 ft) Calcasieu Ship Channel has increased the magnitude and duration of tidal fluctuations causing higher salinity and a broader range of water level fluctuations throughout the lake and the surrounding marshes (LDNR 1993). Construction of the Gulf Intracoastal Waterway, North Line Canal, Central Line Canal, and South Line Canal established an east-west hydrological connection between the previously distinct Calcasieu and Sabine basins, disrupting the natural north-south flow and allowing the saline waters of the Calcasieu Basin to encroach on the Sabine Basin. Water level fluctuations are also highly influenced by local meteorological factors. A strong north wind can cause drastic de-watering

of the marshes, while a strong sustained southerly wind can result in drastic increases in water levels and salinities blown in from the Gulf of Mexico. The extensive system of navigation channels, bayous, oil exploration canals, spoil banks, and trenasses, have allowed increased water fluctuations and salinities to reach the fragile interior marshes in the absence of a strong freshwater head (USDA 1991). Most of the land loss in the project area and surrounding marshes occurred between 1956 and 1978 (Barras et al. 2008), as both large and small-scale changes have resulted in local hydrologic alterations. The construction of spoil levees along the GIWW disrupted the drainage of uplands to the north causing communities to create more efficient drainage via conversion of Black Bayou to the Vinton Drainage Ditch (Vinton Water Way) which empties into the GIWW and is diverted away from the project area. The east side of the project area gradually developed into an impoundment over time due to several separate factors in addition to the GIWW dredge levee along the north (originally 1913-14; current dimensions since 1941). There are other hydrologic impediments surrounding the project impoundment such as an oil company access road running east-west along the southern boundary (1950s), landowner boundary levee running north-south on the west side (1968), and the increasing marsh elevations grading into the uplands of the Gum Cove Ridge on the east side.

The Black Bayou Hydrologic Restoration Project includes structural and non-structural measures designed to:

(1) allow freshwater to flow from the GIWW near its confluence with the Vinton Drainage Canal into the wetlands south of the GIWW between the Sabine River, Gum Cove Ridge, and Black Bayou, and

(2) create a hydrologic head that increases freshwater retention time and reduces salt water intrusion and tidal action in the Black Bayou watershed.

Most Black Bayou structural features construction were completed in November 2001 (Figure 1); some additions or modifications were made later. Structural and non-structural features and their intended functions are listed below:

1. Approximately 22,600 linear ft. (6,889 m) of foreshore rock dikes along the GIWW west of the Gum Cove Ridge to repair breaches in the GIWW spoil bank.

2. A weir with a barge bay, 70 ft (21.3 m) wide, with a sill of -7.0 ft NAVD 88, made of graded stone was constructed at the GIWW in the Black Bayou Cut Off Canal to limit water exchange in and out of the project area.

3. A weir with a boat bay, 15 ft (4.6 m) wide with a sill of -4.0 ft NAVD 88, made of graded stone was constructed in the Burton Canal at its intersection with the Sabine River to limit water exchange in and out of the project area.

4. A rock weir with a 15 ft (4.6 m) wide boat bay at - 3 ft NAVD 88 bottom elevation was constructed at the intersection of Block's Creek with Black Bayou to limit water exchange in and out of the project area.

5. A self-regulating tide (SRT) gate, within a sheet pile weir, 40 ft (12.2 m) wide with a sill at + 0.6 ft NAVD was constructed where it connects to an existing canal that leads to Black Bayou Cutoff Canal to limit flow into the impoundment during and increase drainage after high water events. A hinged flap was installed over the weir on either side of the SRT gate in January 2006 to further limit flow into the impoundment while allowing water to drain out.

6. Two, 30 in (0.76 m) flap-gated culverts (Culvert 1/Culvert 2) were installed along the southeastern boundary of the impoundment in January 2006 to relieve excess waters from the impoundment while preventing water flow into the impoundment.

7. Vegetative plantings of *Schoenoplectus californicus* (bullwhip) in two phases. Single rows of one-gallon trade containers with a minimum of 5 stems per container were installed on 5 ft (1.5 m) centers. Phase I, east side of project area throughout ponds on either side of the Black Bayou Cut-off Canal, contained approximately 30,000 plantings spanning 150,000 linear ft (45,720.5 linear m) and was installed in summer 2002. Plantings within the impoundment were along a plowed terrace and through the open water. Phase II, west side of project area along marsh perimeters, contained approximately 25,570 plantings spanning 127,850 linear ft (38,969.1 linear m) and was installed in summer 2003.

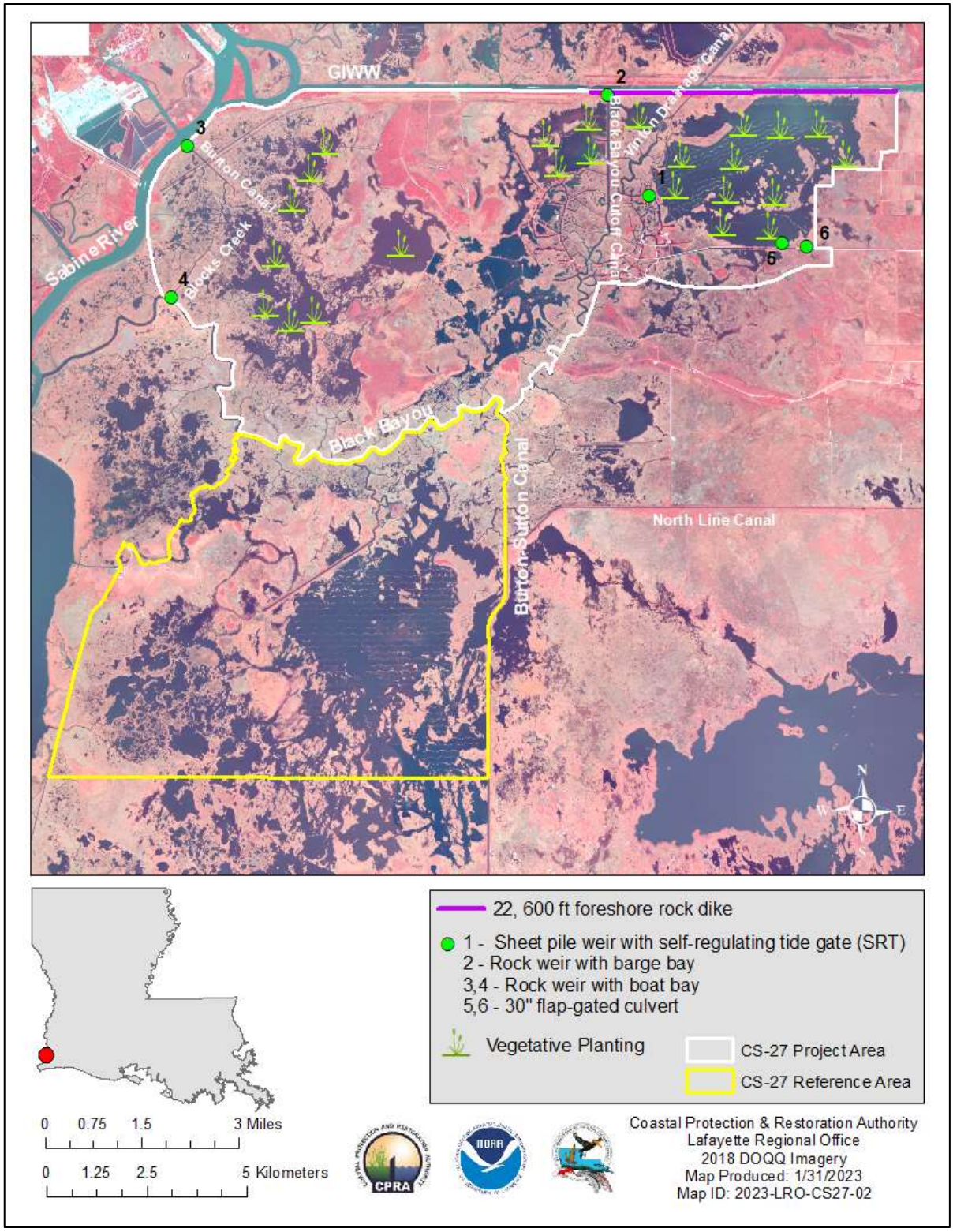

Figure 1. Black Bayou Hydrologic Restoration (CS-27) project and reference boundaries and project infrastructure.

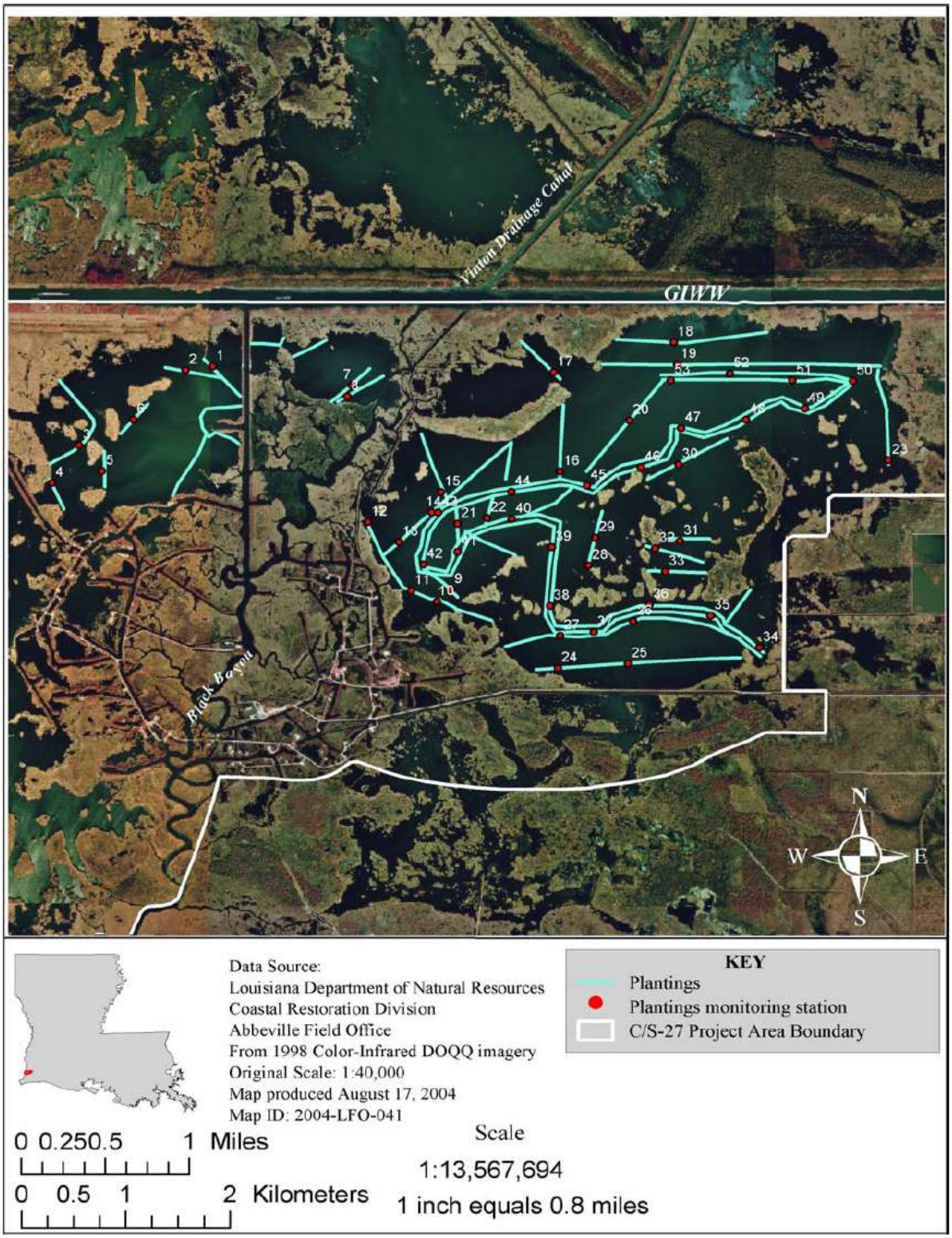

Figure 1a. Phase I vegetative planting layout and sampling stations in east side and large impoundment of the Black Bayou Hydrologic Restoration (CS-27).

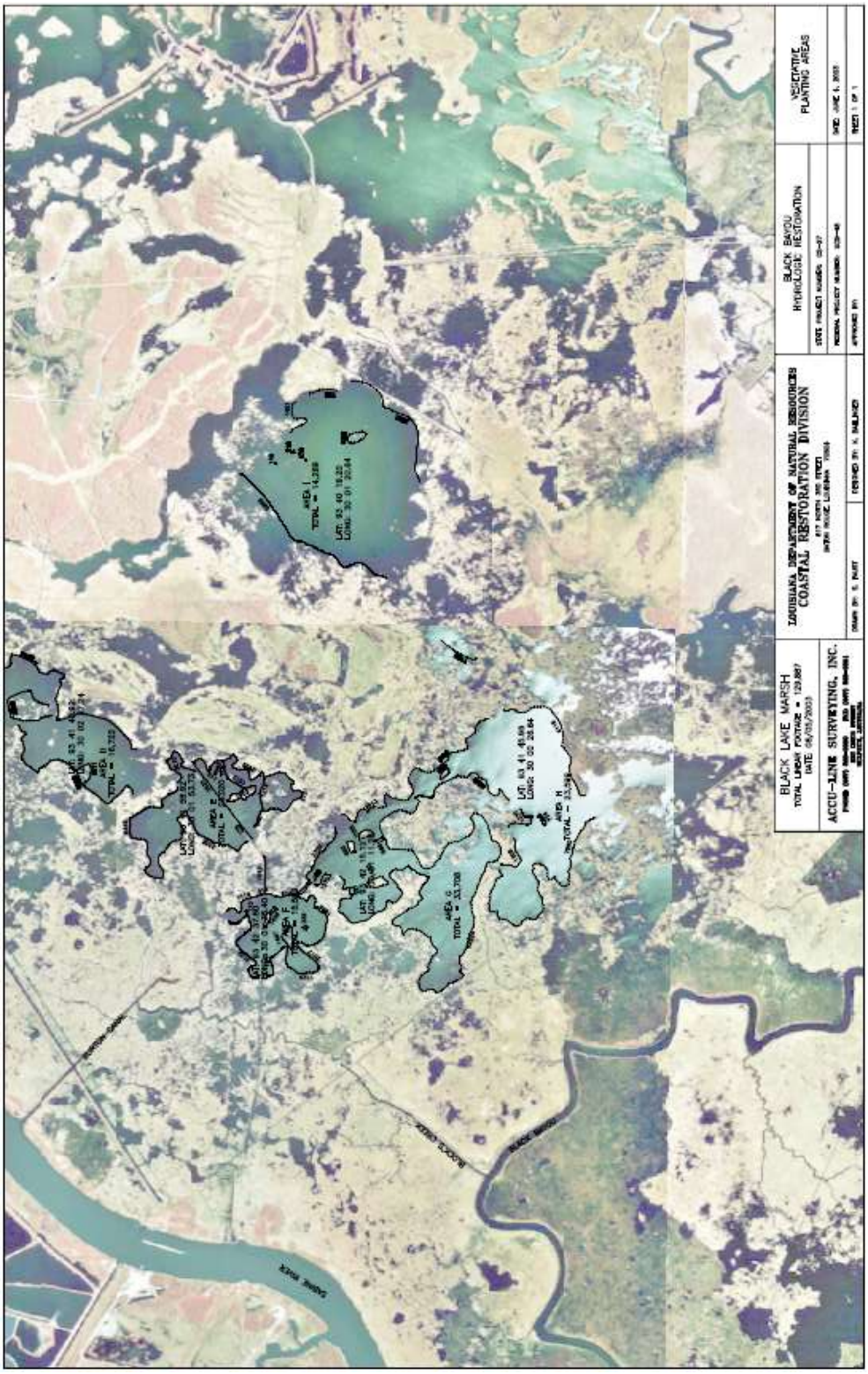

Figure 1b. Phase II vegetative planting layout in west side of the Black Bayou Hydrologic Restoration (CS-27) project.

II. Maintenance Activity

a. Project Feature Inspection Procedures

The purpose of the annual inspection of the Black Bayou Hydrologic Restoration Project (CS-27) is to evaluate the constructed project features to identify any deficiencies and prepare a report detailing the condition of project features and recommended corrective actions needed. Should it be determined that corrective actions are needed, CPRA shall provide, in the report, a detailed cost estimate for engineering, design, supervision, inspection, and construction contingencies, and an assessment of the urgency of such repairs. The annual inspection report also contains a summary of maintenance projects, if any, which were completed since completion of constructed project features and an estimated projected budget for the upcoming three (3) years for operation, maintenance, and rehabilitation. The three (3) year projected operation and maintenance budget is shown in Appendix B.

An inspection of the Black Bayou Hydrologic Restoration Project (CS-27) was held on July 13, 2022 under partly cloudy skies and warm temperatures. In attendance were Stan Aucoin, Jody White, and Phillip Parker of CPRA; NOAA Fisheries was represented by Brandon Howard. Parties met at the Lafayette Regional Office of CPRA and traveled to the boat launch in Vinton, LA. The annual inspection began at the structure on Burton Canal at approximately 11:30 am. A private landowner from the area, Mr. Richard Jones, met us at the Burton Canal Structure to voice concerns regarding water bypassing the newly constructed weir.

The field inspection included a complete visual inspection of most features. Staff gauge readings were used to determine approximate elevations of water, rock weirs, earthen embankments, steel bulkhead structures and other project features. Photographs were taken at each project feature (see Appendix A), and Field Inspection notes completed in the field to record measurements and deficiencies are summarized below.

b. Inspection Results

Block's Creek

The rock weir appears to be in excellent condition after the repairs performed during the maintenance event of 2019. Arrow signs and navigational lights are present and functional. (Photos: Appendix A, Photo 1)

Burton Canal

The new structure and signage are all functioning as intended and stable. A private landowner, Mr. Jones, explained a potential issue regarding water bypassing the structure via a trenasse beginning to form on the north side of the structure; however, nothing obvious was noted during this inspection. (Photos: Appendix A, Photo 2)

Black Bayou Cut-Off Canal

Additional rock to repair scouring around the structure during the last maintenance event has apparently stabilized the area. Navigational lights and signs are inspected quarterly by contractor. Channel marker on the east side of the weir is broken. (Photos: Appendix A, Photos 3-4)

Self Regulating Tide Gate (SRT)
The structure is showing signs of significant rust on the top railings, but nothing to prevent it from working as designed. Pillow blocks, signage, railings, wing walls, etc. remain in good condition. (Photos: Appendix A, Photos 5-6)

Rock Plug
The rock dike is functioning as designed. Concrete sacks are solid. Tie-ins are stable. No maintenance required. (Photos: Appendix A, Photo 7)

GIWW rock dike
Tie-ins on both the east and west end of the dike are stable. Repairs to the gaps during the last maintenance event are stable. Build-up of sediment continues between the dike and the shoreline. Emergent vegetation has established in large areas behind the dike between the dike and the shoreline. (Photos: Appendix A, Photos 8-9)

Culvert 1/Culvert 2:
These culverts were last inspected on June 26, 2015. They appeared to be in very good, post construction condition and in no need of repair. No concerns have been expressed by the landowners.

c. Maintenance Recommendations

i. Immediate/ Emergency Repairs
None

ii. Programmatic/ Routine Repairs
The following item was identified in the Annual Inspection:

1. Possibly repair the broken directional sign on the east end of the Black Bayou Cut Off weir.

d. Maintenance History

General Maintenance: Below is a summary of completed maintenance projects and operation tasks performed since December 2003, the construction completion date of the Black Bayou Hydrologic Restoration Project.

December 2003 - Construction Adjustments: Although construction of the original project components was completed in December 4, 2001, it was determined that leaks along the GIWW rock dike would have detrimental effects on the project. The rock dike along the GIWW was removed at four separate locations and plugs consisting of "C" stone were constructed at "water" connections between the marsh area and the GIWW existing to the north to reduce or eliminate tidal flow through these locations. The original signs installed at the Black Bayou Cut-Off Structure on timber pilings were either leaning or missing. Signage was relocated on concrete bases on top of the rock weir. Also, at the SRT gate, a railing was constructed on the sheet pile cap to reduce the chance of persons falling into the water in the area around the structure. This work was completed in December 2003 and construction was considered to have been complete after these adjustments.

July 2003 - Navigational Aid Light Repairs: A letter was received from the US Coast Guard in July 2003 reporting problems with the navigational lights at the Black Bayou Cut-Off Canal weir. The problem was investigated and repaired in October 2003 by Wet-Tech Energy, Inc. at a total cost of $1,250.00.

During March 2006, DNR/CED/LFE, via a Purchase Order employed WET TECH Energy, Inc. to inspect and report thereon on damages caused by Hurricane Rita to any of the navigation lights and support structures of the Black Bayou Project that were in place as appurtenant parts of the various structure features of the Project. The cost of the inspection/report was $2,000.00.

The damages reported were as follows:

(1) The Black Bayou CutOff Channel west light needed a new battery box and the replacement of two batteries. The east light did not need repairs.
(2) The Block's Creek Structure lights and supports needed no repair work.
(3) The Burton Canal Structure light experienced major damage and the entire light assembly, solar cell, and battery system needed to be replaced.

Later, during May 2006, the damages reported above were all corrected on each respective structure of the project by WET TECH Energy, Inc. by a separate purchase order for Hurricane Rita repairs for a total of $3,842.00. The sum of the costs for the inspection/report and thence the repair efforts was $5,842.00. This entire sum was reimbursed by FEMA for reason of the storm damage.

July 2005 - SRT Gate modification and culvert installation: In the spring of 2005, it was determined that water was "stacking up" on the southeast corner of the project area. In order to correct the situation, the cross sectional area of the SRT Gate was increased by attaching a flap to the railing. Also, two 30" flap gated culverts on the southern boundary of the project will relieve excess waters. A Notice to Proceed dated July 20, 2005 was issued to Duphil, Inc. of Orange, Tx. Construction was accepted as complete on January 4, 2006 at a total construction cost of $84,976.87. Engineering & design, construction oversight, and as-built drawings were provided by C. H. Fenstermaker & Associates at a total cost of $39,856.77.

Navigational Light Maintenance:
Automatic Power, Inc. inspects, and if needed, repairs the navigational aid lights at Burton Canal, Block's Creek, and Black Bayou Cut-Off Canal on a quarterly basis.

2009 Maintenance Event:
This maintenance event consisted of general repairs to the flap on the SRT Gate, installation of new, different signs at Burton Canal, and repairs to the closures behind the rock dike as well as a repair to the GIWW dike near Vinton Canal. The work was accomplished by Reeve's Development, Inc. at a total contract cost of $169,997.18. Engineering, design, and construction oversight was provided by Acadian Engineers & Environmental Consultants, Inc. at a cost of $46,292.90.

2012 Landowner Event:
In early 2012, the landowners in the area, under their own construction contract, repaired breaches that had occurred around two of the four plugs behind the rock dike.

2019 Maintenance:
During the Annual Inspection in 2014-2015, scour holes were found on each side of the rock weirs on Black Bayou Cut Off, Burton Canal, and Block's Creek. Previously repaired breaches behind the rock dike on the GIWW had also opened up again. This maintenance event repaired the scour holes on Block's Creek and Black Bayou Cut Off as well as the breaches behind the rock dike. The Department of Energy reimbursed the project for concrete matting that was needed around their pipeline near the Black Bayou Cut Off structure. The rock weir on Burton Canal had to be removed and a new one constructed further up the canal due to numerous oil field pipelines in the vicinity of the original structure. The final construction costs were $3,137,890.07. Design and construction oversight was provided by HDR Engineering at a total cost of $470,891.82.

III. Operation Activity

a. Operation Plan

No water control structures are associated with this project that require manual operation; therefore, no structural operation plan is required.

b. Actual Operations

There are no active structural operations associated with this project.

IV. Monitoring Activity

Pursuant to a CWPPRA Task Force decision on August 14, 2003 to adopt the Coastwide Reference Monitoring System-*Wetlands* (CRMS) for CWPPRA, updates were made to the CS-27 Monitoring Plan to merge it with CRMS and provide more useful information for modeling efforts and future project planning while maintaining the monitoring mandates of the Breaux Act. There are four CRMS sites located in the project area (CRMS0658, CRMS0662, CRMS0663, and CRMS2166), and three located outside the project area used as reference locations in similar marsh habitat (CRMS660, CRMS0665, and CRMS2189) as well as other similar marsh habitat in the CS Basin.

a. Monitoring Goals

The objectives of the Black Bayou Hydrologic Restoration project are:

1. Increase freshwater retention that reduces salt-water intrusion in the project area.
2. Establish emergent wetland vegetation in shallow open water areas.
3. Protect emergent marsh in project area by reducing erosion along GIWW.
4. Increase occurrence of SAV in project area.

The following goals will contribute to the evaluation of the above objectives:

1. Reduce mean salinities within the project area.
2. Increase the land to water ratio within the project area.
3. Reduce mean erosion rate of protected shoreline along GIWW.
4. Increase SAV in interior ponds within the project area.

b. Monitoring Elements

Aerial Photography

Near-vertical color-infrared aerial photography (1:24,000 scale) was used to measure vegetated and non-vegetated areas for project specific project and reference areas. The photography was obtained in 2000 prior to project construction and post-construction in 2004, 2010, 2015, and 2018. The photography was checked for flight accuracy, color correctness, and clarity and was subsequently archived. Aerial photography was scanned, mosaicked, and georectified by U.S. Geological Survey at the National Wetlands Research Center (USGS/NWRC) personnel according to standard operating procedures to develop land:water analyses (Steyer et al. 1995, revised 2000). Differences in percent land over time within the project and between the project and reference areas are calculated from the land and water analyses.

Aerial photography (color infrared, CIR) and satellite imagery (Landsat Thematic Mapper, TM) have been collected for the entire coast through CRMS. The aerial photography is analyzed for CRMS stations at one-meter resolution. The satellite imagery is analyzed to determine land and water areas for the entire coast. This imagery will be a subset and used to evaluate changes in

land and water areas within the CS-27 project area at a coarse (30m) resolution. The CRMS spatial viewer provided historic data for land water quantification in the project area starting in 1985. Land Values are displayed for available cloud free Landsat images during the late fall for 1985-2016. The data provided by this tool is at a large spatial scale and is designed to show trends in land loss, not exact acreages or locations.

Salinity

Salinity data from both discrete (YSI 30) and continuous recorder (sonde) stations were monitored to characterize the spatial variation in salinity throughout the project area and to determine if salinity was reduced in the project area. Discrete salinities were monitored: (A) monthly from June 1999 (preconstruction) through March 2004 (post construction) at designated stations throughout the project and reference area (Figure 2) and (B) during submerged aquatic vegetation surveys in the fall of 1999, 2003, 2005, 2007, 2012, 2014 and 2017. In addition, two discrete surface water salinity stations provided data inside and outside of project structures during sonde servicing beginning in March 2012 through 2017.

Hourly salinity and water levels (ft, NAVD88) were monitored with a continuous recorder in the impoundment side of the SRT gate (station CS27-25) from May 2000 to 2018. Started in 2006/2007, salinity data is also currently being monitored hourly utilizing CRMS-*Wetlands* stations (0658, 0662, 0663, and 2166) within the project area and selected reference sites (0660, 0665, and 2189). Continuous data were used to characterize average annual salinities throughout the project and reference areas. Salinity data collection from the discrete stations and a continuous recorder (station CS27-22) was discontinued in March 2004 to be replaced by CRMS-*Wetlands* stations. Continuous recorders were deployed within the project area starting in February 2008 (CRMS0658 replaced CS27-22).

Discrete porewater from the soil salinity at 10 and 30 cm was collected at all of the vegetation plots during vegetation sampling. Porewater was extracted with a sipper tube assembly (rigid aquarium tubing, flexible hose, and syringe), and salinity was measured using a hand held salinity meter (YSI 30 Salinity, Conductivity, Temperature Meter).

Vegetation Plantings

Schoenoplectus californicus (California bullwhip) plantings were installed in two phases; Phase I was completed in July 2002 in the east side of the project area (Figure 1a), and Phase II was completed in August 2003 in the west side of the project (Figure 1b). Individual plantings were recorded as live (green) or dead (all brown or absent) in Phase I was determined after one growing season post construction in September 2003 in approximately 3% of the vegetation plantings (see Castellanos and Juneau 2004 for more details). Average percent survival was determined for Phase I overall, open water in smaller ponds, open water in impoundment, and along terraces within the impoundment. Phase II plantings were not sampled at the vegetation station level. Desktop observations of 2005 and 2022 aerial imagery in Google Earth were compared to qualitatively determine the recent presence of plantings.

Shoreline Change

To document the effectiveness of the foreshore rock dike to reduce erosion and protect the emergent vegetation in the breached areas of the impoundment along the GIWW, shoreline surveys were conducted using a sub-meter differentially corrected Global Positioning System (dGPS) to map the vegetated edge. Surveys were conducted 1.66 years preconstruction in March 2000, immediately (4 months) post-construction in March 2002, and 2.75 years post-construction in August 2004. Analyses of shoreline change were performed by digitally overlaying mapped line features for each dataset in a Geographic Information System (GIS, ArcGIS). Polygon features were then created for all areas within closed intersections of the two polyline datasets. The generated polygon features represent the total change in land area as defined by the difference in shoreline position during the sampling interval. The total area of all polygons between the line features was calculated and each polygon feature was defined as gain or loss. The total land area in acres of gain and loss was then calculated. The reference area shoreline was compromised because of another rock dike construction during the time between the 2000 and 2002 GPS surveys; therefore, we evaluated only the project shoreline change over time. The data is presented in two increments, pre- to immediately post-construction (2000-2002) and post construction (2002-2004). No additional shoreline surveys were scheduled or conducted. The change in areas between the foreshore rock dike and shoreline in the breached areas (as described above) and on either side from 2004 to 2022 were qualitatively described by comparing aerial imagery in Google Earth Historical Imagery tool.

Submerged Aquatic Vegetation (SAV)

To document changes in the occurrence of SAV, project areas (1-6) and a reference area were monitored over time using the modified rake method (Chabreck and Hoffpauir 1962) (Figure 3). Three transects oriented northeast to southwest were established across open water in each area. Submerged aquatic vegetation was sampled repeatedly along each transect by dragging a rake on the pond bottom for one second. The presence or absence of vegetation was recorded for each sample to determine percent occurrence on a transect (% occurrence = (number of samples with SAV/number of samples) × 100). When vegetation was present, the species was recorded in order to determine the frequencies of individual species (Nyman and Chabreck 1996). SAV was monitored before construction in fall 1999 and after construction in fall 2003, 2005, 2007, 2010, 2012, 2014, and 2017. No additional SAV surveys are scheduled.

CRMS Supplemental Data

Hydrologic, vegetative, and marsh elevation data are collected at CRMS sites that can help describe the effects of the project objectives on overall marsh health. The CRMS website synthesizes data from each data type into indices (https://lacoast.gov/crms/dataDescr.aspx). Data presented in this report are from four CRMS sites located within the CS-27 project area (0658, 0662, 0663, and 2166) and ~36 sites with similar marsh types throughout the CS Basin. The resultant graphs depict the average index values of project area and reference sites over time with the backdrop of the distribution of all CRMS sites across the Louisiana's coastal zone.

- **Hydrology**

The Hydrologic Index (HI) assesses the relationship between the combined effect of mean salinity and percent time flooded on vegetation primary productivity for 5 different marsh classifications in coastal Louisiana (swamp, fresh, intermediate, brackish, and saline). The index score ranges from 0 - 100, representing the percent of maximum vegetation productivity expected to occur if the separate effects of salinity and inundation on productivity interact in a multiplicative fashion.

- **Vegetation**

Vegetation composition and cover was estimated from 10 permanent 2x2 m plots that are randomly distributed along transects in the emergent marsh within each of the 1 km^2 CRMS-*Wetlands* sites (Folse et al. 2020). The percent cover of the stations and of each species was fed into a floristic quality index (FQI) based on the marsh type the data was collected. This FQI was developed by Jenneke Visser and an expert panel on Louisiana coastal vegetation as part of CRMS analytical working group in 2007, revised 2011 (Cretini et al., 2011). The panel provided an agreed upon score (Coefficient of Conservatism or CC Score) from 0 to 10 for each species in a list of ~500 plant species occurring in Louisiana's coastal wetlands (Table 1). CC scores are weighted by percent vegetative cover and summed to determine the FQI for the CRMS site.

Table 1. Coefficient of Conservatism (CC) scores of different plant species used to develop a Floristic Quality Index.

CC Score	General Description	Coastal Louisiana Description
0	Alien taxa or native invasive species	Invasive or non-native plants
1-3	Wide spread taxa found in sites with different levels of disturbance	Opportunistic plants of disturbed areas
4-6	Taxa that display fidelity to a community but can tolerate moderate disturbance	Occur primarily in less vigorous coastal wetland communities
7-8	Taxa that are typical of communities which have sustained only minor disturbance	Common plants in vigorous coastal wetland communities
9-10	Taxa that exhibit a high degree of fidelity to a narrow set of ecological conditions	Dominant plants in vigorous coastal wetland communities

- **Marsh Surface Elevation Change**

The marsh surface is measured repeatedly over time from surface elevation tables (RSET) to determine rates of surface elevation change at each CRMS site. Marsh surface elevation and water levels, averaged over the past five years of data, are projected from the surface elevation change rate and eustatic sea-level rise, respectively, five years into the future to assess the marsh surface elevation relative to the hydrologic frame to assess the submergence vulnerability of the CRMS site. The Submergence Vulnerability Index (SVI) score relates the projected marsh surface elevation relative to the projected water-level distribution; lower SVI scores indicate more flooding vulnerability than higher SVI scores (Stagg et al. 2013).

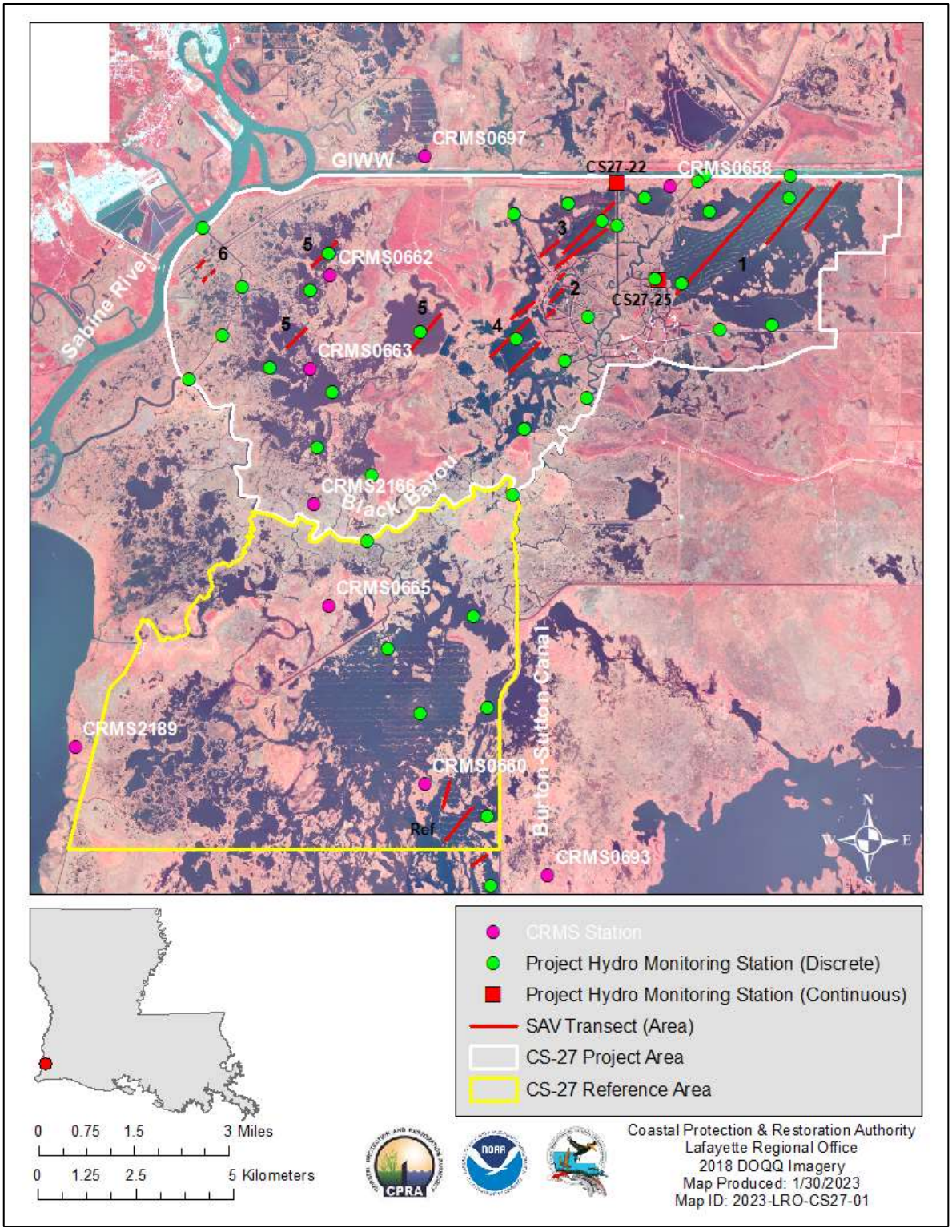

Figure 2. Black Bayou Hydrologic Restoration (CS-27) project continuous recorder stations, discrete salinity stations, CRMS sites, and SAV transects located within the project and reference areas.

IV. Monitoring Activity (continued)

c. Monitoring Results and Discussion

Aerial Photography

The U.S. Geological Survey acquired and analyzed land and water aerial photography before construction in November 2000 and after construction in 2004, 2010, 2015, and 2018 by (Figures 4 a-e). Land change in the CS-27 project area was characterized by consistently maintaining land area over the project life; whereas, the reference area responded to disturbances negatively (Figure 5). From 2000 to 2004, 1 year pre-construction to 3 years post-construction, the project area gained 0.6% of land while, the reference area gained 2%. The difference in the 2000 to 2004 period suggests the entire area was becoming more vegetated, and the higher rate of land gain in the reference area suggests this change was not due to project features. From 2004 to 2010, the project area lost -0.6% of land while the reference area lost -6%. Landloss from 2004 to 2010 was due to Hurricanes Rita (2005) and Ike (2008). Hurricane Rita was more associated with sediment deposition in the CS-27 project and reference areas, as well as the surrounding region. Conversely, Hurricane Ike was associated with large areas of marsh scour, resulting in shallow open water. Field observations after Hurricane Ike in the CS-27 reference area showed areas of marsh scoured by the storm, and later marsh die-off in fresher areas due to the influx and retention of high salinity water from the storm surge (Figure 5). Project features may have played a part in reducing marsh loss in the months following the storms, as the reduction of rapid water exchange may have allowed for greater recovery of affected vegetation and the deposition of suspended sediments.

Beginning in 2010 through 2015, a relatively calmer period in the CS Basin was marked by a drought in 2010-2011, the project area recovered to very near pre hurricane (2004) levels gaining 0.5 % land area while the reference area continued its previous negative trend at more gradual -0.8 %. From 2015 to 2018, heavy upland rain fall and localized flooding dominated the project area, punctuated by Hurricane Harvey in 2017 and the ensuing release of Toledo Bend flood waters (Figure 6). These events exacerbated flooding but also freshened the area while bringing in some nutrients from the upstream basins. Through hurricanes, floods, and droughts the CS-27 project area has maintained land or slightly increased percent land over preconstruction levels, while the references area has perceptibly lost land over the same two decades. The 2020 hurricane season saw Hurricanes Laura and Delta among others impact the project area and without direct evidence the previous project performance during extreme environmental conditions would suggest that the project area was able to maintain its marsh platform and recover as necessary. The larger scale CRMS coastal satellite TM land water analysis strongly concur with the project specific trends of overall stability in the project area (Figure 7). Over this same time interval, the Calcasieu Sabine basin as a whole was losing land annually (-0.12%) (CRMS 2018). This stability occurred while the basin as a whole lost land due to multiple major hurricane landfalls, which had limited impact on the project area due in some part to project features and proximity.

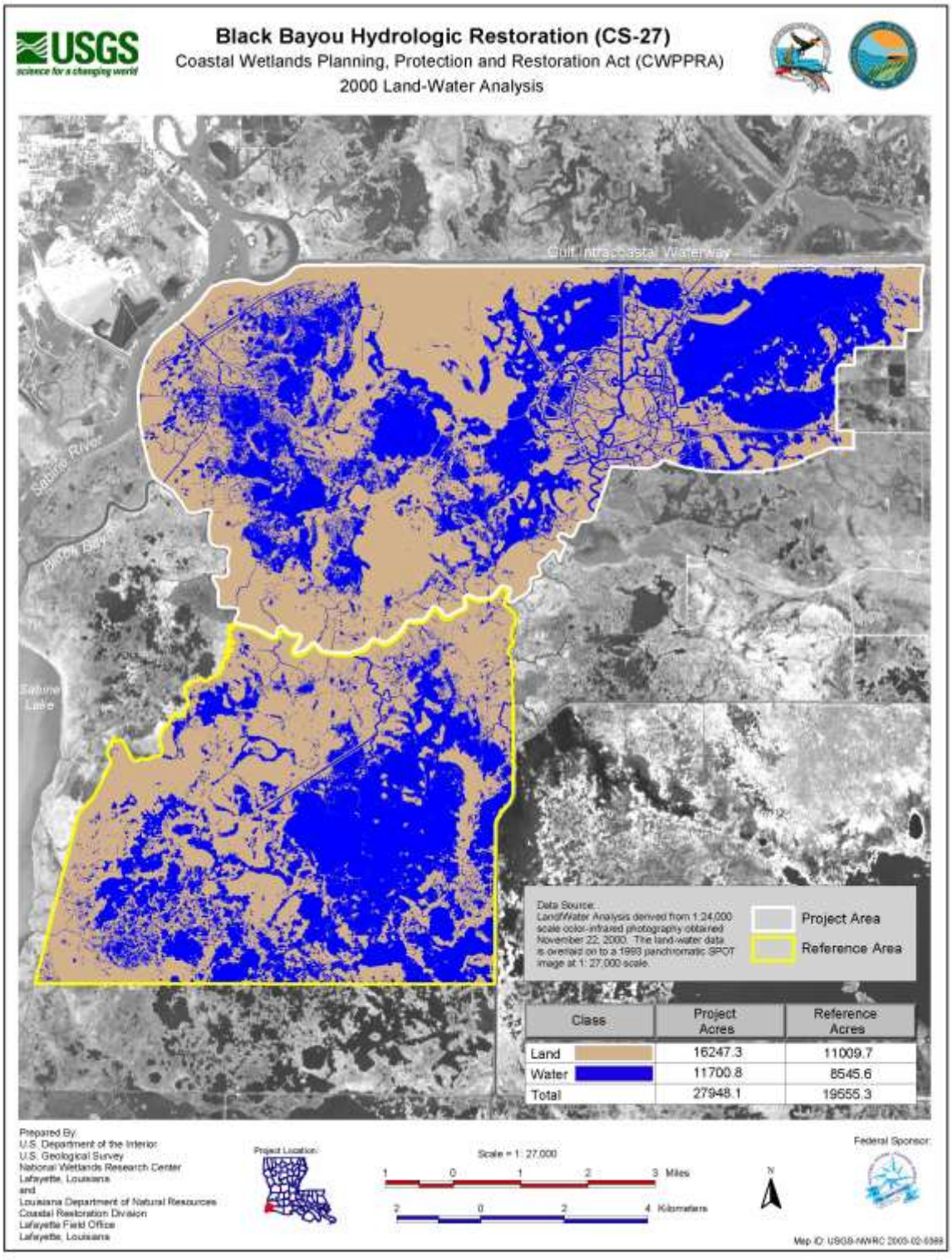

Figure 4a. Preconstruction land water analysis of Black Bayou Hydrologic Restoration (CS-27) project and reference areas from photography taken November 20, 2000.

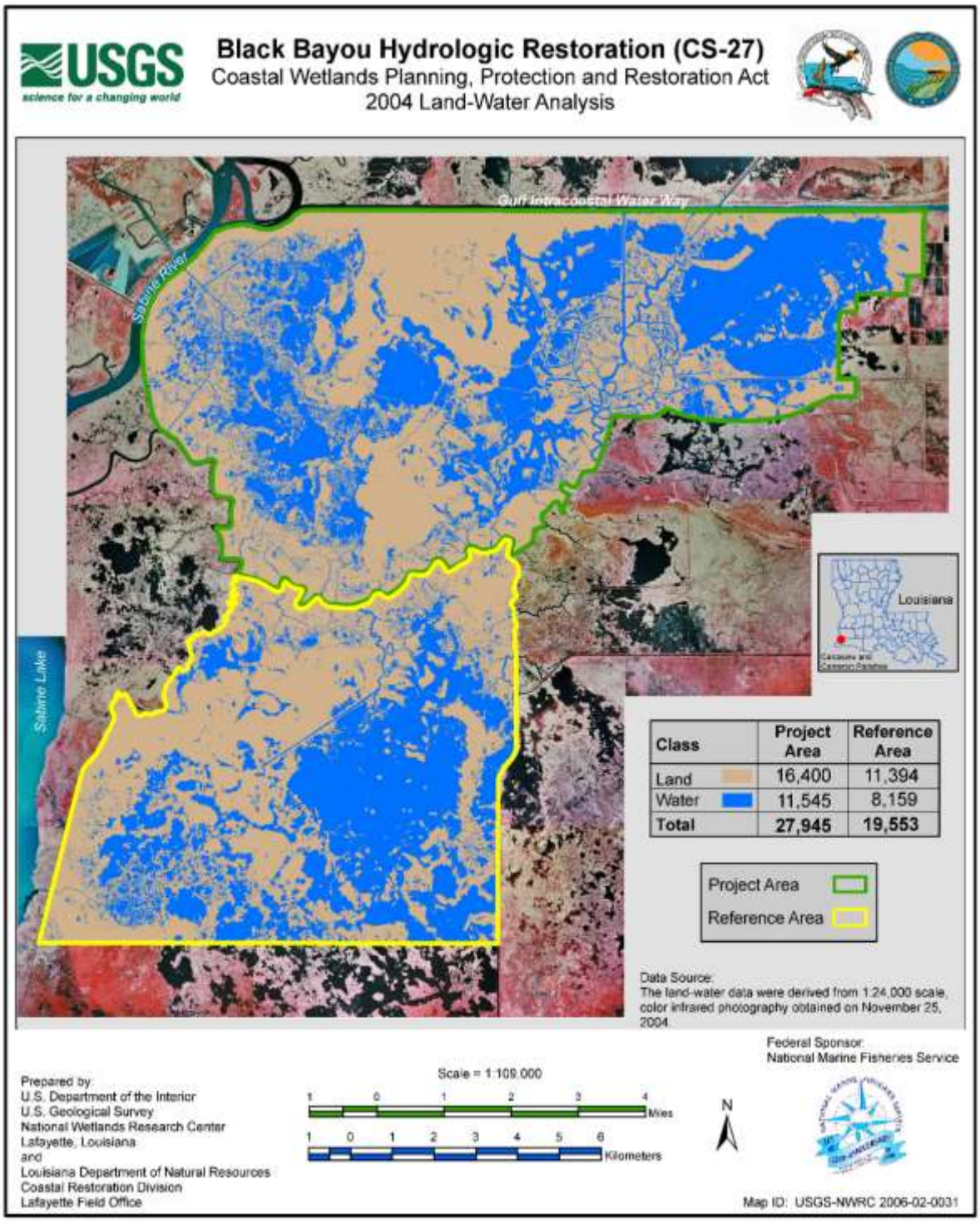

Figure 4b. Post-construction land water analysis of Black Bayou Hydrologic Restoration (CS-27) project and reference areas from photography taken November 25, 2004.

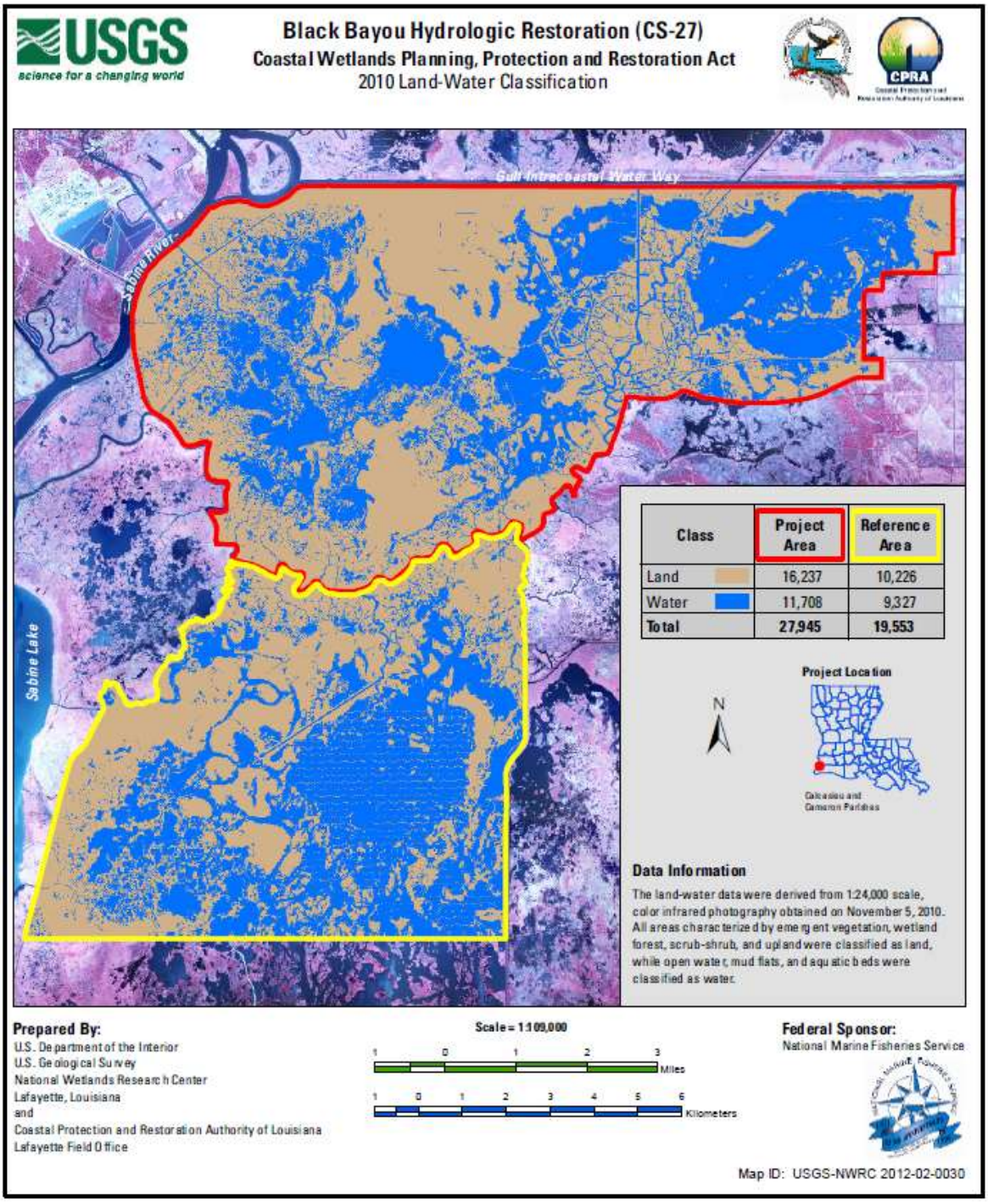

Figure 4c. Post-construction land water analysis of Black Bayou Hydrologic Restoration (CS-27) project and reference areas from photography taken November 5, 2010.

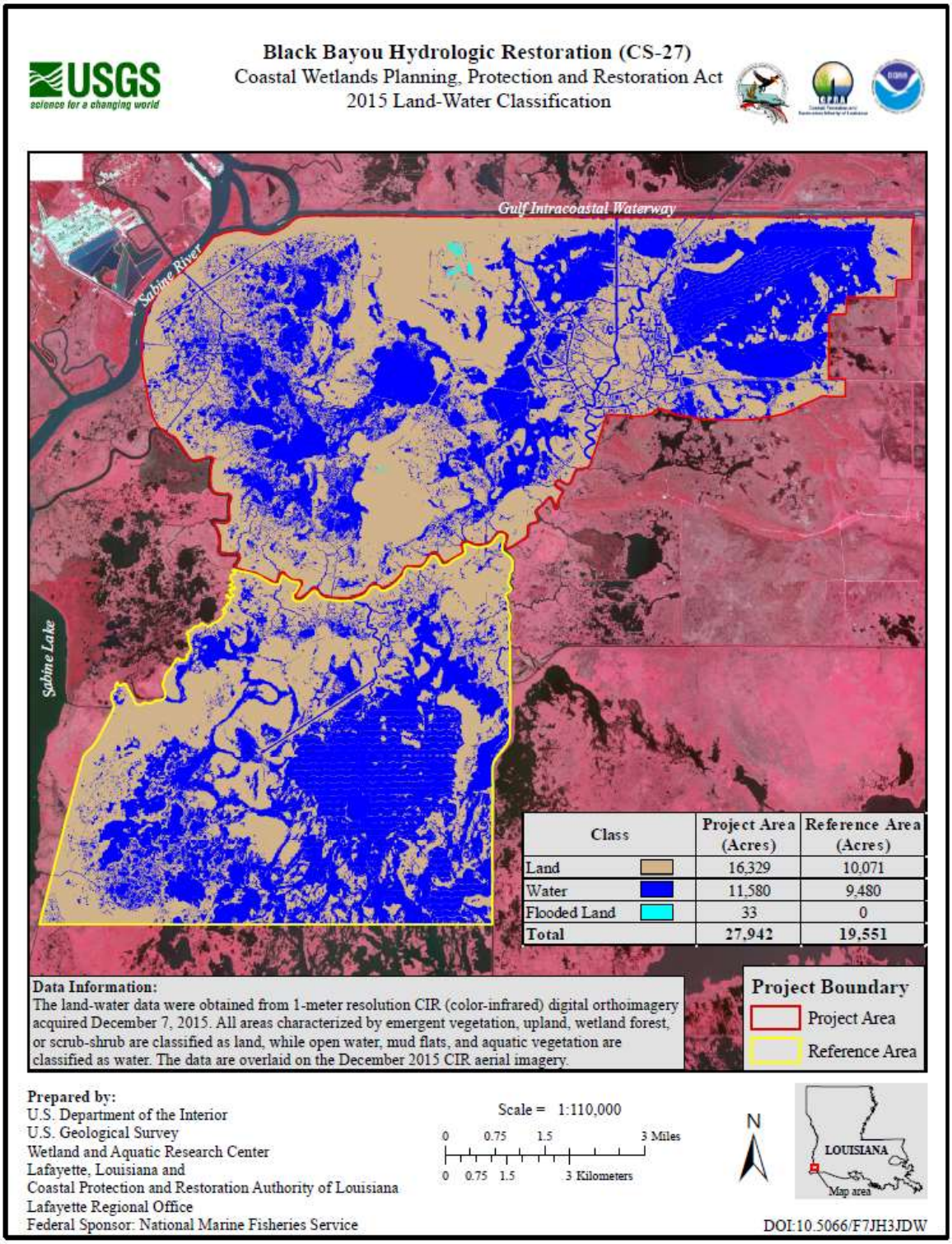

Figure 4d. Post-construction land water analysis of Black Bayou Hydrologic Restoration (CS-27) project and reference areas from photography taken December 7, 2015.

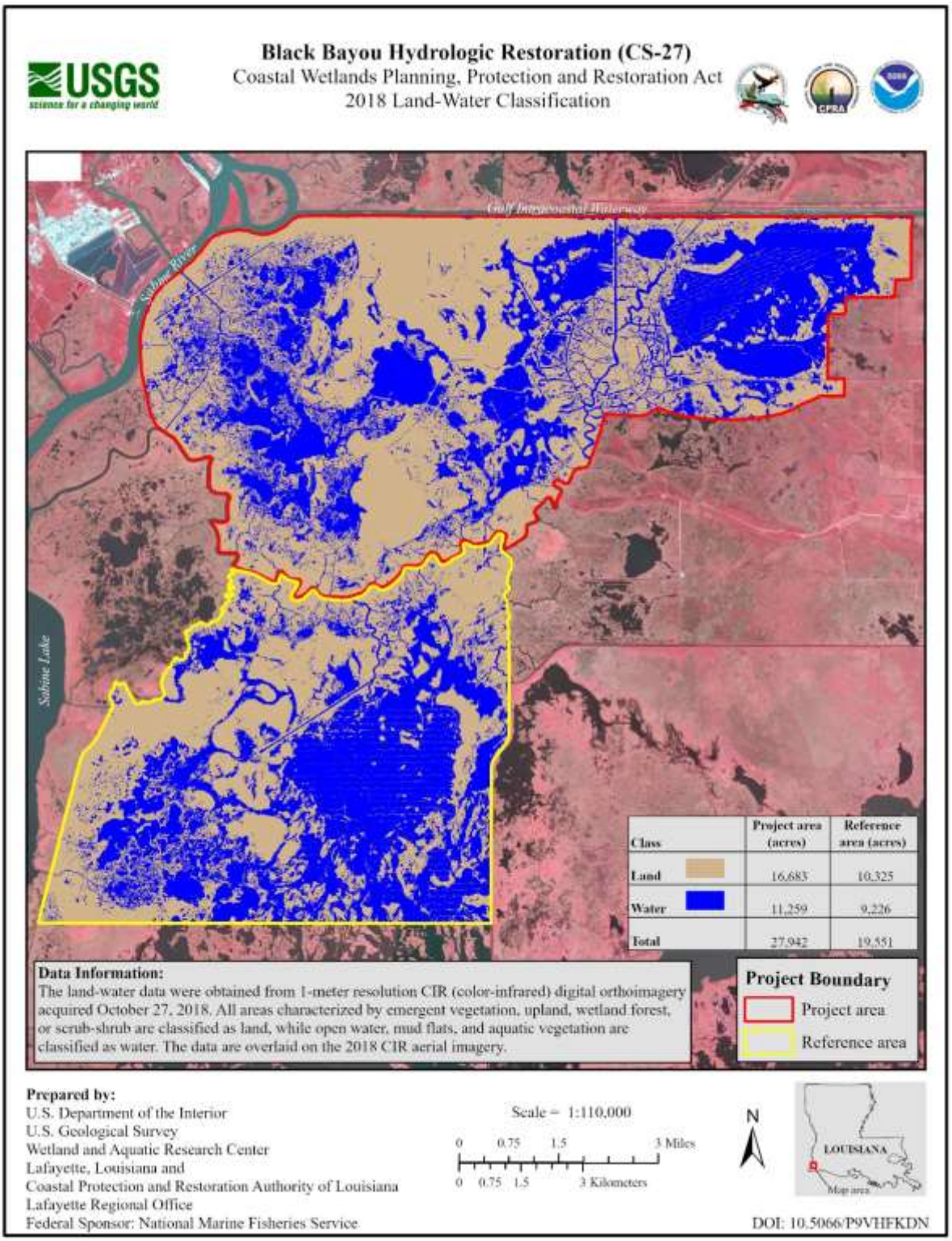

Figure 4e. Post-construction land water analysis of Black Bayou Hydrologic Restoration (CS-27) project and reference areas from photography taken October 27, 2018.

Figure 5. Area of marsh converted to open water by hurricane scour in the Calcasieu Sabine Basin near CS-27.

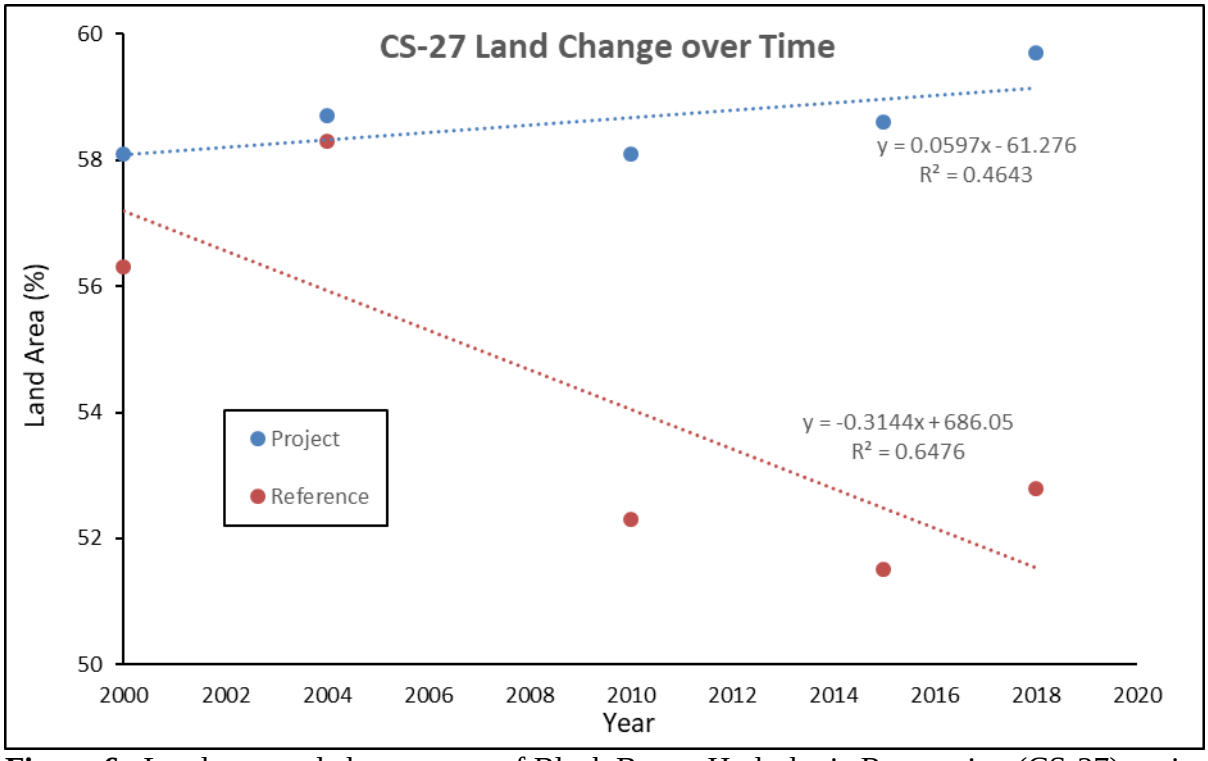

Figure 6. Land area and change rates of Black Bayou Hydrologic Restoration (CS-27) project were compiled from high resolution imagery collected by the USGS-National Wetlands Research Center pre-construction (2000) and post-construction (2004, 2010, 2015, and 2018). Initial construction was completed in November 2001; Hurricanes Rita, Ike, and Harvey occurred in September 2005, September 2008, and August 2017, respectively.

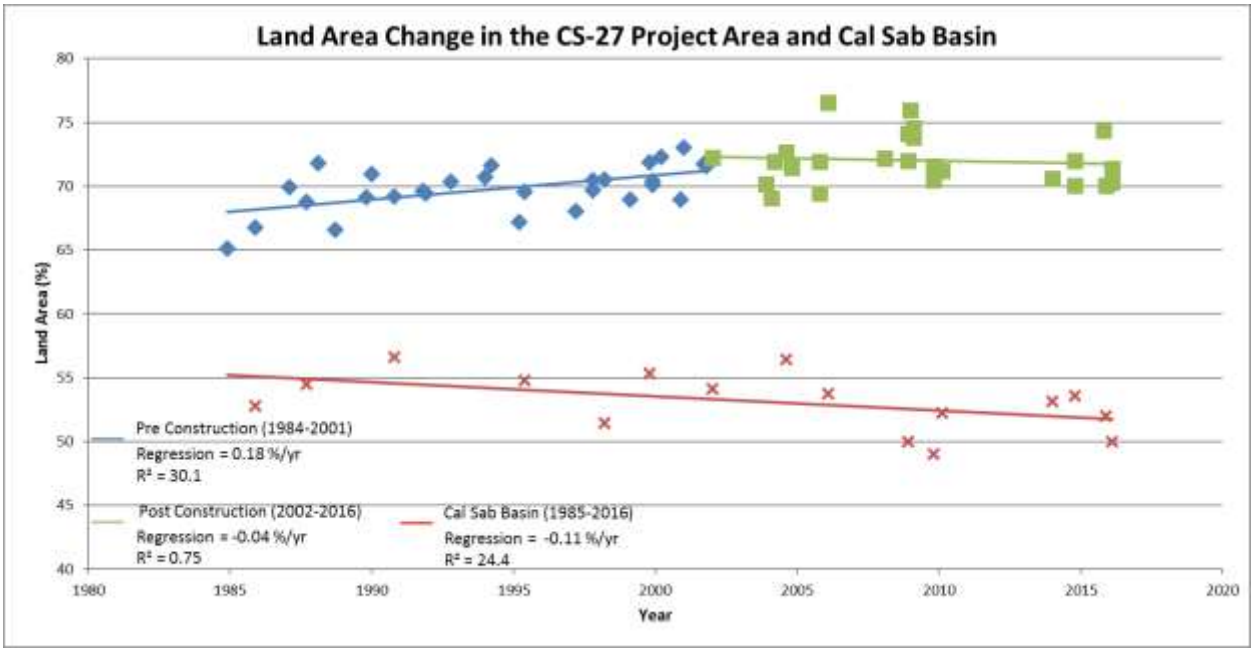

Figure 7. Black Bayou Hydrologic Restoration (CS-27) project and basin scale percent land analysis for years 1985 to 2016 of cloud free Landsat images (CRMS spatial viewer land/water, Couvillion et al. 2017).

Salinity

Since the establishment of the Coastwide Reference Monitoring System – *Wetland* (CRMS) in 2006, the project area (CS27-25, CRMS0658, CRMS0662, and CRMS0663) continuous salinity stations have generally recorded lower average monthly salinity values than the reference stations (CRMS0660, CRMS0665, and CRMS2189) (Figure 8). This effect was evident during several salinity spikes highlighted around Hurricane Ike in 2008 when the project area salinity was on average half that of the reference area for more than two years. This difference in salinity between the project and reference was reduced as a result of the 2011 drought, and the project area did not begin to experience fresher conditions than the reference area until 2012; the extreme salinity experienced in the CS basin was nearly twice the average of salinity spikes brought on by Hurricane Ike. This drought effect was repeated in 2018 and 2022, although to a lesser magnitude, following shorter winter/spring droughts. Otherwise, the project area has remained substantially fresher than the reference area from 2012-2017, often with less than half the salinity of the reference stations. Since Hurricane Harvey in 2017, salinity has drawn closer in the project and references areas with salinity typically greater in the reference area. This indicates the effectiveness of the project features in preventing saltwater intrusion into the project area even under tropical storm conditions. The projects effectiveness was muted by the droughts likely due to the lack of a fresh water head to the north.

Discrete, surface-water, salinity data was collected monthly throughout the project and reference areas from 1999-2004 and from 2012-2017. The east and west regions of the project areas have similar salinities. The reference area generally exhibited the same salinity pattern as the project area, though the reference area is typically more saline. This data is very similar to the continuous recorder data over the same period. Discrete salinity measurements collected during SAV sampling generally agreed with other methods of salinity data collection (Wood and Aucoin 2018).

In order to determine the effectiveness of the impoundment at controlling salinity within the northeast portion of the project area, hourly measurements were taken continuously from 2004 to 2017 (Figure 9; CRMS0658 replaced the project specific station CS27-22 in 2008). An analysis of the continuous salinity data revealed that 2011 was significantly more saline than any other year measured and 2015, 2016, and 2017 were the freshest years recorded but not different from one another ($F_{9,1055}$=147.7, p=<.0001) (Figure 10). The weekly mean difference in salinity inside and outside of the impoundment was only marginally different in 2011 and was not different in any other year. Under most conditions, the inside of the impoundment is very similar to the outside of the impoundment, suggesting that the areas are not hydrologic separated. Water exchanges via the overtopping of the SRT gate and through the multiple rock plugs in the GIWW spoil bank and the rock plug near the SRT gate. This exchange is extremely limited compared to the pre project conditions and the exchange rates of water and organic material is substantially reduced; however, the salinity similarity inside and outside of the freshwater impoundment shows enough exchange takes place to keep salinity similar in both locations.

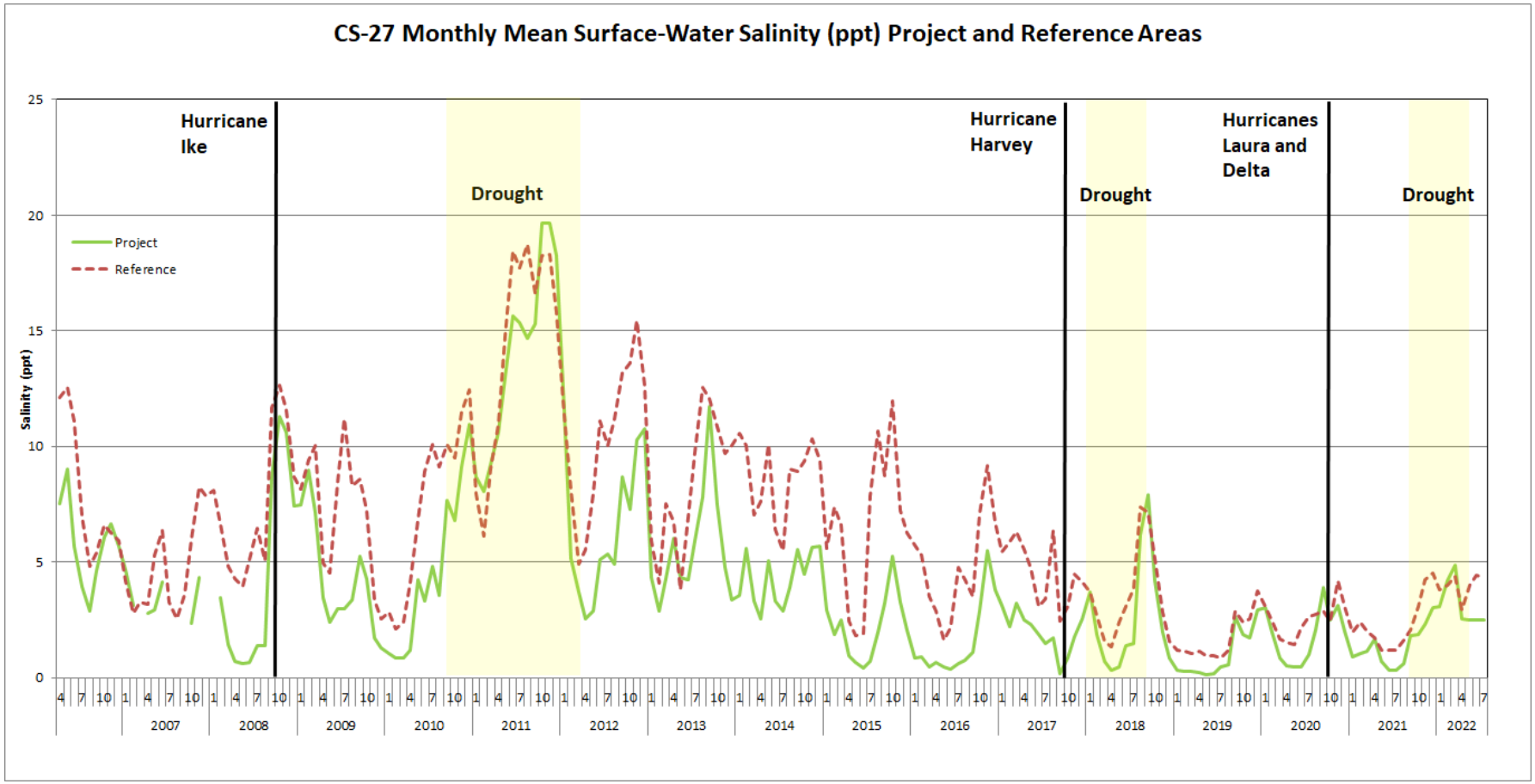

Figure 8. Monthly means of continuous salinity collected at stations in the Black Bayou Hydrologic Restoration (CS-27) project since Coastwide Reference Monitoring System – *Wetland* (CRMS) establishment, 2006 – 2022. Project is CS27-25, CRMS0658, CRMS0662, CRMS0663, and Reference is CRMS0660, CRMS0665, and CRMS2189.

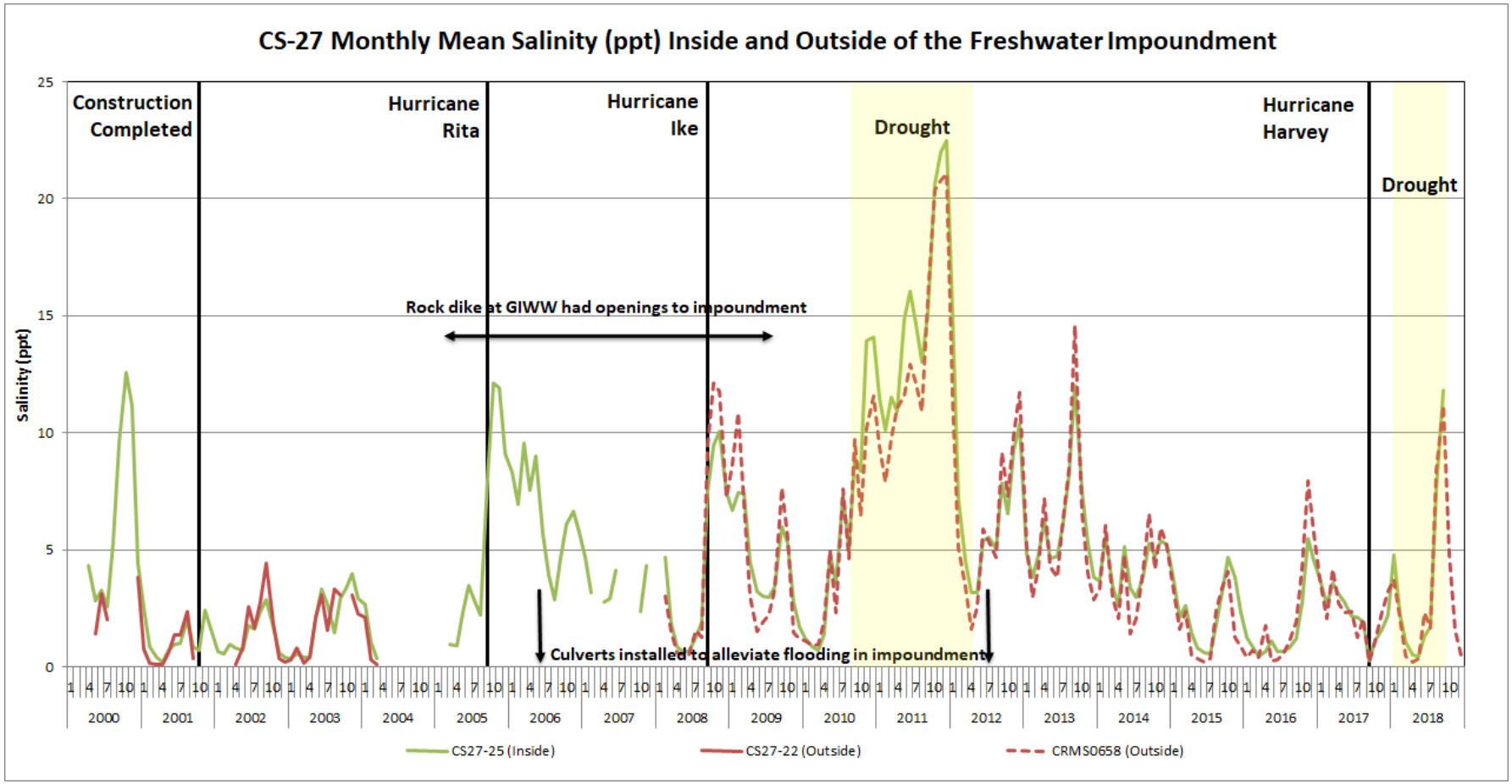

Figure 9. Monthly means of continuous salinity collected at stations CS27-22 and CRMS0658 (outside the impoundment; CRMS0658 replaced the project specific station CS27-22 in 2008) and CS27-25 (inside the impoundment) within the Black Bayou Hydrologic Restoration (CS-27) project area from 2000-2018. From 2005-2009 the rock dike along the GIWW had openings which were repaired by the landowner, also culverts were installed to alleviate flooding in 2006 and 2012.

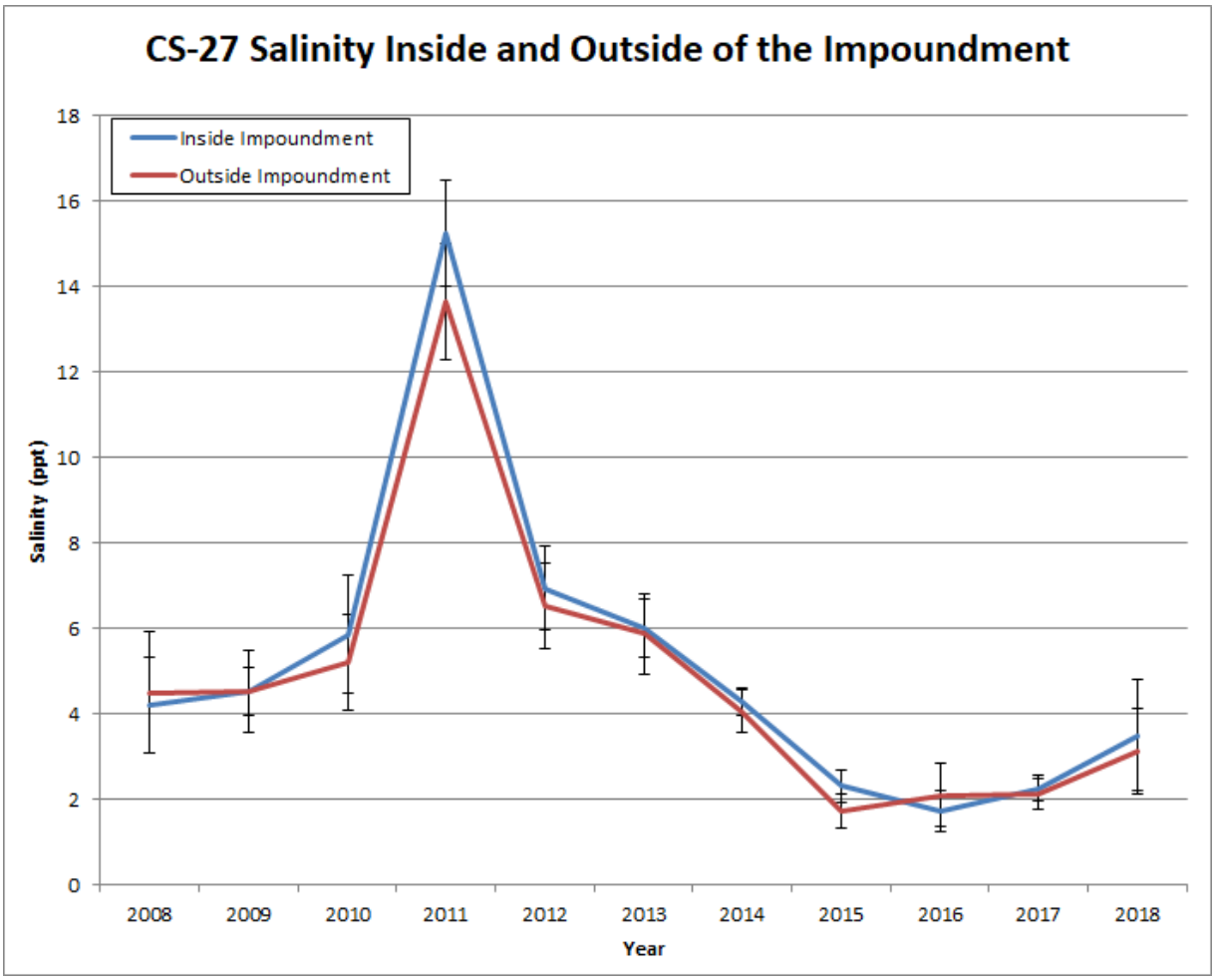

Figure 10. Yearly means and standard errors of continuous salinity collected at project stations CRMS0658 (outside impoundment) and CS27-25 (inside impoundment) within the Black Bayou Hydrologic Restoration (CS-27) project area from 2008-2017.

Soil porewater salinity, which is encountered by plant roots, was higher in the reference area from 2007-2022 with difference from the project area averaging 2.08 ppt (Figure 11). Porewater salinity differences were generally smaller than might be ecologically meaningful except in 2009-2010 and 2012 when the salinity differences averaged 4.3 ppt annually; porewater salinity peaked in both areas in 2011 during the height of a large-scale drought (Figure 12). The differences in soil porewater salinity were the closest from 2020-2022 averaging 0.95 ppt, which includes the 2020 hurricanes, as annual salinities were among the lowest of the project life in 2020 before rebounding in 2022. Overall the project has kept porewater salinity below reference over the life of the project but probably not at an ecologically meaningful level to facilitate a fresher species cohort, which is reflected in the vegetation data.

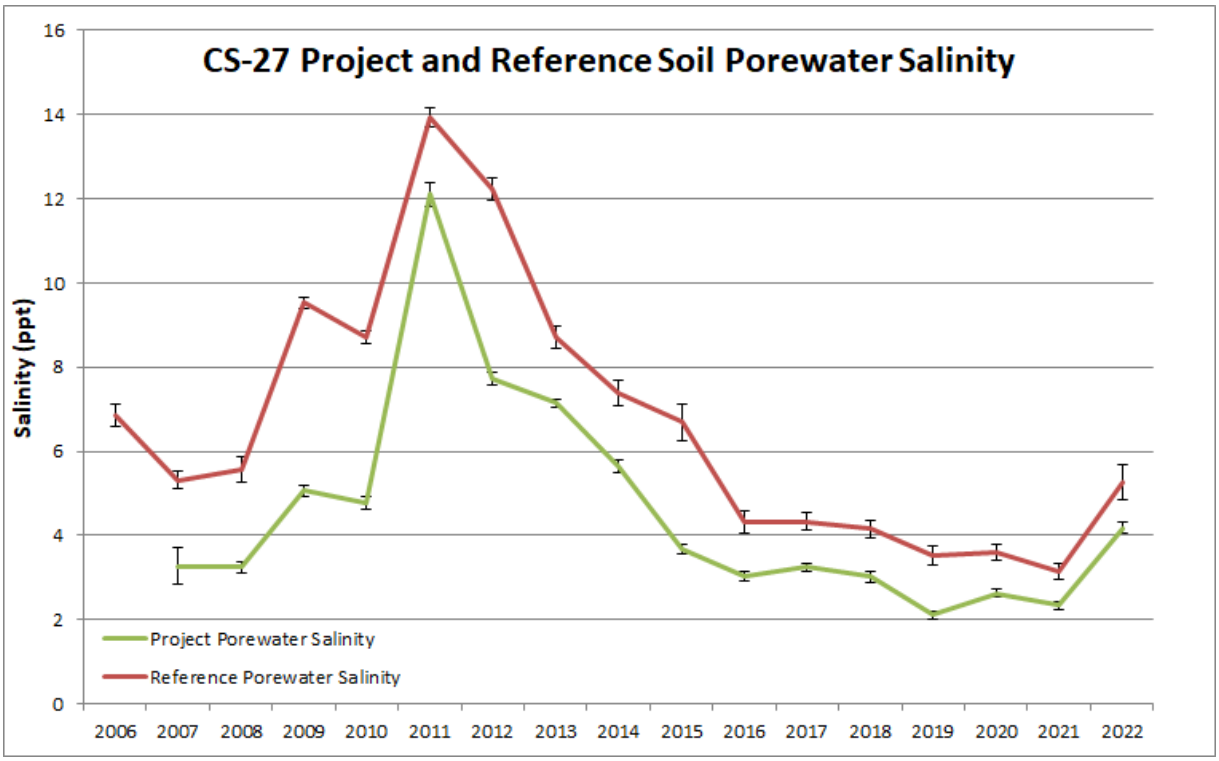

Figure 11. Yearly means and standard errors of soil porewater salinity collected at Black Bayou Hydrologic Restoration (CS-27) project and reference stations 2006-2022.

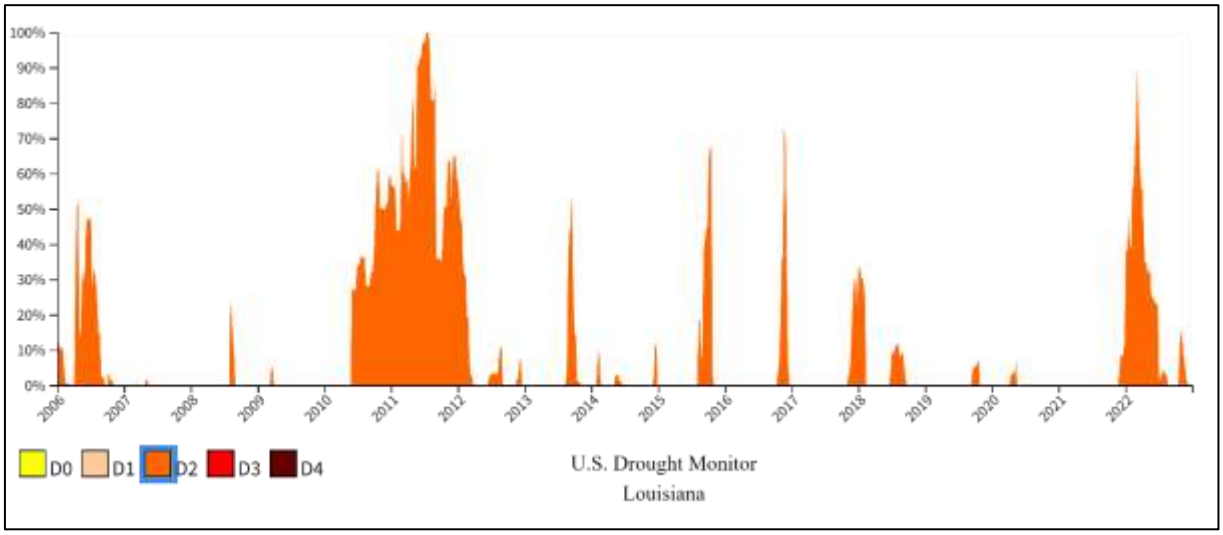

Figure 12. Since 2006, the longest duration of drought (D1-D4) in Louisiana lasted 107 weeks beginning on April 20, 2010, and ending on May 1, 2012. The most intense period of drought occurred the week of June 21, 2011, where D4 affected 64.94% of Louisiana land.

Vegetation Plantings

Schoenoplectus californicus (bullwhip) plantings were installed on the east side (Phase I – 2002) and on the west side (Phase II – 2003) of the project area. Phase I plantings were monitored in September 2003, approximately 1 year after planting. Sample plots had varying survival success; except for a few, most plants counted as dead were absent. The mean percent survival of all planting stations (Overall) was 68 ± 26%. Survival within the smaller ponds on either side of the Black Bayou Cut-Off Canal was greater than both the Open Water and along the Terraces in the Impoundment (ANOVA: df = 2, F = 5.06, p = 0.0100). Variability in survival was higher in the Impoundment than small ponds and was highest along the terrace, which was thin and deteriorating (Table 2, Figure 13). Some plots had robust, healthy plants that were almost indistinguishable from one another, whereas other plots had plants with few stems in deteriorated condition (Castellanos and Juneau 2004). Phase II plantings were not field monitored.

Planting presence prior to Hurricane Rita and almost 20 years later was qualitatively assessed within the planting areas (Figures 1 a and b) by looking at April 2005 and May 2022 aerial imagery in the Google Earth Historical Imagery tool. The Phase I imagery from 2005, about 3 years after installation, showed about 75 % of the plantings remaining in the smaller ponds on either side of the Black Bayou Cut-Off Canal, 40 % remaining in the open water of the impoundment, and 55 % remaining along the terraces. By 2022, the smaller ponds had about 10-15 % of the plantings remaining and no plantings remained in open water or along terraces. About 60% of the original terraces remained in the 2022 imagery, and many large, duck-wing terraces were constructed in the impoundment by March 2012. Phase II imagery from 2005, about 2 years after installation, showed plantings mainly visible along the perimeters of the marsh; rows of vegetation were typically thinner along the southeast pond edges. By 2022, no plantings were visible in Phase II; although, some other plantings and small terraces are visible.

Table 2. Planting survival in Phase I vegetative plantings in east side and large impoundment of the Black Bayou Hydrologic Restoration (CS-27) project were monitored in September 2003. Values are means ± 1 SD; standard deviations were used to display variability among areas with imbalanced sample sizes. Differences among the areas are indicated by different letters in the Student's t posttest; the Overall category is for demonstration purposes and was not included in the comparison among areas.

Location	Percent Survival (% ± 1 SD)	Student's t Post Test
Phase I - Overall	68 ± 26	Not Included
Black Bayou Cut-Off Ponds	92 ± 05	A
Impoundment – Open Water	67 ± 19	B
Impoundment - Terraces	60 ± 32	B

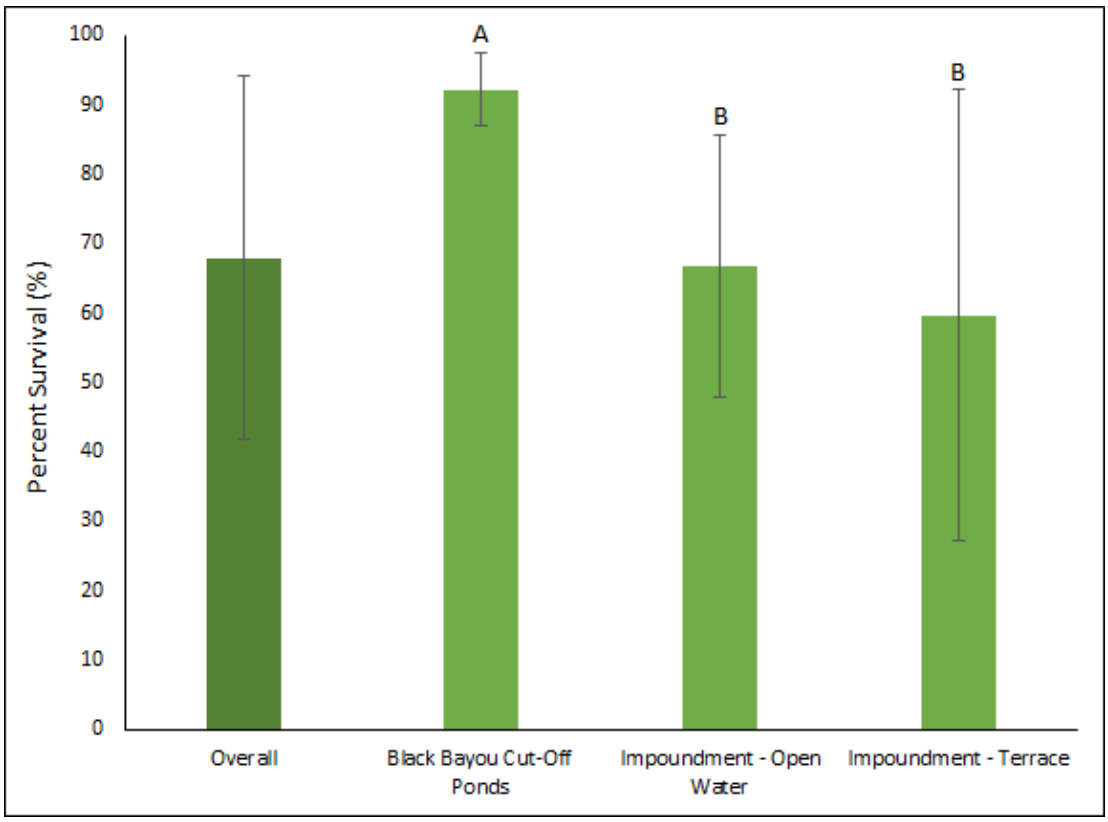

Figure 13. Planting survival in Phase I vegetative plantings on the east side and the large impoundment of the Black Bayou Hydrologic Restoration (CS-27) project in September 2003.

Shoreline change

A foreshore rock dike was completed in November 2001 along the southern shoreline of the GIWW on the northeastern side of the project area between the Black Bayou Cut-off Canal and Gum Cove Ridge north of the impoundment. Crushed stone was added in December 2003 to close the breaches that connected the GIWW to the impoundment. To evaluate the effectiveness of the dikes effect on decreasing erosion, shoreline surveys (dGPS) of the breached portion of the GIWW shoreline along the northern boundary of the impoundment were conducted before construction in March 2000, soon after the rock dike was constructed in March 2002, and about three years after construction in August 2004. Sediments were trapped and settling in the low energy area behind the dike, and mud flats were colonized by vegetation (Figure 14). Overall, the dike was successful at reducing the mean erosion rate of the project along the GIWW by gaining land in the protected area by more than twice as fast during the post construction period than the preconstruction period (Table 3; Figures 15 A and B) (Castellanos and Juneau 2004).

Figure 14. Sedimentation and vegetative growth between the GIWW rock dike and dredge material levee along the north side of the impoundment within the Black Bayou Hydrologic Restoration (CS-27) project.

Table 3. Net land gain and rates along the GIWW shoreline/northern impoundment boundary protected by the foreshore dike within the Black Bayou Hydrologic Restoration (CS-27) project.

Time Period	Net Land Gain	Land Gain Rate
2000-2002 (mainly preconstruction)	0.125 acres	0.063 acres/yr
2002-2004 (post construction)	0.317 acres	0.131 acres/yr

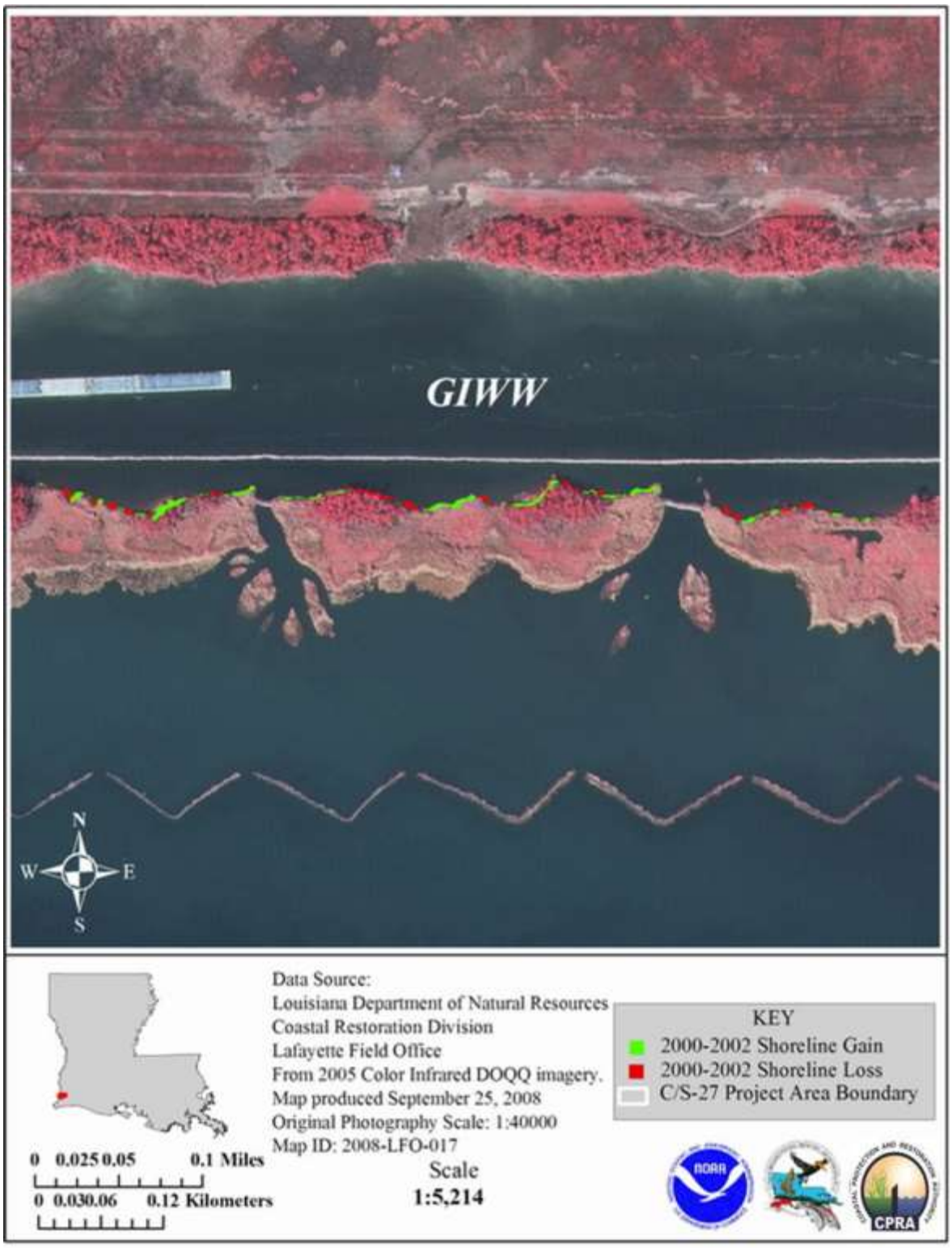

Figure 15a. Shoreline change from surveys conducted in March 2000 and March 2002 along the GIWW shoreline/northern impoundment boundary protected by the foreshore dike within the Black Bayou Hydrologic Restoration (CS-27) project.

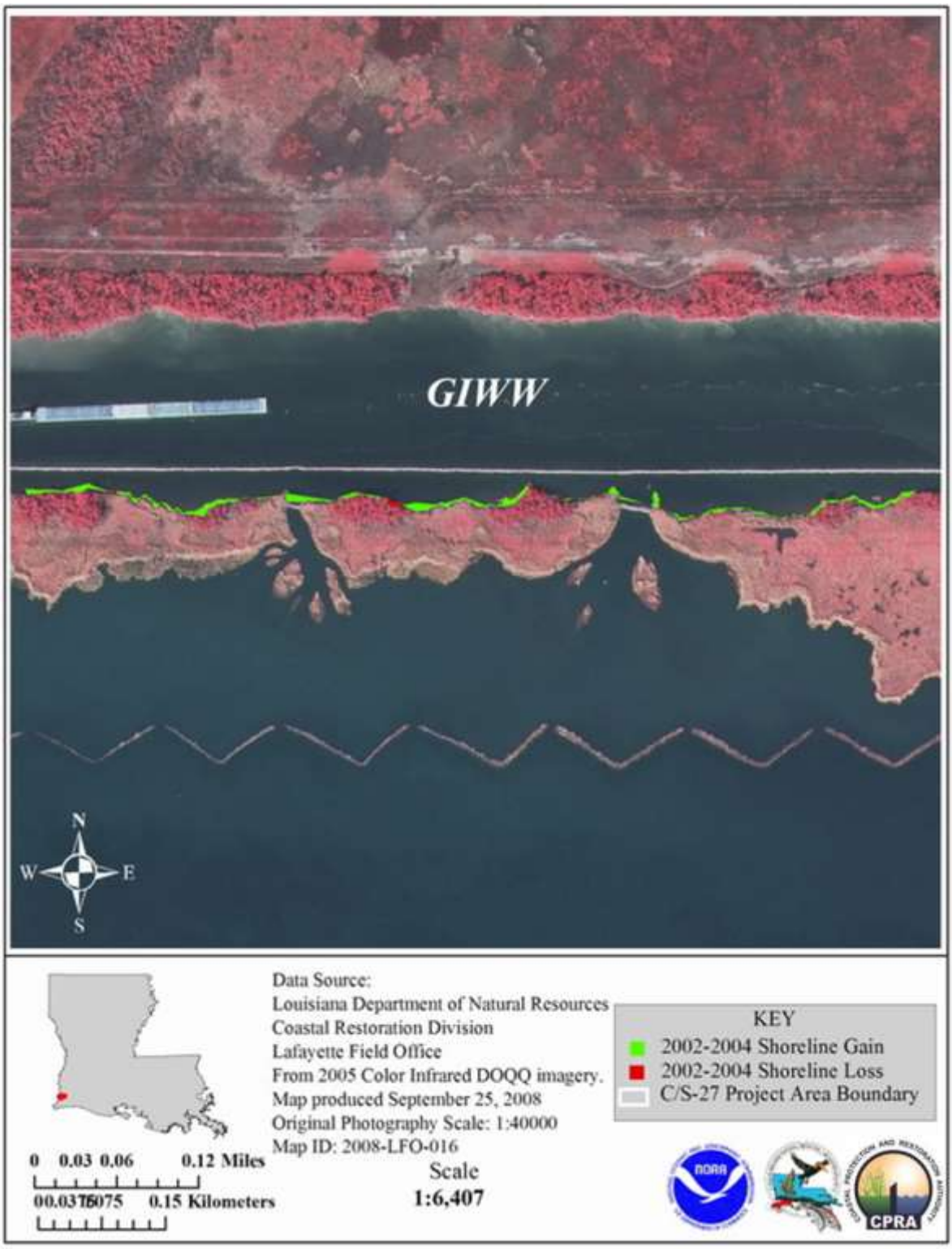

Figure 15b. Shoreline change from surveys conducted in March 2002 and August 2004 along the GIWW shoreline/northern impoundment boundary protected by the foreshore dike within the Black Bayou Hydrologic Restoration (CS-27) project.

Since 2004, the breached shoreline detailed in the GIS analysis remained steady with areas east and west of the breach filling in between the shoreline and dike (Figure 16A). The east end appears to have been filling in as intended with the exception of ponding near the breaches. The unprotected shoreline east of the dike has eroded about 130 ft (~6 ft/y) since installed (Figure 16B). Areas such as the breached stretches are deeper between the dike and the shoreline from the sediment being exported into the impoundment as evident from the delta splays that form at the breaches. In-filling of these deeper areas are difficult to determine by only looking at the shoreline change. A more conclusive monitoring would need topographic/bathymetric surveys to determine elevation changes and possibly soil volume changes over time.

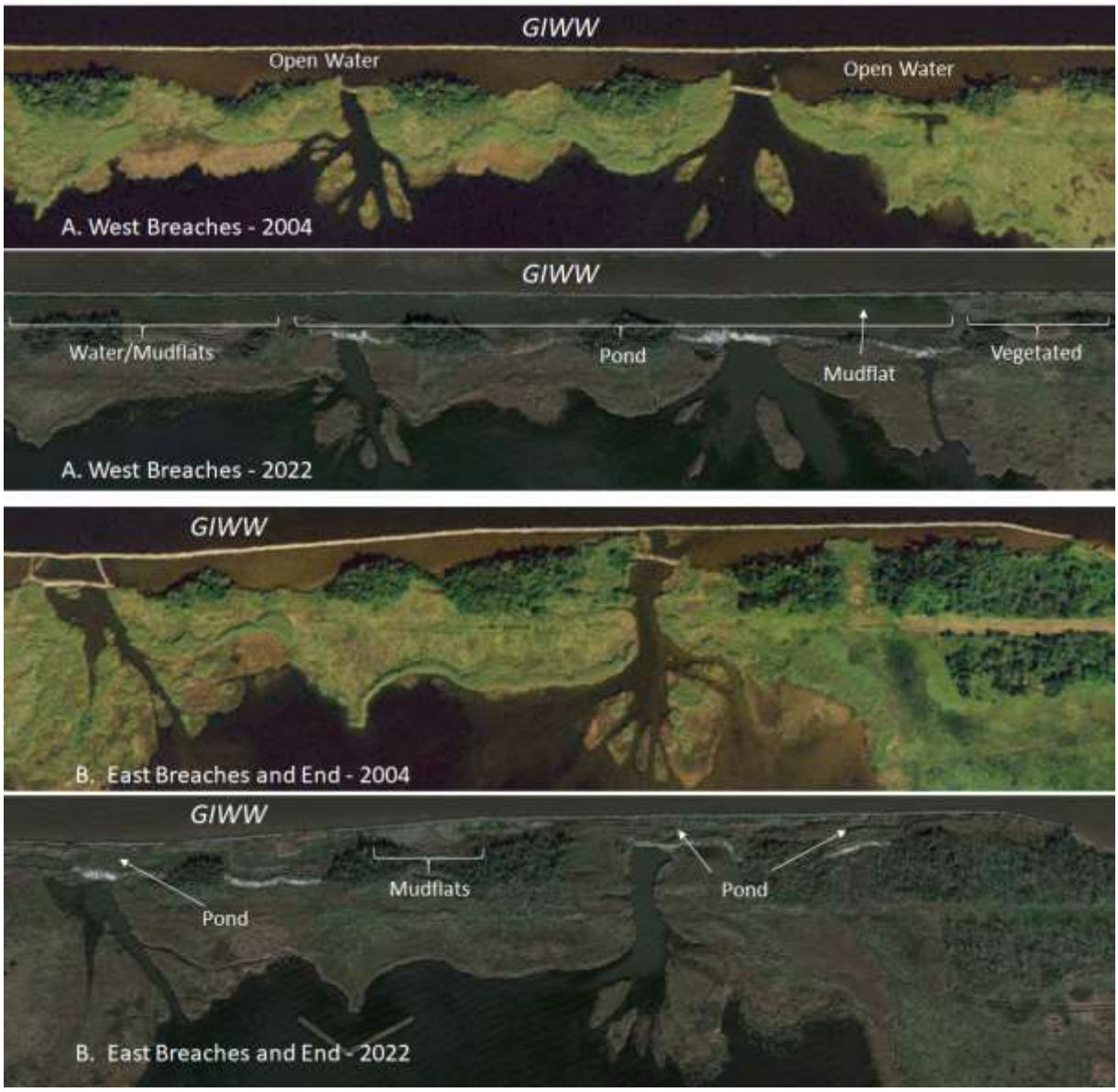

Figure 16A-B. Changes in the area between the foreshore rock dike and shoreline along the GIWW were described from 2004 and 2022 Google Earth imagery.

Submerged Aquatic Vegetation (SAV)

Submerged aquatic vegetation (SAV) transects were sampled in ponds throughout the project and reference areas from 1999 through 2017 (Figure 3). Overall, SAV coverage has remained high (>50% occurrence) in the project area, with a sharp reduction in occurrence in 2005 following Hurricane Rita and 2012 following the prolonged drought in 2011 (Figure 17). Subsequently, the project area fully rebounded to pre disturbance levels of SAV as of the 2017 sampling effort. The project has increased the SAV in the interior ponds within the project area, which assisted with the population recovery from environmental disturbances. This trend was not evident in the reference area as the crash in SAV after Hurricane Rita continued through the 2011 drought to less than 5 % occurrence and took over a decade to recover towards 2003 levels in 2017. Both the project and the reference area have seen an impressive increase in SAV from 2014 to 2017, which included five years of abundant rain and fresh conditions. Transects in the large, eastern impoundment of the project area (Project Area 1) has had lower frequency of SAV than the other project areas and was more similar to the Reference area (Figure 18); the impoundment was a large open water area until terraces were installed between the 2012 and 2014 surveys. A more comprehensive discussion of SAV is in the CS-27 2018 OM&M Report (Wood and Aucoin 2018).

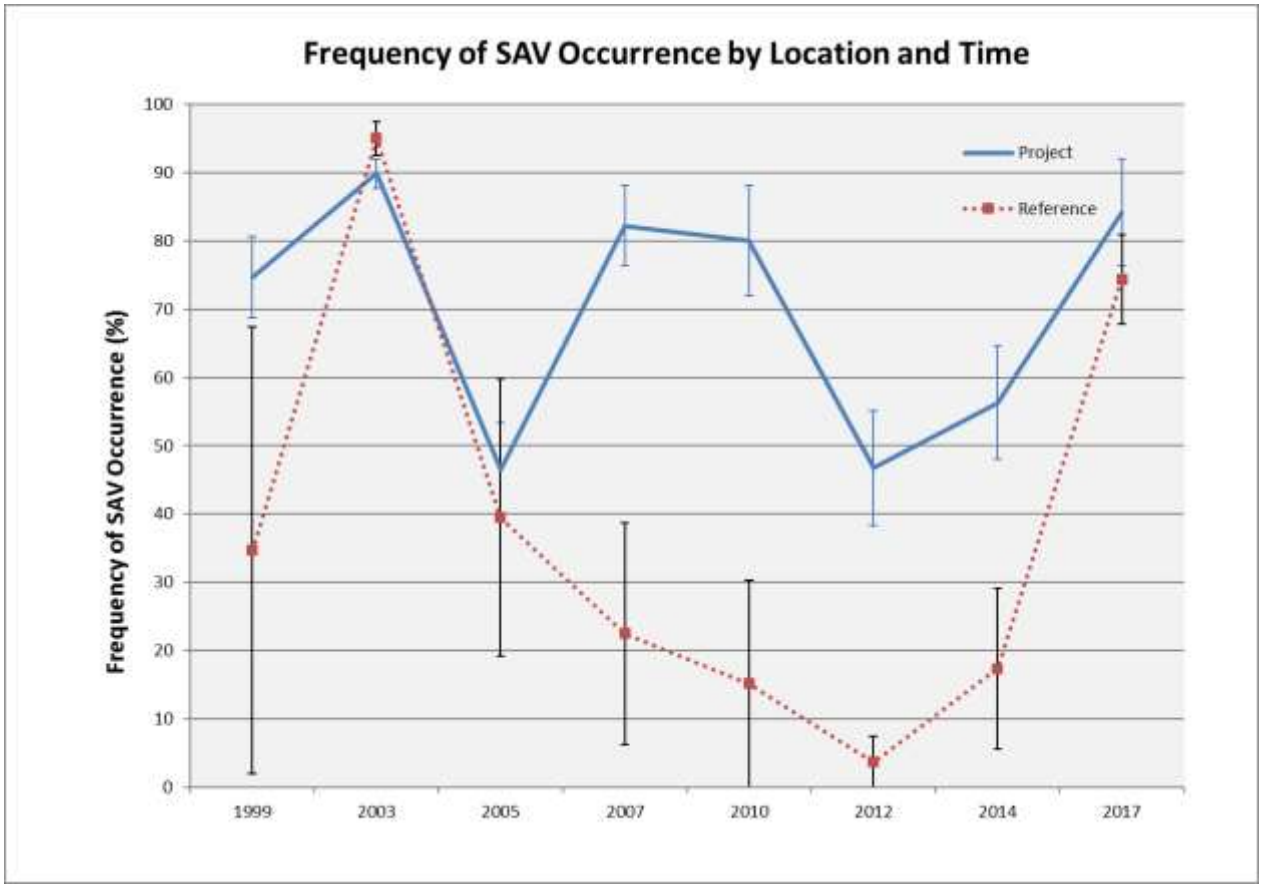

Figure 17. Mean and standared errors for Submerged Aquatic Vegetaion (SAV) frequency of occurrence in the project and reference areas from pre-project in 1999 to 2017.

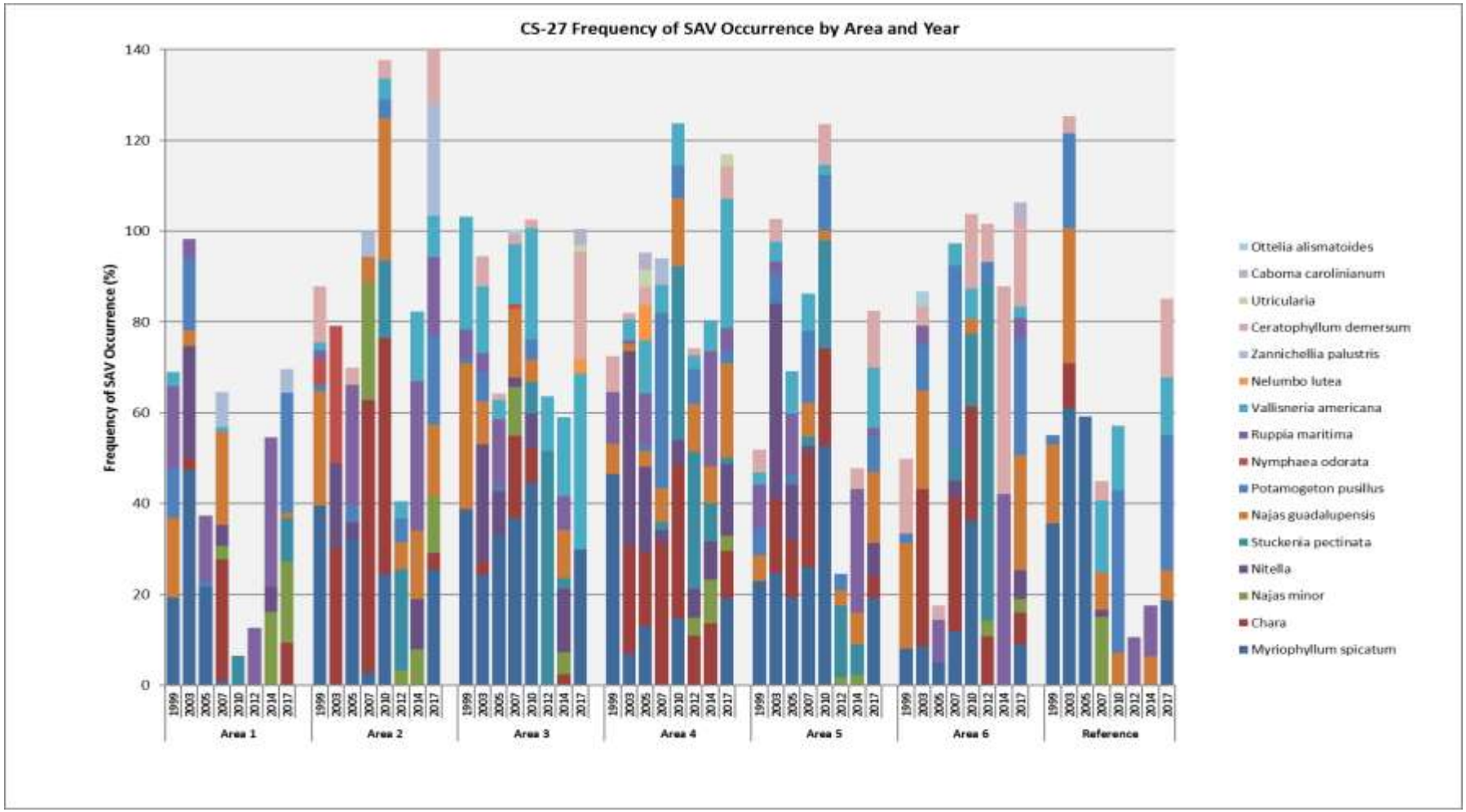

Figure 18. Percent occurrence of SAV species by sample area collected before construction in 1999 and post construction in 2003, 2005, 2007, 2010, 2012, 2014 and 2017 within the Black Bayou Hydrologic Restoration (CS-27) project and reference areas. Values are the mean of transect values (n=3) per area for each year except for area 2 in 2003 (n=1), 2005 (n=2), and 2007 (n=1).

CRMS Supplemental Data

Hydrologic, vegetative, and marsh elevation data are collected at CRMS sites that can help describe the effects of the project objectives on overall marsh health. The CRMS website synthesizes data from each data type into indices.

- **Hydrologic Index**

Hydrologic Index (HI) scores quantify the relationship between the hydrologic conditions of flooding and salinity and the potential vegetation production in a given marsh type; higher HI scores represent better plant growth. In general, CS-27 sites experienced three phases of HI scores: low scores from 2009 through 2013 with the exception of 2010, higher scores from 2014 through 2018, and decline to lower scores from 2019 – 2021 (Figure 19). The lower HI scores from 2009-2013 were driven by high salinity concentrations, especially during the extreme drought of 2010-2011 (Figure 20, see 2011 example). Higher scores from 2014-2018 were driven by low salinities which moderated the higher flooding (Figure 20, see 2018 example). Scores from 2019-2021 declined as time flooded increased despite salinity decreasing (Figure 20, see 2021 example). Hydrology in the CS-27 project area is driven by regional climate conditions; the project area excels when overall hydrologic conditions improve compared to HI scores at reference sites in the CS Basin. However when conditions deteriorate the project is more in line with reference sites as there is no local source of freshwater during drought conditions and excessive floodwaters inundate the basin as a whole.

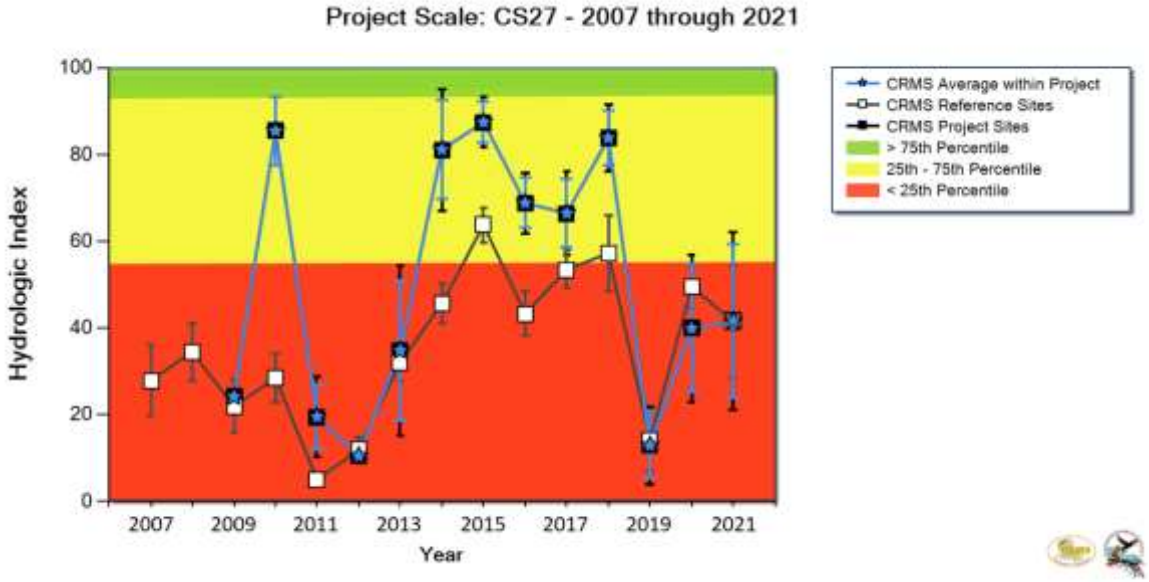

Figure 19. Hydrologic Index scores for CRMS sites in the Black Bayou Hydrologic Restoration (CS-27) project areas shown relative to all other CRMS sites in intermediate/brackish marsh types within the Calcasieu/Sabine Basin over time. The background describes the distribution of all CRMS sites. CS-27 project area site CRMS2166 was excluded from the HI analysis because it is a marsh well site and not comparable to the other sites surface water locations. This figure was obtained from https://lacoast.gov/chart/Charting.aspx?laf=crms (CPRA 2022).

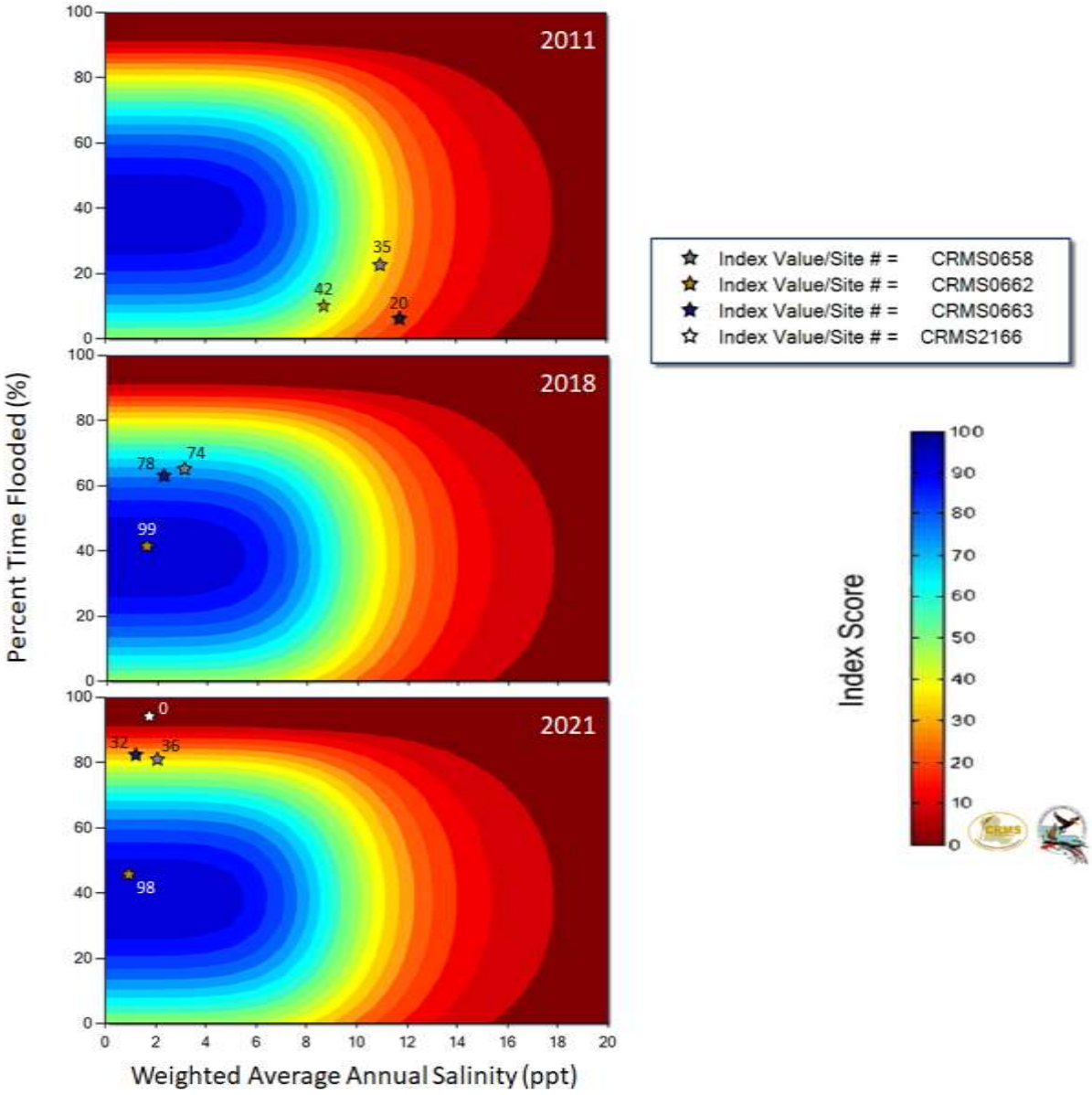

Figure 20. Examples of Hydrologic Index scores from high salinity (2011), moderate (2018), and high flooding (2021) years in CRMS sites of the Black Bayou Hydrologic Restoration (CS-27) project. CRMS2166 was excluded from the HI analysis in 2011 and 2018 because it is a marsh well site and not comparable to the other sites surface water locations. This figure was modified from charts obtained from https://lacoast.gov/chart/Charting.aspx?laf=crms (CPRA 2022).

- **Vegetation**

The CS-27 project and reference areas are heavily dominated by *Spartina patens* (saltmeadow cordgrass*)* and to a lesser extent *Juncus roemerianus* (black needlerush) and *Ipomoea sagittata* (saltmarsh morning-glory) and more recently in the reference area by *Phragmites australis* (common reed). Which are all native perennial species common to intermediate marshs (Figure 21). As such any conditions that are not favorable to the continued growth of *Spartina patens* will adversely affect large areas of both the project and reference areas. The CRMS vegetation surveys in the project and reference area began after the area had already recovered from Hurricane Rita but the effects of Hurricane Ike are fully evident in the 2008-2010 percent cover and FQI scores. This effect is especially evident at the reference site CRMS0660 as it was completely denuded of vegetation and never recovered thus was eventually moved to a new location in 2011. Another reference site CRMS0665 also was significantly affected dropping below 50% cover and FQI score during the subsequent season. A slight to moderate decline in percent cover and FQI score in the project and reference area started in 2012 and persisted through 2014, as the coverage of *Spartina patens* was reduced without being replaced by another species. This could be attributed to higher water levels in the years following 2011 as high local and upland rains freshened the system. In both the reference and project areas 2015-2019 were typically stable in regards to FQI and percent cover. However the 2020 hurricane season increased salinity, flooding, and mechanical damage to the marshes of the CS basin. The CS-27 project area was spared the worst impacts of Hurricanes Laure and Delta but did see a decline in cover and subsequently FQI score. Both the project features and the northerly location of the project have consistently protected the fragile marshes located in the project against an ever increasingly dynamic climate.

An investigation into the project and reference areas marsh salinity type shows the project area has a slightly more saline cohort of species than the reference area. The marsh salinity type displays the aggregation of all species containing a similar salinity regime for emergent marsh species in the given location (Figure 22). The overall trend in marsh salinity type is that the project area is supporting less of the fresh through intermediate marsh types while maintaining a small but stable brackish saline species contingent annually. This may still be a remnant of hurricane and drought disturbance that is still being expressed in the marsh salinity type and vegetation as a whole. Project CRMS sites support a generally stable amount of both brackish and fresh mash vegetation after 2012 through 2021, with most of the variation coming from the inter-brackish category. The reference area sites show an increase of the fresher vegetation cohorts between 2009 and 2021. This is due to an increase of *Phragmites australis* and *Typha* species as fresher flooded conditions have become normalized. The overall vegetation salinity patterns inside and out of the project area seem very stable in this corner of the upper Calcasieu Sabine basin and have rebounded well from hurricanes and extreme droughts, which has not been true of the basin as a whole.

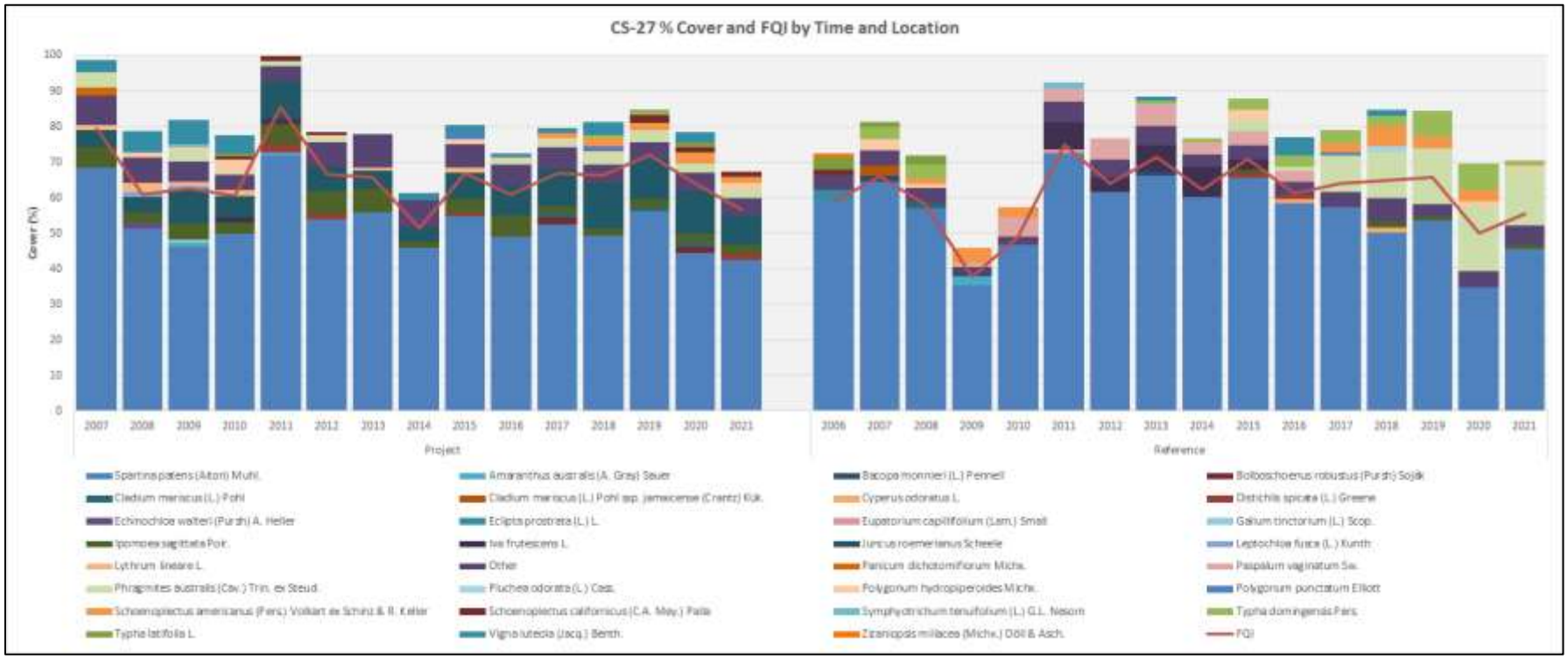

Figure 21. The percent coverage and FQI scores in the project and reference area vegetation data collected 2006-2021 from CRMS sites. Project sites are CRMS0658, CRMS0662, CRMS0663, and CRMS2166 with three reference locations in similar marsh habitat CRMS660, CRMS0665, and CRMS2189. Reference site CRMS0660 shows a complete loss of vegetation post Hurricane Ike and was reestablished in 2011 in a vegetated location after failing to recover for two years.

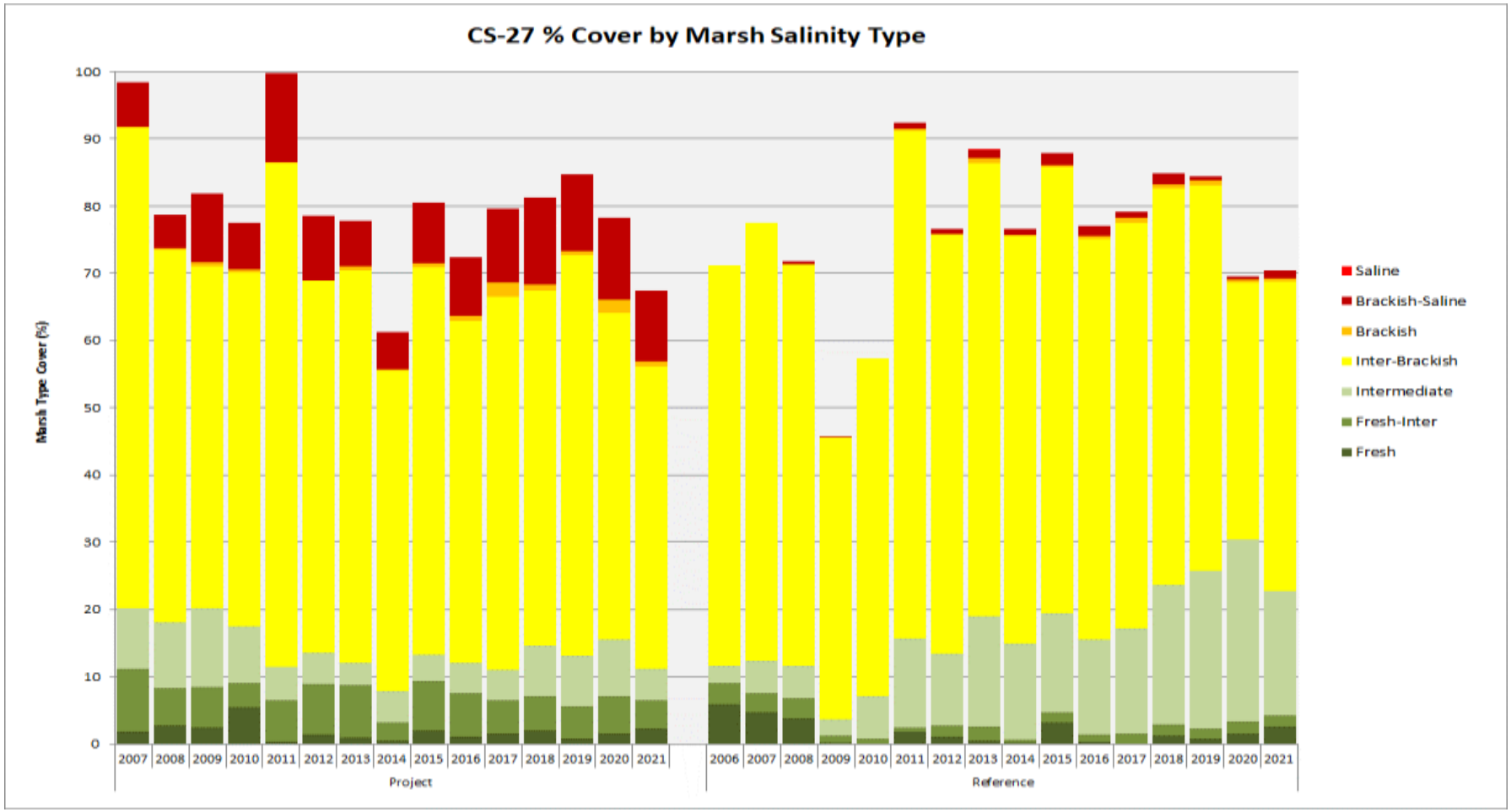

Figure 22. The percent coverage of emergent vegetation by marsh salinity type in the project and reference area vegetation data collected from 2006-2021. Project sites are CRMS0658, CRMS0662, CRMS0663, and CRMS2166 with three reference locations in similar marsh habitat CRMS660, CRMS0665, and CRMS2189. Reference site CRMS0660 shows a complete loss of vegetation post Hurricane Ike and was reestablished in 2011 in a vegetated location after failing to recover for two years.

- **Marsh Surface Elevation Change**

Elevation change and accretion data collected at the CS-27 project (0658, 0662, 0663, and 2166) and reference (0660, 0665, and 2189) CRMS sites show the project area had a slightly higher and more consistent rate of elevation gain (0.30 ± 0.06 cm/y) while the reference area was more variable (0.19 ± 0.21 cm/y) (Figure 23). Projections relative to the Gulf of Mexico are concerning. Elevation change at neither project nor reference sites are keeping up with long-term (1958-2020) relative sea-level rate (RSLR) of 0.62 ± 0.07 cm/y determined at Sabine Pass NOAA tide gauge (NOAA 2022 https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8770570#tab50yr accessed on 09/21/2022).

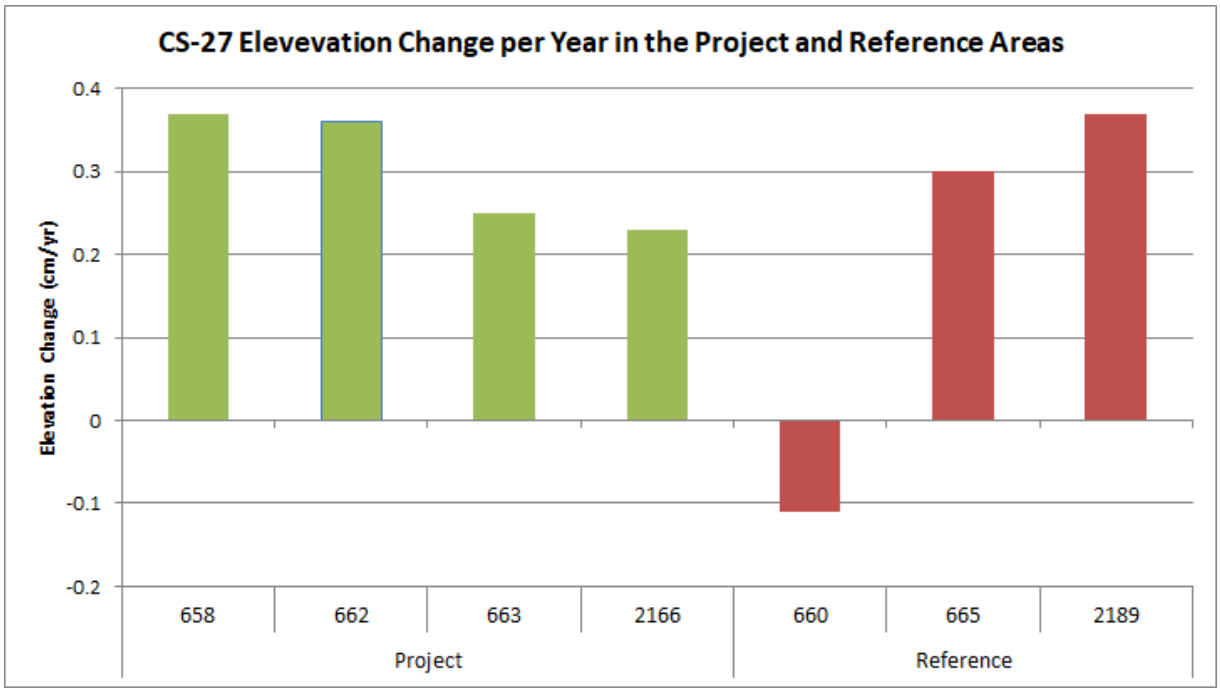

Figure 23. Elevation change per year experienced at CRMS sites in the Black Bayou Hydrologic Restoration (CS-27) project and reference areas through spring 2022.

The Submergence Vulnerability Index (SVI) is an index that forecasts marsh elevation relative to water levels at CRMS sites in 5 years (Stagg et al. 2013). A SVI score of 50 indicates that marsh elevation will equal the mean water elevation in 5 years; higher SVI scores indicate less flooding while lower scores indicate more flooding. Averaged SVI scores show that averaged marsh elevations in the CS-27 project CRMS sites have been projected to keep up with local water-level rise more so than other CRMS sites in similar vegetation types within the CS Basin since 2016 (Figure 24). The relative stability and consistency of the CS-27 project area sites is likely a result from the project features that reduce the tidal export of sediments and organic materials from the project area.

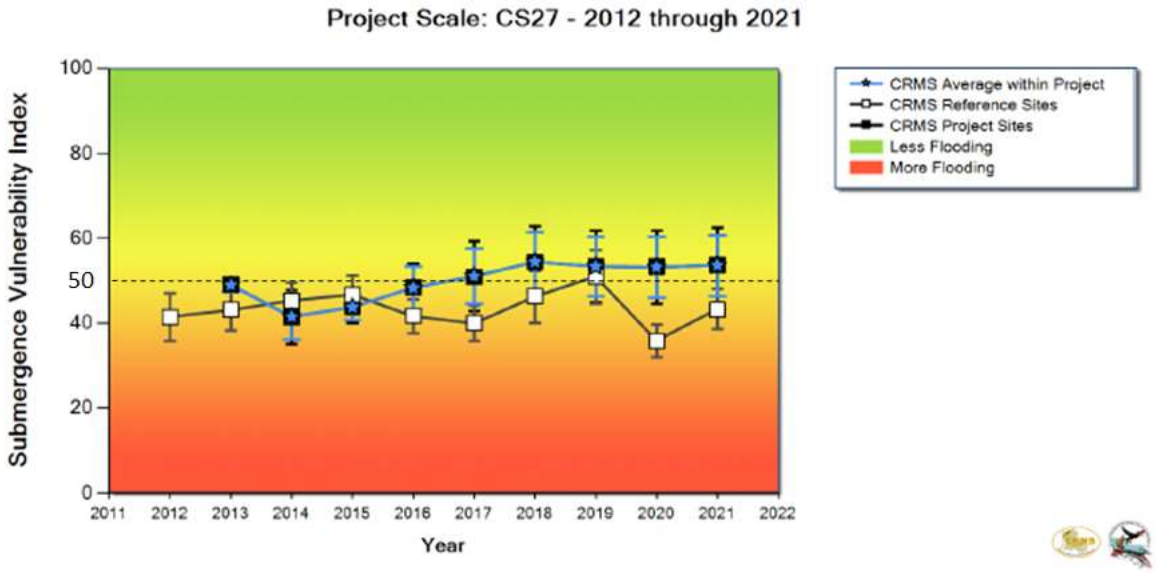

Figure 24. Submergence Vulnerability Index (SVI) scores were averaged from CRMS sites within the CS-27 project area (blue stars on black boxes) and all other intermediate/brackish vegetation-type CRMS sites in the Calcasieu/Sabine Basin (white boxes) over time. The background provides additional context for the SVI scores. This figure was obtained from https://lacoast.gov/chart/Charting.aspx?laf=crms (CPRA 2022); the 50 SVI score line was added to indicate where projected marsh elevation equaled water elevation.

V. Discussion

The CS-27 project has meet and surpassed many of its goals even with substantial climate upheaval and dramatic hurricane effects in 2005, 2008, and 2020. Land loss in the project area was largely mitigated, with the project maintaining stability. This project stability coincided with the Calcasieu Sabine basin losing land annually. This stability also occurred while the basin saw multiple major hurricane landfalls, which had limited impact on the project area due in part to project features and proximity. Salinities within the project area have been reduced, with both surface water and porewater remaining lower than the reference areas. This indicates the effectiveness of the project features at preventing saltwater intrusion into the project area even under tropical storm conditions. The projects effectiveness was muted by drought, likely due to the lack of a freshwater head to the north. However the freshwater impoundment component of the project never actually materialized, as enough exchange took place to keep salinities similar. Erosion along the GIWW shoreline has not only ben reduced but sediments were trapped and settling in the low energy area behind the dike, and mud flats were colonized by vegetation. Overall, the dike was successful at reducing the mean erosion rate of the project along the GIWW by gaining land in the protected area more than twice as fast during the post construction period than the preconstruction period.

The project has increased the SAV in the interior ponds within the project area, which assisted with the population recovery from environmental disturbances. This trend was not evident in the reference area as the crash in SAV after Hurricane Rita continued through the 2011 drought to less than 5 % occurrence and took over a decade to recover to 2003 levels in 2017. Both the project and the reference area have seen an impressive increase in SAV from 2014 to 2017, which included five years of flooded fresh conditions. Hydrology in the CS-27 project area is driven by regional climate conditions; the project area excels when overall hydrologic conditions improve compared to HI scores at reference sites in the CS Basin. However when conditions deteriorate the project is more in line with reference sites as there is no local source of freshwater during drought conditions and excessive floodwaters inundate the basin as a whole. The CS-27 project area was spared the worst impacts of Hurricanes Laure and Delta but did see a decline in cover and subsequently FQI score. Both the project features and the northerly location of the project have consistently protected the fragile marshes located in the boundaries against an ever increasingly dynamic climate. The overall vegetation salinity patterns inside and out of the project area seem very stable in this corner of the upper Calcasieu Sabine basin and have rebounded well from hurricanes and extreme droughts. The original project features and the ongoing efforts of operations and maintenance have kept the project functioning as designed and increased the project's effectiveness over the project life. This was achieved by timely and effective repairs as needed, sometimes dictated by storms but also the dynamic nature of the project areas location where the floodwaters of both the Gulf and uplands meet.

VI. Conclusions

a. Project Effectiveness

Overall, the project successfully reduced salt-water intrusion into the project area during most environmental conditions as indicated by reduced salinities in the project area relative to the reference area except during the extreme drought of 2011. Four breaches in the GIWW spoil bank allowed the impoundment to exchange saltwater with the GIWW until repaired in 2012. Although hydrologic exchange is reduced in the impoundment, water is able to exchange though the rock rip-rap repairs and high water routinely overtops the SRT gate enough to keep salinity comparable to outside conditions, which caused the project impoundment to not be successful at increasing freshwater retention in the project area.

From 2000 to 2018, the project area emergent marsh has remained very stable through multiple negative episodic events, while the reference area has lost land area presumably due to hurricanes and tidal forces.

The foreshore rock dike effectively reduced shoreline erosion along the GIWW. The widening of the mudflats and shoreline along the northern boundary of the impoundment has provided protection to the emergent wetland vegetation within this portion of the project.

The frequency of occurrence of submerged aquatic vegetation (SAV) in the project areas has been high except immediately after Hurricane Rita in 2005 and the 2011 drought.

b. Recommended Improvements

The project impoundment is not a separate successfully controlled hydrological unit from the rest of the project area. Whether this is due to water flow over the SRT gate, through the various rock plugs or from a previously unidentified source, synoptic salinity surveys under varying water levels may help in determining the imperfections in the impoundment and identify potential corrective measures.

c. Lessons Learned

Warning signs in areas of severe current caused by installation of rock or sheet pile weirs should always be included. These signs should be installed in concrete blocks out of the way of traffic since this has proven to be very effective.

Impoundments are designed to hold more water than surrounding areas and are difficult to maintain because of additional hydrodynamic forces on the boundary levees and structures. As such, breaches are difficult to stop and repair within a reasonable timeframe as to not cause disruptions to the project area. A more robust containment levee would be necessary to prevent such breaches in the future. The culverts installed in the southeast corner of the impoundment in addition to the SRT gate proved helpful in relieving high water levels after Hurricane Rita and Ike.

Emergent marsh vegetation can be slow to respond to the hydrologic forces in the project and reference areas, where as the SAV community is much more intrinsically coupled to the bulk water chemistry. This is likely due to the buffering capacity of the soil and the soil porewater that affects the emergent marsh but not the SAV community. As such, SAV annual monitoring may be an extremely insightful component of hydrologic restoration project monitoring. For SAV occurrence, larger, open-water areas should be avoided. Occurrence of SAV is typically lower in larger water bodies because of greater wave energy and turbidity and may not represent the full project reference disparity.

In-filling of the deeper areas between the shoreline and foreshore rock dike are difficult to determine by only monitoring shoreline change. A more conclusive monitoring would be topographic/bathymetric surveys to determine elevation changes and possibly soil volume changes over time.

During the annual inspection in 2014-2015, scour holes were found on each side of the rock weirs on Black Bayou Cut Off, Burton Canal, and Block's Creek. The rock weir on Burton Canal had to be removed and a new one constructed further up the canal due to numerous oil field pipelines in the vicinity of the original structure. Future projects in such high flow environments should armor the water bottoms adjacent to similar structures or plan to monitor and preform maintenance and repairs as needed.

d. End of Project Life

The CS-27 project has successful archived many of its goals during an energetic period in Louisiana's costal restoration history, marked by floods, droughts, and numerous named storms. This project has proven worthy of continued usage as the project features have maintained hydrologic stability which has allowed the emergent marsh, submerged aquatic vegetation, and the wildlife that use these resources to thrive. Extensive maintenance was recently completed to not only repair the project but improve its features and functions for coming years. The CS-27 project is expected to continue performing as expected into the future, including during episodic climate events, storms, and as sea levels rise.

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APPENDIX A
(Inspection Photographs)

Photo 1—Navigational Aids and signage at Block's Creek

Photo 2—New Burton Canal Structure

Photo 3—Black Bayou Cut Off Canal structure

Photo 4—broken sign on Black Bayou Cut Off weir

Photo 5—pillow block on SRT Gate flap & railing rust

Photo 6—SRT Gate

Photo 7—Rock plug near SRT Gate

Photo 8—Typical section of rock dike

Photo 9—typical section of dike

APPENDIX B
(Three Year Budget Projection)

BLACK BAYOU HYDROLOGIC RESTORATION/ CS27 / PPL 6

Three-Year Operations & Maintenance Budgets 07/01/2022 - 06/30/2025

Project Manager	O & M Manager	Federal Sponsor	Prepared By
Stan Aucoin	Stan Aucoin	NMFS	Stan Aucoin

	2022/2023 (-18)	2023/2024 (-19)	
Maintenance Inspection	$ 14,000.00	$ -	
Navigational Aid Inspection	$ 10,000.00	$ 10,000.00	
State Administration	$ 6,000.00	$ 5,000.00	
Federal Administration	$ -	$ 1,000.00	
Corps. Administration	$ -	$ 1,511.00	

22/23 Description:

E&D		
Landrights		
Construction Oversight		
Sub Total - Maint. And Rehab	$ -	

23/24 Description:

E&D		$ -	
Construction	(Incl. 25% Contingency)	$ -	
Construction Oversight		$ -	
	Sub Total - Maint. And Rehab	$ -	

Description:

E&D			$ -
Construction			$ -
Construction Oversight			$ -
		Sub Total - Maint. And Rehab	$ -

	2022/2023 (-18)	2023/2024 (-19)	0
Total O&M Budgets	$ 30,000.00	$ 17,511.00	$ -

O &M Budget (3 yr Total)	**$ 47,511.00**
Unexpended O & M Budget	**$ 2,072,168.80**
Remaining O & M Budget (Projected)	**$ 2,024,657.80**

End of life Nov. 3, 2023

OPERATION AND MAINTENANCE BUDGET WORKSHEET

BLACK BAYOU HYDROLOGIC RESTORATION PROJECT / PROJECT NO. CS-27 / PPL NO. 6 / 2022/2023

DESCRIPTION	UNIT	EST. QTY.	UNIT PRICE	ESTIMATED TOTAL
O&M Inspection and Report	EACH	1	$14,000.00	**$14,000.00**
General Structure Maintenance	LUMP	0	$0.00	**$0.00**
Engineering and Design	LUMP	0	$0.00	**$0.00**
Operations Contract/ Navigational Aid Inspec.	LUMP	1	$10,000.00	**$10,000.00**
Construction Oversight	LUMP	0	$0.00	**$0.00**

ADMINISTRATION

STATE Admin.	LUMP	1	$6,000.00	$6,000.00
FEDERAL SPONSOR Admin.	LUMP	0	$0.00	$0.00
SURVEY Admin.	LUMP	0	$0.00	$0.00
CORPS. Admin.	LUMP	0	$0.00	$0.00
			TOTAL ADMINISTRATION COSTS:	**$6,000.00**

MAINTENANCE / CONSTRUCTION

SURVEY

SURVEY DESCRIPTION:					
Secondary Monument	EACH	0	$0.00	$0.00
Staff Gauge / Recorders	EACH	0	$0.00	$0.00
Marsh Elevation / Topography	LUMP	0	$0.00	$0.00
TBM Installation	EACH	0	$0.00	$0.00
OTHER				$0.00
			TOTAL SURVEY COSTS:	**$0.00**

GEOTECHNICAL

GEOTECH DESCRIPTION:					
Borings	EACH	0	$0.00	$0.00
OTHER				$0.00
			TOTAL GEOTECHNICAL COSTS:	**$0.00**

CONSTRUCTION

CONSTRUCTION DESCRIPTION:					
Rip Rap	LIN FT	TON / FT	TONS	UNIT PRICE	
Rock Rip rap	0	0.0	45,800	$0.00	$0.00
Aggregate Surface Course	0	0.0	0	$0.00	$0.00
	0	0.0	0	$0.00	$0.00
Filter Cloth / Geogrid Fabric		SQ YD	0	$6.00	$0.00
Navigation Aid		EACH	0	$0.00	$0.00
Signage		EACH	0	$0.00	$0.00
General Excavation / Fill (Burton Sutton Degrading)		CU YD	0	$10.00	$0.00
Dredging		CU YD	0	$0.00	$0.00
Sheet Piles (Lin Ft or Sq Yds)			0	$0.00	$0.00
Timber Piles (each or lump sum)			0	$0.00	$0.00
Timber Members (each or lump sum)			0	$0.00	$0.00
Hardware		LUMP	0	$0.00	$0.00
Materials		LUMP	0	$0.00	$0.00
Mob / Demob		LUMP	0	$250,000.00	$0.00
Contingency (25%)		LUMP	0	$1,102,000.00	$0.00
General Structure Maintenance		LUMP	0	$0.00	$0.00
Surveys		LUMP	0	$145,000.00	$0.00
Concrete Sacks		CU YD	0	$420.00	$0.00
OTHER				$0.00	$0.00
				TOTAL CONSTRUCTION COSTS:	**$0.00**

TOTAL OPERATIONS AND MAINTENANCE BUDGET: $30,000.00

OPERATION AND MAINTENANCE BUDGET WORKSHEET

BLACK BAYOU HYDROLOGIC RESTORATION PROJECT / PROJECT NO. CS-27 / PPL NO. 6 / 2023-2024

DESCRIPTION	UNIT	EST. QTY.	UNIT PRICE	ESTIMATED TOTAL
O&M Inspection and Report	EACH	0	$0.00	**$0.00**
General Structure Maintenance	LUMP	0	$0.00	**$0.00**
Engineering and Design	LUMP	0	$0.00	**$0.00**
Operations Contract/ Navigational Aid Inspec.	LUMP	1	$10,000.00	**$10,000.00**
Construction Oversight	LUMP	0	$0.00	**$0.00**

ADMINISTRATION

STATE Admin	LUMP	1	$5,000.00	$5,000.00
FEDERAL SPONSOR Admin	LUMP	1	$1,000.00	$1,000.00
SURVEY Admin	LUMP	0	$0.00	$0.00
USACE Admin		1	$1,511.00	$1,511.00
			TOTAL ADMINISTRATION COSTS:	**$7,511.00**

MAINTENANCE / CONSTRUCTION

SURVEY

SURVEY DESCRIPTION					
Secondary Monument	EACH	0	$0.00	$0.00
Staff Gauge / Recorders	EACH	0	$0.00	$0.00
Marsh Elevation / Topography	LUMP	0	$0.00	$0.00
TBM Installation	EACH	0	$0.00	$0.00
OTHER				$0.00
			TOTAL SURVEY COSTS:	**$0.00**

GEOTECHNICAL

GEOTECH DESCRIPTION					
Borings	EACH	0	$0.00	$0.00
OTHER				$0.00
			TOTAL GEOTECHNICAL COSTS:	**$0.00**

CONSTRUCTION

CONSTRUCTION DESCRIPTION					
Rip Rap	LIN FT	TON / FT	TONS	UNIT PRICE	
Rock Rip rap	0	0.0	0	$0.00	$0.00
Aggregate Surface Course	0	0.0	0	$0.00	$0.00
	0	0.0	0	$0.00	$0.00
Filter Cloth / Geogrid Fabric		SQ YD	0	$0.00	$0.00
Navigation Aid		EACH	0	$0.00	$0.00
Signage		EACH	0	$0.00	$0.00
General Excavation / Fill		CU YD	0	$0.00	$0.00
Dredging		CU YD	0	$0.00	$0.00
Sheet Piles (Lin Ft or Sq Yds)			0	$0.00	$0.00
Timber Piles (each or lump sum)			0	$0.00	$0.00
Timber Members (each or lump sum)			0	$0.00	$0.00
Hardware		LUMP	0	$0.00	$0.00
Materials		LUMP	0	$0.00	$0.00
Mob / Demob		LUMP	0	$0.00	$0.00
Contingency		LUMP	0	$0.00	$0.00
General Structure Maintenance		LUMP	0	$0.00	$0.00
OTHER				$0.00	$0.00
OTHER				$0.00	$0.00
OTHER				$0.00	$0.00
				TOTAL CONSTRUCTION COSTS:	**$0.00**

TOTAL OPERATIONS AND MAINTENANCE BUDGET: **$17,511.00**