State of Louisiana

Coastal Protection and Restoration Authority of Louisiana (CPRA)

2018 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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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 2018 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 2017, and annual Maintenance Inspections through 2016.

The 2018 report is the 6th 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, and 2015 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 allow freshwater 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 to create a hydrologic head that increases freshwater retention time and reduces salt water intrusion and tidal action in the Black Bayou watershed (Figure 1). Black Bayou structural features construction was completed in November 2001. 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. 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 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). Phase II, west side of project area, contained approximately 25,570 plantings spanning 127,850 linear ft (38,969.1 linear m).

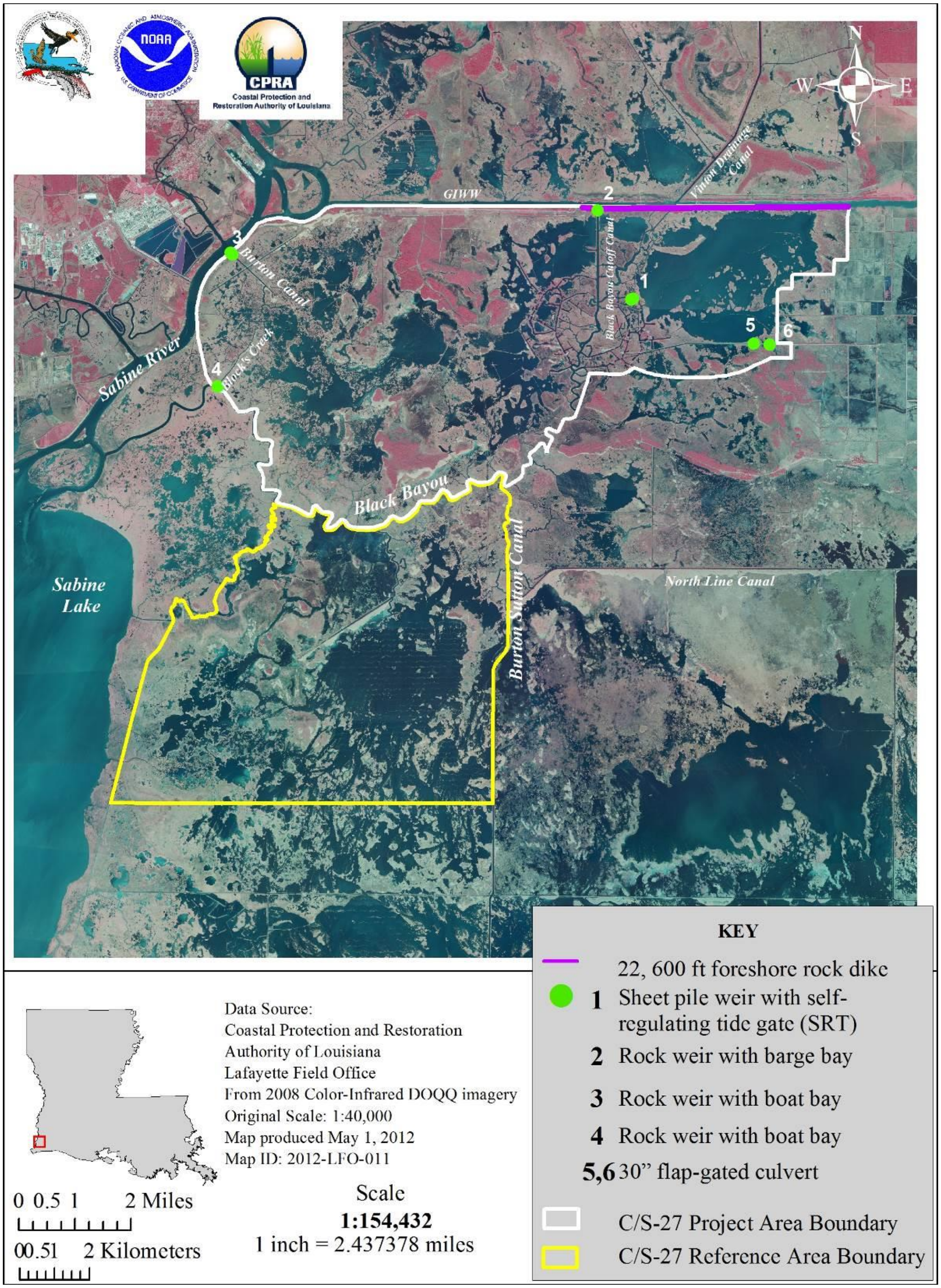

Figure 1. Black Bayou project and reference boundaries and project infrastructure.

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 April 9, 2015 under partly cloudy skies and warm temperatures. In attendance were Stan Aucoin, and Dion Broussard of CPRA. NOAA Fisheries was represented by John Foret. A separate trip was conducted on June 26, 2015 to inspect the culverts under the road on the Gum Cove property. In attendance on this trip were Stan Aucoin, John Foret, and Tim Conner, one of the landowners on the project area. For both trips, parties met at the Lafayette Field Office of CPRA. For the trip to inspect the culverts, parties met Mr. Conner at the Catholic Church in Hackberry and visited the culverts under the road by vehicle. For the other structures, the boat launch in Vinton, LA was utilized. The annual inspection began at the structure on Block's Creek at 12:30pm.

The field inspection included a complete visual inspection of all 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 were completed in the field to record measurements and deficiencies (see Appendix C).

b. Inspection Results

<u>Block's Creek</u>

The rock weir seems to be in excellent condition, however landowners indicated that there was some scouring on the inlet and outlet sides of the weir. Upon further investigation, it was found that water was approximately 20 feet deep on the Black Bayou side and approximately 14 feet deep on the inside of the structure. Water depth at the sill is approximately 4.5 feet deep. The two arrow signs on the Black Bayou side of the structure are still missing and will need to be replaced. The erosion on the SE will continue to be monitored, but has stabilized. Navigational lights and signs are inspected quarterly by contractor. (Photos: Appendix A, Photo 1)

Burton Canal

The situation at this weir is the same as at Block's Creek. Water levels on the Sabine River side are approximately 29.5 feet deep and on the inside of the structure, 33.7 feet deep. The sill is at 6.5 feet deep. The scouring along the canal banks inside of the weir at the end of the dike has stabilized. The arrow sign on the SW side of the structure is missing and will need to be replaced. Navigational lights and signs are inspected quarterly by contractor. (Photos: Appendix A, Photo 2)

Black Bayou Cut-Off Canal

Scouring around the structure has occurred here as well. Water depths were 33.5 feet deep on the GIWW side and 23 feet deep on the inside. Sill depth is 10.5 feet. Navigational lights and signs are inspected quarterly by contractor. Coast Guard signs on the inside of the structure were missing at the time of this inspection. (Photos: Appendix A, Photo 3)

Self Regulating Tide Gate (SRT)

The structure is in very good condition. Pillow blocks, signage, railings, wingwalls, etc. remain in excellent condition. The railing along the top of the gate continues to rust and will have to be monitored. The seams at the sheet piles are rusting also, however there is no need for maintenance at this time. Colonies of oysters were noticed on the rocks on the outside of the structure and none on the inside. (Photos: Appendix A, Photos 4-6)

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. The first and second gaps from the east are solid. The third has a connection through the marsh on the west side that is approximately six feet wide and appears to be fairly deep with significant flow noticed. There is also now a small breach near the fourth plug. As mentioned in previous inspections, the warning signs at both the Vinton and Black Bayou closures have been stolen. The spoil placed behind the rock dike at the Black Bayou Canal has washed away on the western end. Several small gaps along the dike were noticed, however rock is still at the base providing shoreline protection but allowing some exchange to take place. There are a few low spots on the rest of the main dike, apparently caused by barges but these areas are still functioning and are not in need of repair. The repair to the dike across from the Vinton Canal with concrete sacks continues to work extremely well. Significant build-up of sediment continues and has become even more apparent between the dike and the shoreline. Emergent vegetation has exploded in large areas behind the dike between the dike and the shoreline. (Photos: Appendix A, Photos 8-12)

Culvert 1/Culvert 2:
These culverts were inspected on June 26, 2015. They appear to be in very good, post construction condition and in no need of repair. No concerns have been expressed by the landowners. (Photos: Appendix A, Photos 13-16)

c. Maintenance Recommendations

i. Immediate/ Emergency Repairs

None

ii. Programmatic/ Routine Repairs

The following items were identified in the 2015 Annual Inspection:

1. Replace stolen warning signs at both the Vinton and Black Bayou closures.

2. Task an engineering firm to evaluate the extent of scouring around the three weir structures and estimate a repair cost.

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.

<u>July 2005 - SRT Gate modification and culvert installation:</u> 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. Costs incurred include:

2007 TOTAL	**$8,000.00**
2008 TOTAL	**$6,625.00**
2009 TOTAL	**$6,375.00**
2010 TOTAL	**$7,340.00**
2011 TOTAL	**$7,740.00**
2012 TOTAL	**$3,075.00**
2013 TOTAL	**$6,427.25**
2014 TOTAL	**$1,851.75**
2015 TOTAL	**$2,150.00 (As of 2/26/15)**

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.

III. Operation Activity

a. Operation Plan

There are no water control structures 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).

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, and 2015. 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 are providing data inside and outside of project structures during sonde servicing beginning in March 2012 through present. 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).
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 present. Salinity data is also currently being monitored hourly utilizing three 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).

Vegetation Plantings

Schoenoplectus californicus (California bullwhip) plantings were installed in 2002 and 2003 to establish emergent wetland vegetation in shallow open water areas within the project area. These plantings took place in two phases; Phase I was completed in May 2002 in the east side of the project area (~ 7 acres), and Phase II was completed in May 2003 in the west side of the project (~ 6 acres). The percent survival of vegetative plantings in Phase I was determined after one growing season post construction (2003) in approximately 3% of the vegetation plantings (53 sampling plots). Each sampling plot consisted of 16 plantings from one row with the sampling location determined by a random numbers table and marked with a labeled post. Planting survival was determined as a percentage of the number of live plants to the number initially planted (percent survival = (no. live plants/no. planted) × 100) (Mendelssohn and Hester 1988; Mendelssohn et al. 1991). No further monitoring of the plantings is scheduled.

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 mapping clean 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 for 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 and 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 are scheduled.

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.

Emergent 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. Data was collected at four CRMS stations located within the CS-27 project area (0658, 0662, 0663, and 2166) and three selected reference sites (0660, 0665, and 2189) in the reference area. Emergent vegetation parameters will be evaluated at each CRMS site using techniques described in Steyer et al. (1995) to describe species composition, richness, and relative abundance; in addition, overall percent cover and height of the dominant species will be monitored. Annually at each site, data will be collected and averaged from ten, 4-m^2 sample plots randomly established along a 282.8 m transect that crosses diagonally through a 200m × 200m vegetation plot in middle of the CRMS site. The percent cover of the plot and of each species was fed into a floristic quality index based on the marsh type the data was collected. Floristic Quality Indices (FQIs) have been developed for several regions to determine the quality of a wetland based on its species composition (Cohen et al., 2004; Bourbaghs et al., 2006). 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

Hydrologic Index

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.

Soil Properties

Soil cores were collected to describe major soil properties such as bulk density and percent organic matter. Three, 4" (10.16-cm) diameter cores were collected to a depth of 24 cm and divided into 6, 4-cm sections at each site. The soil was processed by the Department of Agronomy and Environmental Management at Louisiana State University. Soil cores were only collected at the project and reference CRMS sites during station establishment in 2005-2007 and the second series of samples has not yet been collected. Cores were collected at four sites inside the project area, and suitable cores (quality or same marsh type) were collected from two sites outside the project area.

Soil Surface Elevation Change

Soil surface elevation change utilizing a combination of sediment elevation tables (RSET) and vertical accretion from feldspar horizon markers are being measured twice a year at each of the project and reference CRMS sites. These data will be used to describe the general trends in elevation change and accretion rates. The RSET was surveyed to a known elevation datum (ft, NAVD 88) so it could be directly compared to other elevation variables such as water level. Data collected over at least 5 years was used to calculate rates for the project and reference area; therefore the displayed elevation change rates are an estimation of that temporal trend.

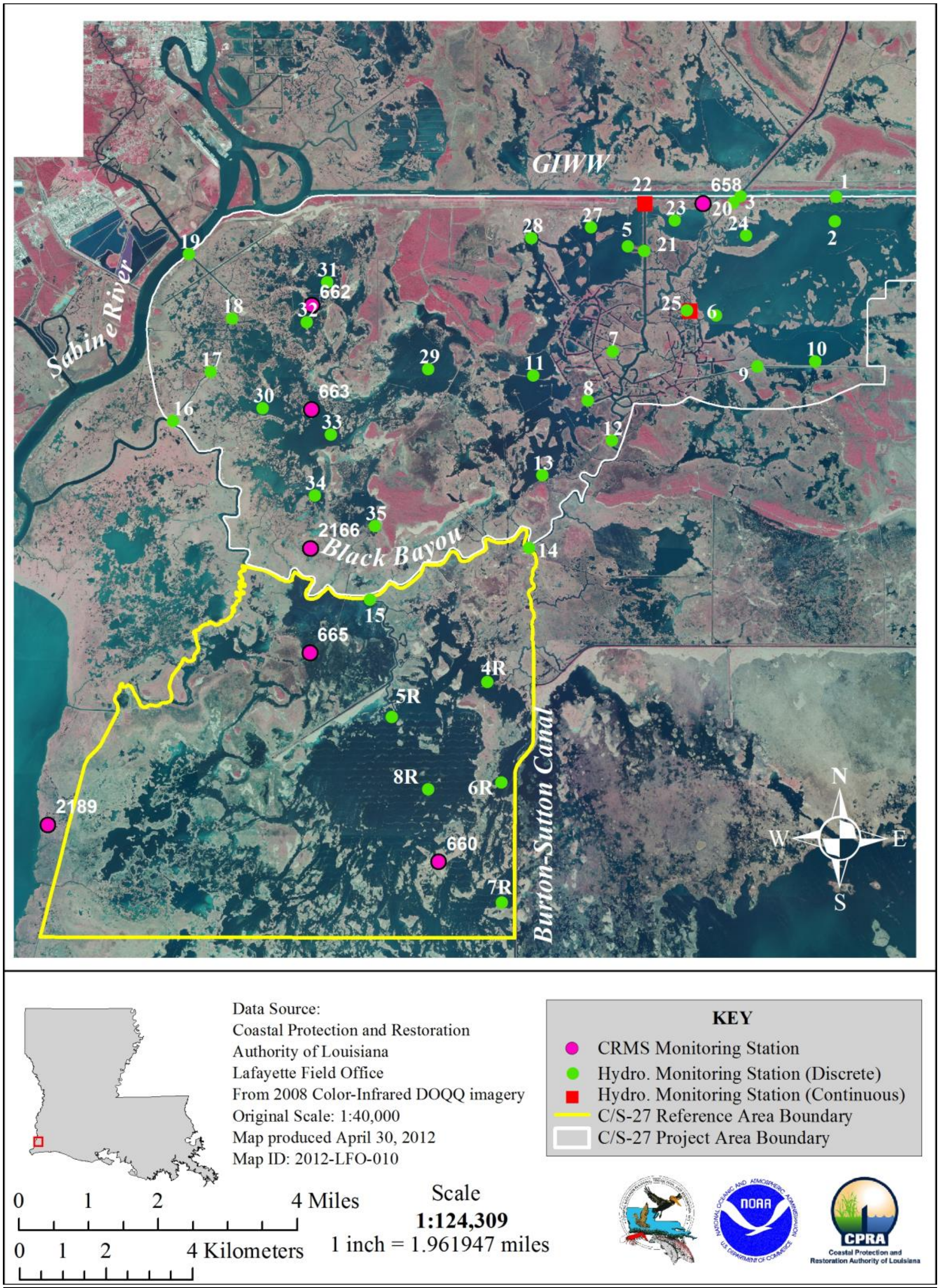

Figure 2. CS-27 continuous recorder station, discrete salinity stations, and CRMS sites located within and the project and reference areas.

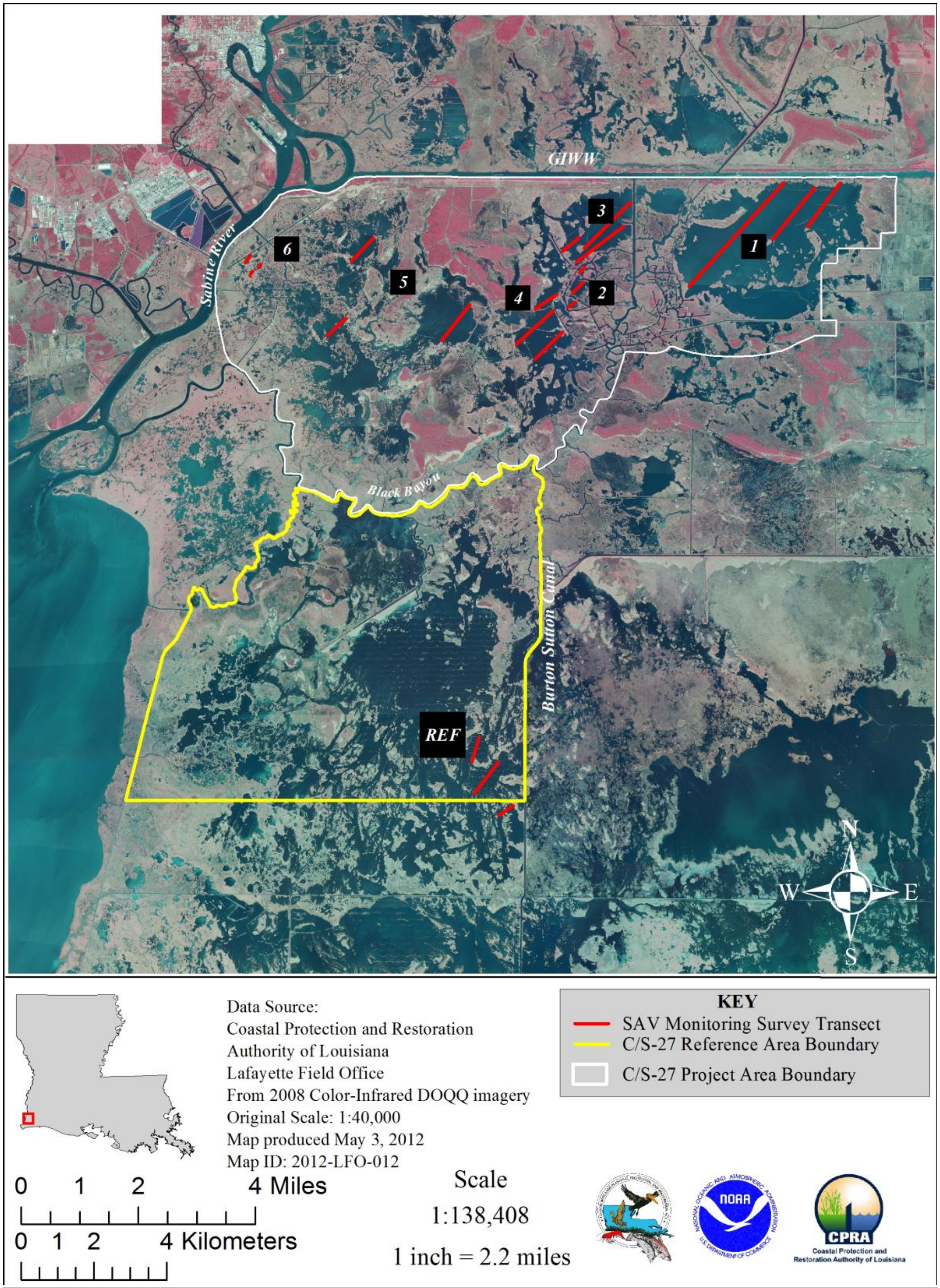

Figure 3. Location of the submerged aquatic vegetation (SAV) sampling transects in the CS-27 project and reference areas.

IV. Monitoring Activity (continued)

c. Monitoring Results and Discussion

Aerial Photography

Land and water aerial photography was acquired and analyzed before construction in November 2000 and after construction in 2004, 2010, and 2015 by the U.S. Geological Survey (Figures 4a-d). The project area gained 153 acres (0.6%) of land from 2000 to 2004 (1 year pre-construction to 3 years post-construction) (Table 2). During this same time, the reference area gained 384 acres (2%) The difference in the 2000 to 2004 time 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 163 acres of land or -0.6% while the reference area lost 1168 acres or -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 (Figure 5). 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. 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. From 2010 to 2015 the project area recovered to very near pre hurricane levels gaining 125 acres (+0.5%) while the reference area continued its previous negative trend though at a more gradual pace losing 155 acres (-0.8%).

Overall, from 2000-2015, there was slight increase in the project areas land to water ratio, while the reference area showed a reduction in land water ratio under similar environmental conditions (Table 2). 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 6). 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.

Table 2. Land area and change rates compiled from high resolution imagery collected by the USGS-National Wetlands Research Center pre- (2000) and post-construction (2004, 2010, and 2015) of CS-27. Initial construction was completed in November 2001; Hurricane Rita occurred in September 2005 and Hurricane Ike occurred in September 2008.

	Project Area							
	2000		2004		2010		2015	
	acres	%	acres	%	acres	%	acres	%
Land	16,247.3	58.1	16,400.0	58.7	16,237.0	58.1	16,362	58.6
Water	11,700.8	41.9	11,545.0	41.3	11,708.0	41.9	11,580	41.4
Total	27,948.1		27,945.0		27,945.0		27,942	
	Reference Area							
	2000		2004		2010		2015	
	acres	%	acres	%	acres	%	Acres	%
Land	11,009.7	56.3	11,394.0	58.3	10,226.0	52.3	10,071	51.5
Water	8,545.6	43.7	8,159.0	41.7	9,327.0	47.7	9,480	48.5
Total	19,555.3		19,553.0		19,553.0		19,551	

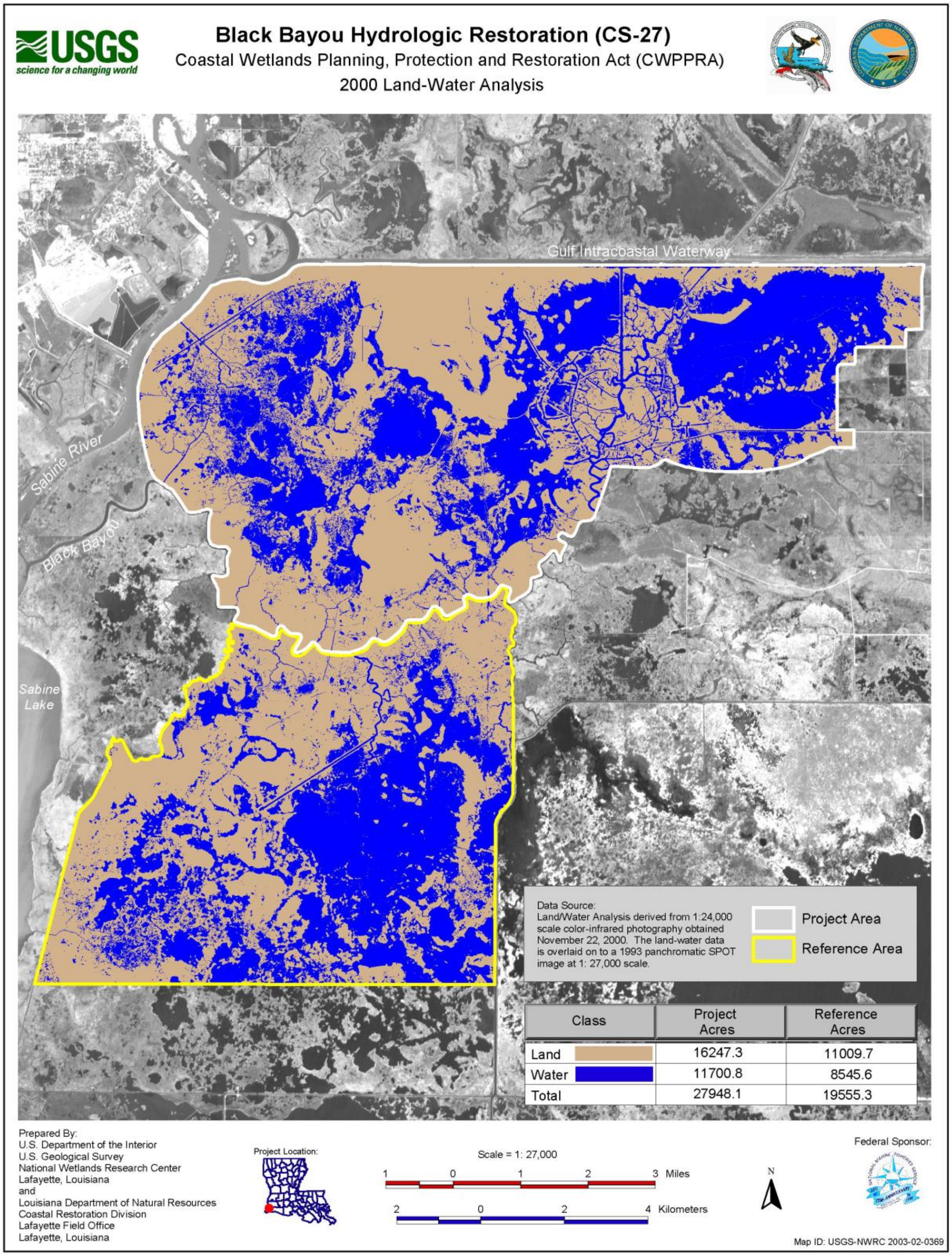

Figure 4a. Preconstruction land water analysis of CS-27 project and reference areas from photography taken November 20, 2000.

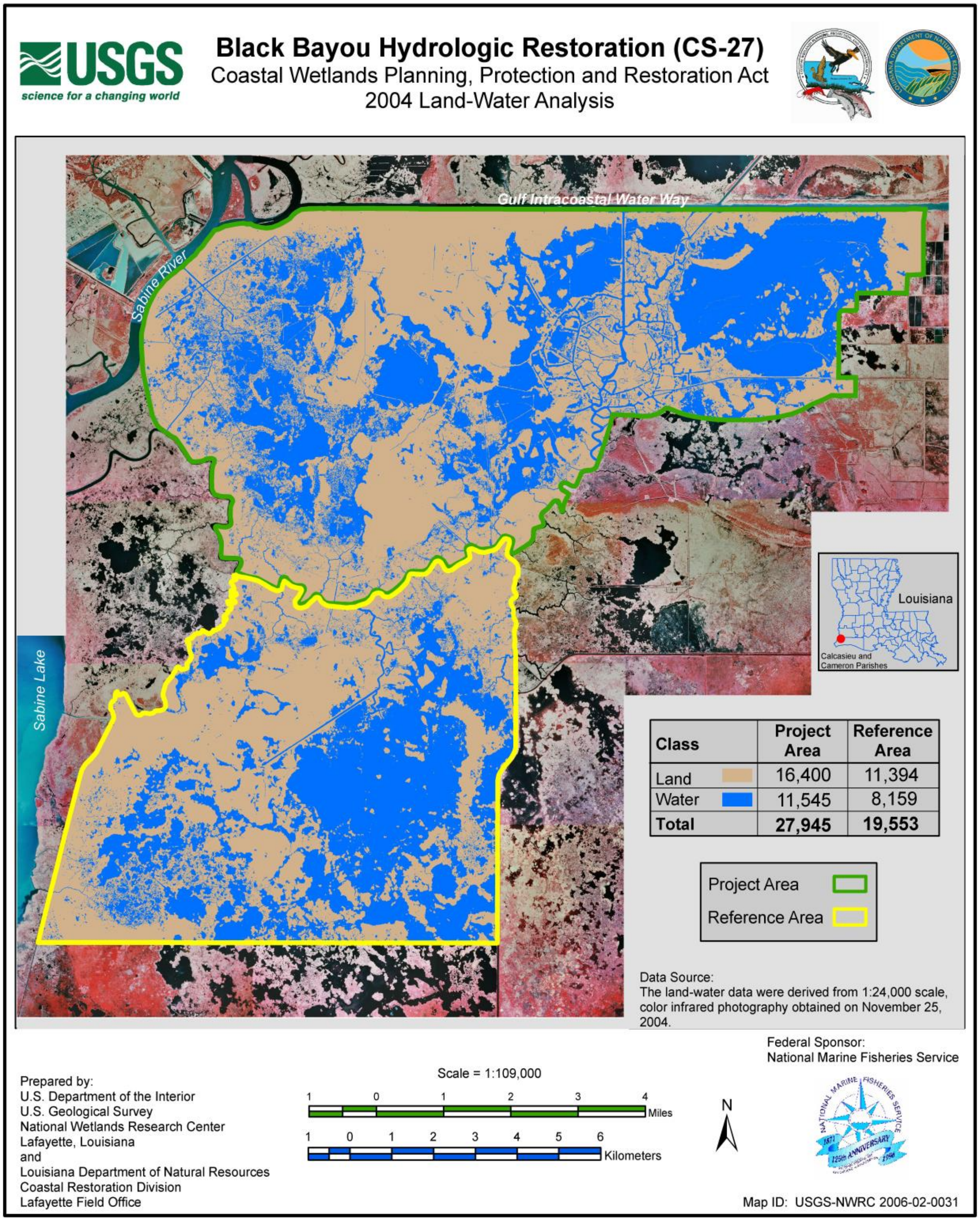

Figure 4b. Post construction land water analysis of CS-27 project and reference areas from photography taken November 25, 2004.

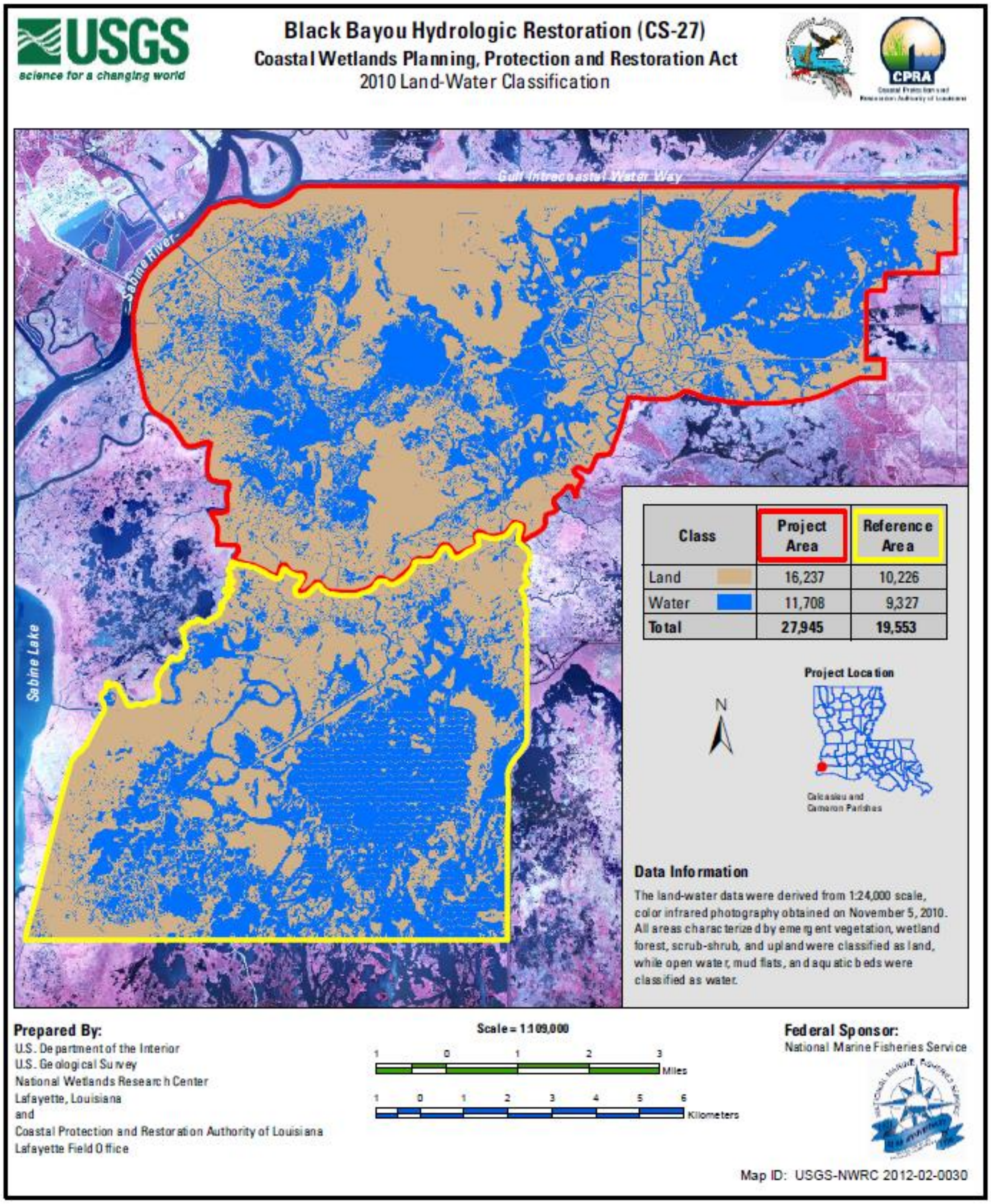

Figure 4c. Post construction land water analysis of CS-27 project and reference areas from photography taken November 5, 2010.

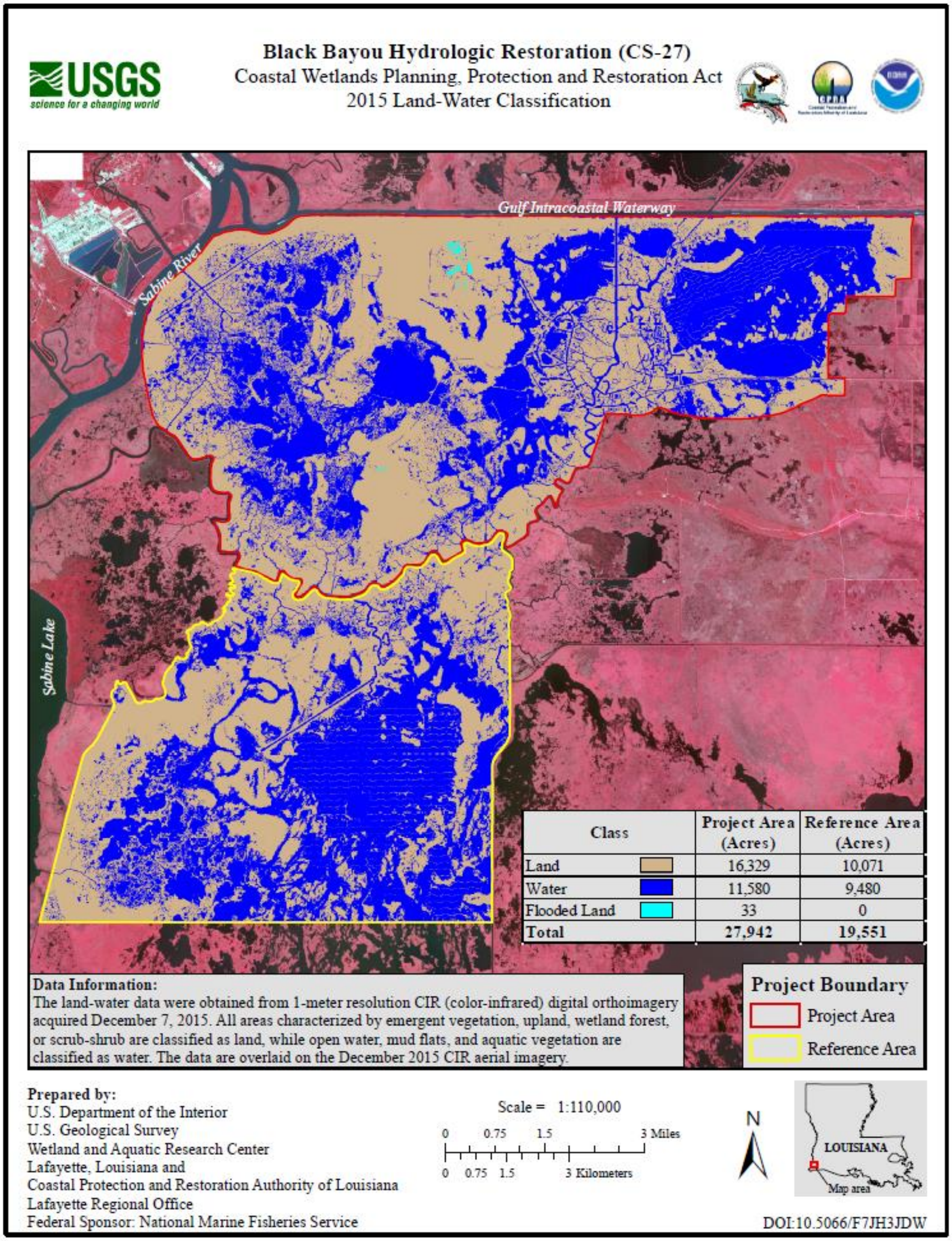

Figure 4d. Post construction land water analysis of CS-27 project and reference areas from photography taken December 7, 2015.

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

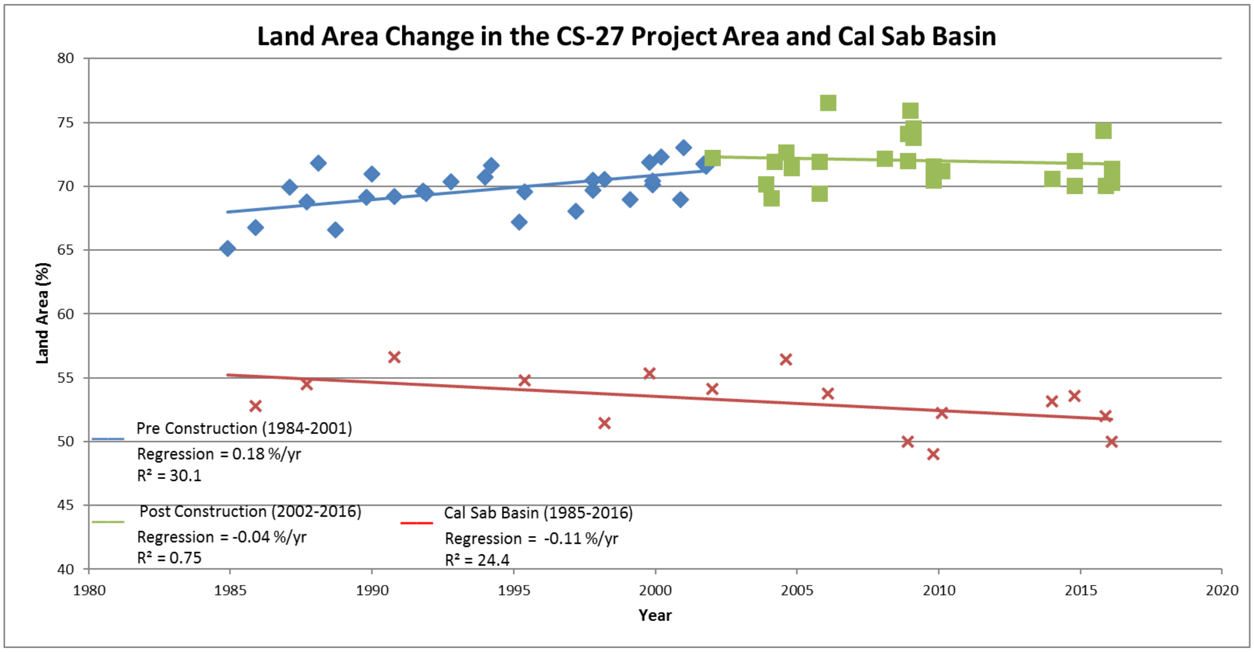

Figure 6. Project and basin scale percent land analysis for years 1985 to 2016 of cloud free Landsat images (CRMS spatial viewer land/water, Couvillion et al. 2017).

Salinity

Discrete 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. Also discrete salinity measurements are collected during SAV sampling and offer an additional opportunity to examine salinity. These SAV discrete measurements generally agree with other methods of salinity data collection (Wood et al. 2015).

Soil porewater was significantly higher in the reference area from 2007-2017 but the differences were generally smaller than might be ecologically meaningful except 2009-2010 and 2012 when the salinity differences were near 5 ppt annually (Figure 7). These differences are also seen in the surface water salinity. The project area (CS27-25, CRMS0658, CRMS0662, and CRMS0663) continuous salinity stations have generally recorded lower average monthly salinity values since installation in 2008 than the reference stations (CRMS0660, CRMS0665, and CRMS2189) (Figure 8). This effect was first evident during several salinity spikes highlighted around Hurricane Ike 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 project area has remained substantially fresher than the reference area from 2012-2017, often with less than half the salinity of the reference stations. This indicates the effectiveness of the project features in preventing saltwater intrusion into the project area even under tropical conditions. The projects effectiveness was muted by the drought during 2011 likely due to the lack of a fresh water head to the north and the extreme salinity experienced in the Cal/Sab basin which was nearly twice the average of salinity spikes brought on by Hurricanes Ike and Rita.

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) (http://www.drought.noaa.gov/index.html.). 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 (weekly means n=542, x^2=3.02, p=.0822). Under most conditions the inside of the impoundment is very similar to the outside of the impoundment, suggesting that consistent hydrologic separation is not maintained. 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 comparable in both locations.

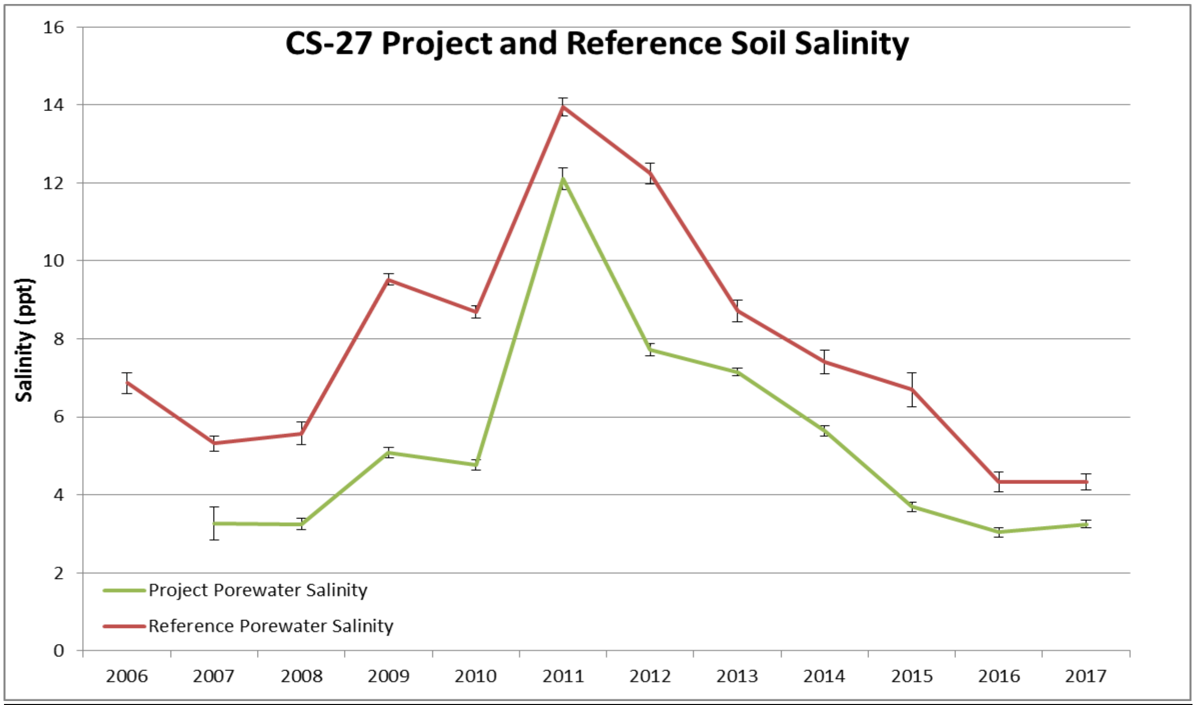

Figure 7. Yearly means and standard errors of porewater salinity collected at project and reference stations 2006-2017.

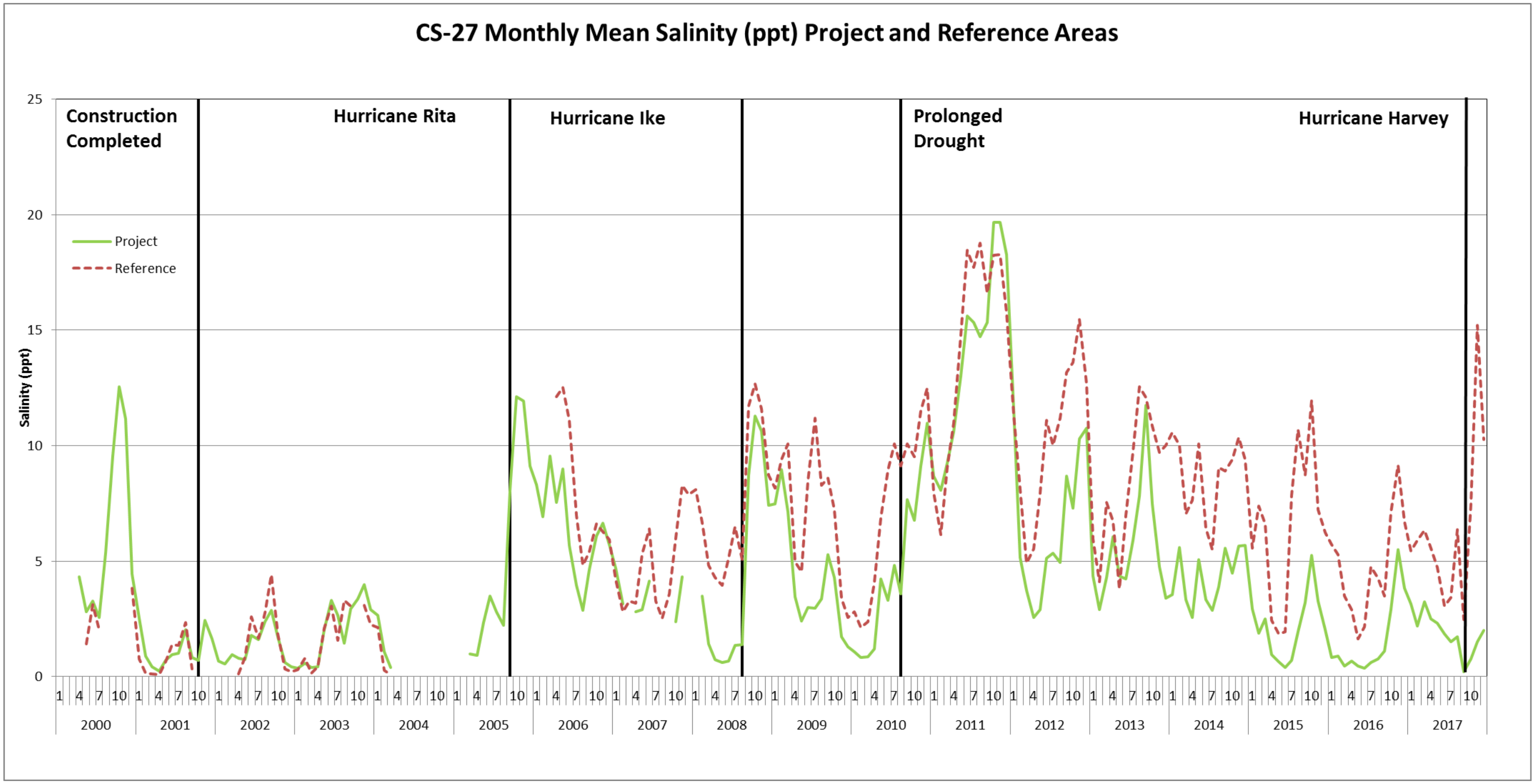

Figure 8. Monthly means of continuous salinity collected at stations in the project (CS27-25, 0658, 0662, 0663) and reference (0660, 0665, and 2189) areas from 2000-2017.

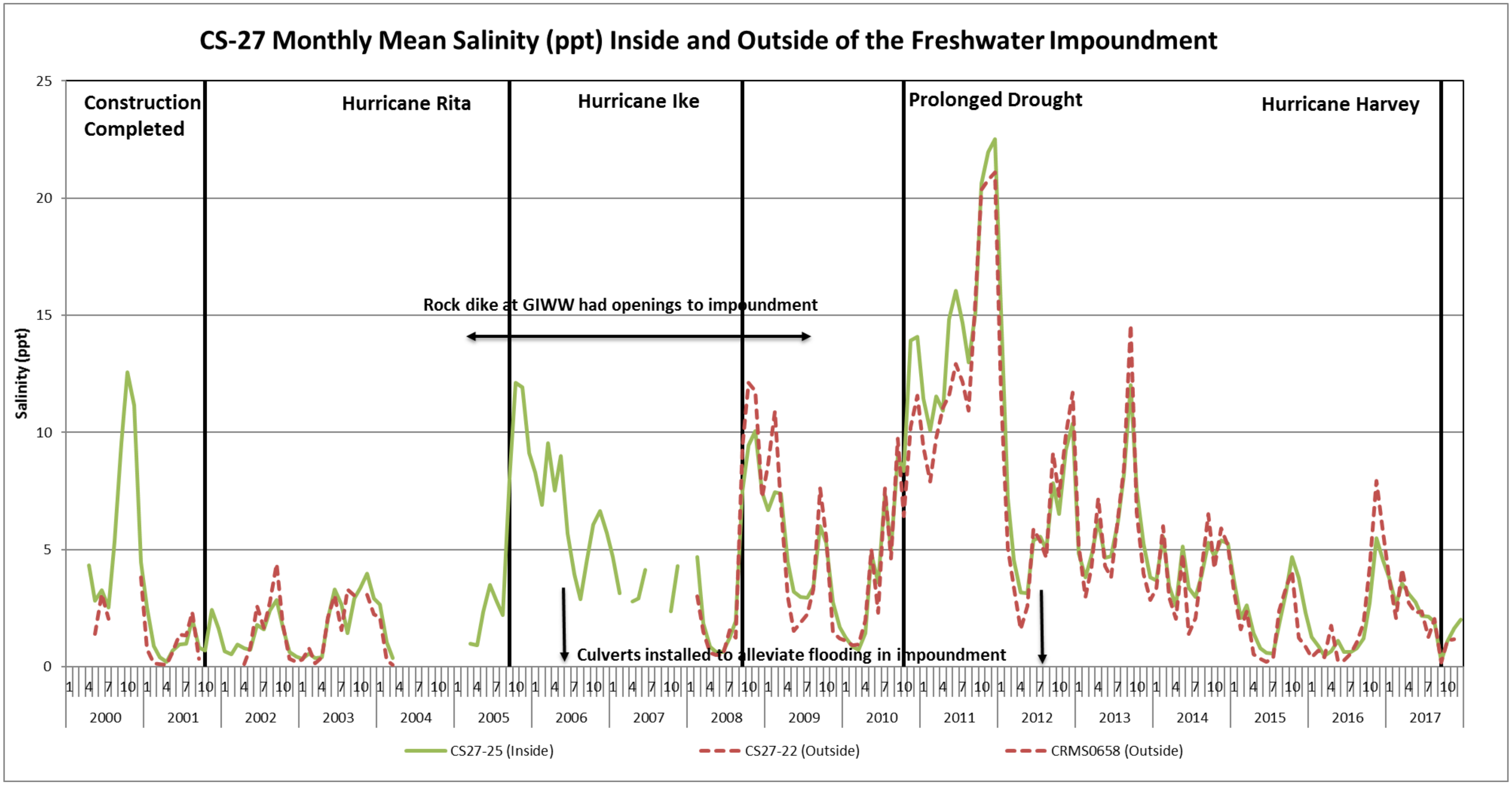

Figure 9. Monthly means of continuous salinity collected at stations CS27-22 and CRMS0658 (outside the impoundment) and CS27-25 (inside the impoundment) within the project area from 2000-2017. From 2005-2009 the rock dike along the GIWW had openings which were repaired by the land owner, also culverts were installed to alleviate flooding in 2006 and 2012.

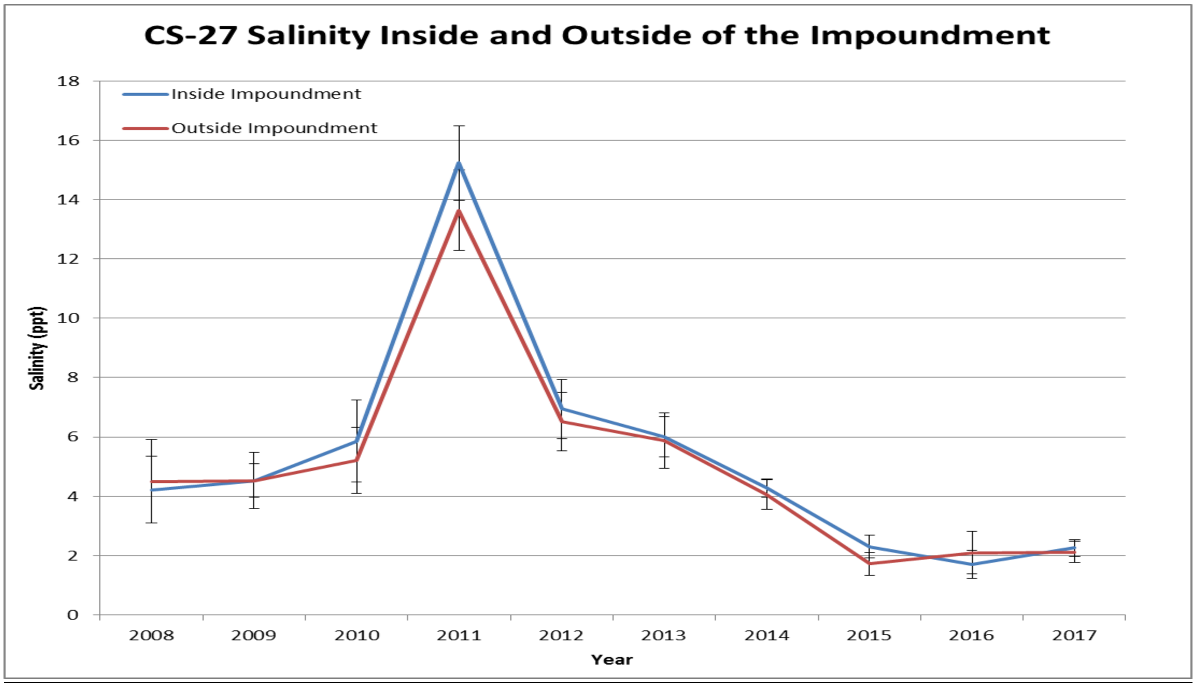

Figure 10. Yearly means and standard errors of continuous salinity collected at project stations CRMS0658 (outside impoundment) and CS27-25 (inside impoundment) from 2008-2017.

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. Monitoring was conducted in September approximately 1 year after Phase I planting. Sample plots had varying survival success. Individual plantings were recorded as alive, absent, or dead. Except for a few, most plants counted as absent or dead were absent. A total of 53 plots containing 848 plants were sampled. The mean percent survival was 68% ranging from 100% to 6% survival depending on location. Some plots had robust, healthy plants that were almost indistinguishable from one another, whereas other plots had plants with few stems in deteriorated condition (LDNR 2004). Similar observations were noted about the Phase II planting in spring 2008.

Shoreline change

A foreshore rock dike was completed in November of 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. 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. Overall, the dike has been 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 11 A and B). Sediments are trapped and settling in the low energy area behind the dike and forming mud flats which are colonized by vegetation (Figure 12).

Table 3. Net land gain and rates along the GIWW shoreline/northern impoundment boundary protected by the foreshore dike

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

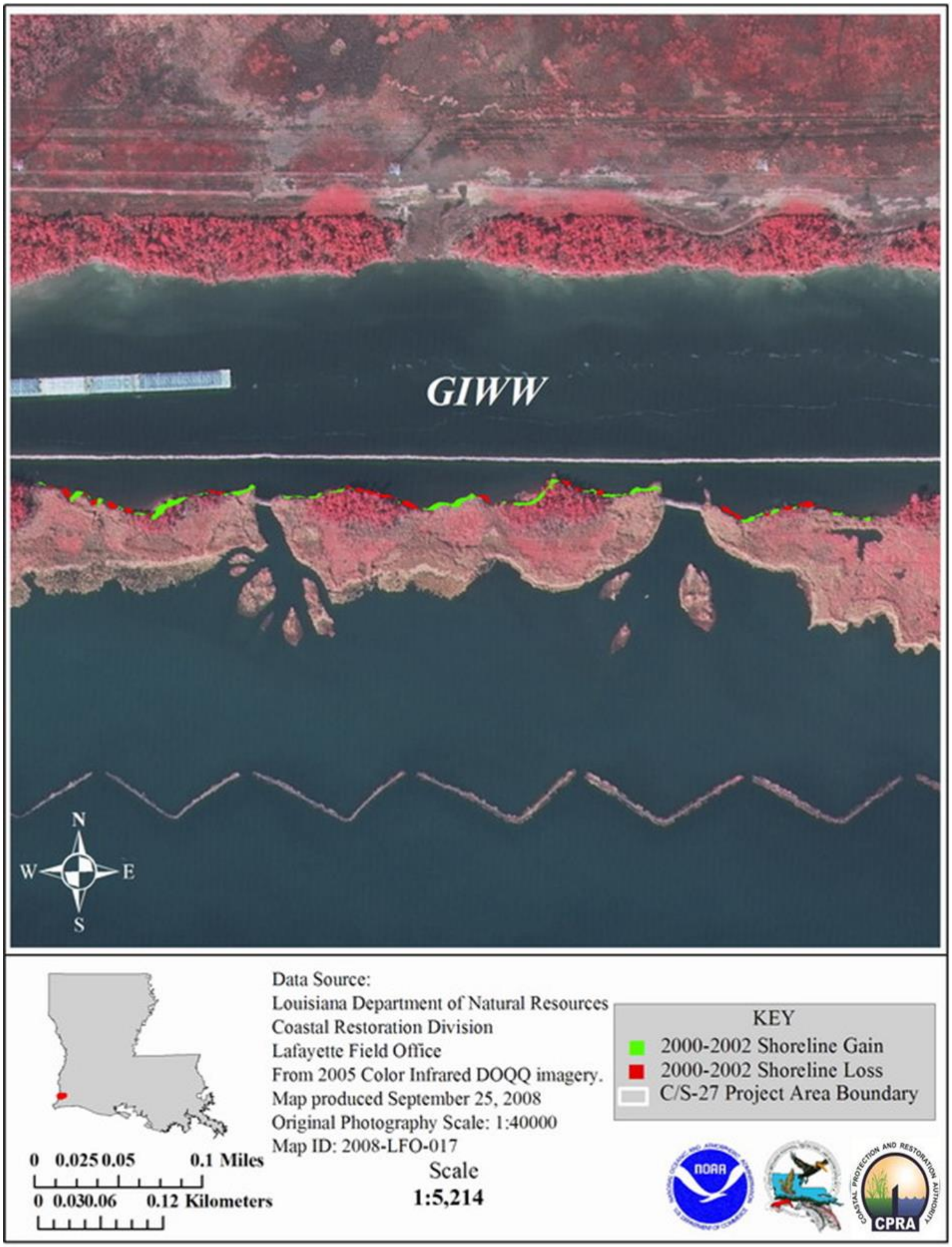

Figure 11a. Shoreline change from surveys conducted in March 2000 and March 2002.

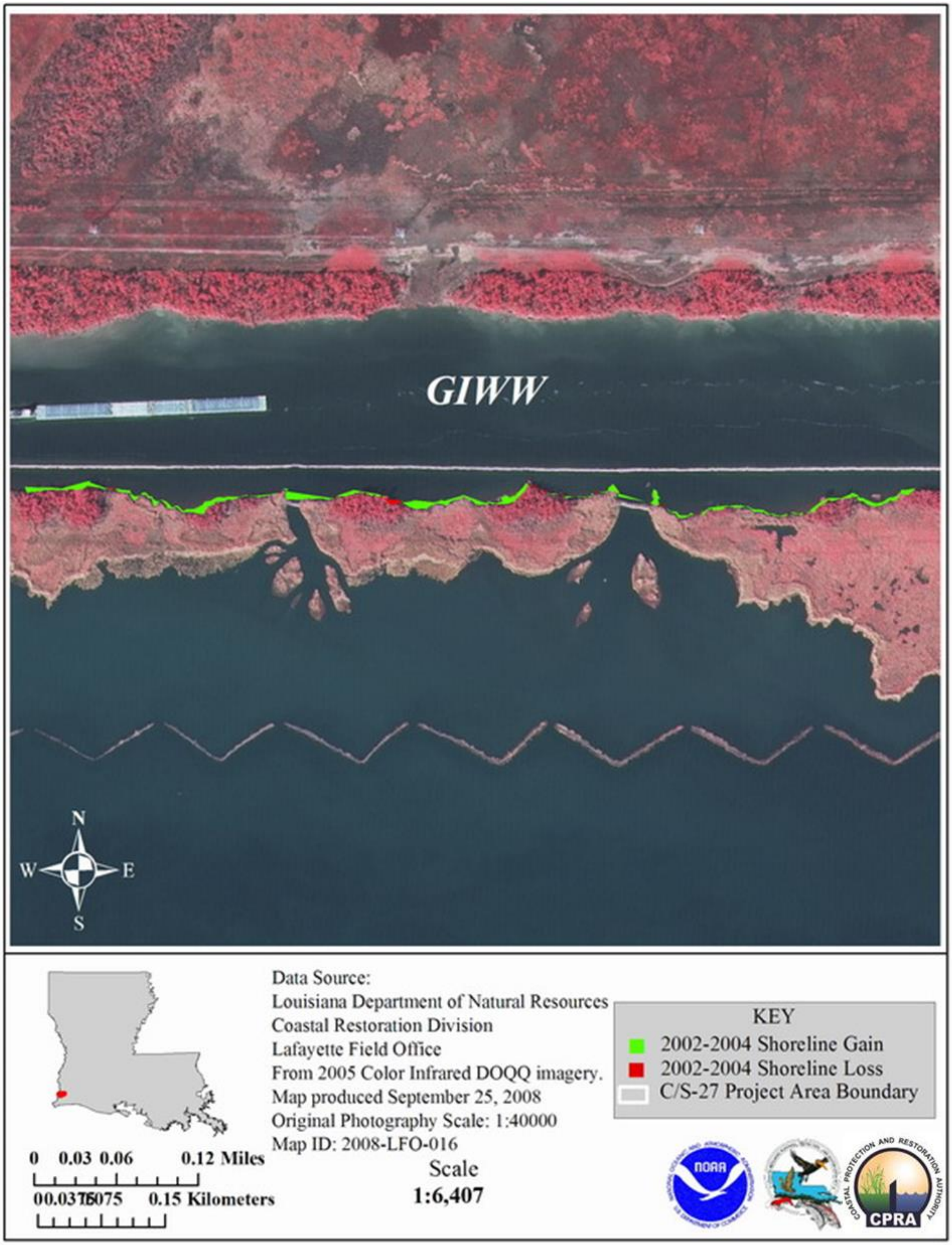

Figure 11b. Shoreline change from surveys conducted in March 2002 and August 2004.

Figure 12. Sedimentation and vegetative growth between the GIWW rock dike and dredge material levee along the north side of the impoundment.

Submerged Aquatic Vegetation (SAV)

Submerged aquatic vegetation 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 ($F_{7,40} = 4.06$; $p = 0.0015$), with a sharp reduction in occurrence in 2005 following Hurricane Rita and 2012 following the prolonged drought in 2011 (Figure 13). However 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 and 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, and took over a decade to finally recover to 2003 levels in 2017. Instead of the sharp rebounds seen in the project area, the reference area continued to fall through 2012 to less than 5%. 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 congruently.

In 2010, frequency of occurrence of SAV was more than 90% in all of the areas west of the Black Bayou Cutoff Canal (Areas 2-6) and less than 15% in the reference area and in the impoundment, Area 1. After Hurricane Rita, SAV was present in all areas although frequency of occurrence was only 12% in Area 6 which may have been due to the close proximity of this area to Sabine Lake/River, a conduit for high salinity water during storms (Figure 14). Collectively, frequency of occurrence of SAV in the project areas has been high except for immediately after Hurricane Rita and the drought of 2011, while it has greatly declined in the reference area and project impoundment over the course of the study period. However the favorable conditions from 2013-2017 have brought all areas and the reference to greater than 50% frequency of occurrence of SAV as of fall 2017. This highlights that fresher conditions eventually improve the SAV populations in the reference and impounded Area one but it takes multiple years with these favorable conditions to reach levels similar to the rest of the project area.

SAV has been diverse in the project areas throughout the project life and assemblages have shifted, being relatively fresh from 1999 to 2003 and 2017, saltier in 2005 and 2012, and intermediate in 2007, 2010 and 2014. In 2003, a decrease in *Ruppia maritima* (widgeongrass), an indicator of more saline conditions occurred and *Nymphaea odorata* (American white waterlily) and *Potamogeton pasillus* (small pondweed) (fresher species) were prevalent (Figure 15). Salinity data also showed a freshening of the project area from 2000 - 2003. *Chara spp.* occurrence began in 2003 following project construction in all areas, but did not remain in the reference area after 2003. Species composition shifted in 2005 as *Ruppia maritima* increased, except in the reference area, concurrent with an increase in salinity levels due to the surge of Hurricane Rita. In 2007 and 2010, species composition again shifted with the absence of *Ruppia maritima* and the presence of *Potamogeton pusillus* and *Ceratophyllum demersum* (coon's tail). *Myriophyllum spicatum* (Eurasian watermilfoil) was also absent in the reference area during this time. Salinity levels during 2007 and 2010 appeared to have returned to pre-hurricane levels prior to the drought of 2011 which again heavily disturbed the project impoundment and the reference area SAV assemblages. Following the drought of 2011 *Ruppia maritima* was dominant in Area 1 and the Reference area but almost absent in the rest of the project area. This could indicate that these areas are experiencing higher salinities than the rest of the project area. In 2014 *Ruppia maritima* was very abundant on most sampling transects indicating that the salinity spike of 2011 thought absent in the surface water by spring of 2012 was still impacting the SAV community three growing seasons post drought. However during the 2017 SAV sampling, *Ruppia maritima* was notably absent from many transects and areas while *Potamogeton pusillus* and a broad assemblage of fresher species were present and thriving in most locations. This indicates that the freshening of the system led to competition for habitat amongst multiple freshwater SAV species.

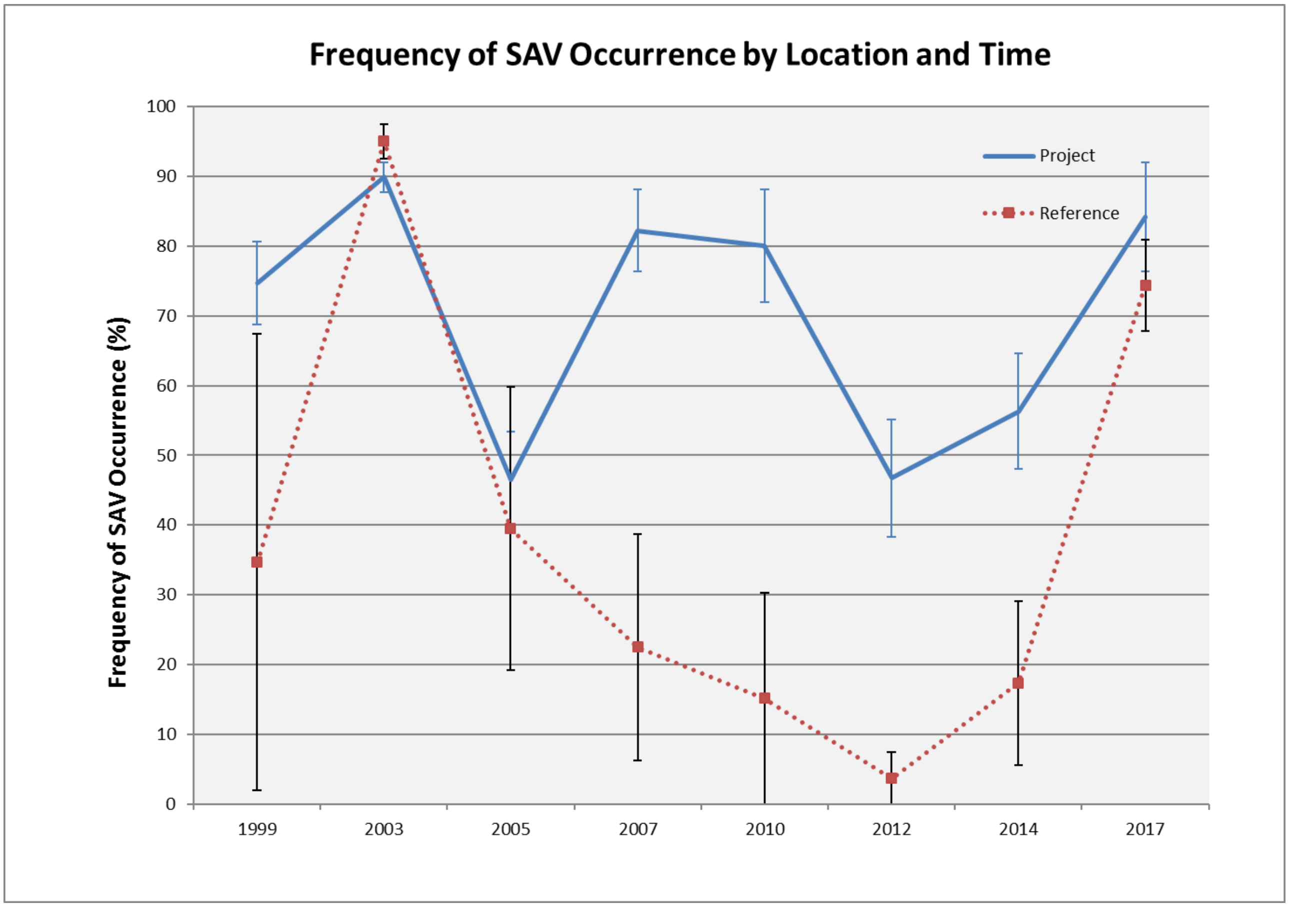

Figure 13. Mean and standard errors for SAV frequency of occurrence in the project and reference areas from pre-project in 1999 to present.

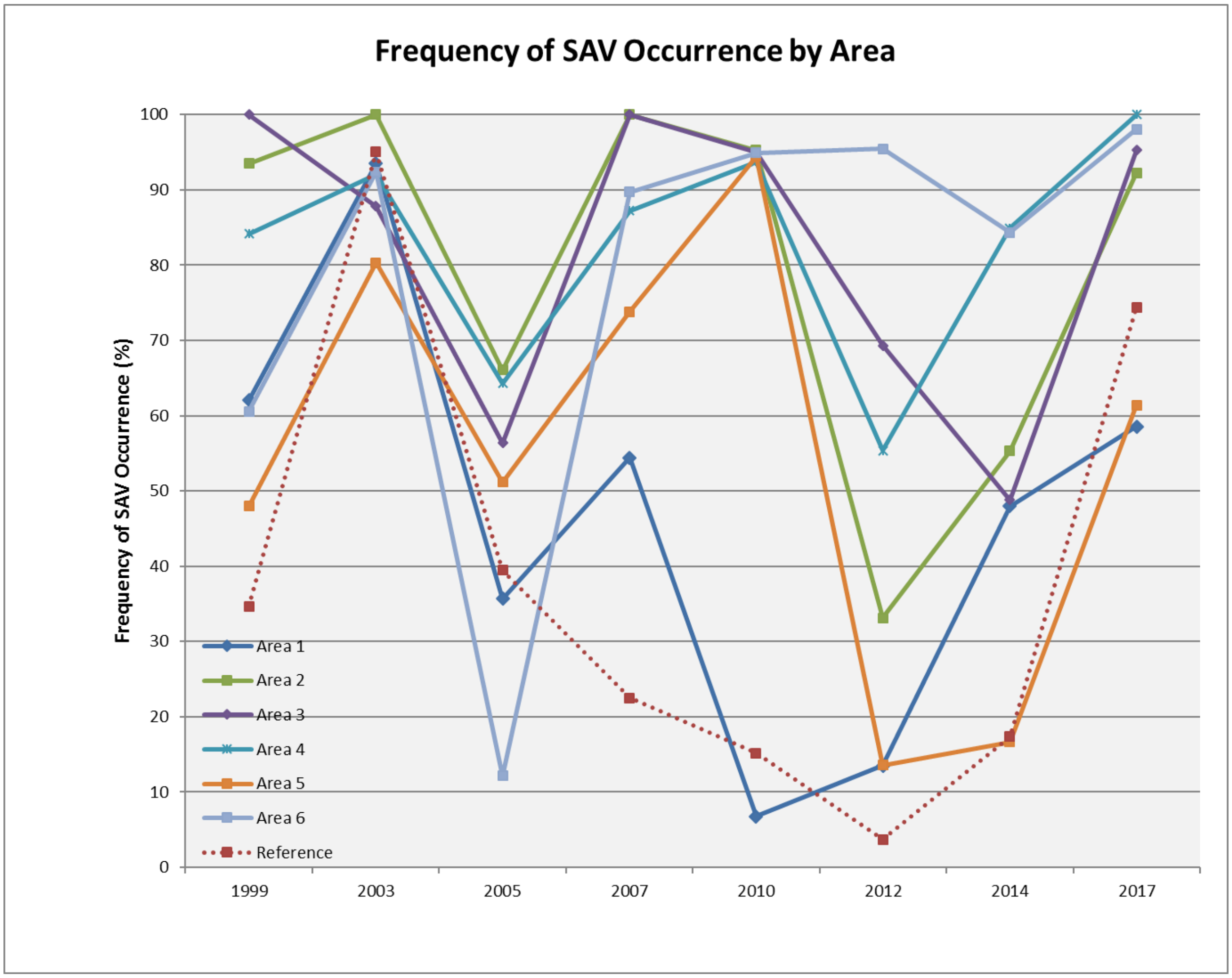

Figure 14. Total percent occurrence of SAV sampled by area and year in late summer. Values are means of three transects (n=3) per area for each year except for area 2 in 2003 (n=1), 2005 (n=2), and 2007 (n=1).

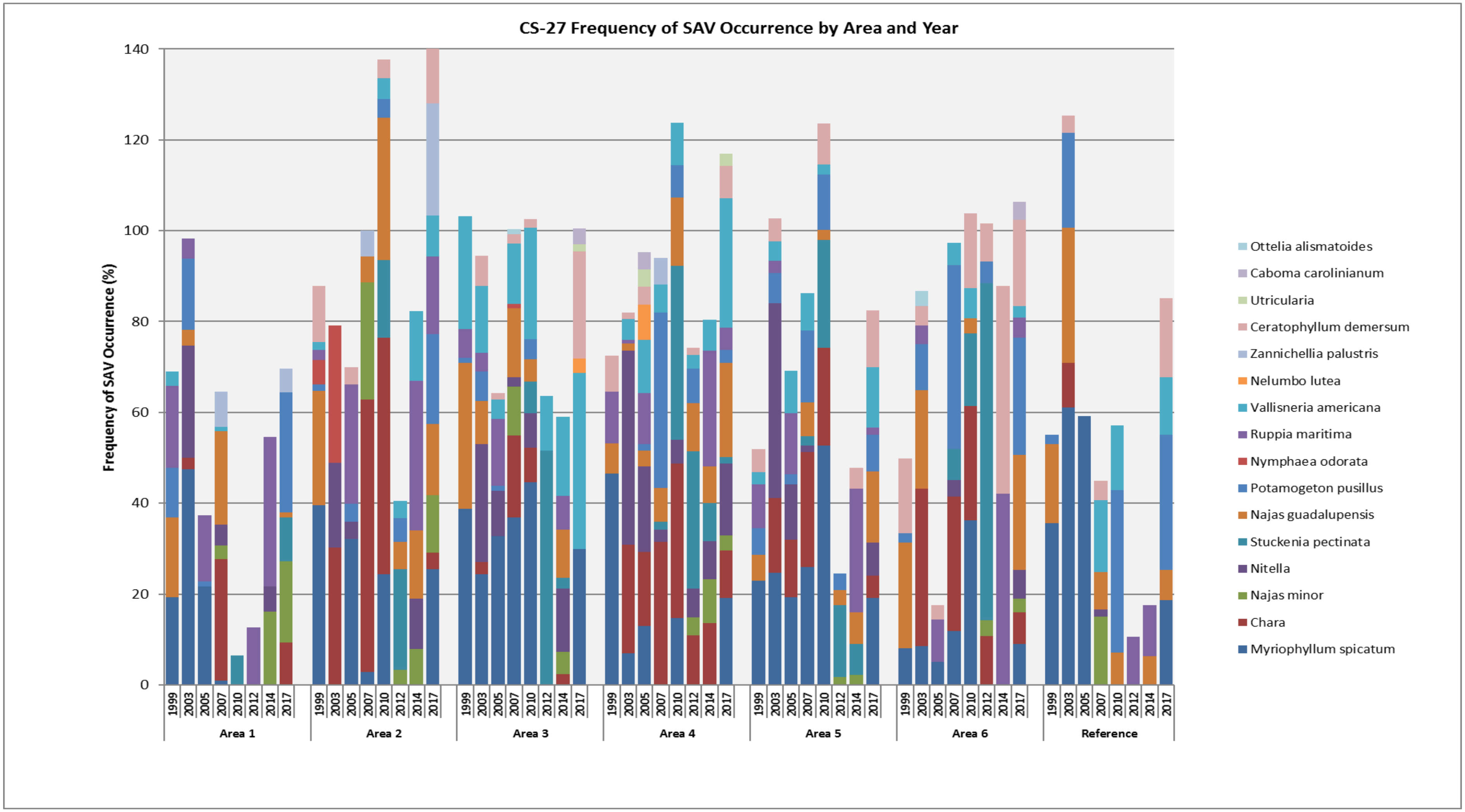

Figure 15. Percent occurrence of SAV species by sample area collected in 1999, 2003, 2005, 2007, 2010, 2012, 2014 and 2017. Values are the mean of transect values (n=3) per area for each year except for area 2 in 2003 (n=1), 2005 (n=2), and 2007 (n=1).

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) which are all native perennial species common to intermediate marsh (Figure 16). 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 2009 and 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 (Southern Regional Climate Center). But it is also likely due to the overall stress and damage to the plant communities due to the extreme soil and water salinities of 2011. As the droughts full effect on percent cover and FQI reduction where not realized until subsequent growing seasons as is evident by the very slow recovery at project CRMS site 2166. In both the reference and project areas 2015-2017 were typically average FQI and percent cover years. Much of the CRMS vegetation data was collected prior to the lengthy flooding brought on by Hurricane Harvey and any negative impacts from this storm will likely manifest themselves in the upcoming 2018 vegetation sampling data.

An investigation into the project and reference areas marsh salinity type shows the project area having 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 17). 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 generally stable amounts of brackish vegetation but show a slight decrease in fresh through intermediate mash vegetation from 2006-7 through 2017. The reference area sites, excluding CRMS 2189 which is unchanged, show a similar loss of the fresher vegetation cohorts. The reference area behaves very similar to the patterns of the project area leading to the conclusion that the overall loss of fresher habitat is indicative of this area and of the Calcasieu Sabine basin as a whole. 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.

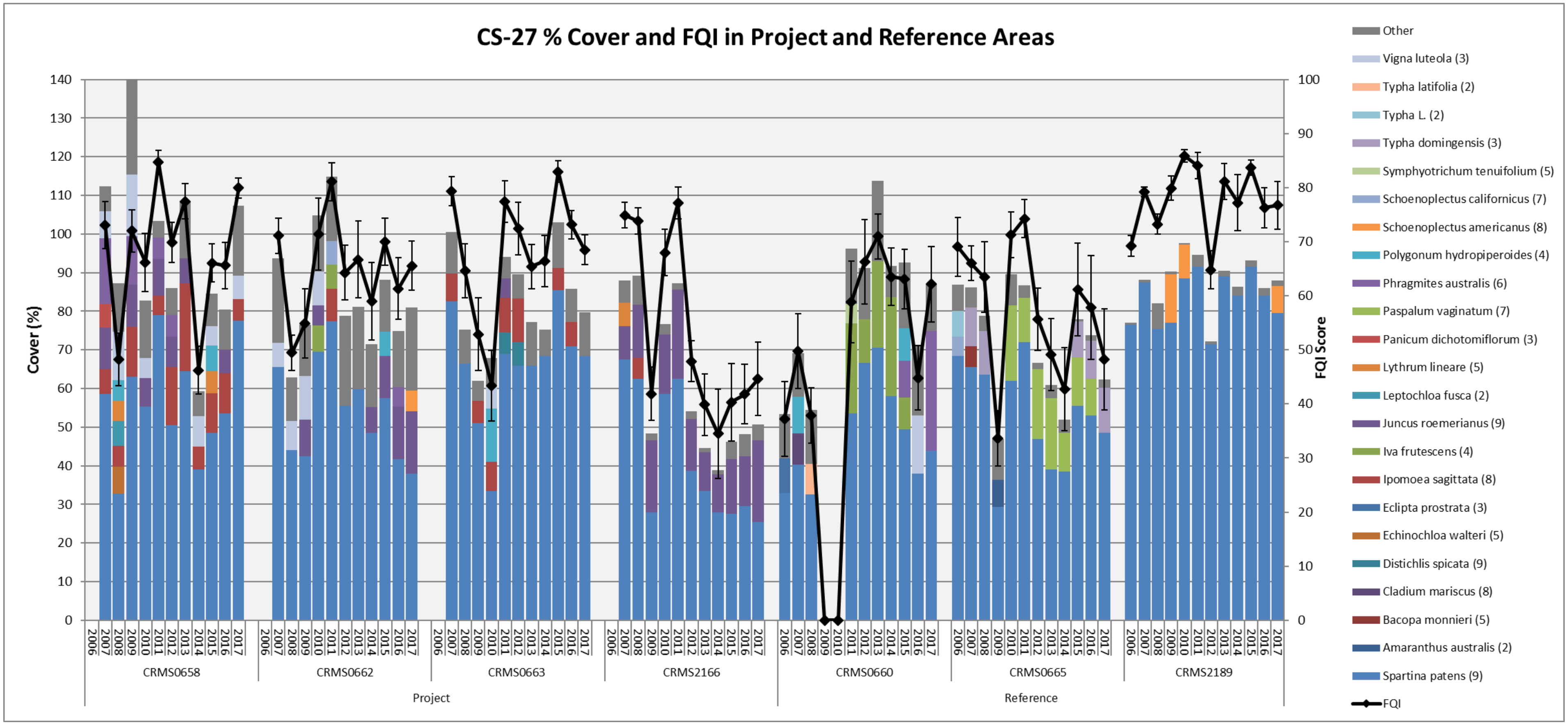

Figure 16. The percent coverage and FQI scores in the project and reference area vegetation data collected from 2006-2017. Reference site CRMS0660 shows a complete loss of vegetation post Hurricane Ike and was reestablished in 2011 in a vegetated location after failing to recover for two years.

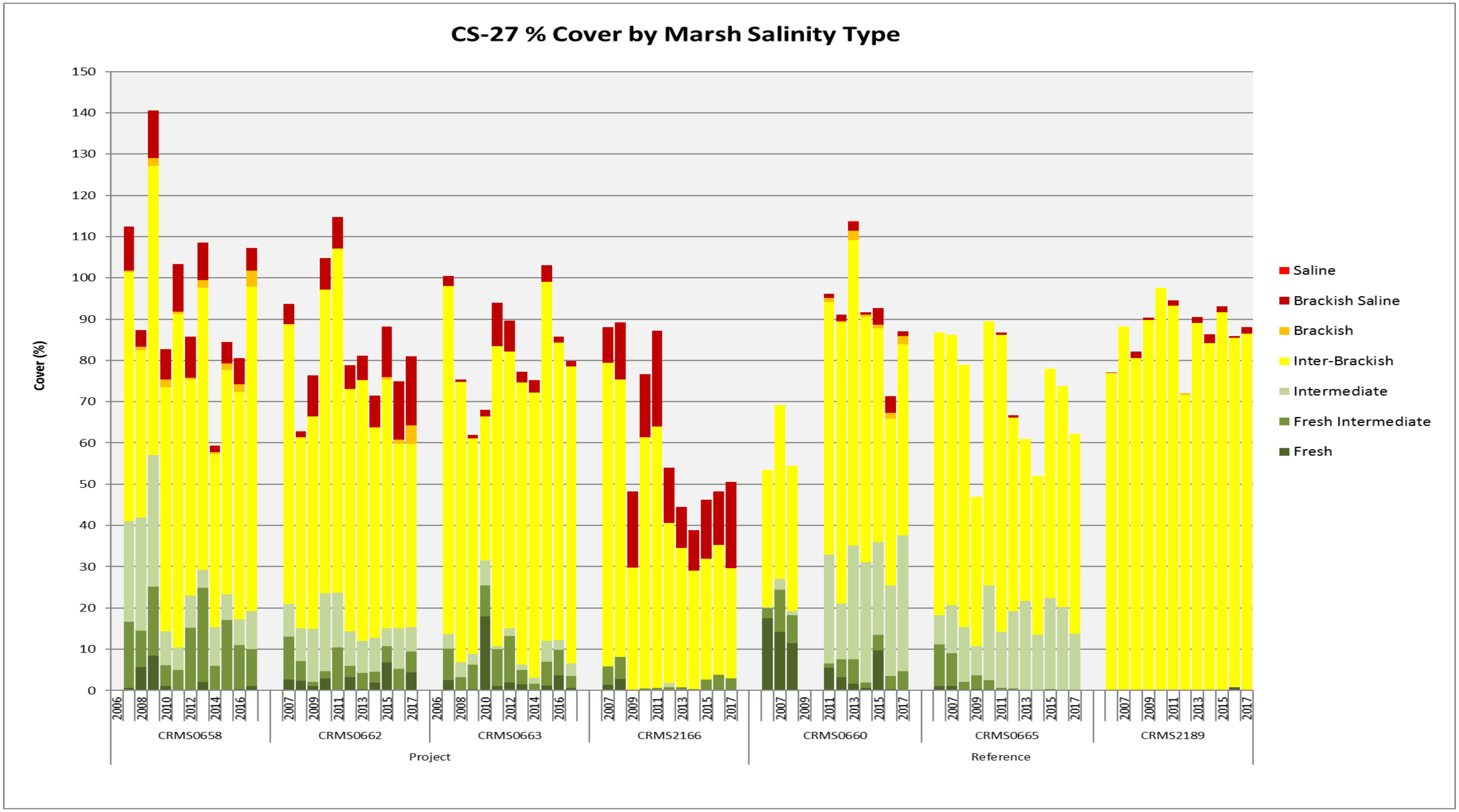

Figure 17. The percent coverage of emergent vegetation by marsh salinity type in the project and reference area vegetation data collected from 2006-2017. Reference site CRMS0660 shows a complete loss of vegetation post Hurricane Ike and was reestablished in 2011 in a vegetated location after failing to recover for two years.

Hydrologic Index

High Hydrologic Index (HI) scores indicate that flooding and salinity conditions are ideal for vegetation growth in a given marsh type. In 2010 the HI scores were higher at CRMS sites within the CS-27 project (CRMS0658, CRMS0662, and CRMS0663) than at CRMS sites outside CS-27 in the same basin and marsh type (Figure 18). In most years the HI scores in the project area were higher than the other sites in the region, except during the years surrounding the drought of 2011 and 2012. At all sites, low scores in 2011 and 2012 were due to very high average annual salinity for the given marsh type and higher salinity combined with moderate flooding respectively.

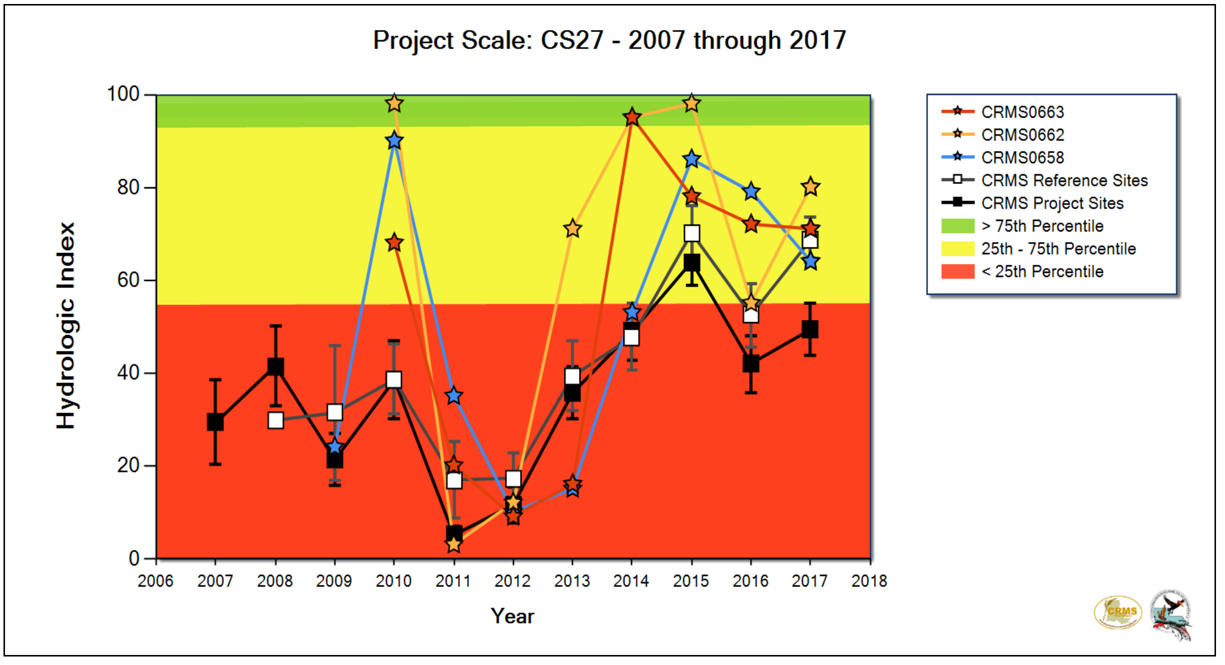

Figure 18. Hydrologic Index scores for CRMS sites in the CS-27 project areas shown over time relative to all other CRMS sites (CWPPRA project and reference) within similar marsh types within the Calcasieu/Sabine Basin. CS-27 project area site CRMS2166 was excluded from the HI analysis because it is a marsh well site and not comparable to the other sites surface water locations.

Soils

Physical soil properties were analyzed from 24 cm (~ 10") deep soil cores collected from four CRMS sites inside the project area and two outside the project area. The soil from the top four to eight cm of all the cores was typical for an intermediate to brackish marsh with low to moderate bulk density (0.05 – 0.15 g/cm^3) (Figure 19). Soil from many sites were noted upon collection has having many roots throughout the core. Soil core samples began to diverge at 12 cm and below, with CRMS0658 and CRMS0660 being more dense relative to the other sites. There does not appear to be any project effect in the bulk density data just local spatial variation. The bottom half and last sample of the project sites CRMS0658 and CRMS0662 respectively were very dense (> 0.2 g/cm^3) and had low organic content (< 30%) relative to the other sites (Figure 20), and upon collection the soil was noted to be very silty with few roots. CRMS0658 is positioned along the GIWW and may be perched on dredged material but it does not differ from CRMS0662 in bulk density or percent organic matter at the lowest segments of the core. This indicates a very mineral and stable subsurface platform through the northern portion of the project area. Whereas the rest of the project and reference CRMS sites where fairly uniform from the top to the bottom depth of 24 cm suggesting these sites have a thicker peat like subsurface and the clay platform lays deeper in these areas.

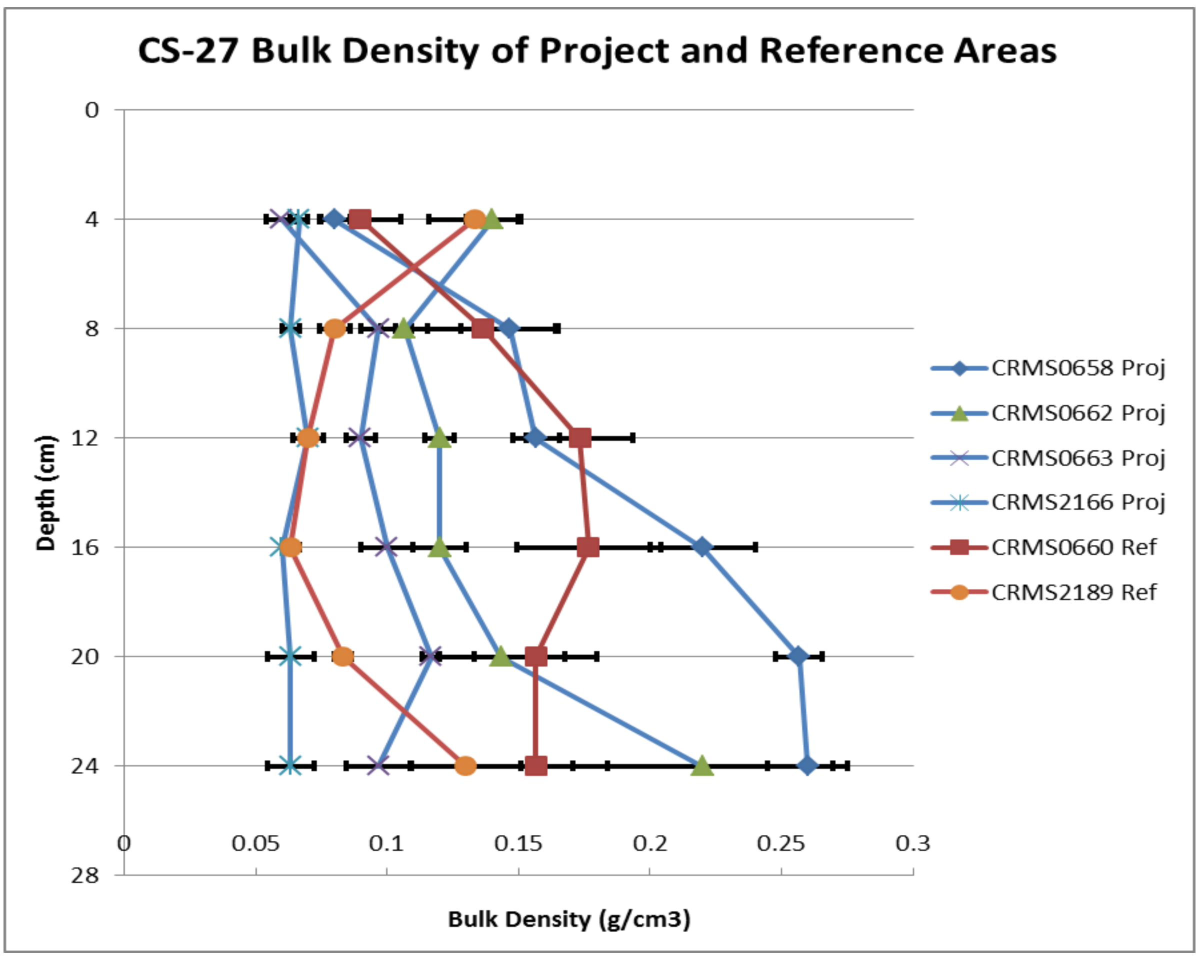

Figure 19. Soil bulk density collected at CRMS sites in the project and reference areas. Values are means and standard errors (n=3).

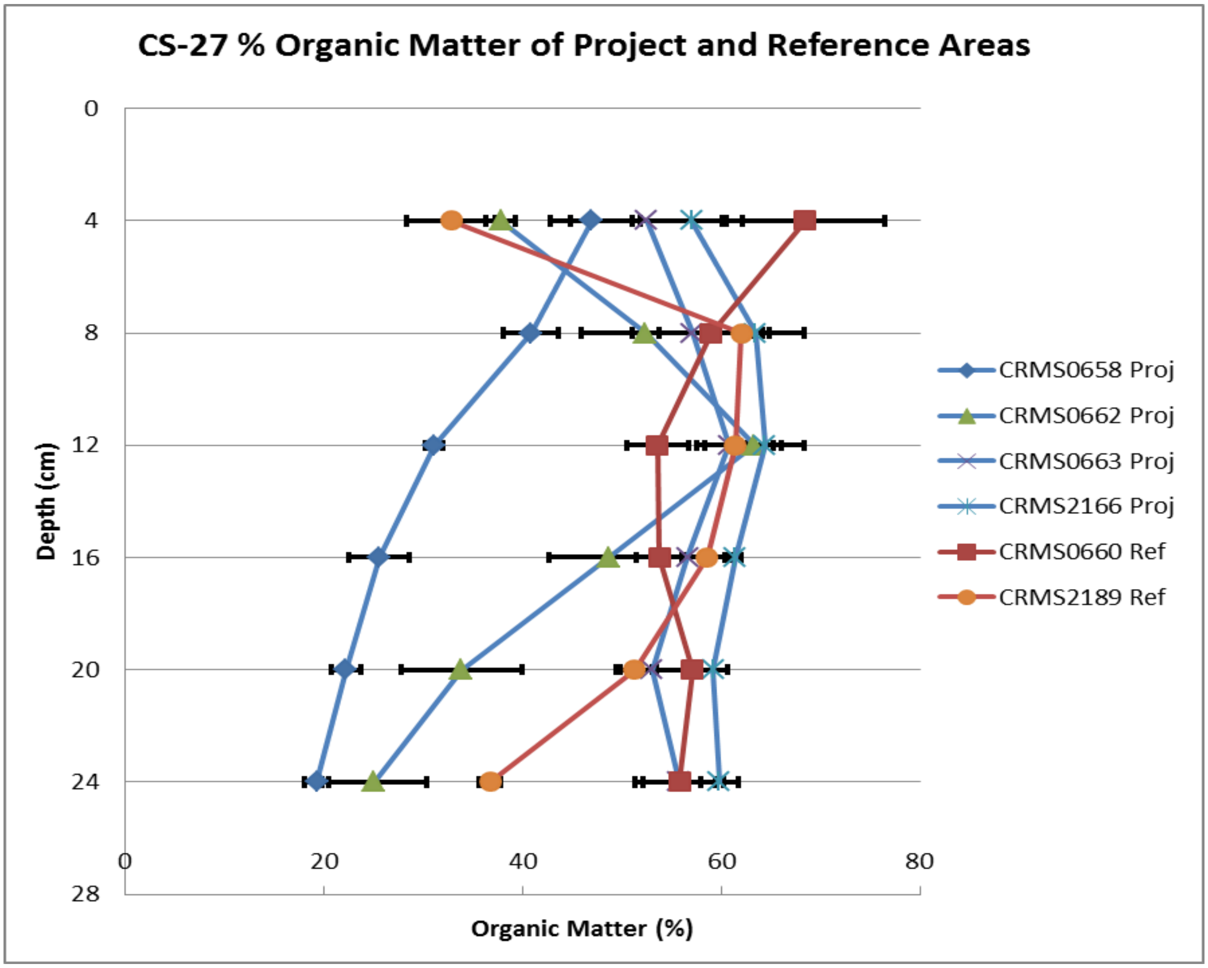

Figure 20. Soil percent organic matter collected at CRMS sites in the project and reference areas. Values are means and standard errors (n=3).

Elevation Change

Elevation change and accretion data collected at the CS-27 project CRMS sites 0658, 0662, 0663, and 2166 along with the reference CRMS sites 0660, 0665, and 2189 generally show the project area had a slight rate of elevation gain (+0.21 to -0.07 cm/yr) while the reference area was highly variable (+0.49 to -0.58 cm/yr) (Figure 21). All of the project sites are likely experiencing slight to moderate increases in inundation when compared to Sabine Pass NOAA tide gauge sea level rise estimate of 0.6 centimeters per year (Zervas 2009). The relative stability and consistency of the 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 22). The reference area is more variable with CRMS2189 gaining elevation due to its proximity to Sabine Lake and the occasional deposition of storm driven sediments. Reference site CRMS0660 however is losing elevation at an alarming rate of -0.58 cm/yr. This area is highly fragmented, sinking, and appears on the trajectory for continued land loss.

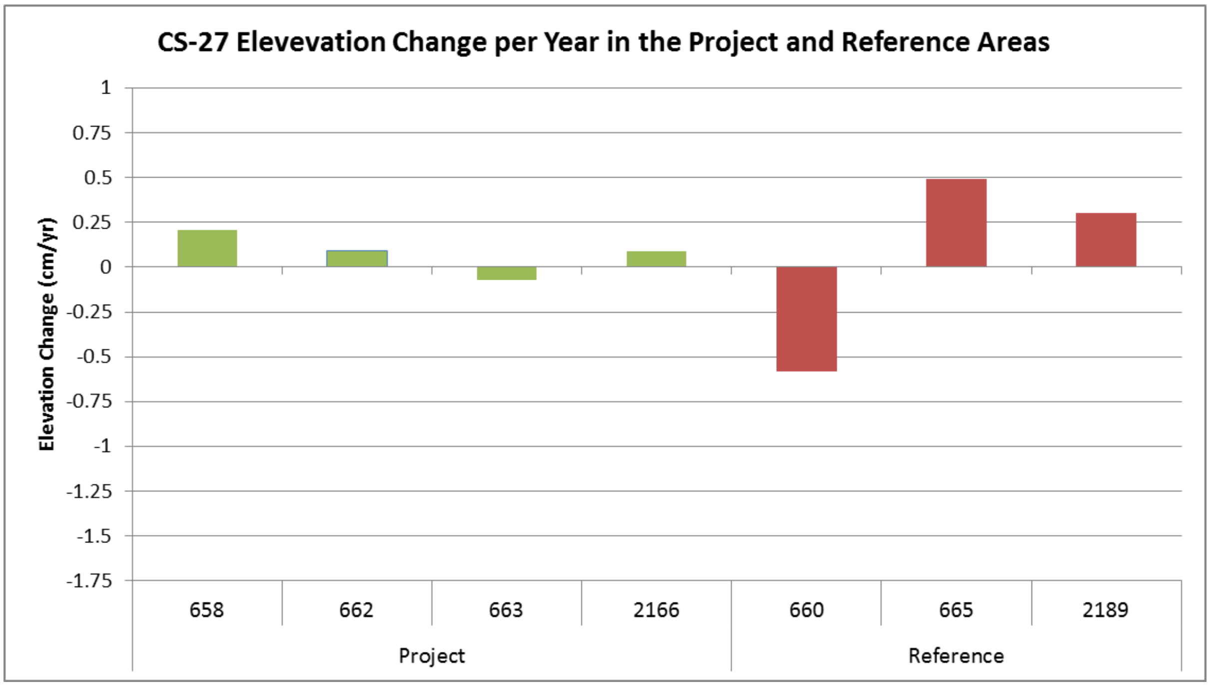

Figure 21. Elevation change per year experienced in the project CRMS sites and reference CRMS sites.

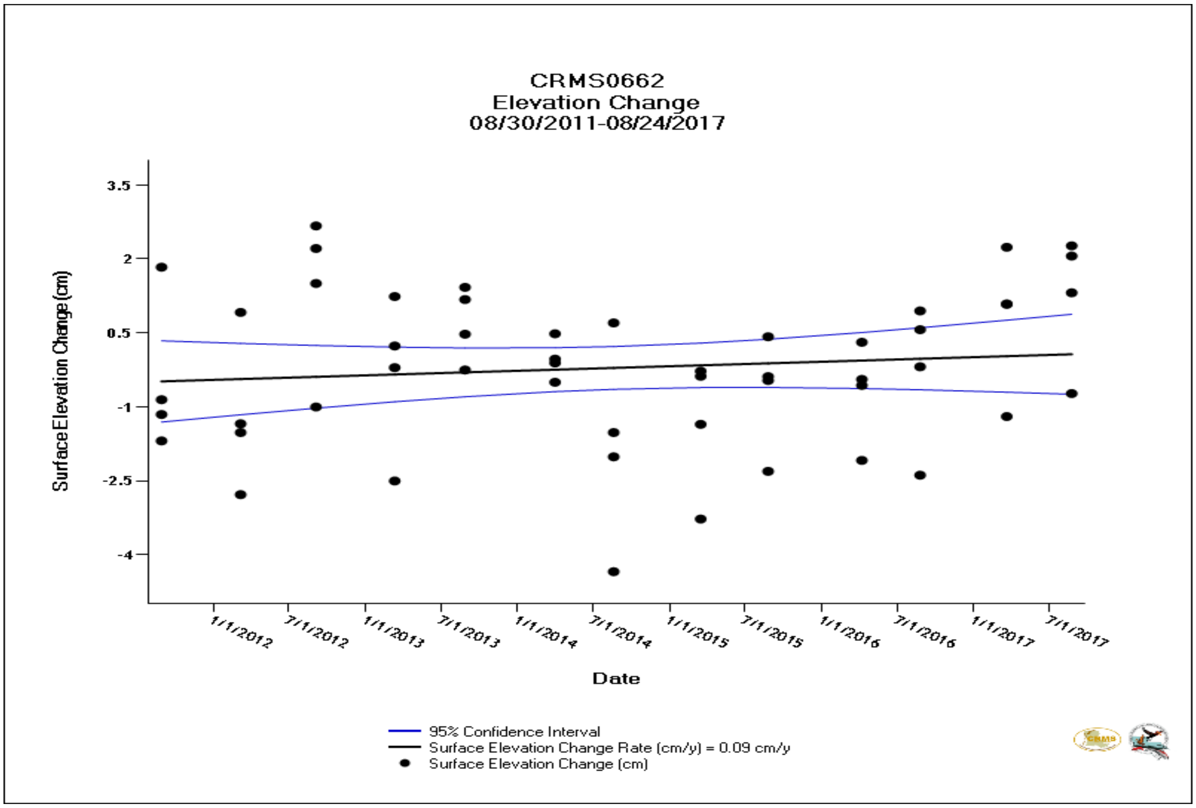

Figure 22. Elevation change from 2011-2017 experienced at a typical project CRMS sites in CS-27, showing a loss and recovery in elevation through time.

V. Discussion

a. General Discussion

The project area hydrology is controlled by larger outside environmental forces but some of these boundary conditions are dampened by project features, such as salinity spikes and tidal amplitude. However flood depth is largely unaffected by the project infrastructure and the pattern of HI is not well supported in the emergent vegetation data that generally shows a peak or stability in 2011 percent cover and FQI. Most of the project and reference CRMS sites show a continual decline in vegetation beginning in 2012 and persisting through 2014 except CRMS2189 which displays the inverse likely due to its higher elevation. This pattern generally reversed itself with stronger vegetation data from 2015-2017. The HI and emergent marsh temporal pattern shift is likely due to a vegetation time lag as the HI responds immediately to physical stimuli while the emergent marsh vegetation takes multiple growing seasons to process and respond to large events such as hurricanes, extreme droughts, and flooding. However the SAV sampled as part of the project specific data, temporally matched the surface water HI much more favorable as elevated HI peak corresponds well with high frequency of occurrence of SAV in the project area. Also the low HI in 2012 was also linked with low SAV occurrence in both areas with the 2014-2017 rebounds in SAV also tracking well with the HI. This close temporal relationship between the HI and SAV occurrence and not emergent marsh may simply be due to the physical proximity of SAV in the water column and the lack of buffering potential such as soil pore water that could cause a time lag in emergent marsh vegetation.

Emergent vegetation in the project area was impacted by Hurricanes Rita and Ike but recovered by 2010-11. From 2012 through 2014, the cover and quality of vegetation generally decreased in both the project and reference area, as a result of the high salinities experienced during the 2011 drought followed by flooding conditions. This trend reversed starting in 2015-2017 as salinity conditions were generally fresh and stable. The projects tidal dampening effect and reduction of salinity allows time for vegetation to recover from damage without the loss of soil elevation capital via tidal scouring and increased soil salinity.

Fluctuations in SAV populations and species compositions over time can be partially attributed to climatologic forcing functions on the region, such as drought (1999 and 2011) and Hurricanes Rita and Ike (2005, 2008). These effects appear to be mitigated by the project features as the majority of the project is less influenced by these large scale regional events compared to the reference area and the impoundment. The project area requiring far less time to rebound to pre event SAV levels near 100% occurrence when compared to the reference area.

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. However there were four breaches in the GIWW spoil bank that were repaired in early 2012 which allowed the impoundment to exchange saltwater with the GIWW. This caused the project impoundment not to be successful at increasing freshwater retention in the project area as it was not a separate hydrologic unit.

From 2000 to 2016, the project area emergent marsh has remained very stable through multiple negative episodic events (+0.5%), while the reference area has lost land mass (-4.8%), presumably due to hurricanes and tidal forces.

The foreshore rock dike has 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. Currently there is little hydrologic exchange through the rock dike, resulting in the minimal tidal export of mineral and organic matter from the project impoundment to the GIWW.

The frequency of occurrence of SAV in the project areas has been high except immediately after Hurricane Rita in 2005 and the 2011 drought, while it has significantly declined in the reference area and in the project impoundment over the same temporal scale.

Some of the constructed components of the project are in need of preventative maintenance. Erosion at previously noted weir locations has continued under the water's surface creating large scour areas on either side of the rock weirs. The depressions on either side of the weirs threaten the future stability of these project features and maintenance plans are currently underway. Repairs made during the last maintenance event are in good condition. The breaches which occurred around two of the four plugs behind the GIWW rock dike have been addressed by landowners at no cost to the project. Observations made during this year's annual inspection such as rusting on the SRT Gate railing and noted sections of displaced rock on the GIWW rock dike do not require maintenance at this time and will continue to be monitored.

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.

For SAV monitoring, 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, though some of the larger lakes in the project area were almost completely vegetated with SAV as of the 2017 SAV survey.

The large scoured areas adjacent to several of the project features are in the final stages of preparation before repairs begin, these repairs will provide long term stability to the project infrastructure.

c. Lessons Learned

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.

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.

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APPENDIX A
(Inspection Photographs)

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

Photo 2—Burton Canal Structure w/ missing SW arrow sign

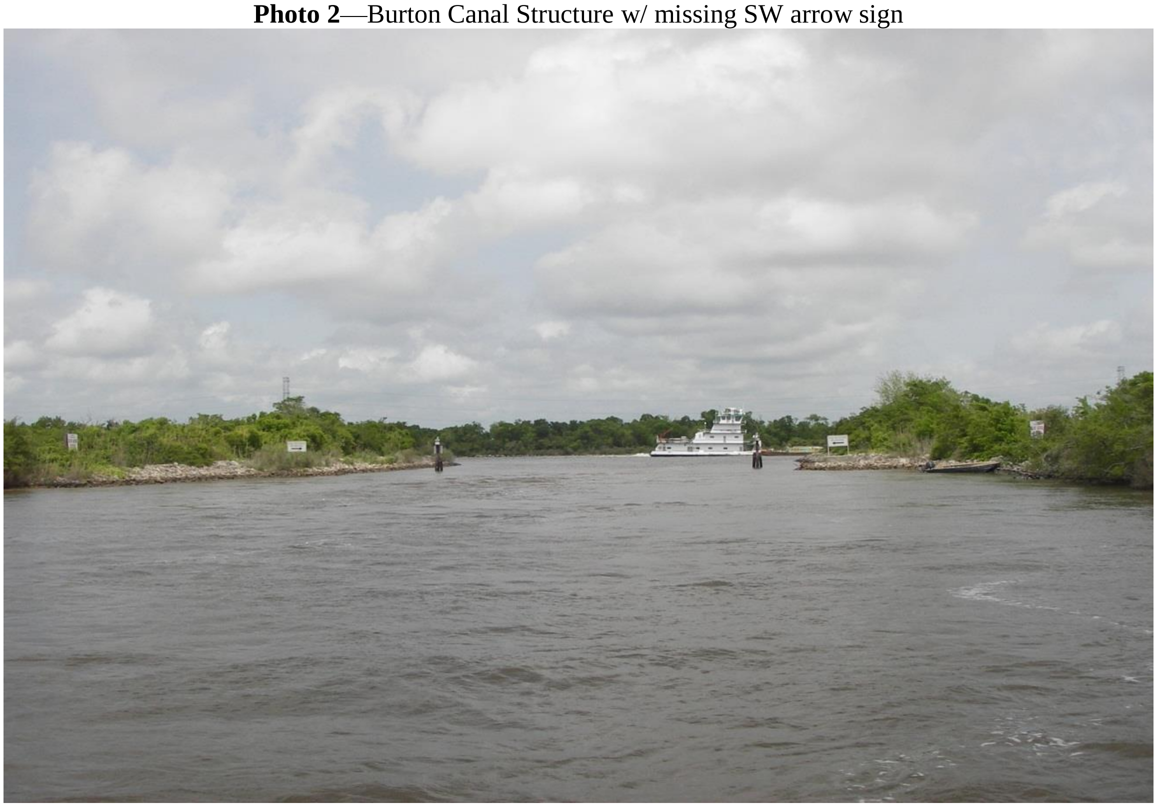

Photo 3—Black Bayou Cut Off Canal structure

Photo 4—SRT Gate

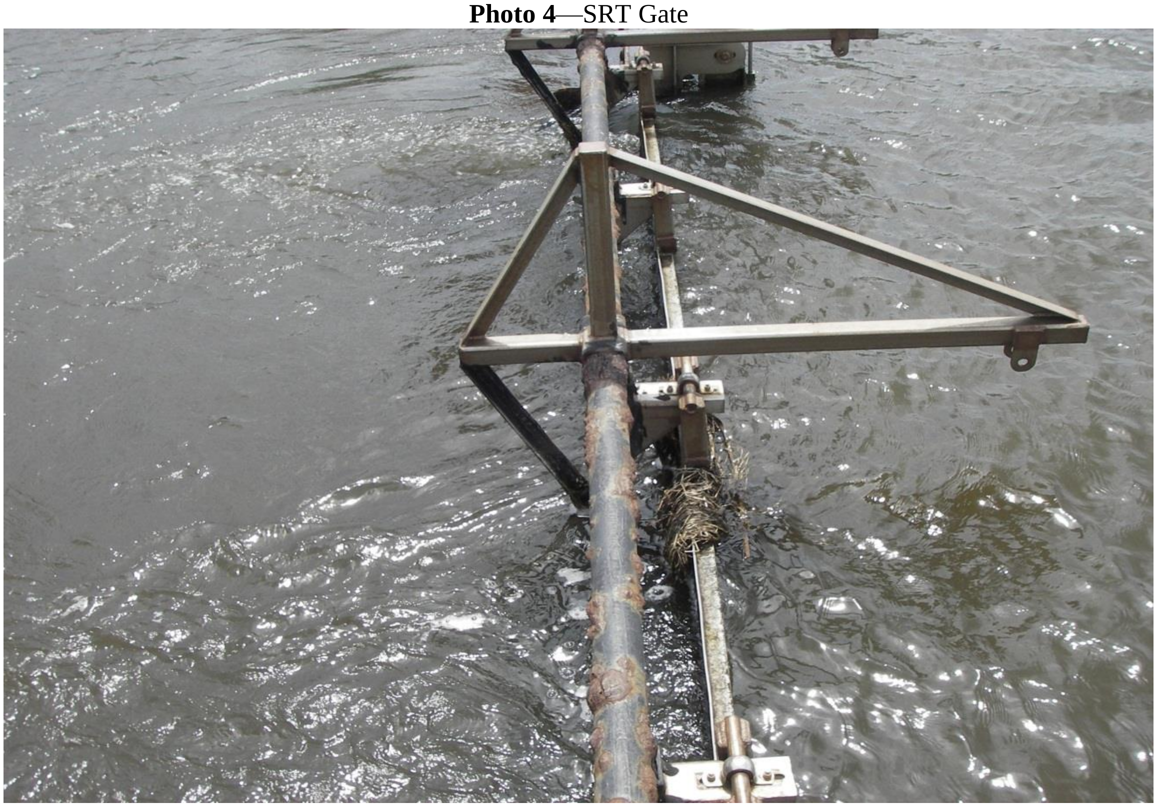

Photo 5—pillow block on SRT Gate flap & railing rust

Photo 6—SRT Gate

Photo 7—Rock plug near SRT Gate

Photo 8—Typical section of rock dike

Photo 9—gap in dike with new vegetation between dike & shoreline

Photo 10—gap in dike

Photo 11—break near closure behind dike

Photo 12—gap in dike and break near closure behind dike

Photo 13—inlet side of eastern culvert

Photo 14—flapgate side of eastern culvert

Photo 15—inlet side of western culvert


Photo 16—flapgate side of western culvert

APPENDIX B
(Three Year Budget Projection)

BLACK BAYOU HYDROLOGIC RESTORATION/ CS27 / PPL 6

Three-Year Operations & Maintenance Budgets 07/01/2015 - 06/30/2018

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

	2015/2016 (-13)	2016/2017 (-14)	2017/2018 (-15)
Maintenance Inspection	$ 6,851.00	$ 7,057.00	$ 7,269.00
Navigational Aid Inspection	$ 5,000.00	$ 5,000.00	$ 5,000.00
State Administration		$ -	$ -
Federal Administration		$ -	$ -

Maintenance/Rehabilitation

15/16 Description: Install staff gauge

	2015/2016 (-13)
E&D	
Construction	$ 7,500.00
Construction Oversight	
Sub Total - Maint. And Rehab.	$ 7,500.00

16/17 Description

	2016/2017 (-14)
E&D	$ -
Construction	$ -
Construction Oversight	$ -
Sub Total - Maint. And Rehab.	$ -

17/18 Description:

	2017/2018 (-15)
E&D	$ -
Construction	$ -
Construction Oversight	$ -
Sub Total - Maint. And Rehab.	$ -

	2015/2016 (-13)	2016/2017 (-14)	2017/2018 (-15)
Total O&M Budgets	**$ 19,351.00**	**$ 12,057.00**	**$ 12,269.00**

O &M Budget (3 yr Total)	**$ 43,677.00**
Unexpended O & M Budget	**$ 252,341.00**
Remaining O & M Budget (Projected)	**$ 208,664.00**

OPERATION AND MAINTENANCE BUDGET WORKSHEET

BLACK BAYOU HYDROLOGIC RESTORATION PROJECT / PROJECT NO. CS-27 / PPL NO. 6 / 2015/2016

DESCRIPTION	UNIT	EST. QTY.	UNIT PRICE	ESTIMATED TOTAL
O&M Inspection and Report	EACH	1	$6,851.00	**$6,851.00**
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	$5,000.00	**$5,000.00**
Construction Oversight	LUMP	0	$0.00	**$0.00**

ADMINISTRATION

LDNR / CRD Admin.	LUMP	0	$0.00	$0.00
FEDERAL SPONSOR Admin.	LUMP	0	$0.00	$0.00
SURVEY Admin.	LUMP	0	$0.00	$0.00
OTHER				$0.00
			TOTAL ADMINISTRATION COSTS:	**$0.00**

MAINTENANCE / CONSTRUCTION

SURVEY

SURVEY DESCRIPTION: Add staff gage.

Secondary Monument	EACH	0	$0.00	$0.00
Staff Gauge / Recorders	EACH	1	$7,500.00	$7,500.00
Marsh Elevation / Topography	LUMP	0	$0.00	$0.00
TBM Installation	EACH	0	$0.00	$0.00
OTHER				$0.00
			TOTAL SURVEY COSTS:	**$7,500.00**

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: **$19,351.00**

OPERATION AND MAINTENANCE BUDGET WORKSHEET

BLACK BAYOU HYDROLOGIC RESTORATION PROJECT / PROJECT NO. CS-27 / PPL NO. 6 / 2016-2017

DESCRIPTION	UNIT	EST. QTY.	UNIT PRICE	ESTIMATED TOTAL
O&M Inspection and Report	EACH	1	$7,057.00	**$7,057.00**
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	$5,000.00	**$5,000.00**
Construction Oversight	LUMP	0	$0.00	**$0.00**

ADMINISTRATION

LDNR / CRD Admin.	LUMP	0	$0.00	$0.00
FEDERAL SPONSOR Admin.	LUMP	0	$0.00	$0.00
SURVEY Admin.	LUMP	0	$0.00	$0.00
OTHER				$0.00
			TOTAL ADMINISTRATION COSTS:	**$0.00**

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: **$12,057.00**

OPERATION AND MAINTENANCE BUDGET WORKSHEET

BLACK BAYOU HYDROLOGIC RESTORATION PROJECT / PROJECT NO. CS-27 / PPL NO. 6 / 2017-2018

DESCRIPTION	UNIT	EST. QTY.	UNIT PRICE	ESTIMATED TOTAL
O&M Inspection and Report	EACH	1	$7,269.00	**$7,269.00**
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	$5,000.00	**$5,000.00**
Construction Oversight	LUMP	0	$0.00	**$0.00**

ADMINISTRATION

LDNR / CRD Admin.	LUMP	0	$0.00	$0.00
FEDERAL SPONSOR Admin.	LUMP	0	$0.00	$0.00
SURVEY Admin.	LUMP	0	$0.00	$0.00
OTHER				$0.00
			TOTAL ADMINISTRATION COSTS:	**$0.00**

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: **$12,269.00**

APPENDIX C
(Field Inspection Notes)

MAINTENANCE INSPECTION REPORT CHECK SHEET

Project No. / Name: CS-27 Black Bayou Hydrologic Restoration
Structure No. ________N/A_____________________

Structure Description: Blocks's Creek Weir w/ Boat Bay
Burton Canal Weir w/ Boat Bay
Black Bayou Cut-Off Canal w/ Barge Bay
Culvert1/Culvert2

Type of Inspection: Annual

Date of Inspection: April 9, 2015 Time: 12:30pm
June 26, 2015
Inspector(s):Stan Aucoin and Dion Broussard (CPRA)
John Foret (NMFS)
Water Level Inside:______________ Outside: _________
Salinity:
Weather Conditions: cloudy and warm

Item	Condition	Physical Damage	Corrosion	Photo #	Observations and Remarks
Block's Creek Weir	Good			1	Scouring taking place on each side of the structure. 20 ft deep on Black Bayou side and 14ft deep on interior. Sill is at 4.5ft. Two arrow signs are missing. No other maintenance required at this time.
Burton Canal Weir	Good			2	Scouring taking place on each side of the of the wier. 29.5ft on Sabine river side and 33.7ft deep on interior. Sill is at 6.5ft
Black Bayou Cut-Off Canal Weir	Good			3	Scouring is taking place on each side of the weir. 33.5ft deep on the GIWW side and 23ft deep on interior. Sill is at 10.5ft deep.
Culvert1/Culvert2	good			13-16	Good condition
Timber Piles	N/A				
Timber Wales	N/A				
Galv. Pile Caps	N/A				
Navigational Aid Lights	Good				Inspected quarterly.
Signage /Supports	Good				See note on Block's creek
Rip Rap	Good				

What are the conditions of the existing levees?
Are there any noticeable breaches?
Settlement of rock plugs and rock weirs?
Position of stoplogs at the time of the inspection?
Are there any signs of vandalism?

MAINTENANCE INSPECTION REPORT CHECK SHEET

Project No. / Name: CS-27 Black Bayou Hydrologic Restoration

Date of Inspection: April 9, 2015 Time: 12:30 am

Structure No. ___ N/A

Inspector(s):Stan Aucoin and Dion Broussard (CPRA)
John Foret (NMFS)

Structure Description: SRT Gate and Rock Plug

Water Level Inside:______________ Outside: _________

Salinity:

Type of Inspection: Annual

Weather Conditions: clear skies and cool temperatures

Item	Condition	Physical Damage	Corrosion	Photo #	Observations and Remarks
Steel Bulkhead / Caps	Good			6	Rusting at sheet pile seams. Will continue to monitor.
Steel Grating	N/A				
Stop Logs	N/A				
Hardware	Good				
Timber Piles	Good				
Timber Wales	Good				
Galv. Pile Caps	Good				
SRT Gate	Good		Moderate	4-6	Pillow blocks were replaced during last inspection. Gate is in good condition. The railing above the gate is showing signs of corrosion. No maintenance required at this time.
Signage /Supports Vinton Canal	Good			4	Good condition.
Rip Rap (fill)	Good				
Rock Plug (Concrete sack repair)	Good			7	Good condition

What are the conditions of the existing levees?
Are there any noticeable breaches?
Settlement of rock plugs and rock weirs?
Position of stoplogs at the time of the inspection?
Are there any signs of vandalism?

MAINTENANCE INSPECTION REPORT CHECK SHEET

Project No. / Name: CS-27 Black Bayou Hydrologic Restoration

Date of Inspection: April 9, 2015 Time: 12:30pm

Structure No. ___ N/A

Inspector(s):Stan Aucoin, Dion Broussard (CPRA)
John Foret (NMFS)

Structure Description: GIWW Rock Dike

Water Level Inside:______________ Outside: _________

Salinity:

Type of Inspection: Annual

Weather Conditions: cloudy skies and warm

Item	Condition	Physical Damage	Corrosion	Photo #	Observations and Remarks
Steel Bulkhead / Caps	N/A				
Steel Grating	N/A				
Stop Logs	N/A				
Hardware	N/A				
Timber Piles	N/A				
Timber Wales	N/A				
Galv. Pile Caps	N/A				
Earthen Plugs	Fair				The spoil behind the rock dike at the natural Black Bayou has washed away on the western end. This will continue to be monitored.
Signage /Supports	Poor				Warning signs at the Vinton and Black Bayou closures are missing.
Rip Rap (fill) GIWW Rock Dike	Good			9-12	There is a gap in the rock dike at the natural Black Bayou in front of the gap in the earthen plug. The rock is approximately 2-3 ft below the water surface. The first and second gaps from the east have solid marsh behind them. The third has a connection through the marsh on the west side approx. six feet wide with significant flow. Several small gaps in the dike were noticed; however, rock is still present at the base providing shoreline protection. Thee are low areas along the rest of the dike but they are still functioning as intended. Tie-ins on both ends of the rock dike are stable. Sediment accretion behind the dike is evident and vegetation is expanding.

What are the conditions of the existing levees?
Are there any noticeable breaches?
Settlement of rock plugs and rock weirs?
Position of stoplogs at the time of the inspection?
Are there any signs of vandalism?