Coastal Protection and
Restoration Authority of Louisiana

State of Louisiana
Coastal Protection and Restoration Authority

2016 Operations, Maintenance, and Monitoring Report

for

Caernarvon Diversion Outfall Management (BS-03a)

State Project Number BS-03a
Priority Project List 2

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Plaquemines Parish

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Preface

The 2016 Operations, Maintenance and Monitoring (OM&M) report format is a streamlined approach that combines the operations and maintenance annual project inspections with the monitoring data and analyses on a project-specific basis. This report includes monitoring data collected from March 2000 through April 2016, and annual maintenance inspections through July 2016. The 2016 Caernarvon Diversion Outfall Management OM&M report is the 4th in a series of reports. For additional information on lessons learned, recommendations and project effectiveness please refer to the 2004, 2008, and 2011 OM&M reports on the CPRA website.

I. Introduction

The Caernarvon Diversion Outfall Management project (BS-03a) was approved on the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) Second Priority Project List. The 18,200-acre (7,365-ha) project area is located in Plaquemines Parish, Louisiana, and lies to the south and west of Big Mar, a failed agricultural impoundment (Figure 1).

From 1932 to 1990, 5,546 acres (2,224 ha) of land were converted to open water in the Caernarvon Diversion Outfall Management project area due to various factors, such as subsidence, storm induced erosion, channelization of streams and rivers, and canal dredging (Dunbar et al. 1992). Land loss rates peaked between 1958 and 1974, exceeding 270 ac/yr (109 ha/yr). The number of oil and gas pipeline canals in Louisiana increased dramatically during this time period, significantly increasing saltwater intrusion throughout the entire portion of the Breton Sound basin. Most erosion occurred in the western portion of the project area, near the intersection of the Reggio and DP canals. In the area west of Tigers Ridge, forested wetlands were once the dominant habitat. During Hurricane Betsy in 1965, highly saline storm surge from the Gulf of Mexico penetrated into these upper reaches of the basin through the network of oil and gas canals. The saltwater became trapped behind the ridge causing severe stress and eventual loss of the forested wetland community. Saltwater-tolerant species were not able to establish themselves because of the lack of a suitable substrate between the subsiding natural levee ridges and the presence of an adverse hydrologic regime (USDA/NRCS 1996).

The increasing effects of saltwater intrusion via canals transformed the project area from a primarily intermediate community in 1968 (Chabreck et al. 1968) to a primarily brackish marsh by 1978. By 1988, all but 3% of the project area was classified as brackish marsh. Pre-construction vegetation surveys for the Caernarvon Freshwater Diversion project (BS-08) between 1988 and 1990 showed *Spartina patens* (saltmeadow cordgrass) to be the dominant species. Less dominant species included *Baccharis halimifolia* (eastern baccharis), *Schoenoplectus americanus* (chairmaker's bulrush), and *Spartina cynosuroides* (big cordgrass). In more saline areas, *Spartina alterniflora* (smooth cordgrass) dominated the community and was often found with *Distichlis spicata* (saltgrass) and *Juncus roemerianus* (black needlerush). Submerged aquatic vegetation (SAV) was often found in open water areas and common species were *Najas guadalupensis* (southern naiad), *Myriophyllum spicatum* (Eurasian water-milfoil), and *Ruppia maritima* (widgeon grass).

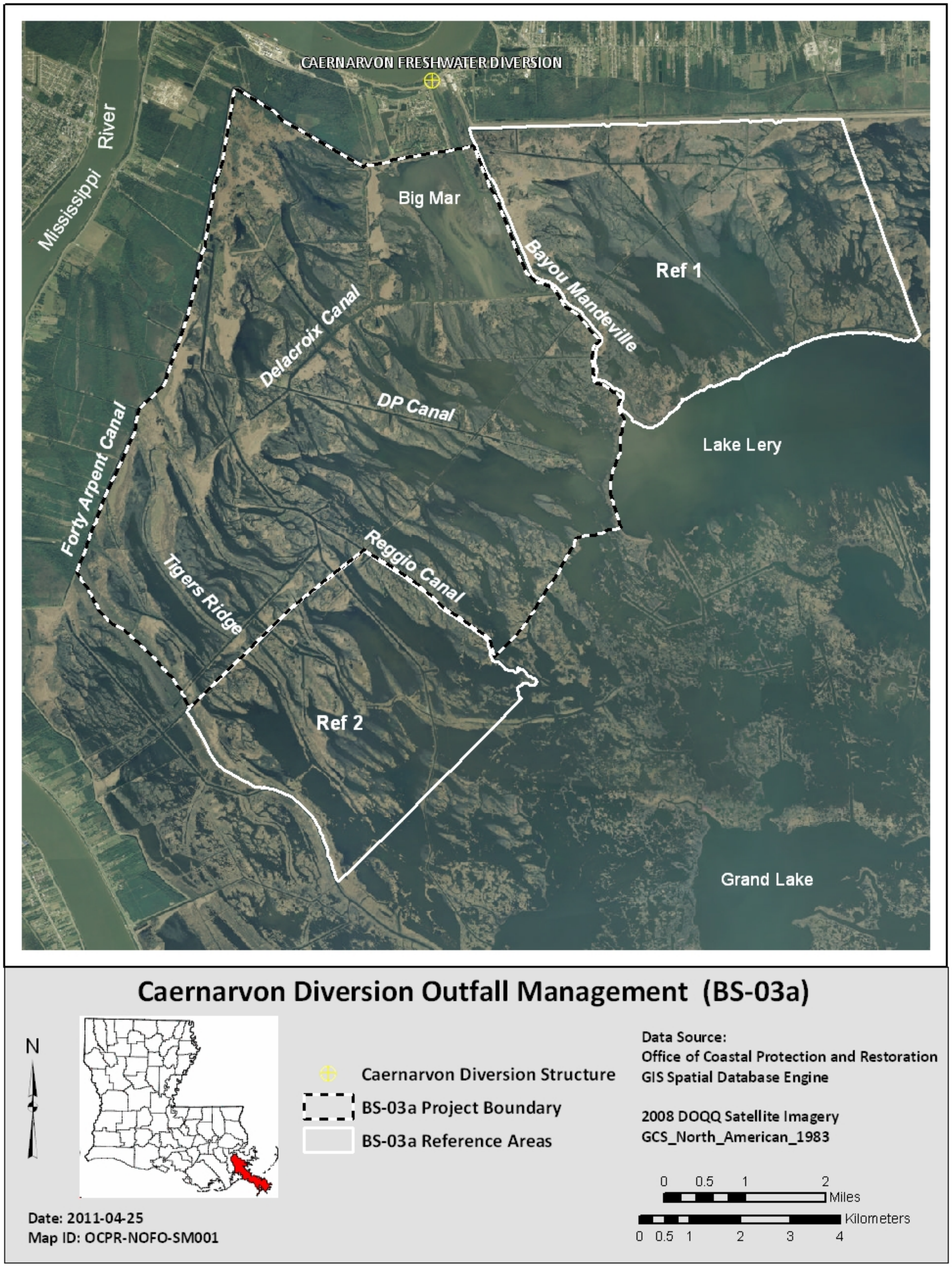

Figure 1. Caernarvon Diversion Outfall Management (BS-03a) project and reference areas.

The Caernarvon diversion structure was constructed between 1988 and 1991 as part of the Caernarvon Freshwater Diversion project (BS-08) for the purpose of diverting fresh water from the Mississippi River into the marshes of the Breton Sound basin. The diversion project was funded under the Water Resources Development Act (WRDA) with the intent of increasing commercial and recreational fisheries and wildlife productivity, enhancing emergent marsh vegetation growth, and reducing marsh loss. The structure has a discharge capacity of 8,000 cubic feet/second (cfs); however, the annual discharges have been much lower than anticipated due to several contributing factors. These factors include oyster industry lawsuits, above normal rainfall and natural crevasse formations freshening the basin, and a commercial fishing industry that prefers to not allow excessive amounts of fresh water in the spring and summer months. Additional information regarding Operations, Maintenance, and Monitoring of the Caernarvon Freshwater Diversion project (BS-08) can be found at the CPRA Resources web site.

The intent of the Caernarvon Diversion Outfall Management project (BS-03a) is to maximize the benefits from the Caernarvon Freshwater Diversion to the marshes immediately south and west of Big Mar (Figure 1) during periods of low discharge from the diversion structure. Prior to the BS-03a project, man-made spoil banks and plugs routed much of the water to the lower southwest reaches of the basin and prevented flow through interior marshes as was originally intended. BS-03a project features, such as plugs, sluice and combination gates, and spoil bank restoration, were designed to allow water from the channels to flow into the marsh interior and be retained for a longer period of time. Sluice and combination gates operate by controlling the passage of water in an open channel, and when fully lowered will restrict water flow as desired. Increased retention time is needed in the interior marshes to facilitate the distribution of fresh water, the deposition of suspended sediments, and the assimilation of nutrients. This goal was approached by enhancing existing spoil banks and installing plugs and water control structures in key locations, utilizing existing natural features to establish hydrologic units where introduced diversion waters once discharged from the interior marshes back into bayous and canals (Figure 2). The following features were constructed as part of the BS-03a project**:**

A. Site/Structure #13 – Rockfill channel plug with riprap armor located along the west bank of Bayou Mandeville. The plug is set at an elevation of +4.0 ft. and is 100 ft. long x 100 ft. wide with 18 inches of riprap armor. The crest of the structure is 10 ft. wide. The plug includes one (1) 48” diameter corrugated aluminum pipe which passes through the rockfill plug at an invert elevation of -3.5 ft. with an aluminum combination gate attached to the pipe on the interior side of the marsh. A timber walkway to the gate is at elevation +4.0 ft.

B. Site/Structure #25 – Earthen and rockfill channel plug with riprap armor located on the Forty Arpent Canal near Big Mar. The plug is set at an elevation of +4.0 ft. and is 169 ft. long x 100 ft. wide with 18 inches of riprap armor. The crest of the structure is 10 ft. wide. The plug includes two (2) 48” diameter corrugated aluminum pipes which pass through the plug at an invert elevation of -4.0 ft. Earth fill was placed on each side of the rock plug. Aluminum sluice gates are attached to the end of each pipe on the exterior side of the marsh. A timber walkway to the gates is at elevation +4.0 ft.

C. Site/Structure #26 – Earthen channel plug with riprap armor plate located along Reggio Canal spoil bank. The plug is set at an elevation of +4.0 ft. and is 154 ft. long x 100 ft. wide with

18 inches of riprap armor. The crest of the structure is 10 ft. wide. The plug includes four (4) 48" corrugated aluminum pipes, which pass through the earthen plug at an invert elevation of -4.0 ft. Aluminum sluice gates are attached to the end of each pipe on the exterior side of the marsh. The pipes and gates are supported by a timber pile system. A timber walkway is installed at an elevation of +4.0 ft.

D. Site/Structure #32 – Riprap channel plug across an unnamed channel that flowed into west side of Lake Lery. The plug is 117 ft. long x 6 ft. wide and the plug crest is set at elevation +4.0 ft. The 70-ft. stretch of channel from the plug eastward to Lake Lery has 2-ft. thick riprap placed on both channel banks.

E. Site/Structure #40 – Earthen and rockfill channel plug with riprap armor along the Reggio Canal spoil bank. The plug is 142 ft. long x 100 ft. wide. The crest of the structure is 10 ft. wide and is set at an elevation of +4.0 ft. The plug includes two (2) 48" diameter corrugated aluminum pipes that pass through the embankment at an invert elevation of -4.0 ft. Earth fill was placed on each side of the rock fill. The entire structure is capped with an 18" thick layer of riprap. Aluminum sluice gates are attached to the ends of the aluminum pipes on the exterior side of the marsh. The pipe and gates are supported by a timber pile system and a timber walkway to the gates is installed at an elevation of +4.0 ft.

F. Site/Structure #50 – Rockfill channel plug with riprap armor along the west bank of Bayou Mandeville. The plug is 55 ft. long x 100 ft. wide. The crest of the structure is 10 ft. wide and is set at an elevation of +4.0 ft. The plug includes one (1) 48" diameter corrugated aluminum pipe through an aggregate embankment at an invert elevation of -3.5 ft. The embankment is capped with an 18" thick layer of riprap. An aluminum combination gate is attached on the pipe end on the interior side of the marsh. The pipe and gate are supported by a timber pile system. A timber walkway to the gate is installed at an elevation of +4.0 ft.

G. Site/Structure #51 – Riprap plug across a pipeline channel that flows into Bayou Mandeville. The plug is approximately 150 ft. long x 30 ft. wide. The plug crest is set at elevation +4.0 ft. This was an existing structure during the construction of the BS-03a Project and will be maintained by the pipeline company.

H. Site/Structure #52 – Rockfill channel plug with riprap armor along DP Canal spoil bank. The plug is 100 ft. long x 100 ft. wide. The crest of the structure is 10 ft. wide and is set at an elevation of +4.0 ft. The plug includes two (2) 48" diameter corrugated aluminum pipes through the embankment at an invert elevation of -3.0 ft. The embankment is capped with an 18" thick layer of riprap. Aluminum combination gates are attached to the end of each pipe on the interior side of the marsh. The two pipes are supported by a timber pile system. A timber walkway to the gates is installed at an elevation of +4.0 ft.

I. Site/Structure #54 – Earthen and rockfill channel plug with riprap armor located at the intersection of Reggio Canal and Promise Land Canal. The plug is 140 ft. long x 150 ft. wide. The crest of the structure is 10 ft. wide and is set at elevation +4.0 ft. The plug includes two (2) 48" diameter corrugated aluminum pipes through the earth fill portion of the embankment at an invert elevation of -4.0 ft. Earth fill was placed at each side of the rockfill. The entire embankment is capped with an 18” thick layer of riprap. Aluminum sluice gates are attached to the end of each pipe on the exterior side of the marsh. The pipes and gates are supported by a timber pile system. A timber walkway to the gates is installed at an elevation of +4.0 ft. The existing spoil bank on the south side of Promise Land Canal was degraded in three locations on the west side of Structure #54. The excavated material was placed on each side of the cuts on the existing spoil bank.

J. Site/Structure #56 – Rock riprap channel plug across an unnamed channel on the east side of the Reggio Canal. The plug is 208 ft. long and the side slopes of the plug are 3 horizontal to 1 vertical. The crest of the structure is 6 ft. wide and is set at an elevation of +4.0 ft.

K. Site #57 – Consists of 5,315 linear ft. of spoil bank restoration along the entire west side of the Reggio Canal between Site #40 and Site #54. The spoil bank restoration consists of an earth fill embankment placed on existing spoil to an elevation of +4.0 ft. with a 12-ft. top width and 3 horizontal to 3 vertical side slopes. The entire length of embankment has been seeded to enhance the growth of vegetation and protect disturbed soil conditions.

L. Site #58 – Consists of 5,244 linear ft. of spoil bank restoration along the west side of Bayou Mandeville between the Delacroix Canal and Site #13. The spoil bank restoration consists of an earth fill embankment placed on existing spoil to an elevation of +4.0 ft. with a 12-ft. top width and 1 horizontal to 1 vertical side slopes. The entire length of embankment has been seeded to enhance the growth of vegetation and protect disturbed soil conditions.

M. Site/Structure #60 – Rockfill channel plug at the intersection of Reggio Canal and an existing pipeline canal. The plug is 200 ft. long x 100 ft. wide. The crest of the structure is 10 ft. wide and set at an elevation of +4.0 ft. The adjacent earth plug with riprap armor includes two (2) 36” diameter corrugated aluminum pipes through the earth plug at an invert elevation of -3.0 ft. The entire length of the plug is capped with an 18” layer of riprap. Aluminum combination gates are attached to the end of each aluminum pipe on the interior side of the marsh. The pipes and gates are supported by a timber pile system. A timber walkway to the gates is installed at elevation +4.0 ft.

Each of the project features influence one of four distinct polygons that were bound by high ridges or spoil banks within the project area (though these features were not considered part of the project maintenance plan); therefore, the project area was subdivided into four strata (Figure 2). Stratum 1 receives fresh water from culverts with exterior sluice gates (site 25).   Stratum 2 is influenced by project features 13, 50, and 51 and restoration of the western spoil bank along Bayou Mandeville (site 58). Stratum 3 receives fresh water from culverts at sites 52 & 60, and plugs at sites 32 and 56 in the spoil bank breaches help that region retain the water brought in by the two culvert sites. Stratum 4 consists of the project area west of the Reggio Canal, where culverts with exterior sluice gates (sites 26, 40, and 54) nourish the area with fresh water. Stratum 5R is the north reference area and stratum 6R is the south reference area. Because these strata are influenced by different project features, it is anticipated that a significant amount of variation in response to the project will be attributable to location within the project area. Therefore, data analyses will be conducted separately for each stratum.

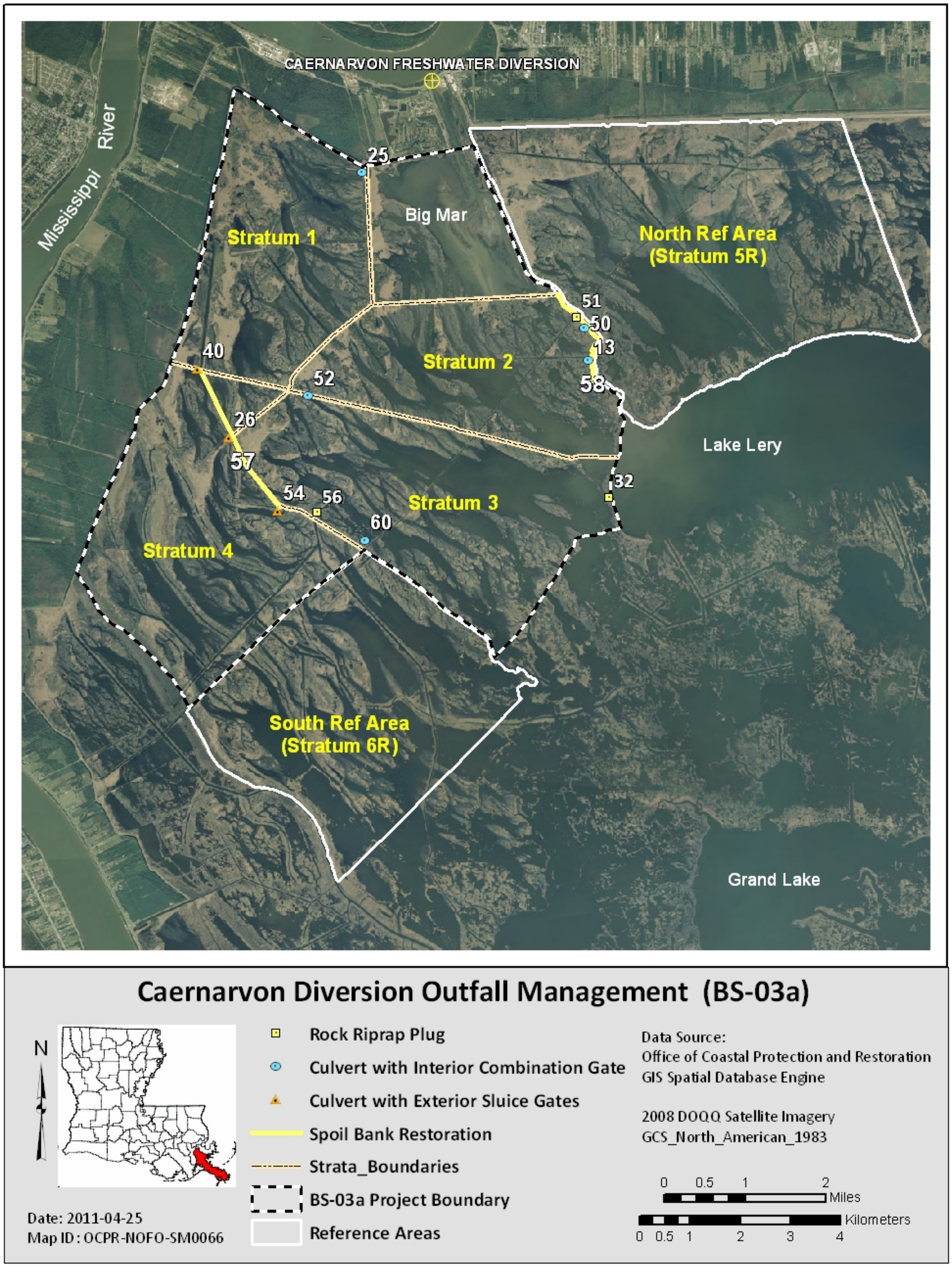

Figure 2. Caernarvon Diversion Outfall Management project (BS-03a) boundaries and features. A combination of culverts, plugs and spoil bank restoration allows water from the channels to flow into the marsh interior and be retained in the marsh for a longer period of time.

Once diversion water enters Big Mar, an estimated 90% of the water currently exits southeast to Lake Lery via Bayou Mandeville, with only 10% of the diversion water flowing southwest to the more deteriorated marshes. Prior to Hurricanes Katrina, Gustav, and Ike, the southeast to southwest flow ratio was closer to 66:34%, with an increased amount of the diversion water flowing as intended to the southwest. Hurricanes Katrina and Rita completely rearranged the topography and hydrology of the Caernarvon project area in 2005. On October 6, 2005, representatives of the CPRA (Brady Carter, John Troutman, and Chuck Villarubia) and USGS (Bryan Perez) performed a damage assessment inspection of the Caernarvon Diversion Outfall Management project. Large areas of land were displaced and deposited towards the northern and western extent of the Breton Basin. Spoil banks, which previously held diverted waters within specific areas of the project, were destroyed. Large areas of marsh were converted to open water, and all canals in the project area were infilled with displaced marsh material. The main canals required dredging to allow passage; however, many canals remained blocked, making operations goals difficult, if not impossible. The collection of hydrographic monitoring data for the BS-03a project was temporarily suspended, due to the destruction of all project stations. Recovery of the project area and repair of project features are ongoing and will be discussed further in the Maintenance section of this report.

II. Maintenance Activity

a. Project Feature Inspection Procedures

The purpose of the annual inspection of the Caernarvon Diversion Outfall Management project is to evaluate the constructed project features, identify any deficiencies, prepare a report detailing the condition of project features, and recommended corrective actions. If corrective actions are needed, the CPRA shall provide a detailed cost estimate for engineering, design, supervision, inspection, construction contingencies, and an assessment of the urgency for repairs (LDNR/CRD 2003). The annual inspection report also contains a summary of maintenance events and an estimated, three (3) year projected budget for operation, maintenance, and rehabilitation. Appendix B contains the three (3) year projected operation and maintenance budget.

The most recent annual inspection of the Caernarvon Diversion Outfall Management project (BA-03a) was performed on July 5th, 2016. Weather consisted of mostly cloudy skies, a temperature of approximately 84°F, and winds out of the SSE at around 6 knots. Taking part in the inspection were: David Chambers, Erin Plitsch, and Kathleen Eubanks of CPRA, the state sponsor; Loland Broussard of NRCS, the federal sponsor; and Rob Buck of SeaTow, the operations and maintenance contractor. On the day of the inspection, the diversion structure was not flowing (0 cubic feet per second). The marsh gauge reading was -0.5 feet NAVD88, and the river gauge reading was +3.4 feet NAVD88. The water level in the channel was +0.20 feet (Photo 22). All photographs taken at the time of the inspection are included in Appendix A.

b. Inspection Results

The diversion structure was closed, providing no additional flow throughout the project area. When flowing, the diverted waters exit Big Mar through Bayou Mandeville to the southeast and

Delacroix Canal to the southwest. Structure #25 is accessible only by airboat, with permission from the landowner. On the date of inspection, Structure #25 was inaccessible to the inspection team, therefore it was excluded from this report. Additionally, structure #32 was excluded from the inspection as it is no longer operational due to the construction of the Lake Lery Shoreline Protection Project (BS-16). The spoil created by the Delacroix Canal dredging in 2011 has vegetated with willow trees, shrubs, and tall grasses.

A. **Site/Structure # 13 –**The combination gate was in the up/open operating position to allow maximum uninterrupted tidal exchange into the marsh. The gate has a slight tilt, but it was not affecting the function. The timber walkway still lays separated from its support beam at one end and the boards are uneven. There was a wood plank in place to connect the timber walkway to the rock dike. The rock from Site #32 used to plug the breach in the rock dike remained in place and at proper elevation. (See Photos 1 - 3)

B. **Site/Structure # 25 –** The inspection team did not attempt to inspect this feature as the site was inaccessible. (No Photo)

C. **Site/Structure # 26 –** The gates were in the open position allowing water flow. There was vegetation covering approximately 30% of the earthen/rock closure, though some had been cleared since the last inspection. The structure and outfall appear to be in good condition. The boardwalk on the back side of the structure was partly covered with water hyacinth. (See Photos 4 & 5)

D. **Site/Structure # 32 –** The team did not inspect this feature. Hurricane Katrina devastated that portion of the lake rim rendering this structure ineffective. It is now being incorporated into the restored lake rim under the Lake Lery Shoreline Protection Project (BS-16). (No Photo)

E. **Site/ Structure # 40 –** The gates remained in the open position. The structure was in good condition. Dead water hyacinth covered the boardwalk on the back side of the structure. (See Photos 6 & 7)

F. **Site/Structure # 50 –** The combination gate was in the up/open position. The breach in the rock dike was repaired with material from Site #32 and remained intact. The boardwalk remained bowed with one plank that was not attached to the support beams. There was vegetation covering approximately 70% of the rock dike. (See Photos 8 - 10)

G. **Site/Structure #51** – Plug was heavily vegetated and remained at proper elevation. (See Photo 11)

H. **Site/Structure #52 –** The two combination gates were in the open position. A breach previously repaired by the dredging contractor had re-opened and was between 20-25 feet in width and estimated to be about 7 feet deep. The breach was allowing unimpeded flow between the channel and marsh. The boards were uneven when walked on and detached in some areas. (See Photos 12 - 14)

I. Site/Structure # 54 – The gates remained in the open position. No flow was visible through the culverts. The rocks were cleared of most vegetation. There were some barnacles on the gate and pilings, although they appeared to be dead. (See Photos 15 & 16)

J. Site/ Structure # 56 –There were large shrubs on approximately 20% of the rock dike. The water was slightly below the crest of the rock dike and there was no water exchange. One warning sign was still severely leaning and needs to be up-righted and cleaned (Hurricane Katrina damage). (See Photos 17 & 18)

K. Site # 57 – The spoil bank along the side of Reggio Canal was well vegetated with trees, shrubs, and grasses. No gaps were noted, however, there was evidence of erosion along the spoil bank, such as exposed tree roots. (No Picture)

L. Site # 58 –The vegetation on the spoil bank along the sides of the Bayou Mandeville includes grasses, shrubs, and trees. No gaps were noted, but there was one noticeable low spot, possibly from boats being pulled over at that point. The spoil bank showed signs of recent erosion, likely caused by increased boat traffic. This has resulted in soil being washed off the roots of trees and the trees falling into the bayou. (See Photo 19)

M. Site/Structure # 60 – The two combination gates were in the up/open position. Overall condition of the structure was good. The small breach on the east side of the structure has been repaired using material from Site #32. There was a low area of rocks on the east side of the backside of the structure where it appears rocks have been moved from the dike into the adjacent water. (See Photos 20 – 22)

c. Maintenance Recommendations

i. Immediate/ Emergency Repairs

No immediate or emergency repairs are suggested at this time.

ii. Programmatic/Routine Repairs

d. Maintenance History

The inspection team recorded no breaches in the project-constructed spoil banks at the time of the 2016 inspection. However, there has been noticeable erosion along the banks of Bayou Mandeville as a result of increased boat traffic. This is evidenced by the soil being washed from the roots of small trees and shrubs, causing them to fall forward into the water. The one breach found was at Site #52. The breach was on the east side of the structure and has been growing since it was last plugged in 2011, to the point where repair would prove difficult. As this area also experienced damage to the natural features following storm events, the decision was made not to repair the breach. The O&M contractor has plugged breaches at Sites #13 and #60 using material from Site #32, which is no longer operational and is being incorporated into the restored shoreline as part of the Lake Lery Shoreline Protection Project (BS-16).

The O&M contractor implements a maintenance schedule that keeps the project features in proper operating condition. Some of the operations and maintenance tasks include: lubricating and periodic operation of each gated structure, cleaning the wood platforms, and spraying of the area for unwanted vegetation and insects. Periodic inspections of all project features are also performed and deficiencies are corrected.

Project Condition

CPRA concludes that the BS-03a project needs evaluation by both federal and state parties to determine the effectiveness of the culverts and plugs. Many of the hydrologic units outlined in the original project no longer have distinct borders, due to the loss of non-project, natural ridges and spoil banks during storm events. A maintenance event for this project would include using rock or sheet piling to close gaps and fill failure areas to reestablish the sector boundaries. The landowner has already submitted a Coastal Use Permit to perform some of this work.

The CWPPRA project, South Lake Lery Marsh Creation and Shoreline Restoration (BS-16), is currently under construction. Although budget constraints have modified the Lake Lery shoreline rehabilitation for the western shoreline, the rock closure (structure #32) will be incorporated into the BS-16 project. The project modification removed the marsh fill cell located behind the western shoreline. Site #32 will be completely covered with the spoil bank restoration feature of that project and will no longer be a component of the BS-03a Project. Construction of the BS-16 Project began in March 2015 and is still in progress as of July 2016. It was scheduled to be completed before the end of the 2016 calendar year.

Priority Gap Closures

There is a gap at Site #52 which has been increasing in size over the past few years. It is estimated to be 20 to 25 feet in width and the depth of the water is estimated to be around 7 feet. CPRA and NRCS recommended using material from site #32, before it is covered, to plug the breach.

Flow Meters

Flow meters were originally installed at structures #26, #40, and #54, to monitor the flow of fresh water into the interior marshes and determine if it was necessary to maintain the associated channels to increase flow through these structures. These flow meters were damaged during Hurricane Katrina in August 2005 and replaced in July 2011. Due to storms and malfunctioning equipment, the first full and complete set of flow data was not received until March 2012.

In September 2012, the flow meter at structure #26 was removed after the sensor was damaged. The decision was made to discontinue the flow monitoring at this site rather than to replace the damaged instrument.

Although the flow data collected since the initiation of this flow monitoring effort is sporadic due to storm damages and equipment malfunctions, the quantity of data collected to date was sufficient to determine that flow through the structure was adequate, and no further maintenance events would be necessary. Therefore, ongoing continuous monitoring of flows at these sites was no longer required, and the flow meters were removed in December 2014.

Flow Meter Data Availability					
	Date Range	Max Value (cfs)	Min Value (cfs)	Avg Value (cfs)	Days of Data
Site #26	7/31/2011-7/6/2012	114.88	-70.60	3.27	191
Site #40	3/4/2012-6/28/2014	31.52	-25.98	3.18	813
Site #54	7/3/2011-6/28/2014	54.52	-37.47	0.17	801

Structures

The CPRA recommends repair of the decks at structures #13 and #50. The deck at structure #13 is not attached to the supports at one end, and the deck at structure #50 is bowed with one plank detached.

The warning sign on the west end of site #56 needs to be cleaned and the piling needs to be re-driven into an upright position.

III. Operation Activity

a. Operation Plan

The gated structure design was selected to allow flexibility in regulating water flow. As outlined in the operation plan, all sluice gates are fully opened to allow maximum flow. Combination gates operate using a flap-gate that only allows flow into the marsh. Combination gates at sites #52 and #60 are locked fully open, except during waterfowl season, during which the landowner has permission to close the two structures. Temporary changes in the normal mode of operation may occur during special conditions such as storm events, extremes in precipitation, or response to real-time monitoring information. Such changes require approval from State and Federal regulatory agencies.

b. Actual Operation

In accordance with the operation schedule outlined in the Operations and Maintenance Plan (LDNR/CRD 2003), none of the structures were operated in 2016, other than during routine maintenance, and all gates were in the open position to allow freshwater in all the marsh areas. The O&M contractor continues to perform periodic operations and maintenance of each of the gated structures. This includes lubricating and operating gates periodically, cleaning and maintaining the timber platforms, implementing vegetation control, and periodic inspections as directed by the CPRA.

IV. Monitoring Activity

This OM&M report includes all data collected from March 2000 through April 2016. In August 2005, Hurricane Katrina destroyed all six hydrologic monitoring stations in the BS-03a project area. These stations were not rebuilt with project funds since the operational plan already called for Coast-wide Reference Monitoring System (CRMS) stations to replace the hydrologic stations in the project area; however, data collection at the CRMS stations did not begin until late 2007. As a result, a data gap exists between August 2005 and the beginning of data collection from the CRMS stations in 2007.

a. Monitoring Goals

The objective of the Caernarvon Diversion Outfall Management Project is to increase freshwater and nutrient dispersion into interior marshes that were isolated from Caernarvon Diversion flow during low discharge periods, and to promote better retention and distribution of freshwater through spoil bank restoration and the incorporation of culverts into existing plugs and spoil banks.

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

1. Reduce marsh loss rates.
2. Reduce salinity variation in the interior marshes.
3. Increase occurrence and abundance of fresh/intermediate marsh type plant species.
4. Increase the occurrence of submerged aquatic vegetation (SAV) in shallow open-water areas. (Discontinued after 2005)

b. Monitoring Elements

Habitat Mapping

To determine the ratio of marsh to open water and land loss rates, color-infrared aerial photography (1:24,000 scale, with ground control markers) was obtained for each stratum in the project area and each reference area. The photography was georectified, photo-interpreted, mapped, ground-truthed, and analyzed with Geographic Information Systems (GIS) by USGS-NWRC personnel using techniques described in Steyer et al. (1995, revised 2000). Photography was obtained in 2000 (pre-construction) and 2006 (post-construction/post-Katrina) and will be collected again in 2018.

Salinity

Salinity was measured hourly from 2000−2005 with continuous recorders at one station inside each project area stratum and reference stratum for a total of six continuous recorder stations (Figure 3). In addition, 12 discrete stations in the project area and 6 discrete stations in the reference areas were established, and salinity at those stations was measured monthly to spatially characterize project-induced changes. Since 2007, CRMS stations have been used in place of the project-specific stations in each of the six strata (LDNR/CRD 2002, Figure 3). These stations were not established until late 2007; consequently, there is a gap in the data from the time the project stations were destroyed by Hurricane Katrina and the deployment of the CRMS stations. Two of the CRMS stations (CRMS0114 and CRMS0117) were installed as marsh well stations due to a lack of open water ponds or channels with sufficient depth to support a typical surface-water station. It has been determined that the salinity of the well environment is not always representative of surface water salinities in the immediate area. Therefore, post-Katrina salinity data are not available for strata 2 and 6R until the stations were converted to surface water stations in 2013. CRMS0115 and CRMS0120 were also converted from marsh well stations to surface water stations in 2009. CRMS0128 salinities are not available past August 2012, when that station was converted from surface water to a well site. Adjusted salinity data are available for the time periods shown below.

CRMS Station Monitoring Dates – Salinity		
Stratum 1	CRMS0128	10/29/2007−08/07/2012
Stratum 2	CRMS0117	03/06/2013−04/21/2016
Stratum 3	CRMS0115	04/09/2009−04/21/2016
Stratum 4	CRMS0125	01/21/2008−04/21/2016
Stratum 5R	CRMS0120	08/18/2009−04/21/2016
Stratum 5R	CRMS4355	01/23/2009−04/21/2016
Stratum 6R	CRMS0114	03/06/2013−04/21/2016

Water Level

To determine if the project objectives of increased freshwater dispersion into and retention within interior marshes are being met, hourly water level data were collected concurrently with the salinity data at the six project-specific sites (pre-Katrina) and the seven CRMS sites (post-Katrina). Average marsh elevation (ft, NAVD 88) was determined at each site, enabling the assessment of frequency, duration, and depth of marsh inundation. Adjusted water level data are available for the time periods shown below.

CRMS Station Monitoring Dates - Water Level		
Stratum 1	CRMS0128	10/29/2007−04/21/2016
Stratum 2	CRMS0117	03/07/2013−04/21/2016
Stratum 3	CRMS0115	10/29/2007−04/21/2016
Stratum 4	CRMS0125	01/21/2008−04/21/2016
Stratum 5R	CRMS0120	10/29/2007−08/21/2015
Stratum 5R	CRMS4355	01/17/2009−04/21/2016
Stratum 6R	CRMS0114	10/29/2007−04/21/2016

Vegetation

Vegetation was surveyed in the project and reference areas using a modified Braun-Blanquet method (Steyer et al. 1995, revised 2000). Six plots ($4m^2$ each) were established in each sampling stratum of the project area and in each reference area (Figure 4). Species composition and relative abundance of vegetation were documented in 2000 (pre-construction) and 2003, 2005, 2006, and 2007 (post-construction). Project-specific sites were discontinued after 2007 and vegetation is now surveyed annually at CRMS stations within each stratum. CRMS vegetation surveys are conducted using a modified Braun-Blanquet method at 10 plots randomly located along a 283-m transect. These data are supplemented with Chabreck and Linscombe (2001) habitat classification data and a Floristic Quality Assessment (FQA). FQA is an ecosystem valuation technique that is used to infer ecosystem integrity (Lopez and Fennessy 2002). The result is a unitless index called the Floristic Quality Index (FQI), which is presented with mean percent cover of dominant vegetative species for each stratum. FQI is typically negatively correlated with degree of significant disturbance and positively correlated with plant diversity indices.

Submerged Aquatic Vegetation (SAV)

Methods described in Nyman and Chabreck (1996) were used to determine the frequency of occurrence of SAV along two transects established in each of two ponds within each project and reference stratum. SAV was sampled during the spring of 2000 (pre-construction) and 2003 (post-construction); however, sampling was discontinued in 2005 due to the effects of Hurricane Katrina on the marsh ponds used for sampling. This monitoring goal is no longer assessed.

Accretion

Although not an explicit goal of the BS-03a project, vertical accretion and subsequent surface elevation change are important variables to monitor with freshwater re-introduction projects. To monitor surface elevation change, one sediment erosion table (SET) was installed in each stratum in the project area and an additional SET was installed in each reference area (Figure 5). Feldspar marker horizon stations were established at the same locations as the SETs to monitor vertical accretion and sediment deposition. These stations were sampled annually between 2001−2003; however, the data cannot be used to quantify elevation changes because the stations were constructed on seasonally floating marsh. The stations were built during the drought when water levels were low and the marsh was not identified as flotant. Accretion and elevation data was collected at CRMS stations from 2009 to present. The stations that are not on floating marsh and therefore produce accretion and elevation data are CRMS0114, CRMS0117, CRMS0120 and CRMS0125.

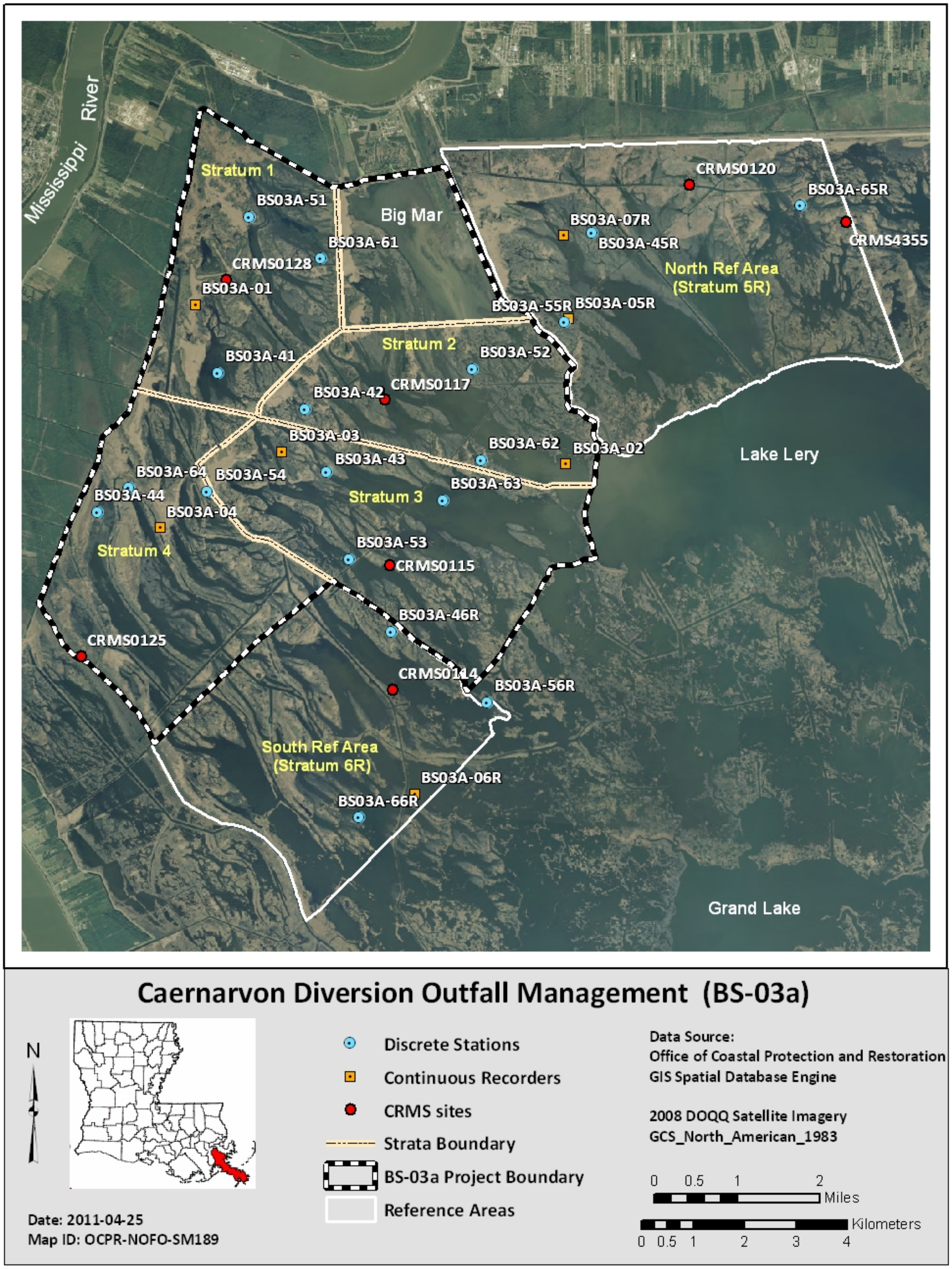

Figure 3. Location of Caernarvon Diversion Outfall Management Project (BS-03a) project-specific and CRMS hydrologic stations. All project-specific continuous and discrete monitoring stations were rendered inoperable by Hurricane Katrina in 2005. CRMS sites have been used for data collection since 2007.

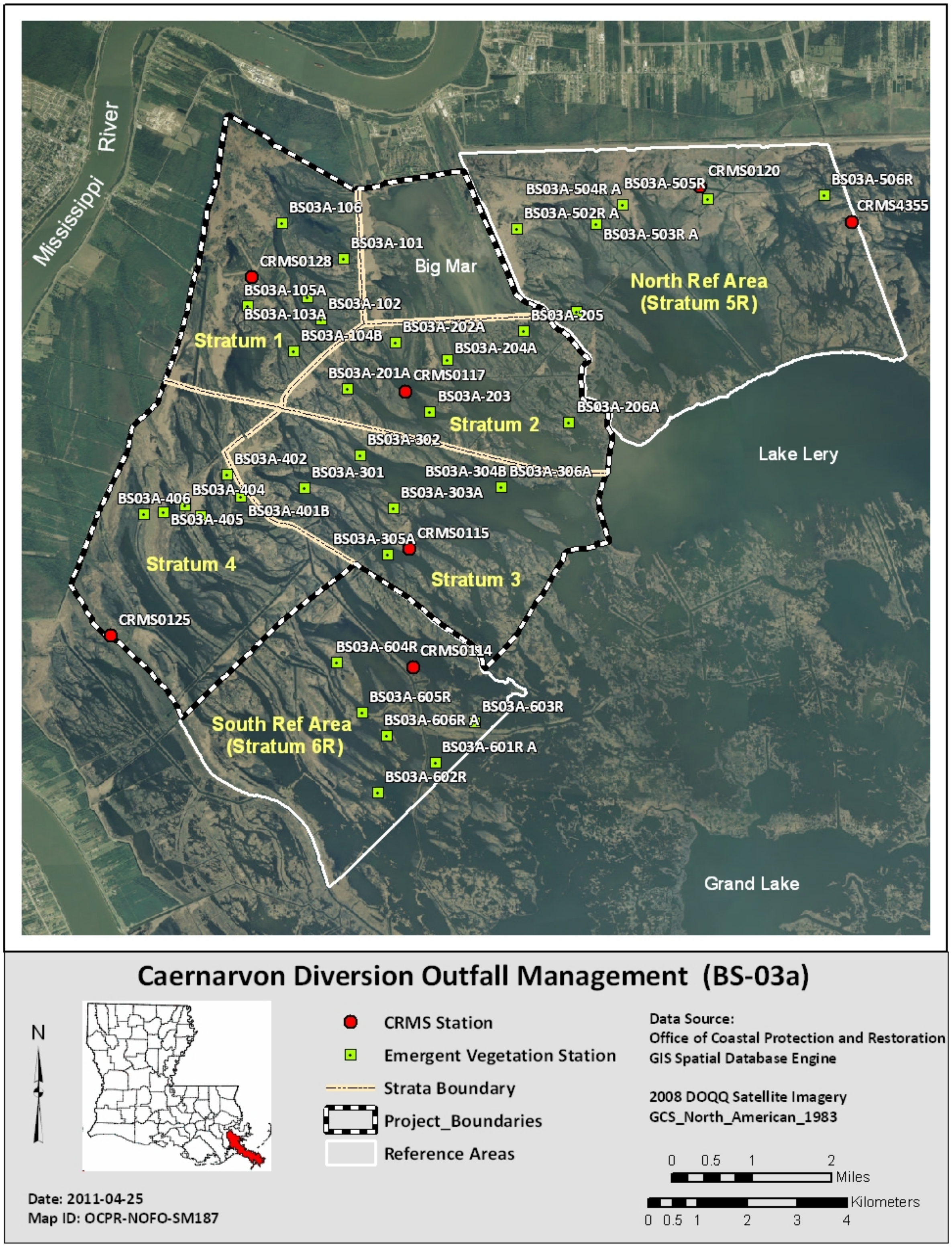

Figure 4. Location of Caernarvon Diversion Outfall Management (BS-03a) project-specific and CRMS vegetation stations. Species composition and relative abundance were documented at project-specific sites in 2000, 2003, 2005, 2006 and 2007; however, these sites were discontinued after 2007. Since 2008, vegetation surveys have been conducted annually at CRMS stations.

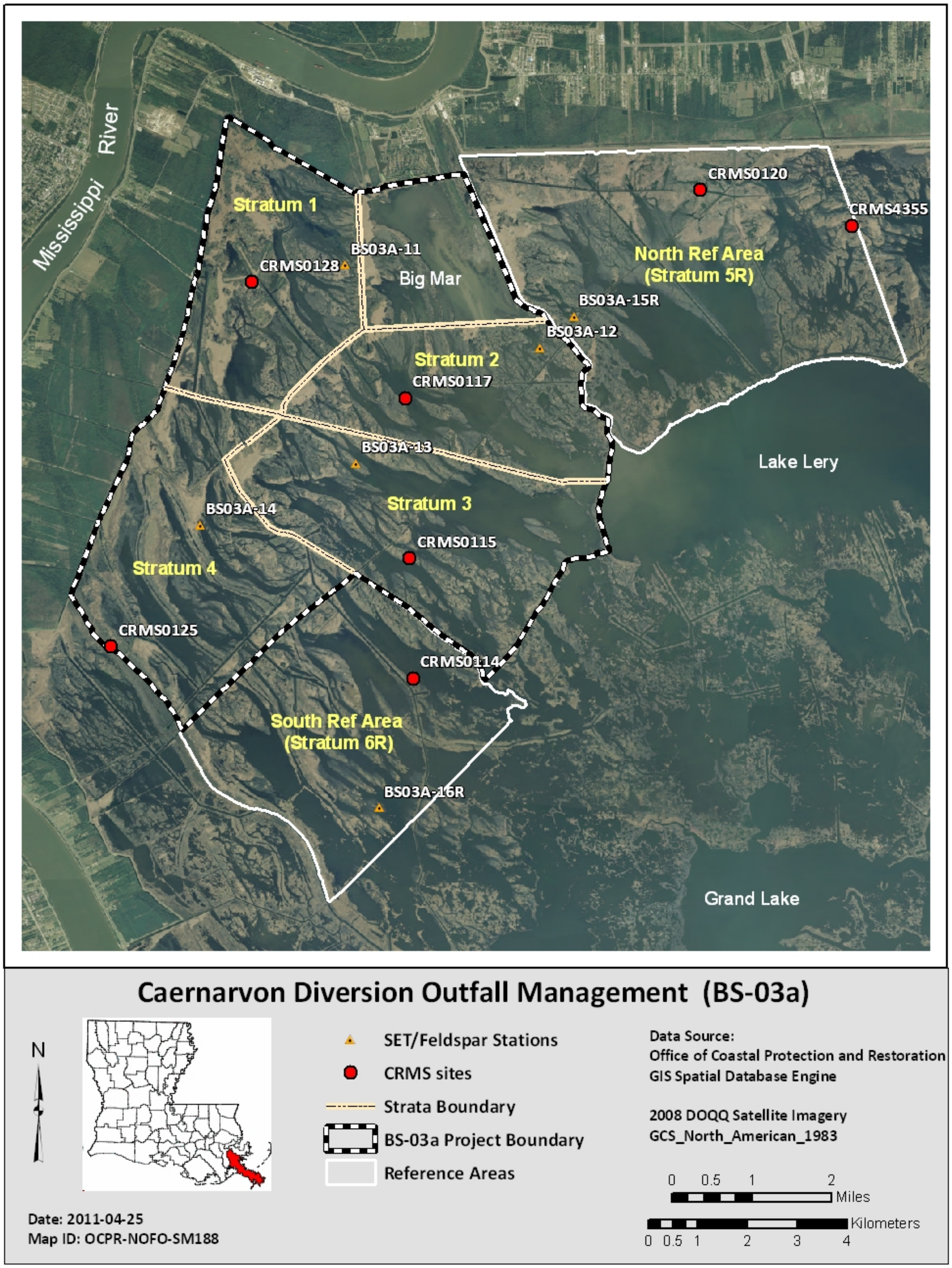

Figure 5. Location of Caernarvon Diversion Outfall Management (BS-03a) project-specific and CRMS accretion sampling stations.

c. Preliminary Monitoring Results

i. Habitat Mapping

Aerial photography obtained in 2000 (pre-construction) was analyzed and is presented in Figure 6. The 2006 aerial photography could not be properly analyzed due to the extent of damage to the marsh from Hurricane Katrina; therefore, a comparative analysis between pre- and post-construction data sets could not be performed. The next acquisition of aerial photography is scheduled for 2018, and updated habitat mapping and analysis of project effects between 2006 and 2018 will be conducted at that time.

While effects of the project could not be identified due to the landscape changes induced by the storm, satellite imagery was analyzed by the USGS to evaluate land losses and gains over time (Figure 7) which shows the effects of Hurricane Katrina and other events in the Caernarvon area. This analysis showed considerable marsh loss during the 2004-2006 period in which Hurricane Katrina occurred. This loss estimate during this period is equivalent to 60% of the total land-to-water change in the Breton Sound area between 1956 and 2004. The USGS (Barras 2006) noted that over 90% of the new water area appearing after the hurricanes in Breton Sound occurred within marshes that had been previously classified as fresh and intermediate.

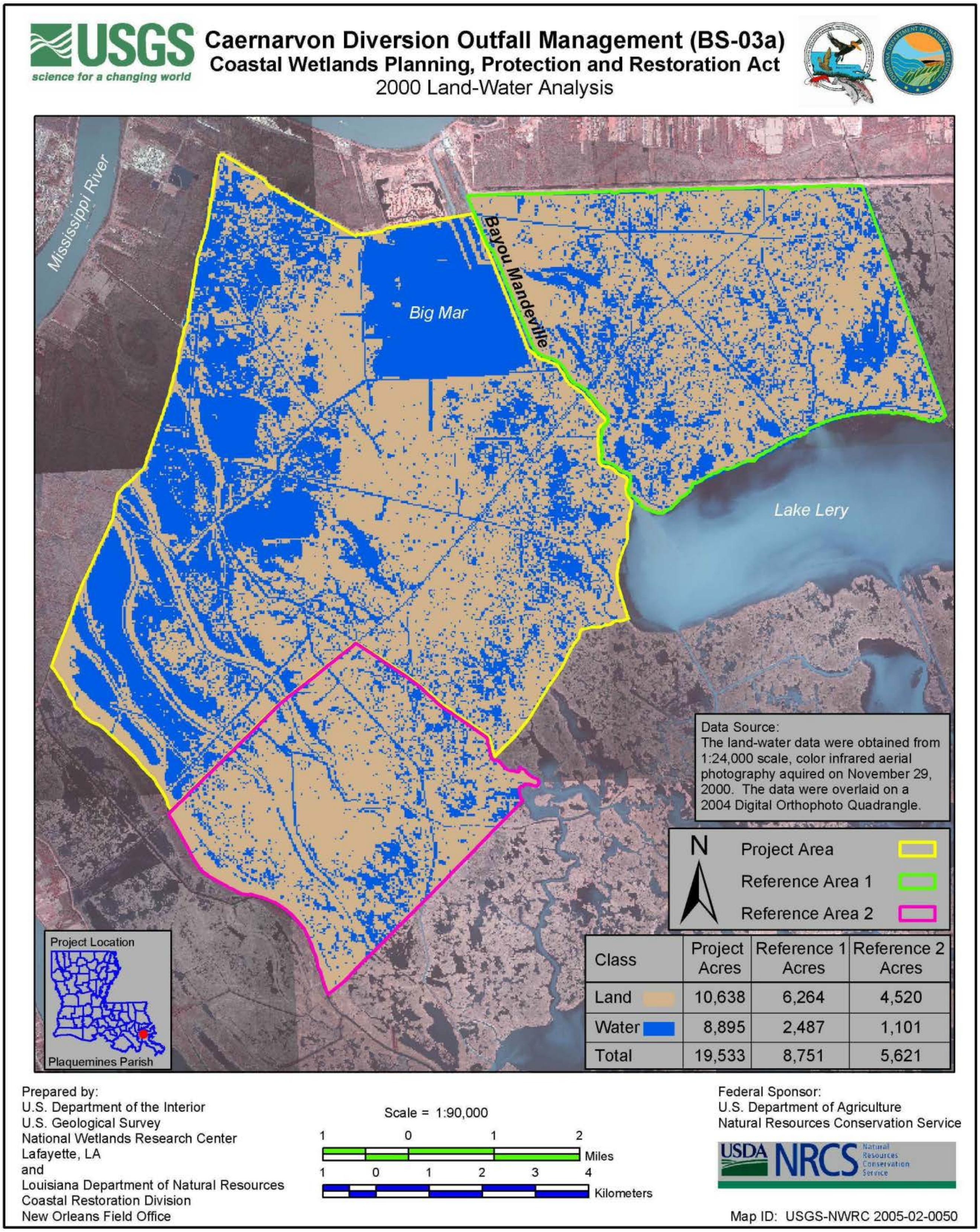

Figure 6. 2000 Land-water analysis for the Caernarvon Diversion Outfall Management (BS-03a) project.

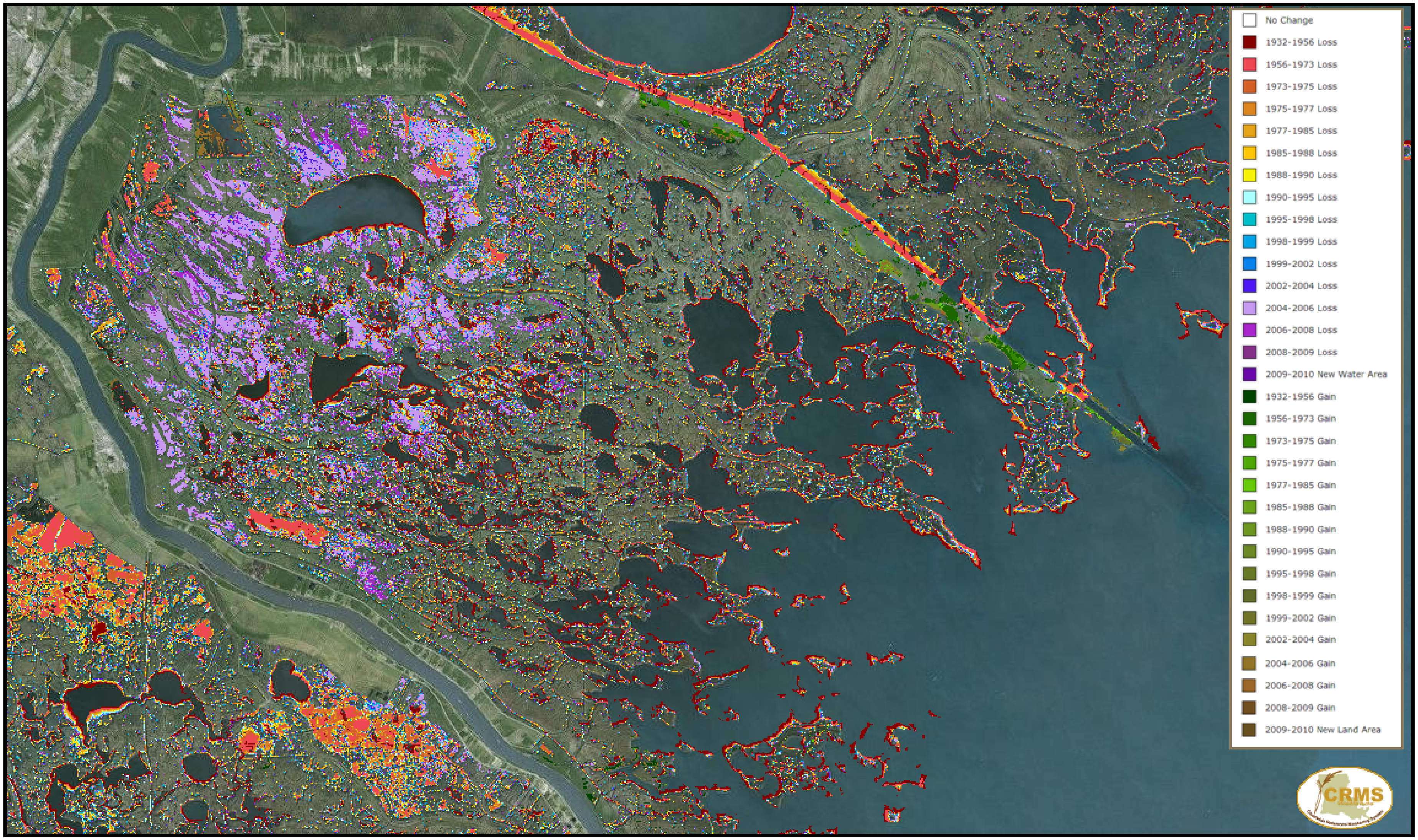

Figure 7. USGS Land Change analysis for the Caernarvon outfall area, 1932-2010.

ii. Salinity

The initial deployment of the Caernarvon Diversion Outfall Management project-specific continuous recorders occurred during a drought that affected southeast Louisiana from August 1999 to December 2000. To show the effect of the drought on salinity prior to deployment of the recorders, salinity data from USGS station DCPBS06 is presented in Figure 8. This station is located in the Reggio Canal near its intersection with Manuel's Canal and was established in January 1999 (LDNR/CRD 2002). It should be noted that the Reggio Canal station is located within a channel and is probably not a direct reflection of the prevailing conditions within immediate interior marshes (Figure 1). Flow data for all analyses are from USGS station DCPBS09, located at the Caernarvon Outfall Channel. Mean weekly salinities normally remain below 2 ppt (Figure 8), but exceeded 5 ppt during the drought. Throughout the drought period, salinity levels were suppressed by diversion waters when the river stage and operational plan allowed (Figure 9a). High salinity events also occurred in 2004, when salinity almost reached 5 ppt due to multiple tropical weather events, and in 2005, when the salinity almost reached 4 ppt due to Hurricane Katrina.

Both project-specific (2000-2005) and CRMS data (2007-2016) for the upper and lower basins follow the same general trend of the Reggio Canal DCP, with rises and falls in salinity in relation to diversion flow (Figures 9 and 10). However, since salinity values are so low throughout the area, brief salinity incursions, such as storms or persistent east and southerly winds, may skew estimates of average salinities (Holm and Sasser 2001). This was likely the case with strata 2, 3 & 4 because of consecutive events such as Tropical Storm Isidore (09/2002), Hurricane Lili (10/2002), Hurricane Ivan (09/16/2004), and Tropical Storm Ivan (09/23/2004). Salinities rose to a maximum of >2 ppt and stayed above 1 ppt until diversion waters were once again at a moderate to high flow (Figure 9a). The typical trend observed is an increase in salinities with drought or tropical weather events, and a decrease as diversion flow provides the area with more fresh water. An example of this flushing effect of diversion water is in response to the 2010 Deepwater Horizon oil spill when the diversion was run at high discharge rates from April-August 2010. These high flows contributed to lowered salinity averages in all strata. At its peak in mid-2010, discharge from the diversion was around 8,500 cfs, which is the highest discharge the diversion has produced. Since the end of 2010, average discharge remained under 3,000 cfs and from mid-2014 to the present, the mean discharge has remained under 1,000 cfs. A spike in salinity was seen in all strata in 2014. While salinities have since decreased, they remain higher than average salinity levels prior to 2014 (Figures 9 and 10).

Yearly mean salinities for project and reference strata typically averaged <.5 ppt from the start of data collection to 2005 for project specific data (Figures 11a). Exceptions are the reference strata 6R where mean yearly salinity was as high as 1.8 ppt, and stratum 4 where the mean yearly salinity ranged from .5 ppt to 1 ppt. Salinity increases were evident in all strata during the 2000 drought and the elevated tropical activity in 2002 and 2004. The effects of Hurricane Ivan in 2004, which made landfall in Gulf Shores, AL before regenerating and making a second landfall in Texas, demonstrated the vulnerability of the project area to tropical events. As Ivan traversed the Gulf in September of 2004, first as a hurricane and then again as a tropical storm five days later, the eyewall remained several hundred miles away from the project area at all times; however, storm surge brought into the basin by this cyclone caused salinity spikes exceeding 2

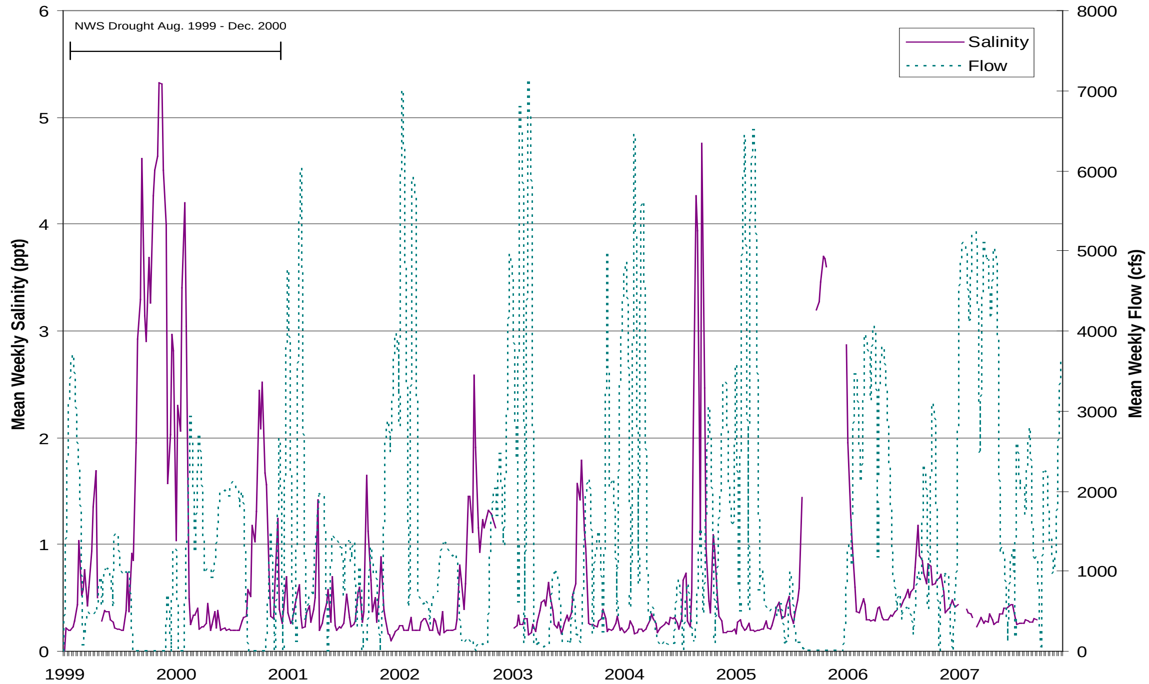

Figure 8. Mean weekly salinity at the Reggio Canal station (DCPBS06), located within the Caernarvon Diversion Outfall Management (BS-03a) project area, and mean weekly flow rates for the Caernarvon Diversion (DCPBS09), 1999–2007.

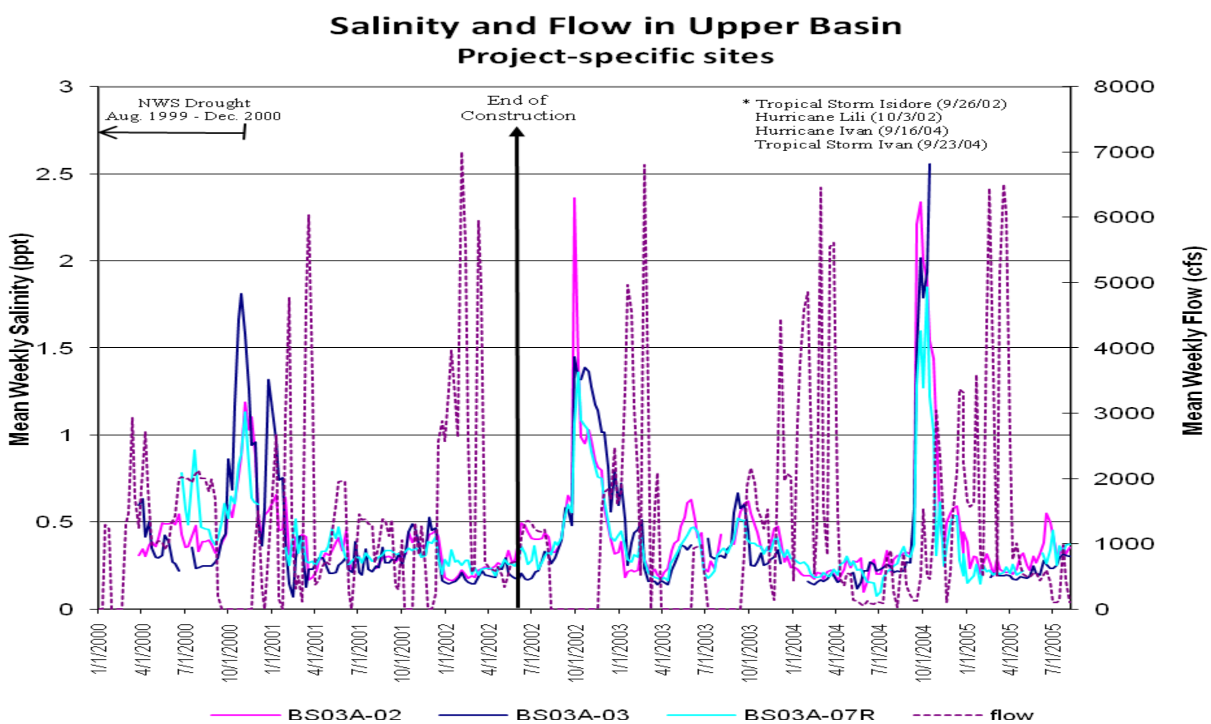

Figure 9a. Mean weekly salinity for stations BS03a-02 & 03 and reference station BS03a-07R within the Caernarvon Diversion Outfall (BS-03a) upper basin, along with flow rates from USGS station DCPBS09. Station BS03a-01, located in stratum 1, was not presented because it shows little variation over the course of record. Vertical arrow marks the end of construction of project features. Horizontal arrow denotes period of drought conditions, and the asterisk provides dates of significant storm events.

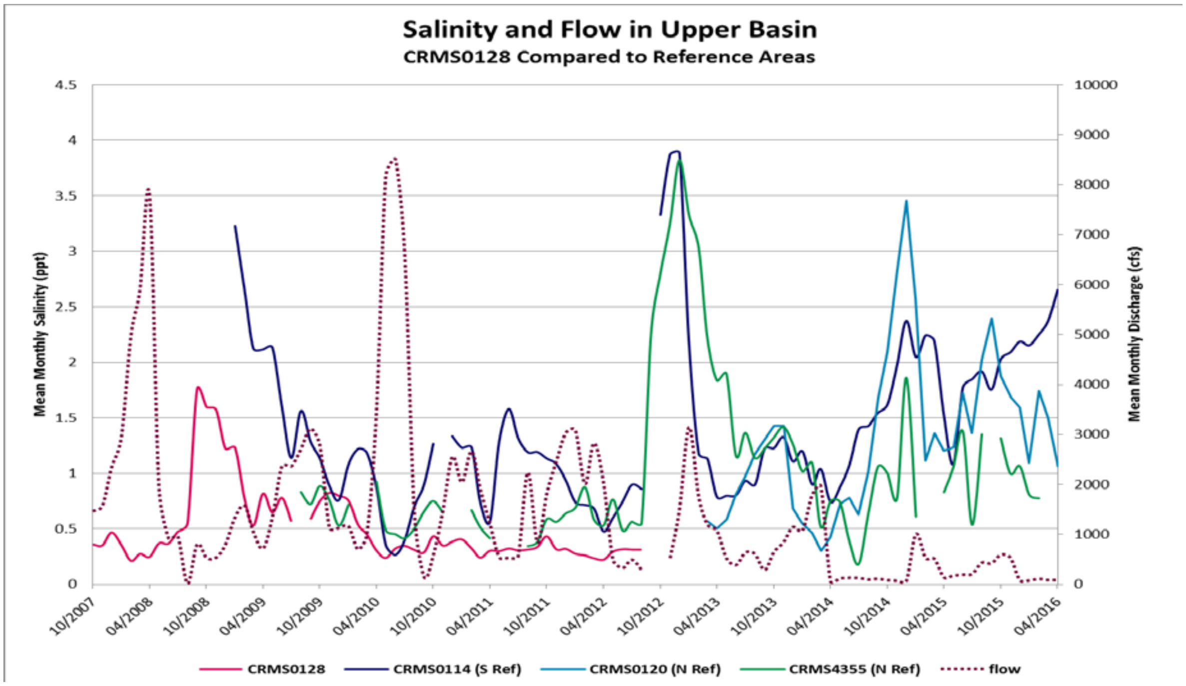

Figure 9b. Mean monthly salinity for CRMS0128 (Stratum 1) within the Caernarvon Diversion Outfall Management (BS-03a) upper basin and reference stations CRMS0114, CRMS0120, and CRMS4355 (October 2007−April 2016), along with flow rates from USGS station DCPBS09, located at the Caernarvon Outfall Channel.

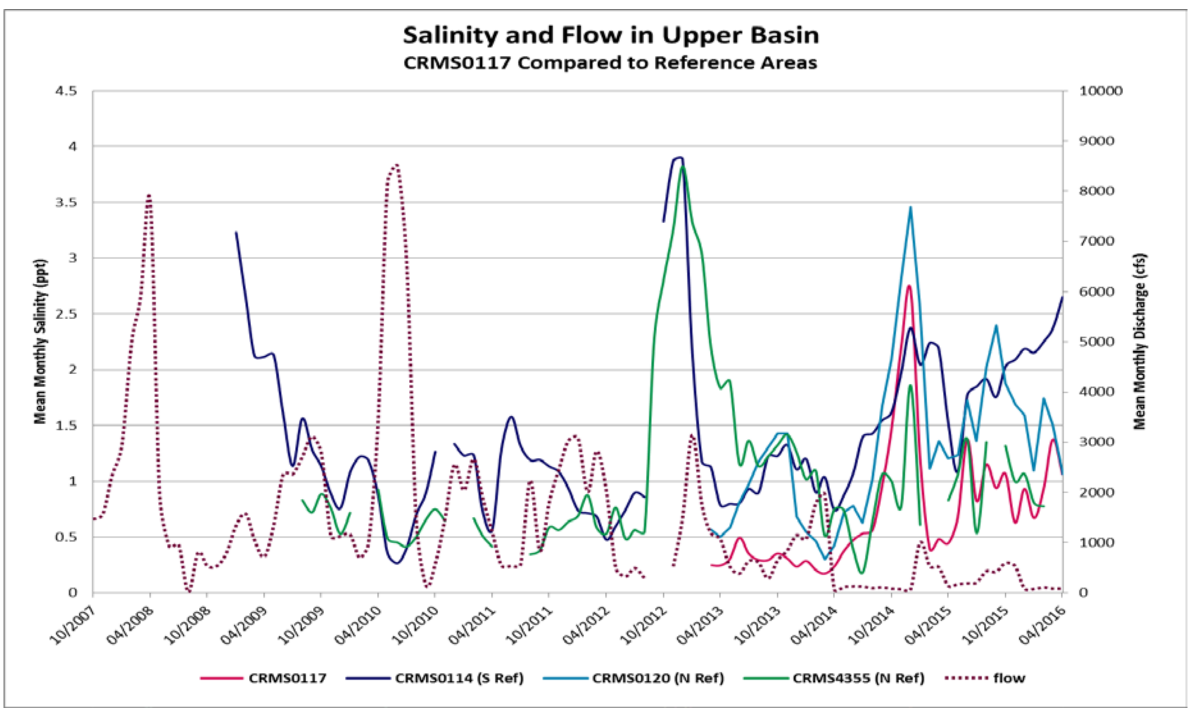

Figure 9c. Mean monthly salinity for CRMS0117 (Stratum 2) within the Caernarvon Diversion Outfall Management (BS-03a) upper basin and reference stations CRMS0114, CRMS0120, and CRMS4355 (October 2007−April 2016), along with flow rates from USGS station DCPBS09, located at the Caernarvon Outfall Channel.

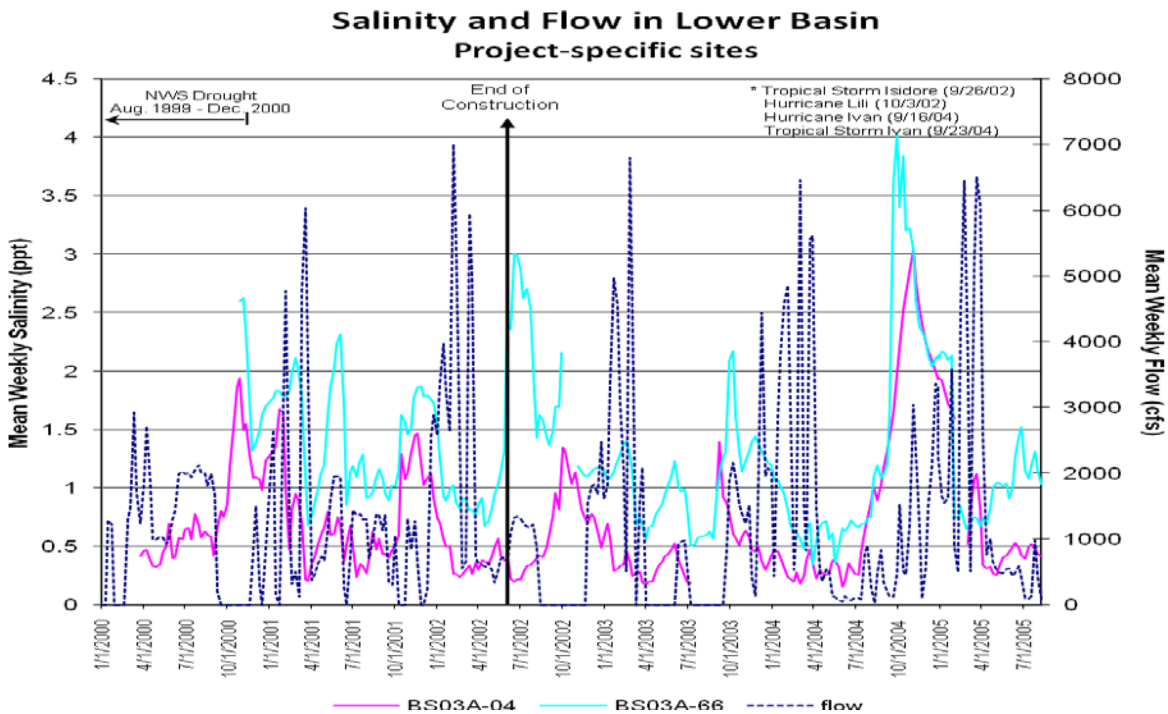

Figure 10a. Mean weekly salinity for project station BS03a-04 and reference station BS03a-66R within the Caernarvon Diversion Outfall Management Project (BS-03a) lower basin, along with flow rates from USGS station DCPBS09, located at the Caernarvon Outfall Channel, 2000−2005.

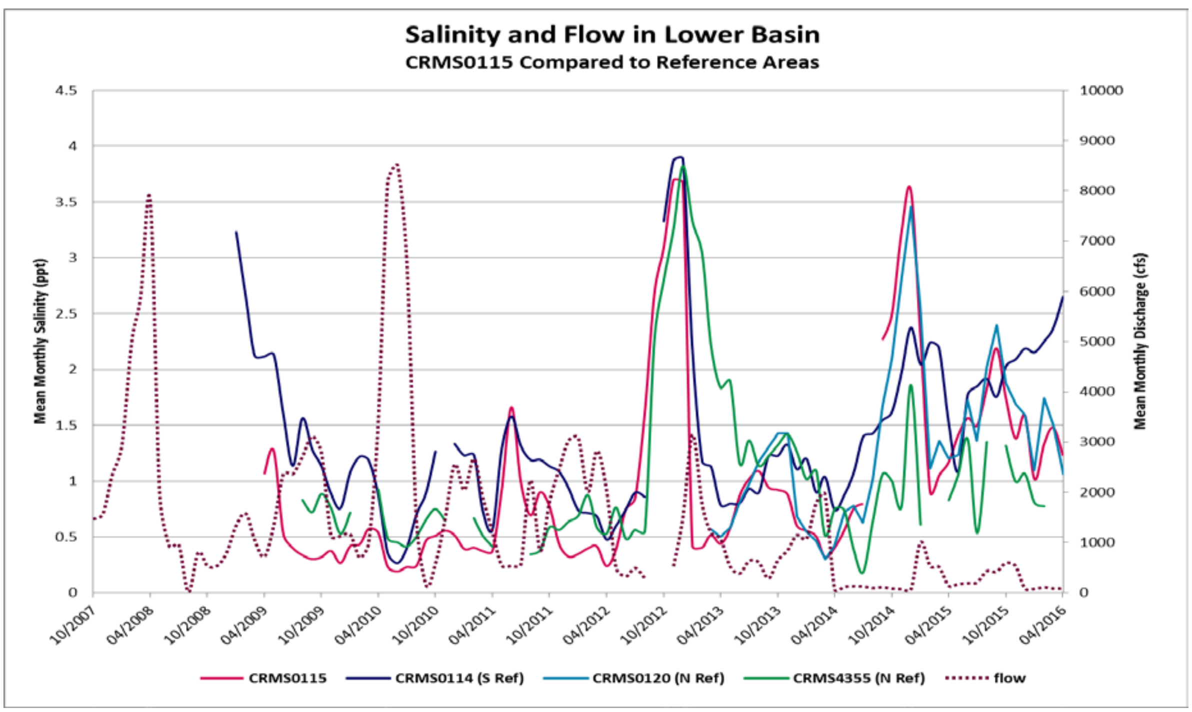

Figure 10b. Mean monthly salinity for CRMS0115 (Stratum 3) within the Caernarvon Diversion Outfall Management (BS-03a) lower basin and reference stations CRMS0114, CRMS0120, and CRMS4355 (October 2007−April 2016), along with flow rates from USGS station DCPBS09, located at the Caernarvon Outfall Channel.

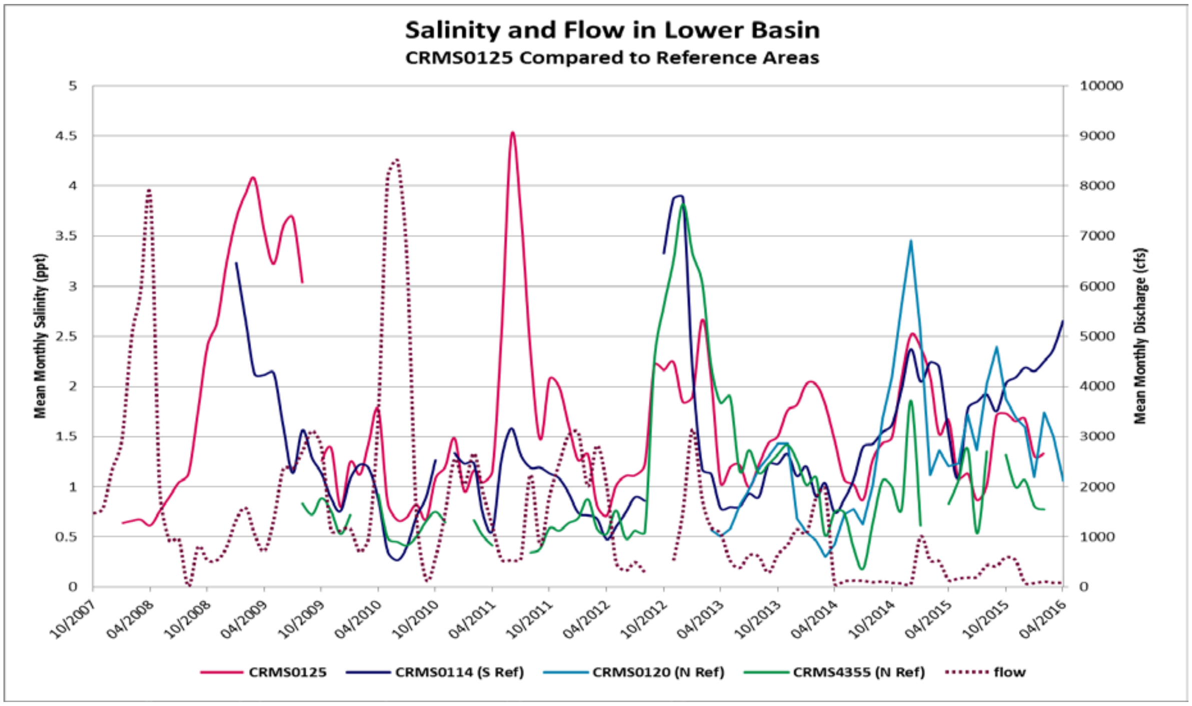

Figure 10c. Mean monthly salinity for CRMS0125 (Stratum 4) within the Caernarvon Diversion Outfall Management (BS-03a) lower basin and reference stations CRMS0114, CRMS0120, and CRMS4355 (October 2007−April 2016), along with flow rates from USGS station DCPBS09, located at the Caernarvon Outfall Channel.

ppt in nearly all strata (Figures 9a and 10a). Storm surge from Hurricanes Gustav and Ike in 2008 and Hurricane Isaac in 2012 also increased salinity in the project area (Figure 11b). The mean yearly salinities from 2007 to 2016 are generally higher and year-to-year changes are more drastic compared to the period before Hurricane Katrina. While all strata, except reference stratum 6R, remained under 1 ppt from 2000 to 2005 (Figure 11a); the majority of strata in the 2007 to 2016 time frame were over 1 ppt with a range of .4-3 ppt (Figure 11b). Additionally, post-Katrina data begins and ends at varying times and is subject to a variety of data gaps, thus complicating the data set. The majority of the sites began to produce data in 2009, and salinity for strata 2 and 6 became available starting in 2013 when recorders were changed to surface water stations after being originally installed within marsh well stations. Decreases in 2010 were due to the "flushing" event after the Deepwater Horizon oil spill in April of 2010, when the diversion was opened to full capacity. The increase in salinity in 2012 in 3 of the 5 sites gathering data at the time may be attributed to Hurricane Isaac. Also, stratum 4 exhibited higher salinities, relative to the other non-reference strata, both before and after Katrina. This may be due to its location at the edge of the project boundary, leaving it more susceptible to saltwater intrusion. The significant salinity spike in stratum 4 in 2009 may be explained by a sensor malfunction, losing some of the data for that year.

Basin-wide salinity data revealed a gradient within the sampling area with the lowest salinities closest to the structure and increasing values further away from it. The strata associated with the BS-03a project seem to follow this gradient during the pre- and post- construction periods, with

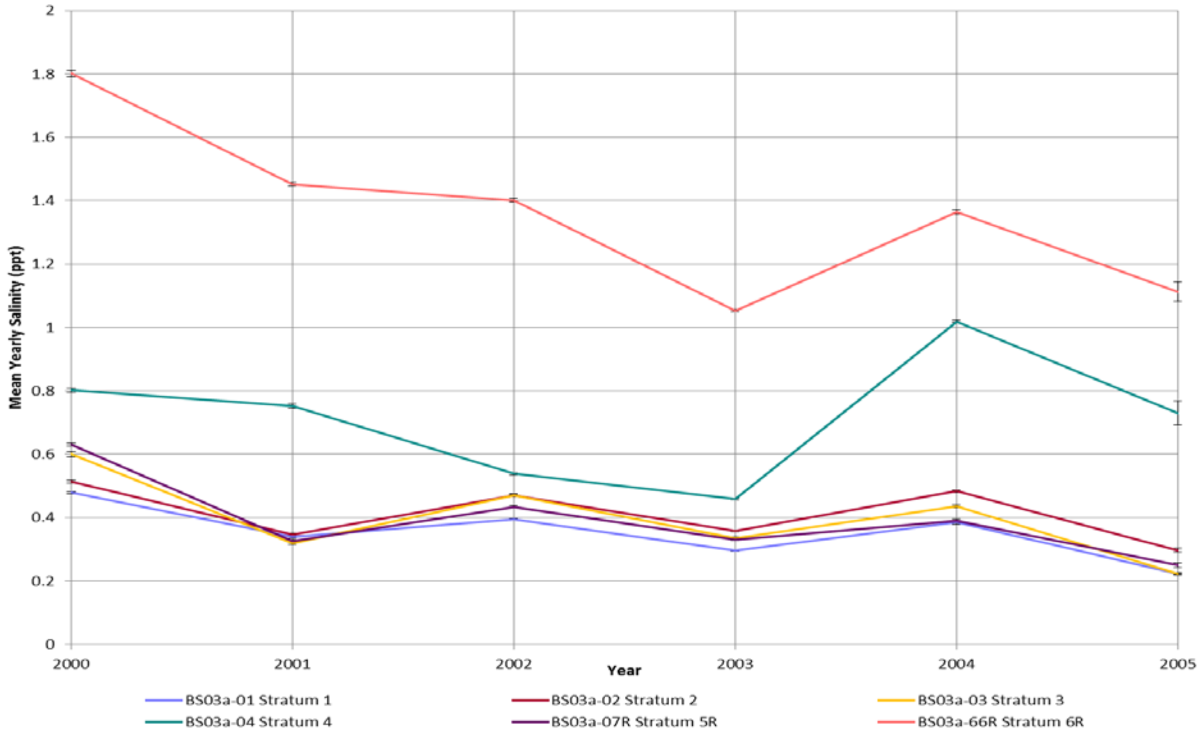

Figure 11a. Yearly mean salinity (±SE) for the project-specific sites in the BS-03a project area, 2000−2005.

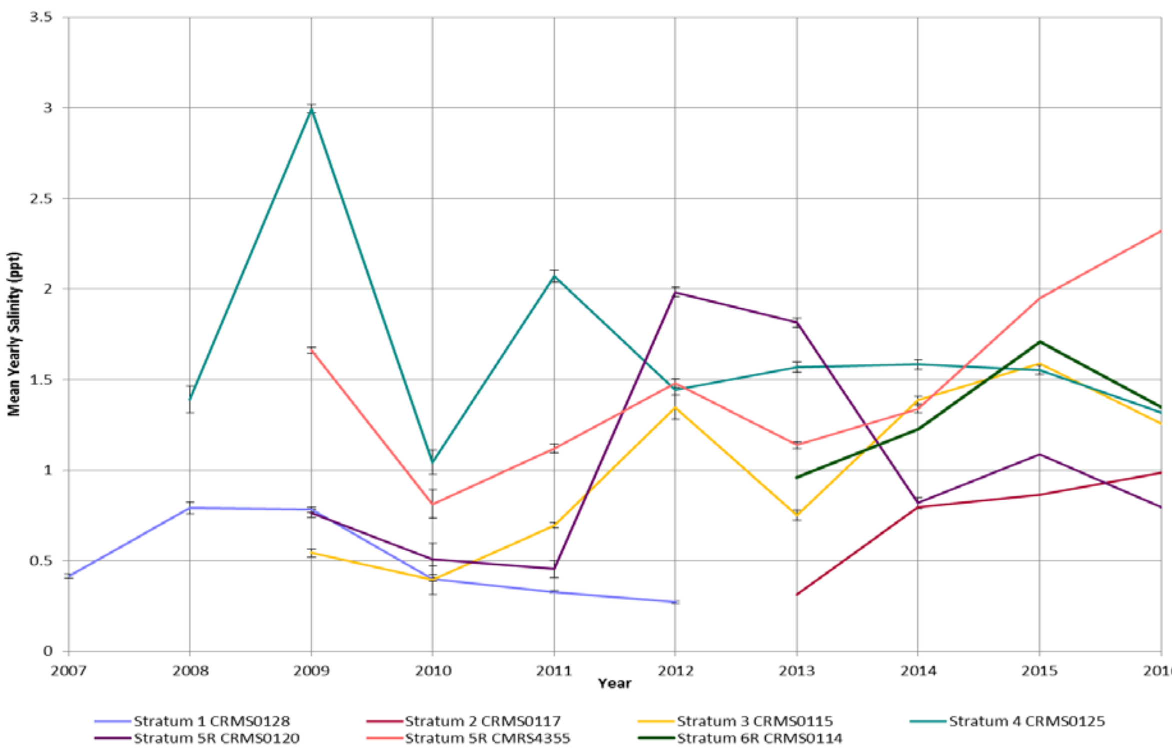

Figure 11b. Yearly mean salinity (±SE) for the CRMS sites in the BS-03a project area, 2007−2016.

stratum 1 (BS03a-01) and the north reference area (BS03a-07R) having the lowest salinity and the south reference area (BS03a-66R) having the highest (Figure 13). The nonconformity of the post-Katrina period to this gradient may be the result of storm related canal blockages near CRMS0128 in stratum 1, and degradation of spoil banks during the storm which allowed more diverted waters into stratum 3. Marsh loss from storm events is likely to have contributed to the increase in annual salinity averages, as there is less of a buffer between the Gulf of Mexico and interior marshes. In addition, prior to Hurricanes Katrina, Gustav, and Ike, the southeast to southwest flow ratio was closer to 66%:34%, with an increased percentage of the diversion water flowing as intended to the southwest compared to pre-construction flow. After Hurricane Katrina, much of the diversion discharge, approximately 90%, flows southeast down Bayou Mandeville to Lake Lery (pers. obs.). It is likely that the southwestern location of Stratum 4, in reference to the outfall, contributes to the higher salinities, as less freshwater is being diverted to that area.

Even with mean salinities of < 1 ppt, diversion benefits are observed in that the mean salinity generally decreases as flow rates increase from no flow to high flow within the project area during the time periods of 2000 – 2005 (Figures 12a) and 2007 -2010 (Figure 12b). Exceptions both before and after Katrina include stratum 4 and reference stratum 6R, which both exhibit deviations from the relationship described with an increase in salinity at medium flow. This may be explained by the location of these strata, as they are farthest from the diversion. In addition to strata 4 and 6, CRMS0120 in reference strata 5R shows a deviation from the general trend post-Katrina. This may be described by the location as well, as it is the farthest north CRMS site and may not be in the direct path of diversion benefits (Figure 12b).

The back-to-back tropical weather events in 2002 and 2004 were likely responsible for the increase in mean daily salinity values from the pre-construction period to the post-construction period (Figure 13). The high mean daily salinity during the post-Katrina period for stratum 4 is largely due to a salinity spike that occurred in 2009. Although no significant storm event or prevailing winds can be associated with this anomaly, it is suspected that the location of this recorder on a channel in the lower portion of the basin leaves the station susceptible to salinity incursions that may not be realized in other areas of the project area. There were no significant changes from pre-construction to post-construction, but significant increases post-Katrina were observed in all but one stratum. Reference stratum 6R is the closest of the strata to the Gulf of Mexico and the most susceptible to salt water and damage from storms. This stratum consistently sees higher salinities than the others (Figure 13).

One goal of the BS-03a project is to reduce salinity variation within the interior marshes. However, mean daily salinity variance increased at five of the six strata in the post-construction period (Figure 14). The large increase in variance in the post-Katrina period was likely due to Hurricane Katrina causing significant damage to the marsh (Figure 7) and structures in the project area. The increase in open water habitat has resulted in a less-restricted hydrologic flow, allowing more saline Gulf waters to easily penetrate these areas and increase mean salinities. The blockages and spoil bank damages also varied the flow of the water from the pre-Katrina conditions. The increases in strata 4 and 5R in particular, are likely attributable to the storm

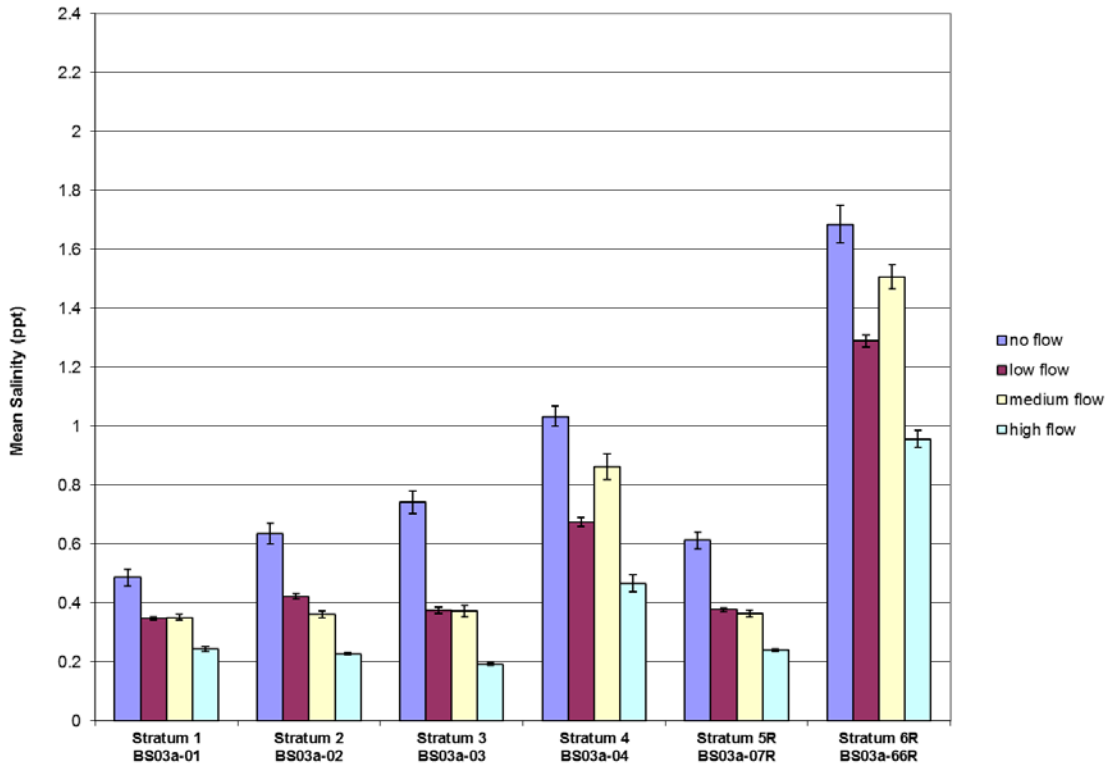

Figure 12a. Mean salinity (±SE) for the period 2000-2005 at continuous recorder stations during 4 operational categories [Low = 1-1999 cfs, Medium = 2000-4000 cfs, High = >4000 cfs] for the Caernarvon Diversion Outfall Management (BS=03a) project area.

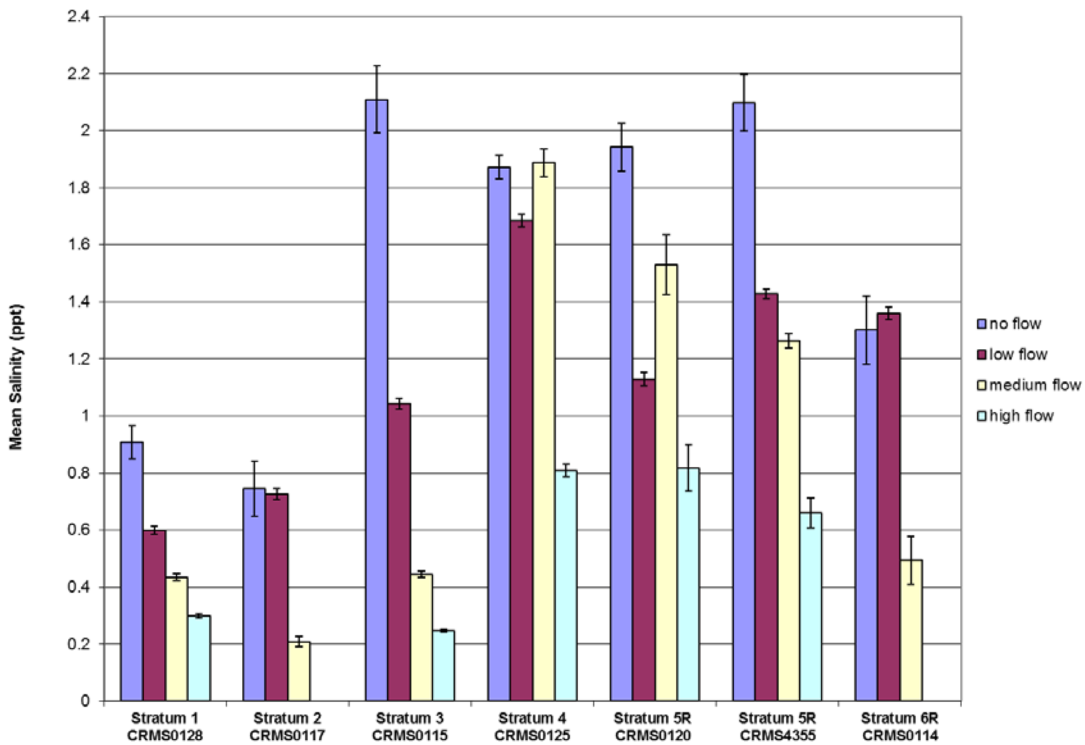

Figure 12b. Mean salinity (±SE) for the period 2007-2016 at CRMS station during 4 operational categories [Low = 1-1999 cfs, Medium = 2000-4000 cfs, High = >4000 cfs] for the Caernarvon Diversion Outfall Management (BS=03a) project area.

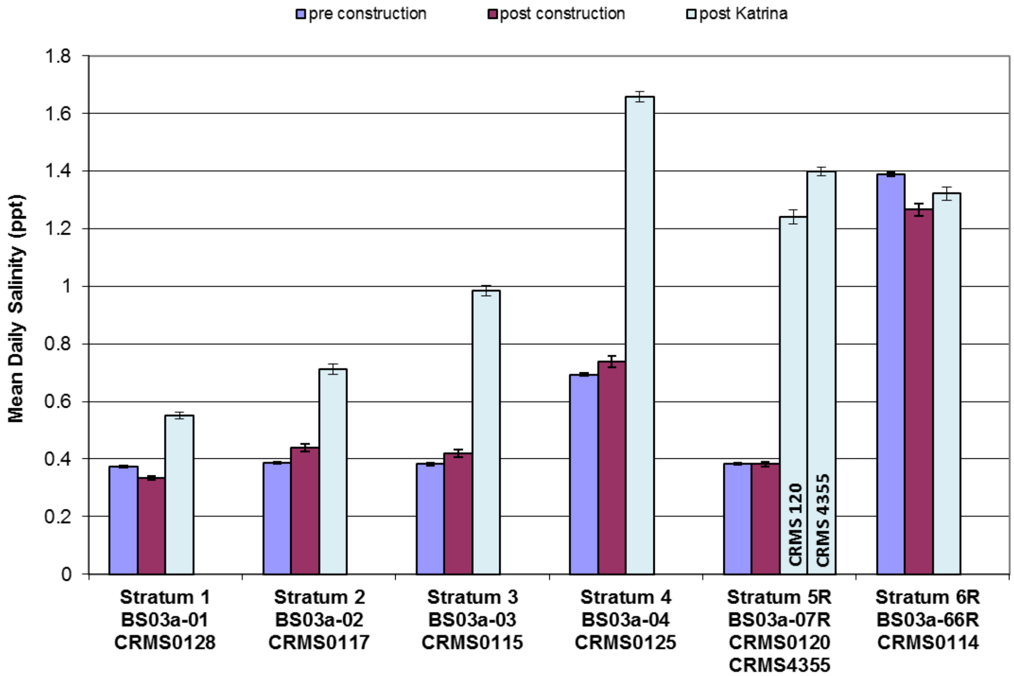

Figure 13. Mean daily salinity (±SE) at project-specific continuous recorders and CRMS stations for the BS-03a project and reference areas during pre-construction (3/27/2000−6/14/2002), post-construction (6/15/2002−8/09/2005) and post-Katrina (Oct 2007−April 2016) periods.

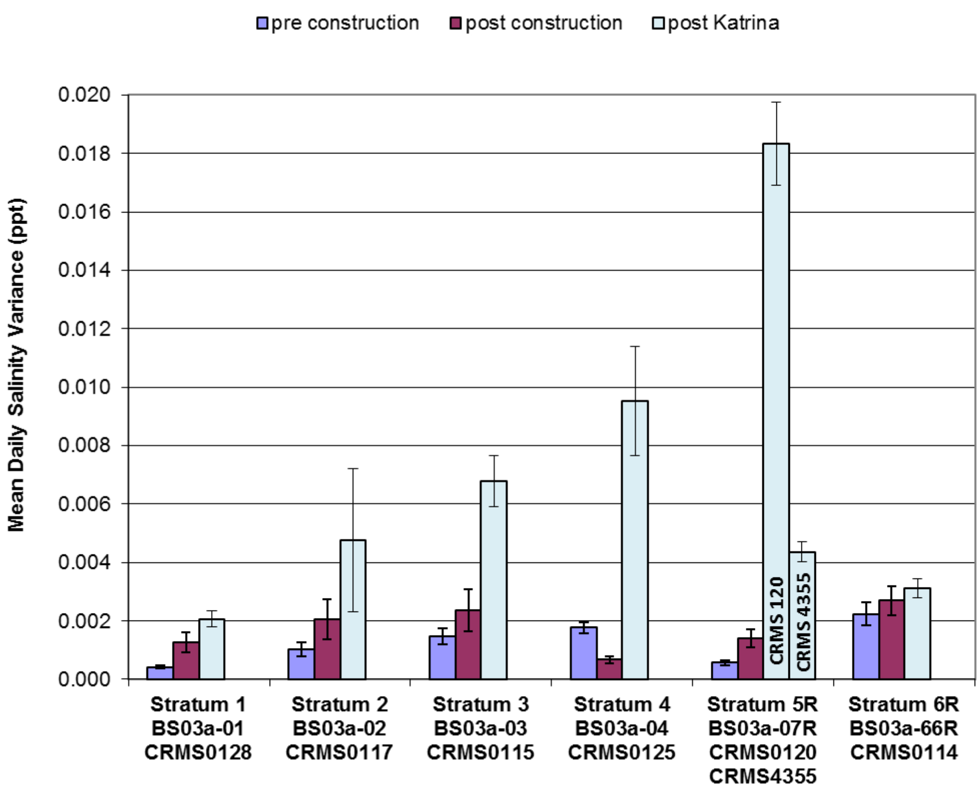

Figure 14. Mean daily salinity variance (±SE) for the Caernarvon Diversion Outfall Management (BS-03a) project and reference areas during pre-construction (3/27/2000−6/14/2002), post-construction (6/15/2002−8/09/2005) and post-Katrina (Oct 2007− April 2016) periods.

events during the 2007 and 2008 hurricane seasons, as well as the previously mentioned anomaly at CRMS0125 (Stratum 4) in 2009.

In 2001, a multi-investigator PULSES project was conducted to study the impacts of restored flood inputs from the Mississippi River into coastal marshes of the Breton Sound estuary. The pulse operations consisted of two, two-week high flow (6,500 cfs) periods, immediately followed by two-week low flow (500 cfs) periods, in the early spring of 2001 and 2002. The high flow pulse resulted in nearly 30% of the discharge flowing over the marsh; while during the low flow pulse, most river water was confined to channels (Day et al. 2003). Overland flow is induced when diversion discharge exceeds 3,500 cfs (Snedden 2006). This likely added to the confounding effect on mean salinities and variances associated with project and reference strata, as diversion flow rarely exceeded this 3500 cfs threshold.

iii. Water Elevation

Mean daily water level increased in all strata except stratum 1 following construction (Figure 15). Stratum 4 had the highest increase (0.27 ft), while stratum 3 had the smallest change (0.05 ft). This across-strata increase could be a function of tropical weather events in 2002 and 2004, and/or the drought during the pre-construction period when water levels were suppressed by lack of freshwater input from rainfall and diversion operations due to low river levels. The post-Katrina period (starting in 2008 for most strata) reflects a decrease in water level in all strata except reference stratum 5R (CRMS 4355) and reference stratum 6R (CRMS0114). Up to 2010, the mean daily water level in Stratum 2 was higher post Katrina than currently recorded levels. This was likely due to strata 2 and 5R being in the “immediate” outfall of the diversion and therefore experiencing increased water levels, augmented by post-Katrina debris blockages at structures 26, 40, & 54 for over 2 years. Since the blockages have been cleared, water flows through stratum 2 rather than being detained and causing higher water levels. The increase at CRMS4355 in reference stratum 5R water levels may be explained by how the flow of water was diverted after Hurricane Katrina. Whereas the structures initially guided more water southwest, the damage done by Hurricane Katrina allowed almost all of water to flow southeast, down Bayou Mandeville and into Lake Lery, therefore flowing along and into reference stratum 5R. The increase in water levels in reference stratum 6R following Hurricane Katrina may be explained by marsh and structure damage, which allows greater tidal influence from the Gulf of Mexico. Reference stratum 6R is also the closest, and therefore most vulnerable, to the water from the Gulf being pushed inward from storms, flooding events, and sea-level rise.

Mean daily water level was compared at various flow operations for the pre-construction (3/2000−6/14/2002), post-construction (6/15/2002−8/09/2005) and post-Katrina (Oct 2007−April 2016) periods (Figure 16). The flow regimes are no flow (0 cfs), low flow (0−2000 cfs), medium flow (2000−4000 cfs), and high flow (>4,000 cfs). Comparing pre-construction to post-construction, water levels increased at all operational flows in strata 2, 4, and reference strata 5R and 6R. The water level at stratum 1 decreased at all flows except high flow at which it increased, and stratum 3 showed an increase in water level at low and no flows and a decrease at high and medium flows. The decrease in stratum 3 at higher flows post-construction can most likely be attributed to diversion water being restricted to fewer entry points. Prior to the construction of project features, water during medium and high flow would move over banks or

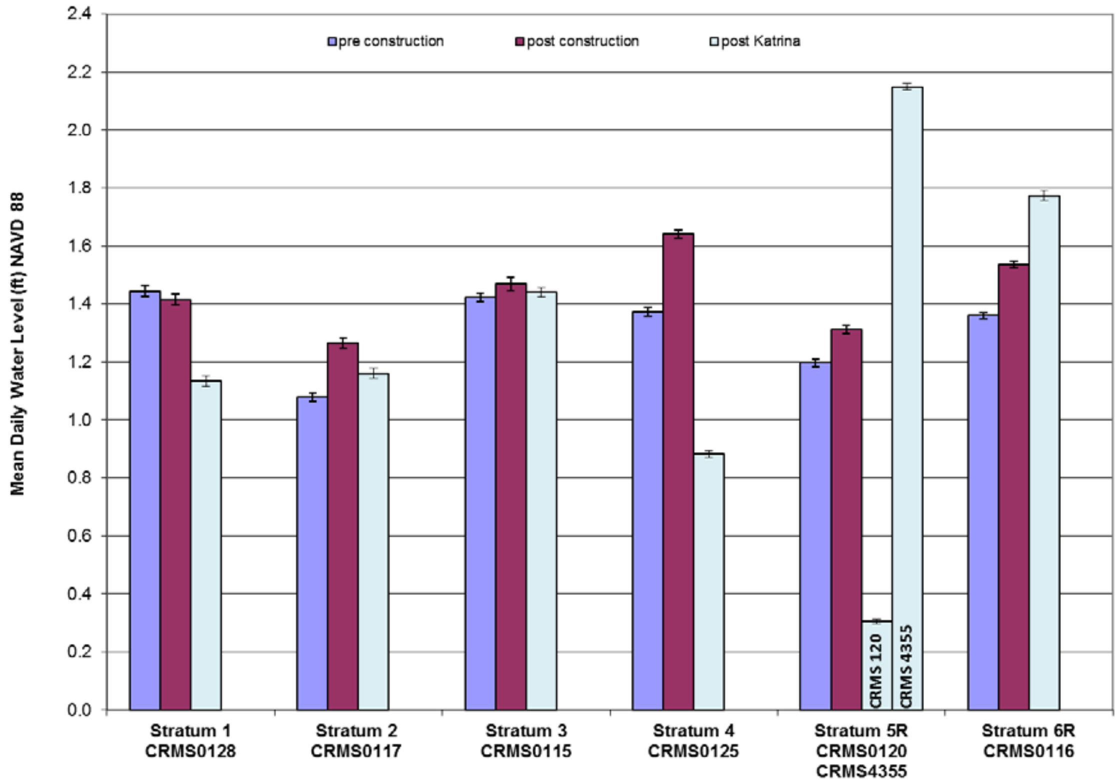

Figure 15. Mean daily water level (±SE) at project-specific continuous recorder and CRMS stations for the Caernarvon Diversion Outfall Management (BS-03a) project and reference areas during the pre-construction (3/2000−6/14/2002), post-construction (6/15/2002−8/09/2005) and post-Katrina (Oct 2007−April 2016) periods.

through openings to reach the interior marshes within each stratum. After construction but prior to Hurricane Katrina, entry points were confined to culverts through higher spoil banks and less water was able to move into the marshes. Comparing post-construction to post-Katrina, stratum 1 once again showed a decrease in water level at all flows except high flow. Stratum 2, 4, and CRMS0120 in reference stratum 5R showed a decrease in water level at all operational flows and CRMS4355 in stratum 5R showed an increase at all flows. The water level in stratum 3 decreased at all flows except low flow, and the water level in reference stratum 6R decreased at medium flow but increased at low and no flow. There was no high flow water level data post-Katrina for stratum 2 or reference stratum 6R. It should be noted that the location of the monitoring stations changed after Katrina due to the shift from the project specific sites to CRMS sites.

Comparing pre-construction water levels to post-Katrina water levels showed that the water level in strata 1, 4, and at CRMS0120 in reference stratum 5R decreased at all flow rates while the water levels in stratum 2, reference stratum 6R, and at CRMS4355 in reference stratum 5R increased at all flow rates. Stratum 3 showed varying results in that the water level decreased at high and medium flows but increased at low and no flows. It should be noted that after construction, more water was being diverted southwest, thus explaining the increase in water levels in most areas post-construction. However, after Katrina, the majority of the water flowed southeast rather than through the marsh. This is shown in the decrease in water level to the

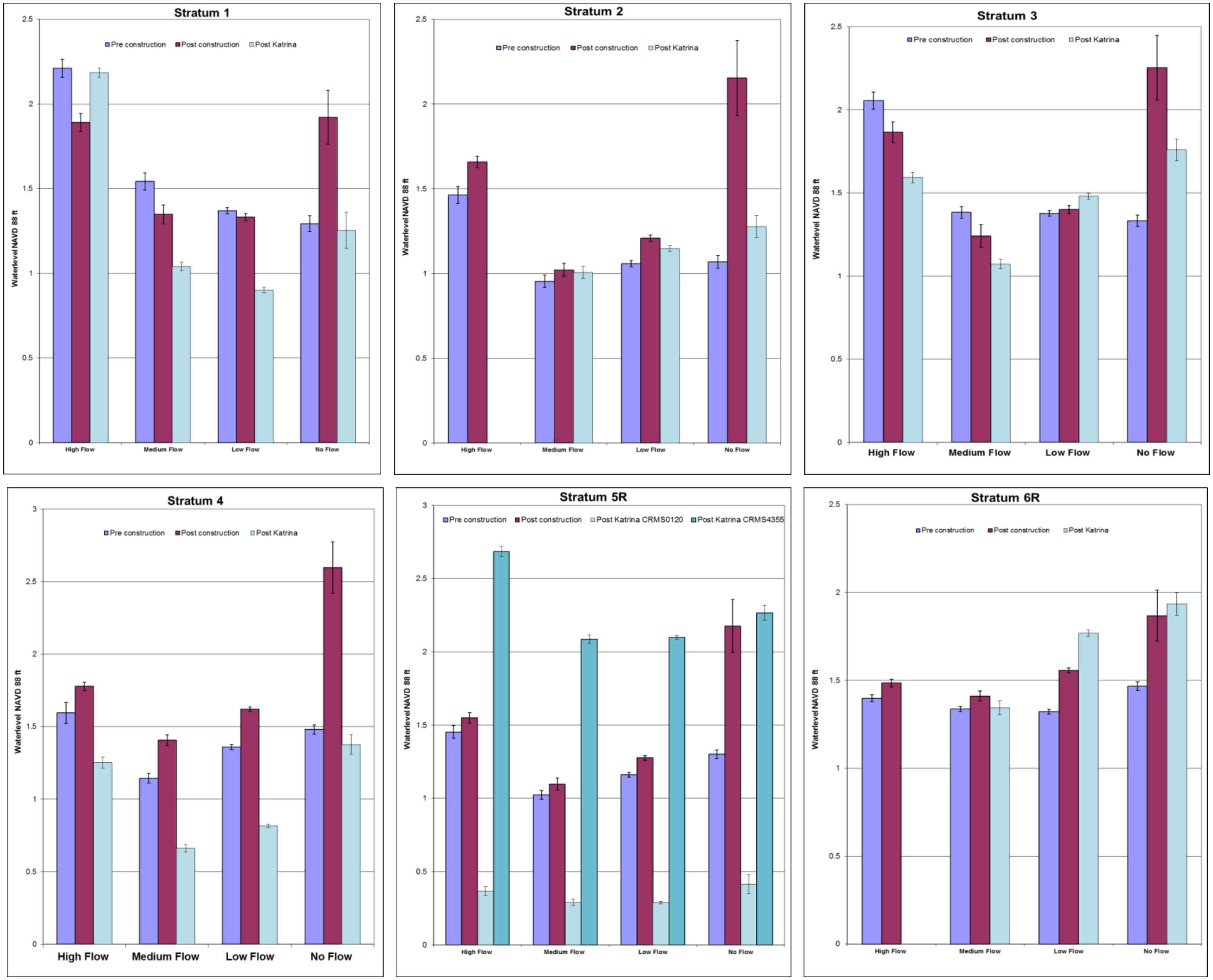

Figure 16. Mean daily water level (±SE) at continuous recorder project-specific and CRMS stations for the BS-03a project under different flow rates during the pre-construction (3/2000−6/14/2002), post-construction (6/15/2002−8/09/2005) and post-Katrina (Oct 2007−April 2016) periods.

southwest of the outfall post-Katrina. The only site that showed an increase in all flow rates was CRMS4355 in reference stratum 5R, which is directly east and slightly south of the outfall. Another trend observed was that in all strata both post-construction and post-Katrina, the water levels were highest at high flow and no flow, while they were lower at medium and low flows. It would appear that at high flow, diversion waters are bypassing project features altogether with little to no water being retained. This suggests that diversion waters are more efficiently retained within each stratum at medium to low flow operations, which reflects an intention of the project design.

Marsh inundation was not compared in all strata due to sites in Stratum 1 and Stratum 3 being located on floating marsh. Marsh inundation levels in all other strata peaked in 2002, around the time construction was completed (Figure 17a). After construction, flooding continued to fluctuate seasonally, but remained higher on average than before construction was complete, indicating that the structures were successful in retaining water in the project area. In the post-Katrina period, there was a shift to less inundation (Figure 17b). When inundation data collection began again in 2008, the only site providing data was CRMS0114 in reference stratum 6R. Inundation was initially similar to the project specific site BS03A-66R before Katrina; however, there has since been a decrease in inundation and the marsh has experienced <0ft of inundation most of the time up to the present. This may be due to the gates remaining mostly in the open position during the past few years, therefore not improving the retention of water.

All strata showed greater water level variance post-construction compared to pre-construction, and the post-Katrina period showed the greatest water level variance of the three periods (Figure 18). This increase in variance can likely be attributed to structural damage, marsh loss, and the subsequent increase in open-water area that occurred as a result of Hurricane Katrina in 2005 and tropical events in 2008 and 2012. The use of the diversion in 2010 to combat the infiltration of oil in the lower basin from the Mississippi Canyon 252/Deepwater Horizon oil spill may have also led to an increase in variance. Notably, the oil spill is likely the reason for increased duration and depth of flooding for stratum 2 in 2010. The duration of flooding increased for all strata during the post-construction period, and was possibly a result of the tropical storms in 2002 and 2004 when most strata stayed flooded for more than 2 months (Figures 19a,b & 20a,b).

The general trend when comparing flow to water level is that discharge is directly related to water level, with a more direct correlation after completion of construction (Figures 19a and 20a). Also, as expected, a stronger correlation is seen in the upper basin, at sites closer to the outfall channel. Slightly higher water levels are present closer to the diversion outfall channel, thus indicating the water initially pools in the upper strata and then flows down to disperse into subsequent strata (Figure 19a). After Katrina, the water level fluctuates to reflect flow variations, but does not follow the previous trend of higher water levels closer to the outfall (Figures 19b, 19c, 20b, 20c). The reference strata 5R and 6R follow the same patterns as the other strata, except at slightly different water levels. This implies that all strata, including reference strata, are hydrologically connected. CRMS0120 in reference stratum 5R exhibits a similar pattern, although at significantly lower water levels than the other strata. This may be because it is the northernmost site and near a canal, and more "cut-off" from the rest of the project area.

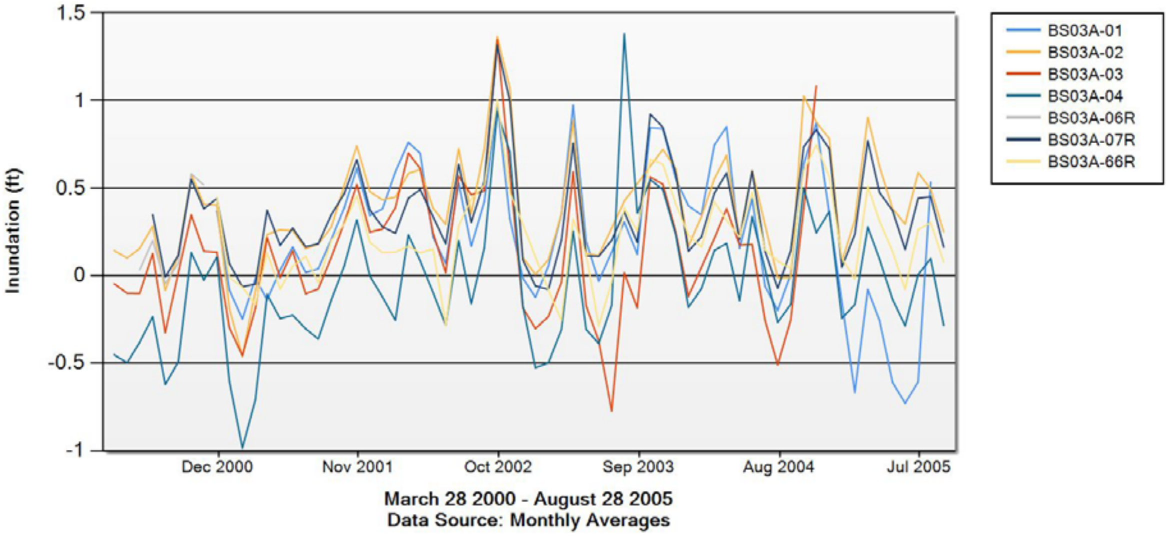

Figure 17a. Inundation (ft) at project specific sites at the Caernarvon Diversion Outfall Management Project (BS-03a) and reference areas from beginning of construction (2000) to Hurricane Katrina (2005).

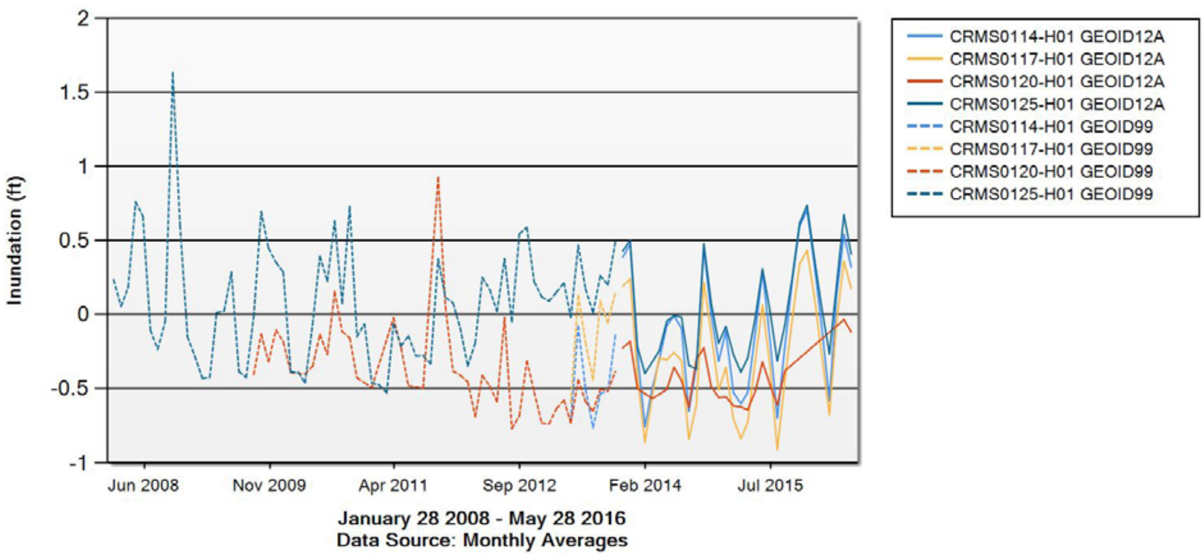

Figure 17b. Inundation (ft) at CRMS sites at the Caernarvon Diversion Outfall Management Project (BS-03a) and reference areas from 2008 to 2016.

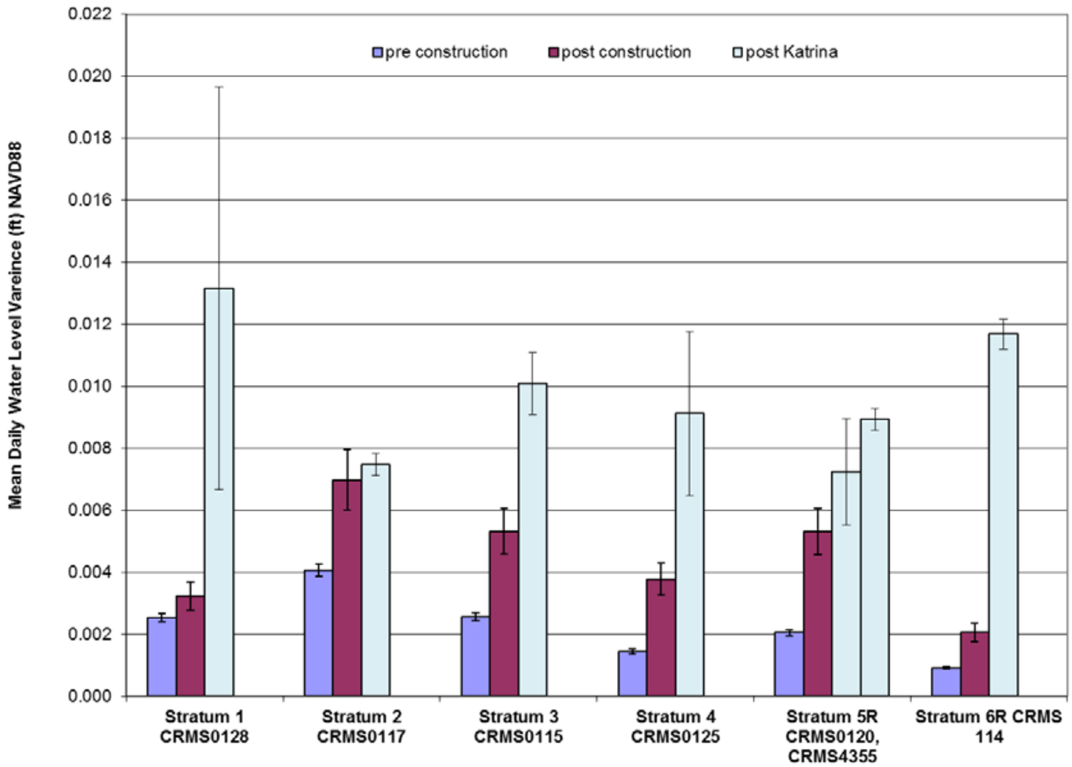

Figure 18. Mean daily water level variance (±SE) at YSI continuous recorder and CRMS stations for the Caernarvon Diversion Outfall Management Project (BS-03a) and reference areas during the pre-construction (3/2000−6/14/2002), post-construction (6/15/2002−8/09/2005) and post-Katrina (Oct 2007-April 2016) periods.

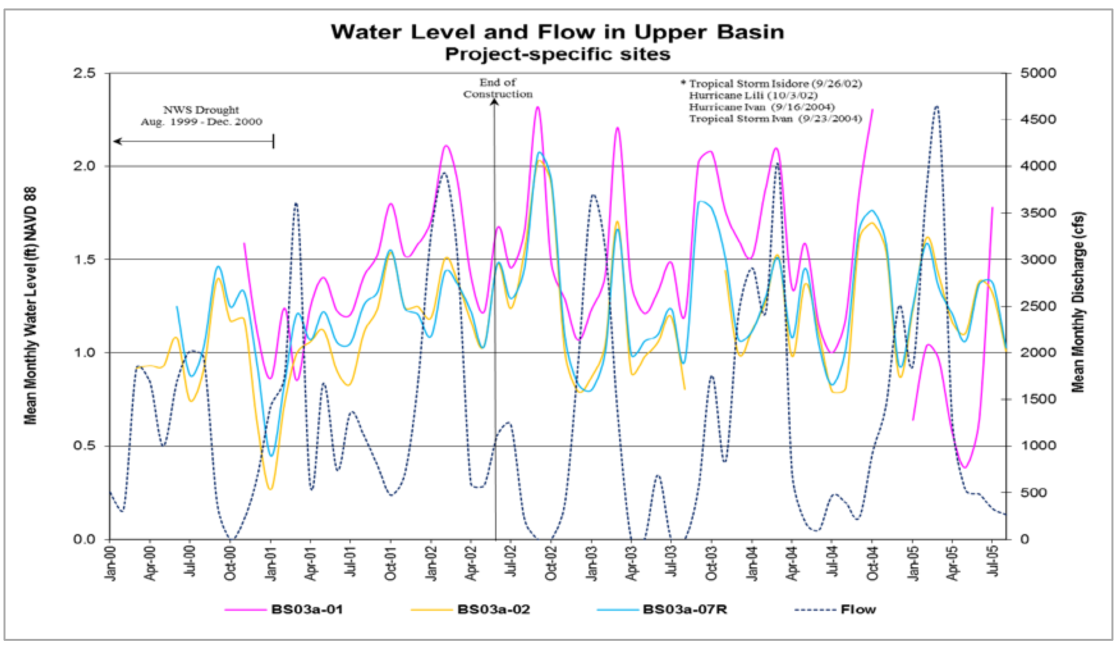

Figure 19a. Mean monthly water level for project stations BS03a-01 & 02 and reference station BS03a-07R within the Caernarvon Diversion Outfall Management (BS-03a) project upper basin, along with flow rates for the Caernarvon Diversion (DCPBS09), 2000 −2005.

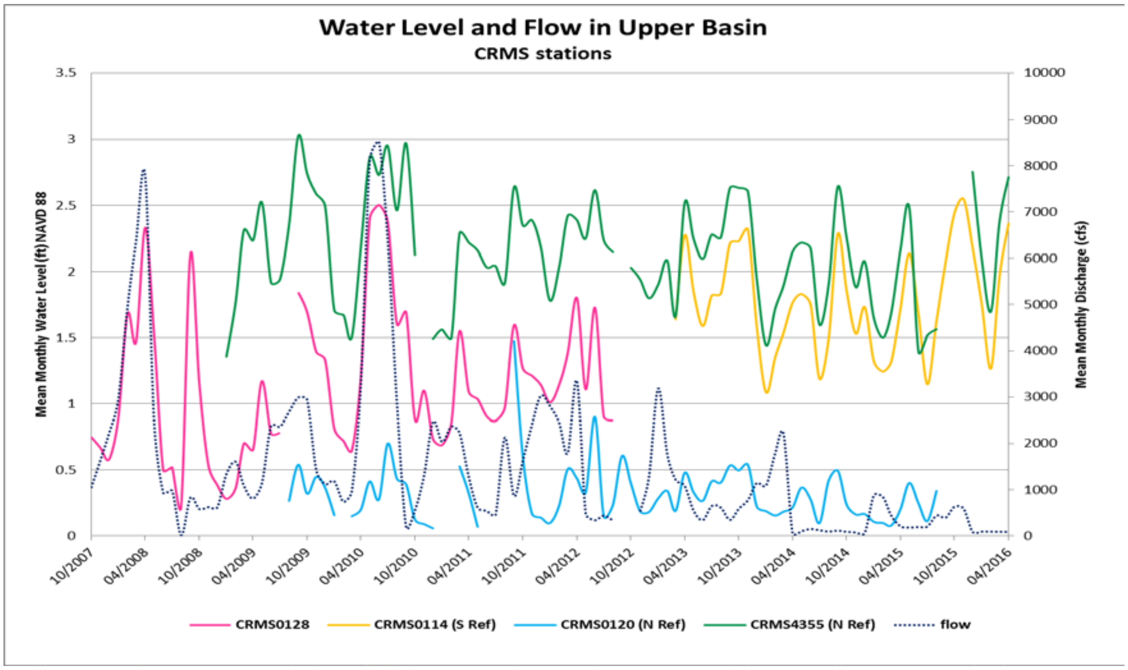

Figure 19b. Mean monthly water levels for CRMS station 0128 (upper basin) in comparison to reference stations CRMS0120, CRMS4355, and CRMS0114 within the Caernarvon Diversion Outfall Management (BS-03a) project upper basin, along with flow rates for the Caernarvon Diversion (DCPBS09), Oct 2007−April 2016.

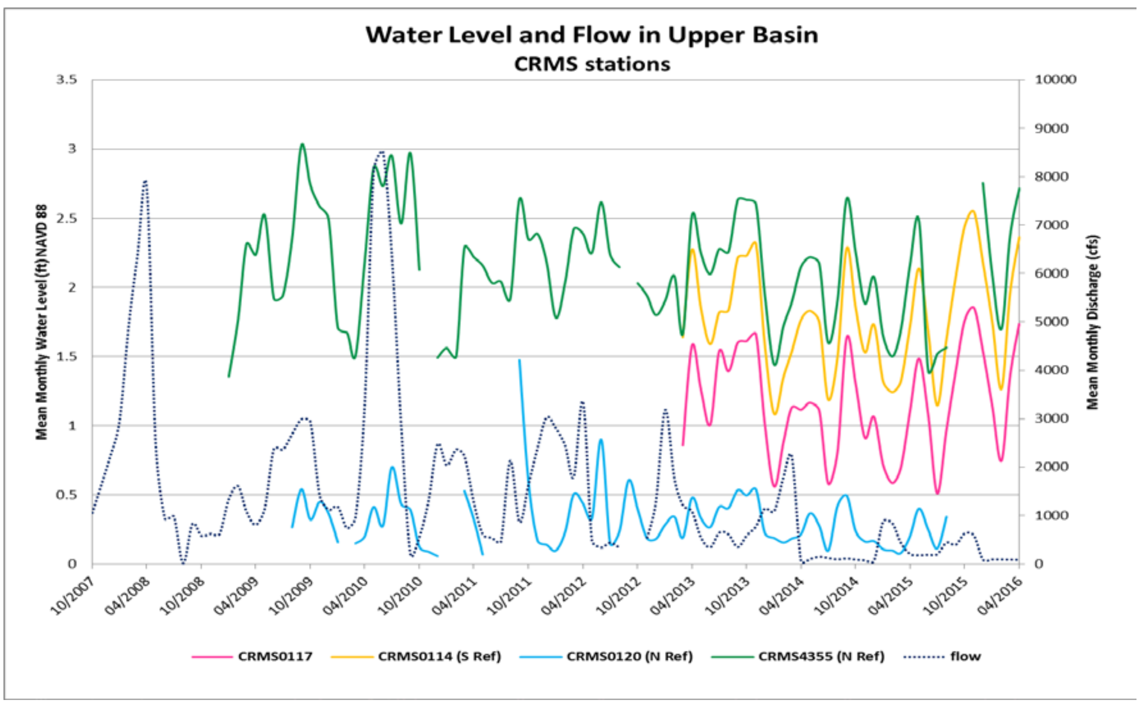

Figure 19c. Mean monthly water levels for CRMS station 0117 (upper basin) in comparison to reference stations CRMS0120, CRMS4355, and CRMS0114 within the Caernarvon Diversion Outfall Management (BS-03a) project upper basin, along with flow rates for the Caernarvon Diversion (DCPBS09), Oct 2007−April 2016.

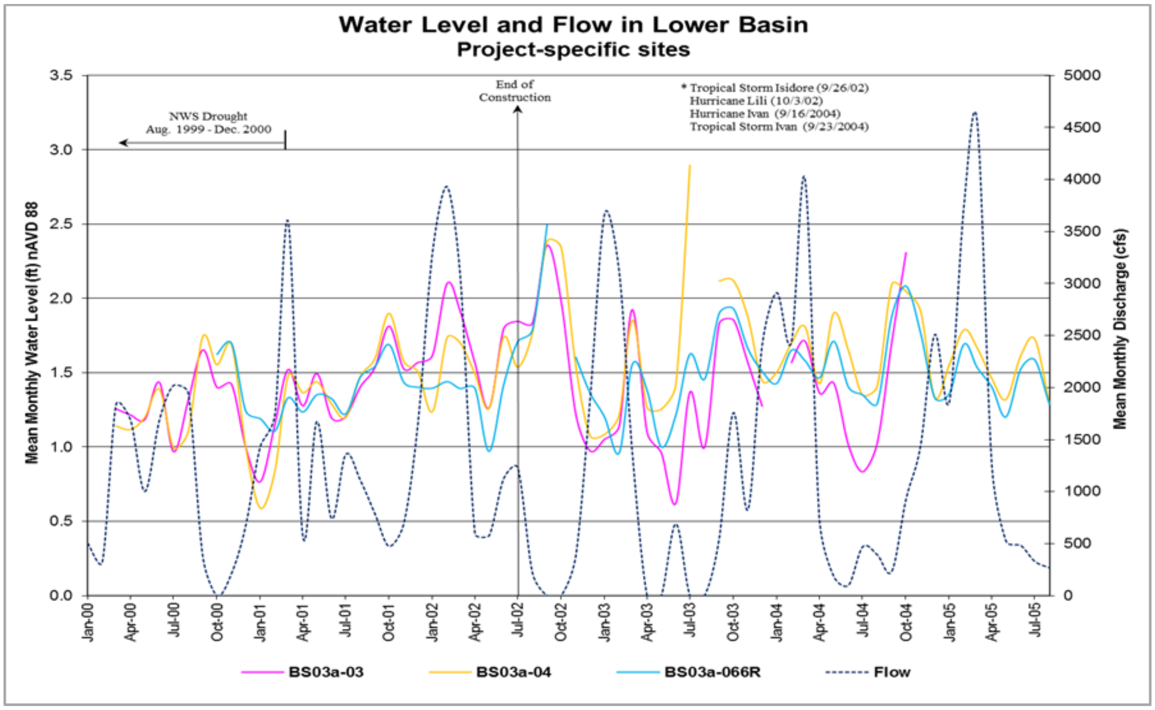

Figure 20a. Mean monthly water levels for project station BS03a-04 and reference station BS03a-66R within the Caernarvon Diversion Outfall Management (BS-03a) project lower basin, along with flow rates for the Caernarvon Diversion (DCPBS09), 2000−2005.

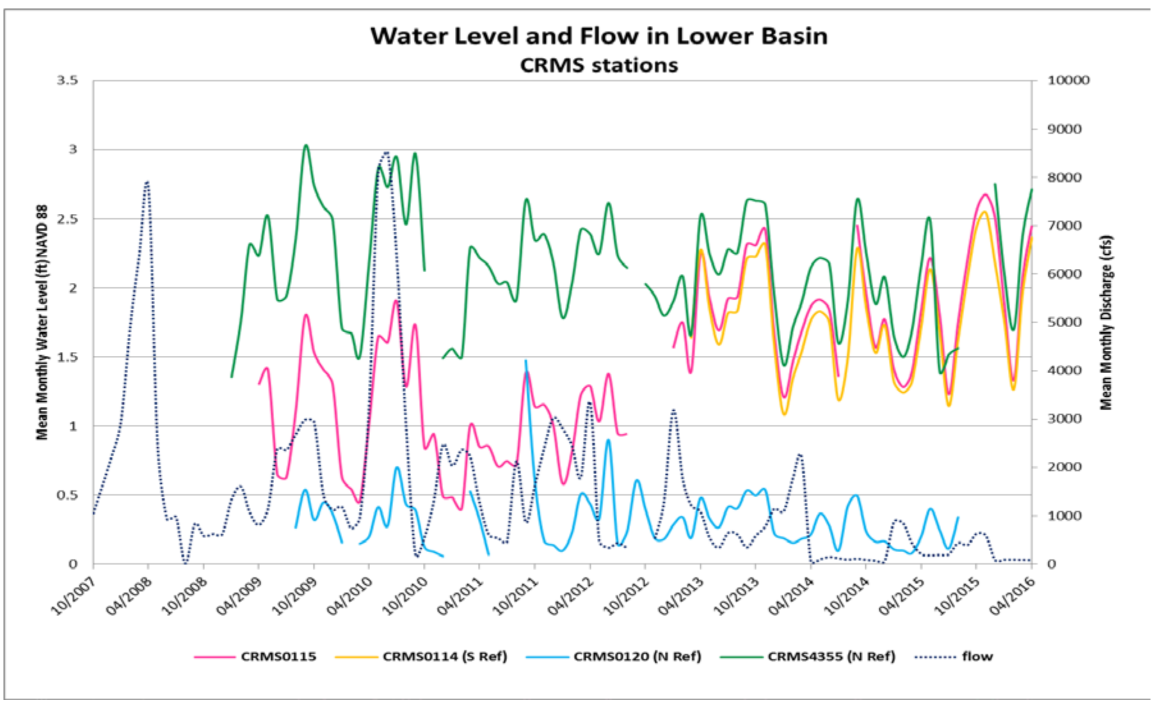

Figure 20b. Mean monthly water levels for CRMS station 0115 (lower basin) in comparison to reference stations CRMS0120, CRMS4355, and CRMS0114 within the Caernarvon Diversion Outfall Management (BS-03a) project upper basin, along with flow rates for the Caernarvon Diversion (DCPBS09), Oct 2007−April 2016.

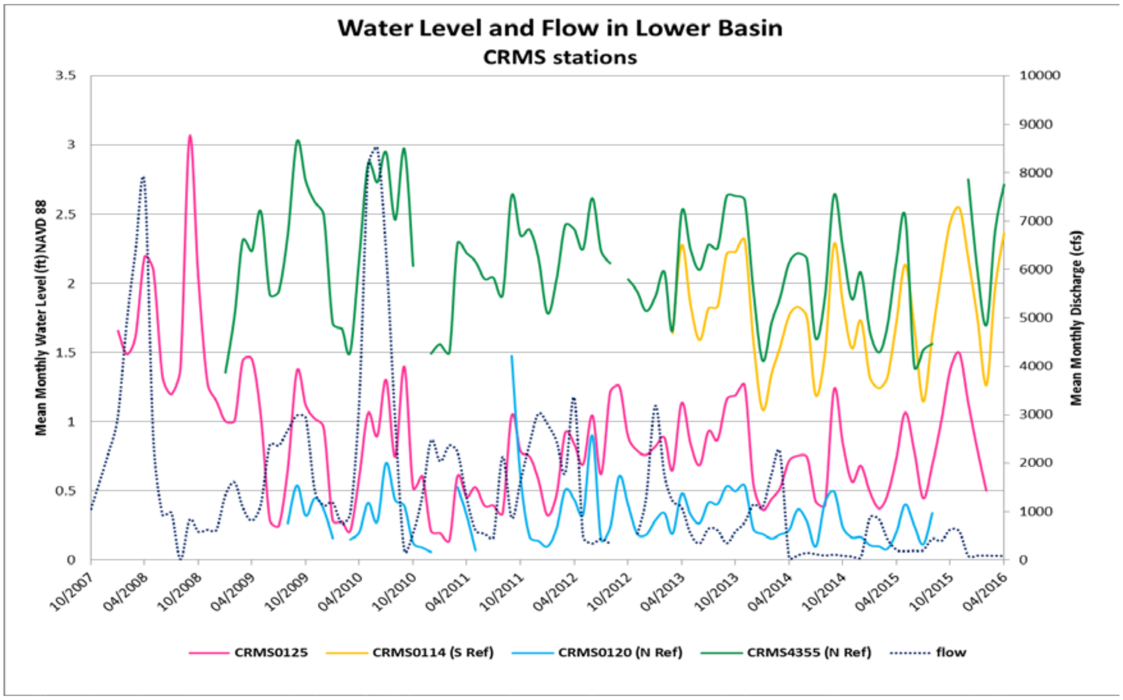

Figure 20c. Mean monthly water levels for CRMS station 0125 (lower basin) in comparison to reference stations CRMS0120, CRMS4355, and CRMS0114 within the Caernarvon Diversion Outfall Management (BS-03a) project upper basin, along with flow rates for the Caernarvon Diversion (DCPBS09), Oct 2007−April 2016.

iv. Vegetation

Vegetation surveys were conducted at project specific sites from 2000 to 2007. Some of these sites had to be relocated after Hurricane Katrina in 2005. Beginning in 2007, vegetation surveys were conducted at CRMS sites within each stratum and reference area. This resulted in surveys being conducted at both project-specific and CRMS sites in 2007. The differences in results between these sites are due to differences in station locations within the strata and the number of plots surveyed within each stratum.

Each site was measured based on species present, percent cover, and the Floristic Quality Index (FQI). Individual species percent cover is the visual estimation of the percent cover for each species of vegetation at a station. Because the covers for species can overlap due to different heights and growth forms, the sum of the individual species covers at a station can exceed 100%. The Floristic Quality Index (FQI) is used to quantitatively determine the condition of a particular habitat using the plant species composition (Cretini et al. 2009). It has been regionally modified for coastal Louisiana by a panel of local plant experts in order to determine changes in wetland conditions based upon the presence of non-native, invasive and disturbance-prone species across community types. The coefficient of conservatism (CC) is a score from 0 to 10 assigned by the panel to flora and is used, along with percent cover, to calculate the FQI. Species are scored highest if they are characteristic of a vigorous coastal wetland (9-10) and lowest if they are invasive (0). The panel did not assign CC scores to 1) submerged aquatic vegetation, 2) parasitic species, 3) plants identified only to genus or family, or 4) unidentifiable plants. While the FQI scores have fluctuated over time, there was been a downward shift from before construction to the present. However, some of the decrease can be explained by a fresher environment because fresh marsh species tend to have lower CC scores than more saline species.

Spartina patens (saltmeadow cordgrass) had the greatest cover in most strata in 2000, 2003, and 2005. Exceptions included higher percent covers for *Alternanthera philoxeroides* (alligator weed) in 2000 (stratum 4), *Sesbania herbacea* (bigpod sesbania) in 2003 (stratum 4), *Eleocharis parvula* (dwarf spikerush) in 2003 (stratum 6R) and *Bacopa monnieri* (herb of grace) in 2005 (stratum 5R) (Figures 21−26). In 2005, 8 of the 36 vegetation stations were inaccessible and of the 28 reached, 18 were missing or damaged following Hurricane Katrina. The open water stations were relocated in 2006 to the closest land adjacent to their original locations. This re-establishment of stations in the year post-Katrina resulted in 30 stations being monitored in 2006. Between the 2005−2006 vegetation surveys, *Polygonum sp.* (smartweed) increased in cover and was dominant in strata 2, 4 and 5R in 2006, while the cover of *S. patens* declined in all but stratum 5R.

Vegetation surveys were conducted at both project-specific and CRMS sites in 2007. The differences in results between these sites are due to differences in station locations within the strata and the number of plots surveyed within each stratum. In 2007, 29 project-specific stations were surveyed because one station became inaccessible from the previous year. *Polygonum sp.* decreased in percent cover at all project-specific sites between 2006−2007, except in reference strata 6R; however, this decrease in percent cover for the genus *Polygonum* was short-lived. Since CRMS vegetation monitoring began in 2007, there has been a consistent presence and a notable increase in percent cover for *Polygonum punctatum* (dotted smartweed). The FQI decreased between 2000 and 2003 in all strata except stratum 2, possibly reflecting the completion of construction of the project. From 2000 to 2003, percent cover increased in all strata but reference stratum 6R and species richness increased in all strata except stratum 4 (Table 2). Both the decrease in FQI and increase in species richness may be explained by the increase in retention of freshwater in the area due to the construction of the structures. Additionally, all strata showed a decrease in salinity between 2000 and 2004 (Figure 11a). FQI, percent cover, and species richness then declined sharply at all vegetation stations in November 2005 (Figures 21−26) less than three months after Hurricanes Katrina and Rita. Despite an increase in FQI in 2006, there was an overall continuing downward trend for this metric at project-specific sites from 2000−2007. Reference stratum 6R is the only stratum that showed an increasing FQI from 2006 through 2007. The increase in FQI can be attributed to an increase in percent cover for two brackish species with high CC scores, *S. patens* (CC score: 9) and *Schoenoplectus americanus* (chairmaker's bulrush) (CC score: 8). In 2007, most strata also saw a decrease in percent cover. The exceptions were stratum 1 and reference stratum 5R, the two northernmost strata.

In 2010, in response to the Deepwater Horizon Oil Spill, the Caernarvon Freshwater Diversion was run at full discharge to "flush" the marsh with fresh water to avoid intrusion of oil into the marsh. The project area reflected this flushing with a decrease in salinity in all strata (Figure 11b). Also, an increase in cover of vegetation, species richness, and FQI was noticed when comparing 2010 to 2011 in most strata. Exceptions include a decrease in FQI in stratum 5R, decrease in percent cover in stratum 3, and decrease in species richness in strata 5R and 6R (Figures 21-26).

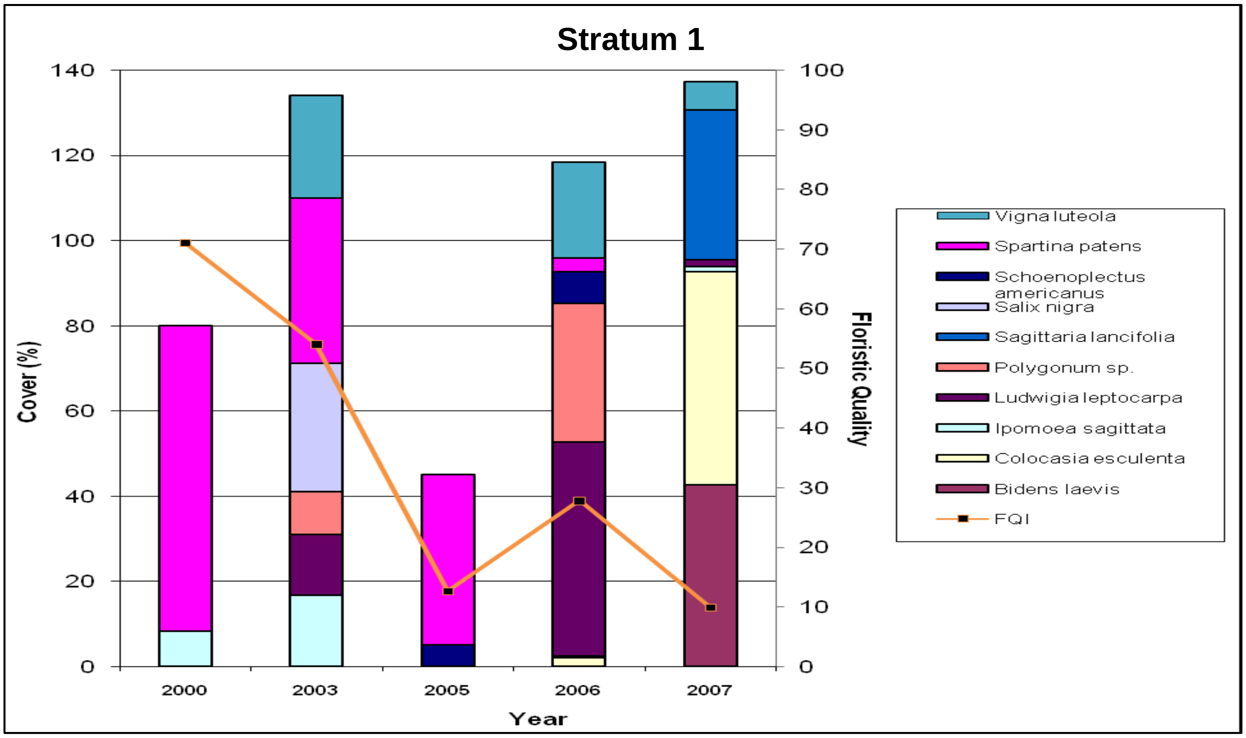

Figure 21a. Mean vegetation % cover and FQI for dominant species at project-specific stations in stratum 1 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2000−2007 surveys.

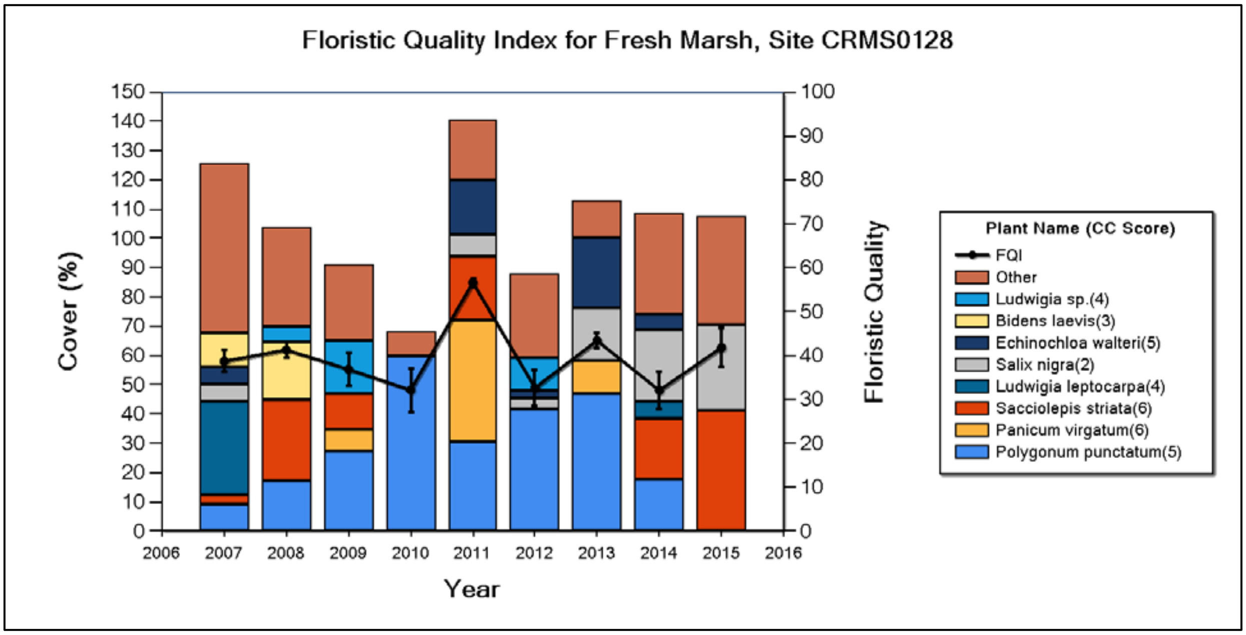

Figure 21b. Mean vegetation % cover and FQI at CRMS0128 in stratum 1 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2007−2015surveys.

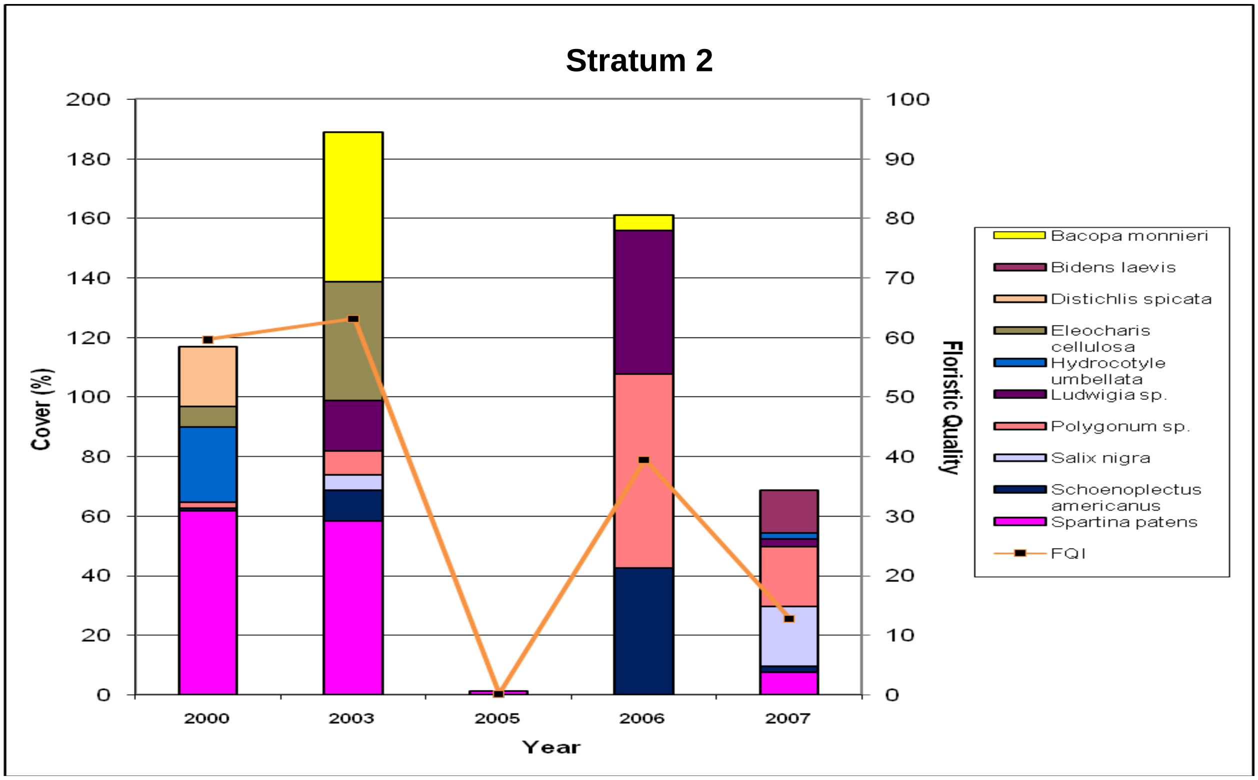

Figure 22a. Mean vegetation % cover and FQI for dominant species at project-specific stations in stratum 2 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2000–2007 surveys.

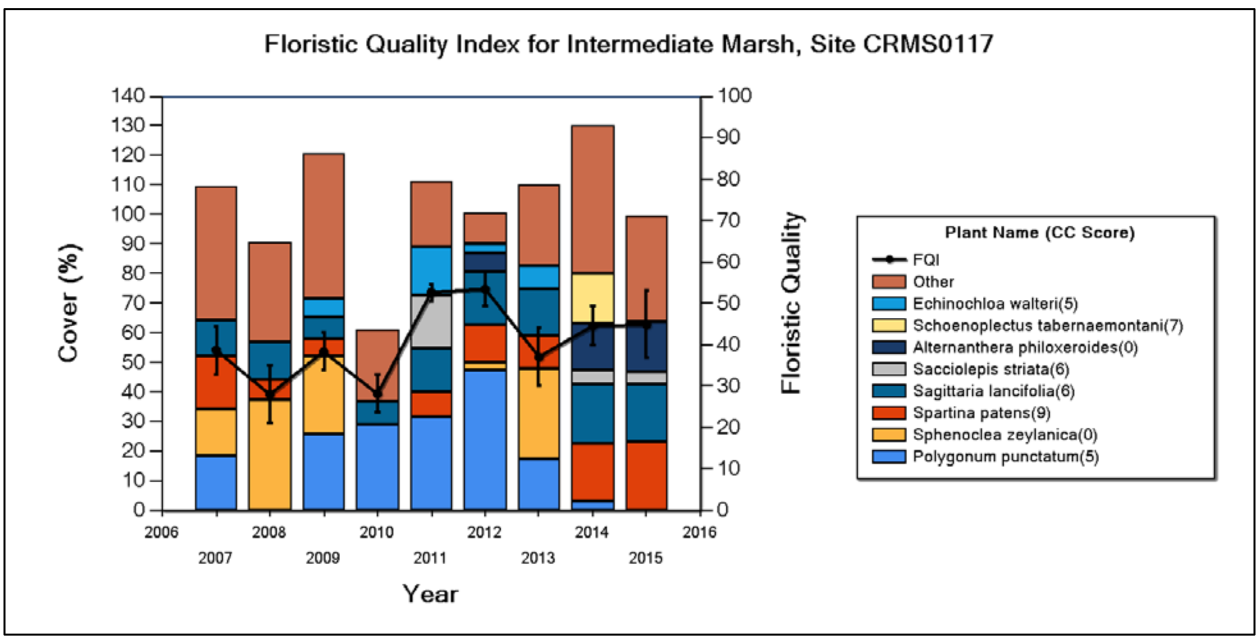

Figure 22b. Mean vegetation % cover and FQI at CRMS0117 in stratum 2 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2007–2015 surveys.

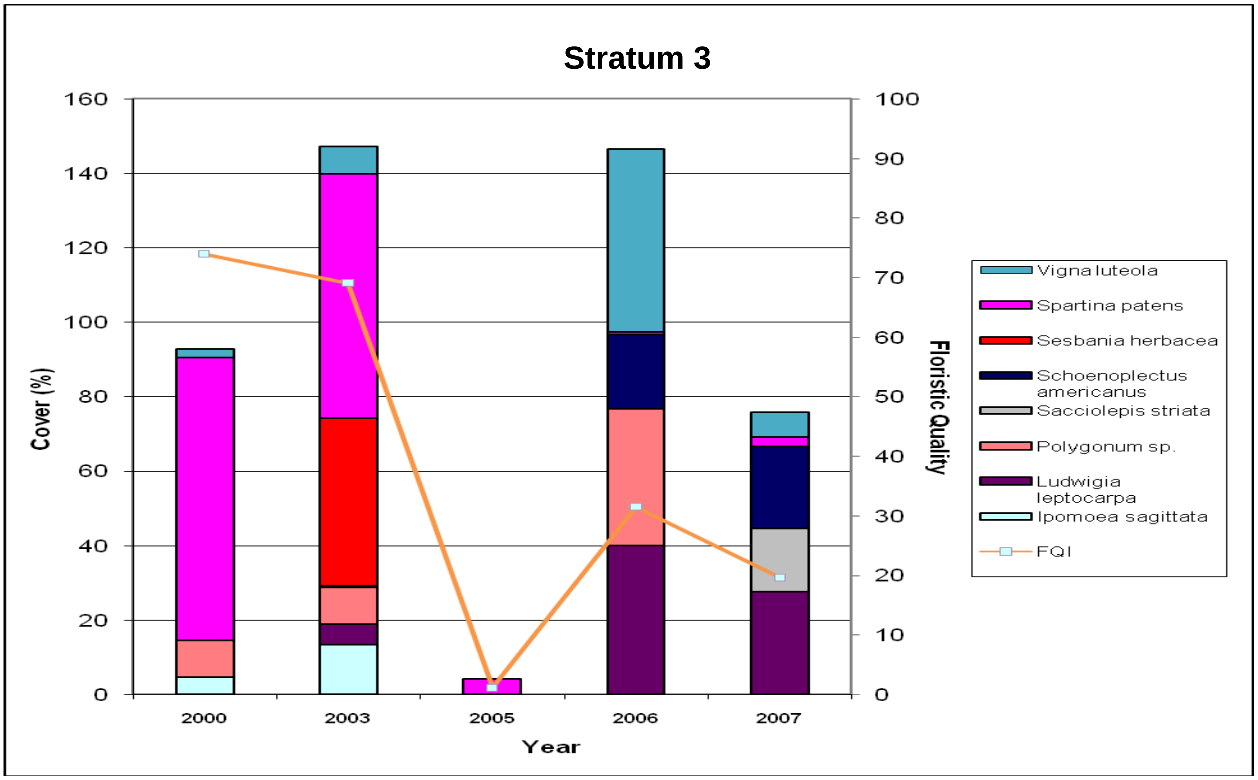

Figure 23a. Mean vegetation % cover and FQI for dominant species at project-specific stations in stratum 3 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2000−2007 surveys.

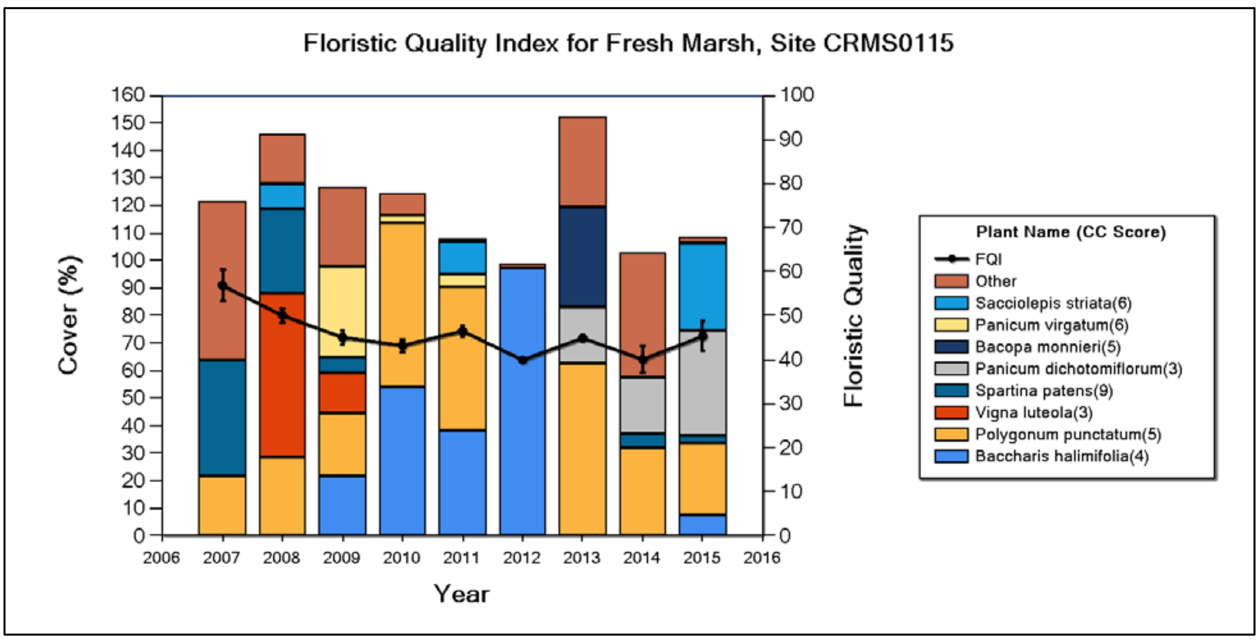

Figure 23b. Mean vegetation % cover and FQI at CRMS0115 in stratum 3 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2007−2015 surveys.

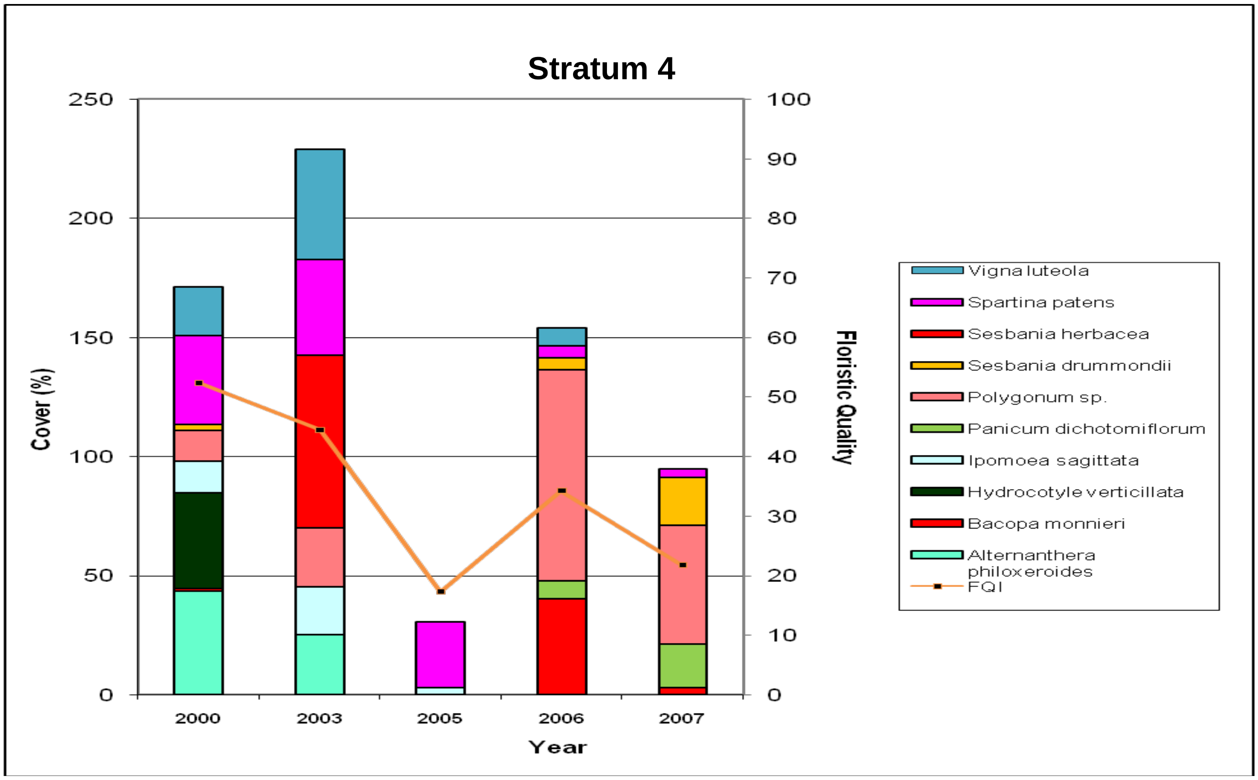

Figure 24a. Mean vegetation % cover and FQI for dominant species at project-specific stations in stratum 4 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2000−2007 surveys.

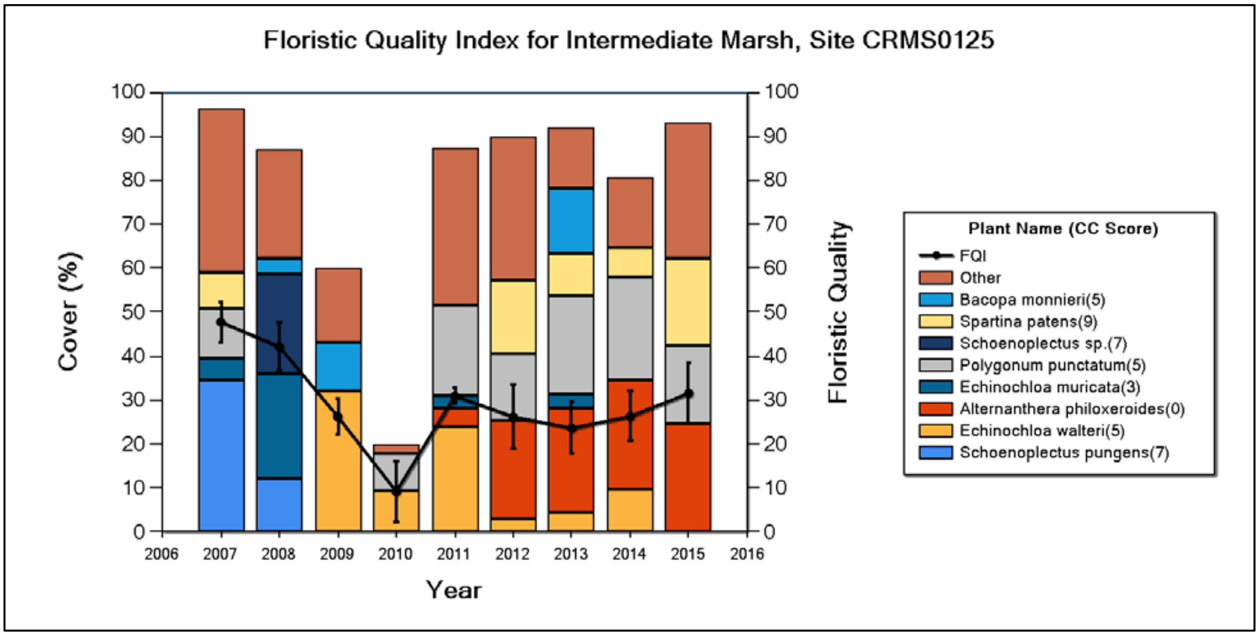

Figure 24b. Mean vegetation % cover and FQI at CRMS0125 in stratum 4 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2007−2015 surveys.

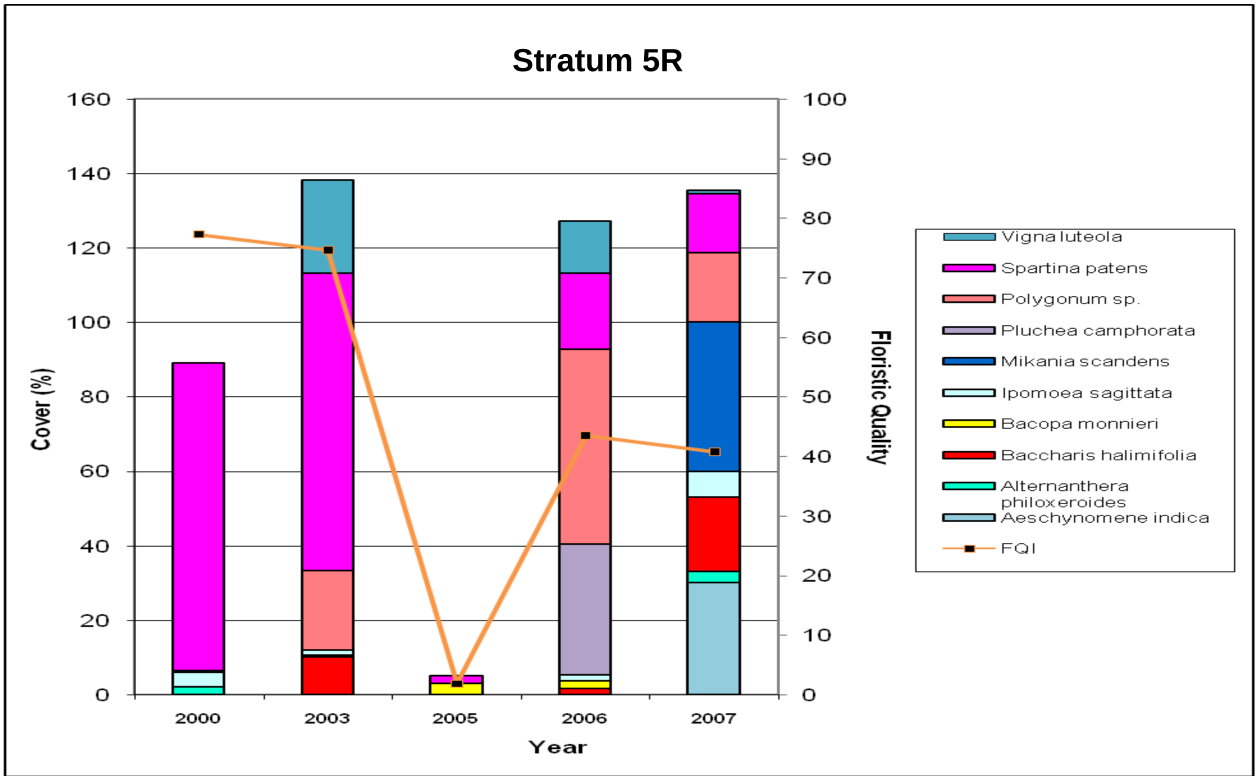

Figure 25a. Mean vegetation % cover and FQI for dominant species at project-specific stations in stratum 5 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2000−2007 surveys.

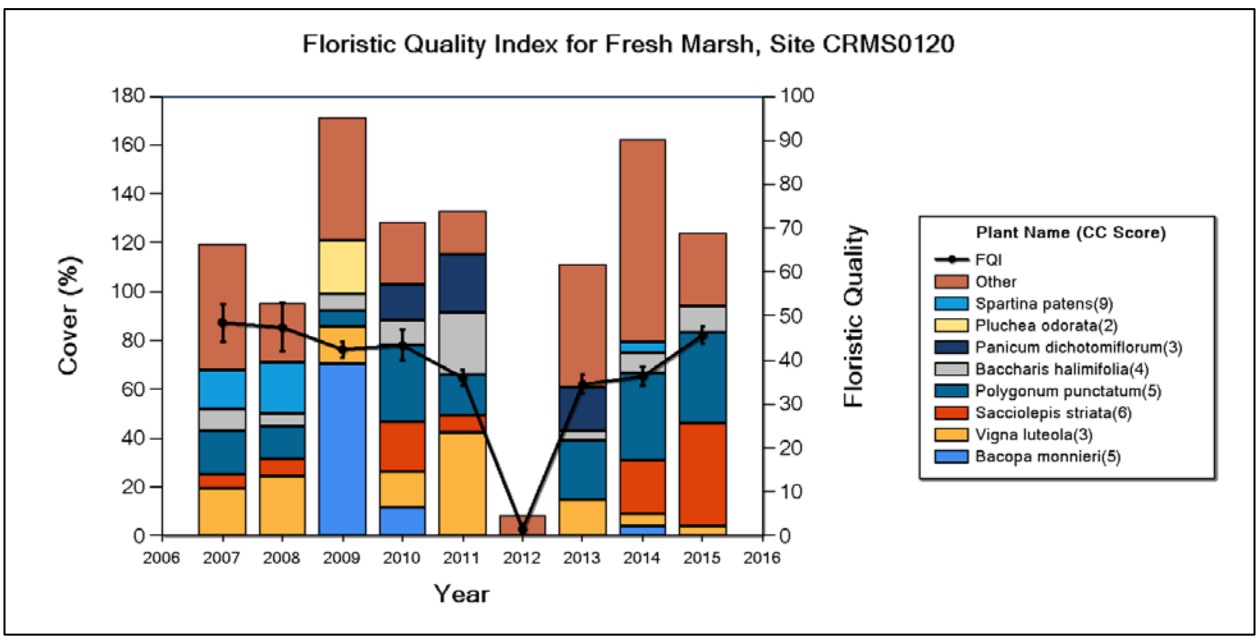

Figure 25b. Mean vegetation % cover and FQI at CRMS0120 in stratum 5 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2007−2015 surveys.

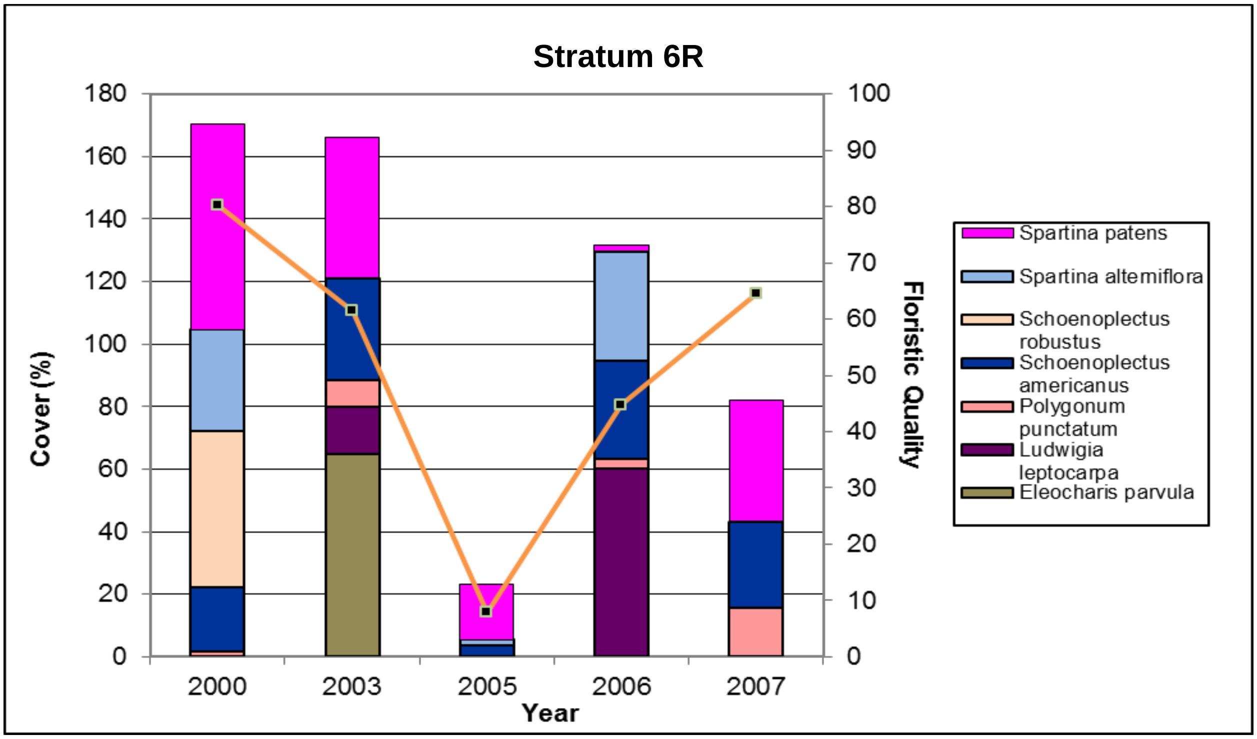

Figure 26a. Mean vegetation % cover and FQI for dominant species at project-specific stations in stratum 6 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2000−2007 surveys.

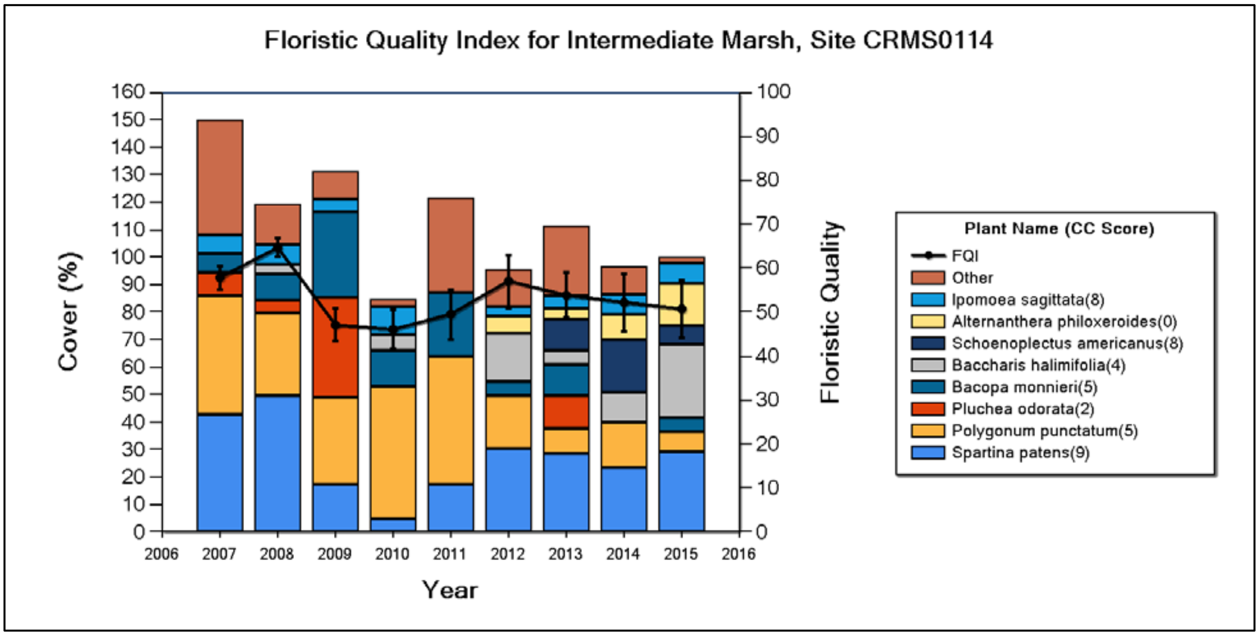

Figure 26b. Mean vegetation % cover and FQI at CRMS0114 in stratum 6 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2007−2015 surveys.

Across all strata, lower coverage of *S. patens* was observed from 2007 to 2016 compared to the pre-Katrina period. Also, a greater presence of *P. punctatum* was observed across strata after 2007. In stratum 1, *P. punctatum* was present every year but 2015, and the freshwater species *Salix nigra* (black willow) and *Sacciolepis striata (American cupscale)* began to increase in 2013. Salinity data for this area is not available after 2012 for comparison due to data gaps following Hurricane Isaac. Stratum 2 also showed a consistent presence of *P. punctatum* through 2014. This stratum also exhibited a steady presence of *S. patens* which increased in 2014 and 2015. Additionally, *Sagittaria lancifolia* (bulltongue arrowhead), a fresh to intermediate species, was present every year from 2007 to 2013. Stratum 3 again showed a consistent presence of *P. punctatum*, with this species dominating the sample for several years. An increase in *Baccharis halimifolia* (eastern baccharis) to almost 100% cover was observed from 2009 until 2012. However, in 2013, *B. halimifolia* was no longer present, likely due to the effects of Hurricane Isaac which hit shortly after vegetation was surveyed in August of 2012. After 2012, *Panicum dichotomiflorum* (fall panicgrass), a fresh-intermediate species, was observed in stratum 3 and remained through 2015. In stratum 4, *P. punctatum* was once again consistently present, in all but two of the surveyed years. *S. patens* was present in 2009 and from 2012 to present, with FQI score concurrently increasing due to its high CC score (CC score: 9). *Echinochloa walteri* (coast cockspur grass), an intermediate species, was also observed in stratum 4 from 2009 until it tapers out in 2014. Stratum 5R consistently showed the presence of *P. punctatum, Vigna luteola* (hairypod cowpea)*, and B. halimifolia*. The one year these species were not present was 2012, during which sharp declines in FQI, percent cover, and species richness are observed. This was likely due to Hurricane Isaac in August 2012, as this site was surveyed three months later in November. The FQI recovered in 2013 with similar species found in 2011. *S. striata*, a fresh species, was also present most years in stratum 5R. In stratum 6R, *P. punctatum* and *S. patens* were present every year. Also, *Ipomoea sagittata* (saltmarsh morning-glory) was present every year but one. In 2012, *B. halimifolia* and *A. philoxeroides*, both fresh intermediate species, appeared and remained present every year through 2015.

Between 2000 and 2003, species richness increased in all strata except strata 4; however, it declined in 2005 following Hurricanes Katrina and Rita (Table 2a). Species richness increased in all strata in 2006, in large part due to the relocation of survey plots that had been in open water the previous year. In 2007, species richness declined in all project-specific strata except in stratum 2 which remained the same. This is likely due to the area becoming more stable two years after the massive disturbance caused by Hurricane Katrina. Between 2008 and 2015, species richness fluctuated, but there was an overall decrease in all strata except CRMS site 4355 in reference stratum 5R. An increase in species richness was seen in every stratum from 2010 to 2011, possibly due to the influx of freshwater from the flush after the Deepwater Horizon oil spill. Species richness in 2012 decreased in all strata except 1 and 4, the two westernmost strata, likely due to the effects of Hurricane Isaac; however, there was an increase in all strata from 2012 to 2013 as the vegetation community recovered from the effects of Hurricane Isaac. Species richness decreased yet again in both 2014 and 2015 in nearly all strata (Table 2b). The salinity of the area has increased slightly post-Isaac (Figure 11b), however, the species seen in recent years remain mostly fresh and fresh-intermediate (Figures 21-26) indicating a fairly stable vegetative environment that recovers well from storm-related saltwater intrusion events, returning to the fresh-intermediate profile in the following growing seasons.

Table 2a. Species richness by stratum for all species found within 4-m^2 plots of the Caernarvon Diversion Outfall Management (BS-03a) project and reference areas during 2000-2007. N=number of stations within each stratum.

Stratum	2000		2003		2005		2006		2007	
1	2.17	*N=6*	6.67	*N=6*	1.0	*N=6*	4.33	*N=6*	1.33	*N=6*
2	3.83	*N=6*	4.33	*N=6*	0.17	*N=6*	3.2	*N=5*	3.2	*N=5*
3	2.67	*N=6*	6.33	*N=6*	0.34	*N=6*	4.83	*N=6*	3.4	*N=5*
4	6.33	*N=6*	4.50	*N=4*	1.0	*N=3*	8.33	*N=3*	4.67	*N=3*
5R	2.83	*N=6*	3.67	*N=6*	3.0	*N=2*	6.83	*N=6*	5.17	*N=6*
6R	4.5	*N=6*	6.0	*N=6*	1.2	*N=5*	6.5	*N=4*	3.5	*N=4*

Table 2b. Species richness by stratum for all species found within 4-m^2 plots of the Caernarvon Diversion Outfall Management (BS-03a) project and reference areas during 2008-2015. N=number of stations within each stratum.

Stratum	2008		2009		2010		2011		2012		2013		2014		2015	
1-CRMS0128	14.8	N= 10	11.7	N= 10	5.8	N= 10	8.3	N= 10	8.3	N= 10	9.1	N= 10	9.7	N= 10	9.6	N= 10
2-CRMS0117	10.5	N= 10	12.4	N= 10	5.9	N= 10	7.6	N= 10	7.3	N= 10	10.0	N= 10	8.4	N= 10	8.1	N= 10
3-CRMS0115	10.7	N= 10	8.0	N= 10	3.1	N= 10	4.9	N= 10	1.6	N= 10	12.4	N= 10	11.2	N= 10	6.3	N= 10
4-CRMS0125	9.7	N= 10	5.1	N= 10	5.3	N= 8	9.2	N= 8	10.1	N= 8	12.3	N= 8	9.8	N= 10	8.6	N= 10
5R-CRMS0120	12.7	N= 10	12.1	N= 10	9.7	N= 10	9.9	N= 10	4.0	N= 7	13.2	N= 10	12.0	N= 10	12.6	N= 10
5R-CRMS4355	2.1	N= 10	11.1	N= 10	5.2	N= 10	11.2	N= 10	5.0	N= 10	11.5	N= 6	6.2	N= 10	2.8	N= 10
6R-CRMS0114	11.8	N= 10	8.5	N= 10	5.4	N= 10	8.6	N= 10	8.4	N= 10	10.8	N= 10	9.1	N= 10	8.5	N= 10

v. Accretion/Elevation

Vertical accretion and surface elevation change are significant variables to monitor throughout freshwater re-introduction projects because these variables can be used to monitor the contribution of freshwater diversions to marsh maintenance and building of land. Delaune et al (2013) discusses that it is critical that organic based accretion be maintained to prevent further land loss in these coastal marshes (2006). All four accretion sites show increases in average long term accretion rates (Figures 27a-d) based on data collected since 2009. CRMS0114 (reference stratum 6R) has an average accretion rate of 1.29 centimeters per year, CRMS0117 (stratum 2) averaged 1.00 cm/y, CRMS0120 (reference stratum 5R) averaged 2.19 cm/y, and CRMS0125 (stratum 4) averaged 0.46 cm/y.

Although all sites exhibited a positive accretion rate, all four sites also showed a negative elevation change (Figures 28a-d), thus indicating that other factors such as erosion and subsidence are acting on the sites and resulting in an overall decrease in surface elevation. CRMS0114 (reference stratum 6R) decreased at an average rate of -0.13 centimeters per year, CRMS0117 (stratum 2) at -0.31 cm/y, CRMS0120 (reference stratum 5R) at -0.15 cm/y, and CRMS0125 (stratum 4) at -0.20 cm/y.

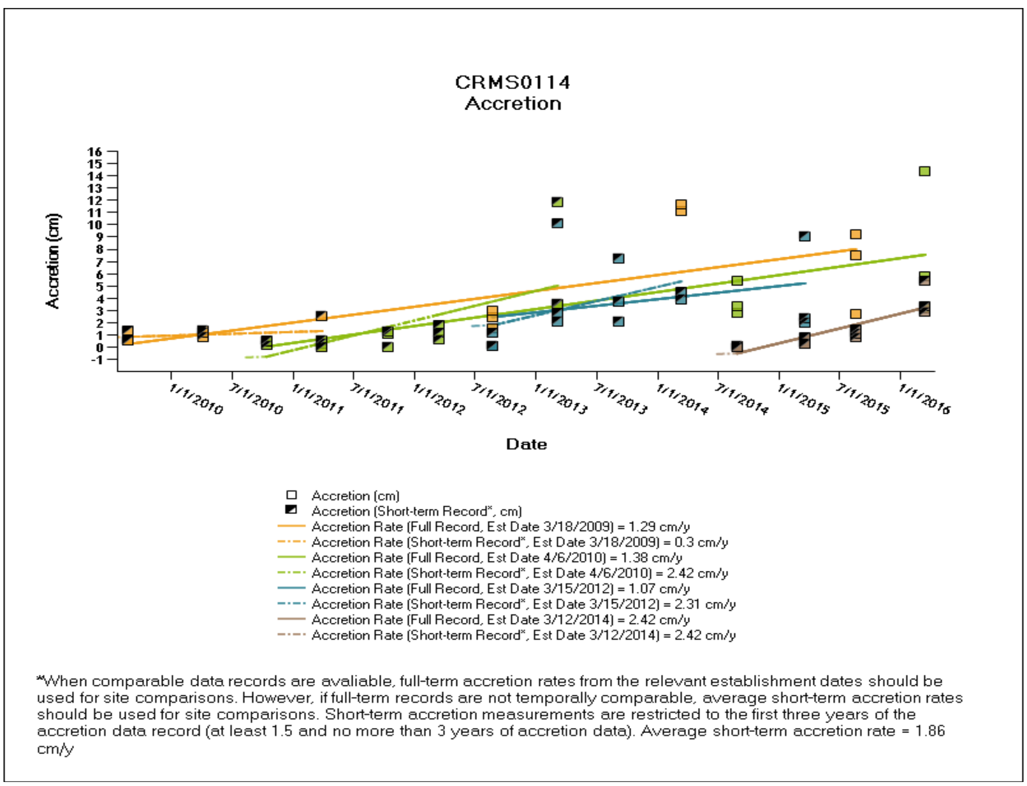

Figure 27a. Accretion rate at CRMS0114 in reference stratum 6R at the Caernarvon Diversion Outfall Management (BS-03a) project for the 2009–2016 surveys.

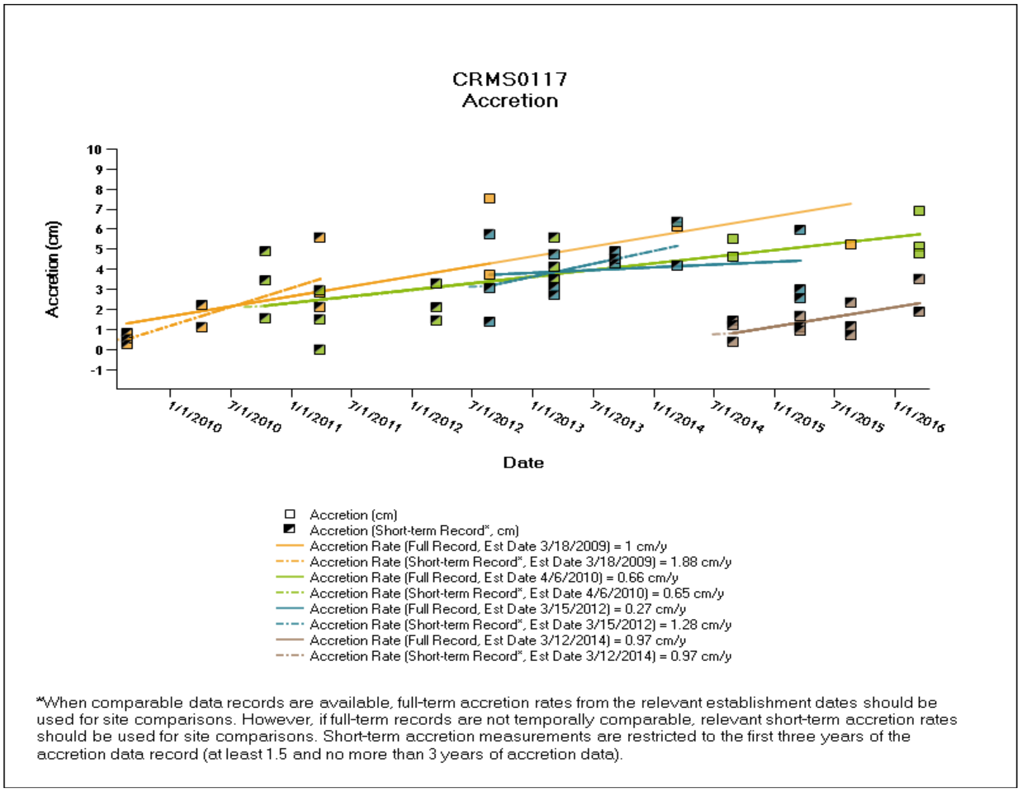

Figure 27b. Accretion rate at CRMS0117 in stratum 2 at the Caernarvon Diversion Outfall Management (BS-03a) project for the 2009‒2016 surveys.

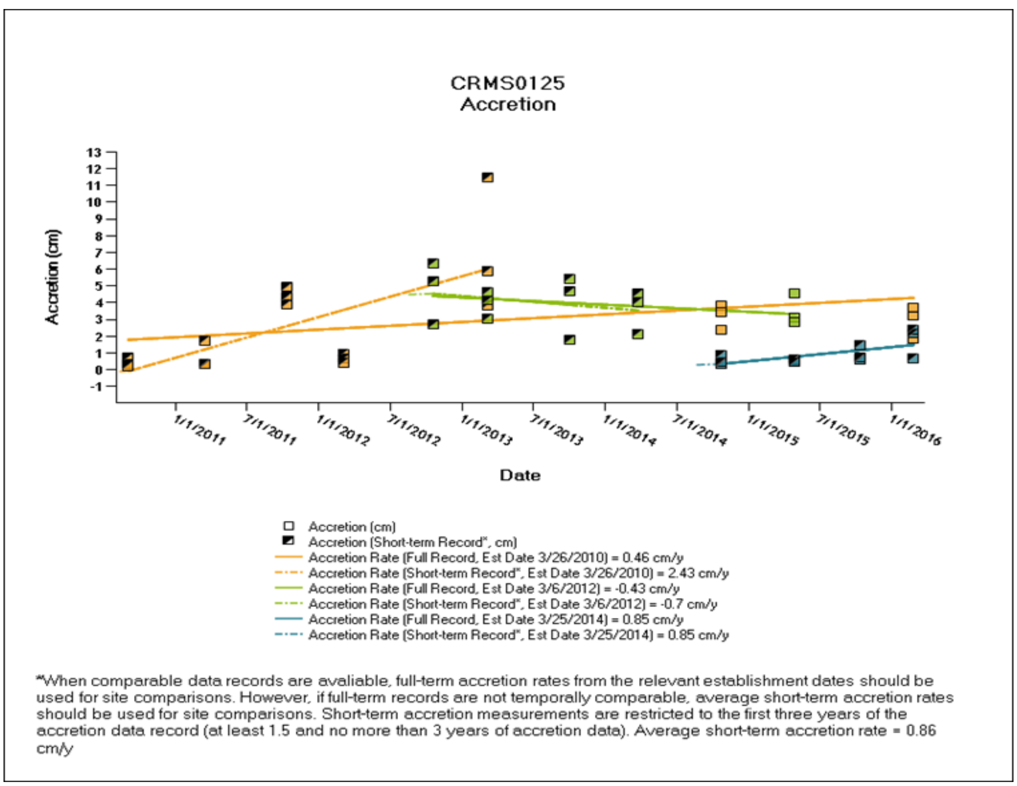

Figure 27c. Accretion rate at CRMS0125 in stratum 4 at the Caernarvon Diversion Outfall Management (BS-03a) project for the 2009‒2016 surveys.

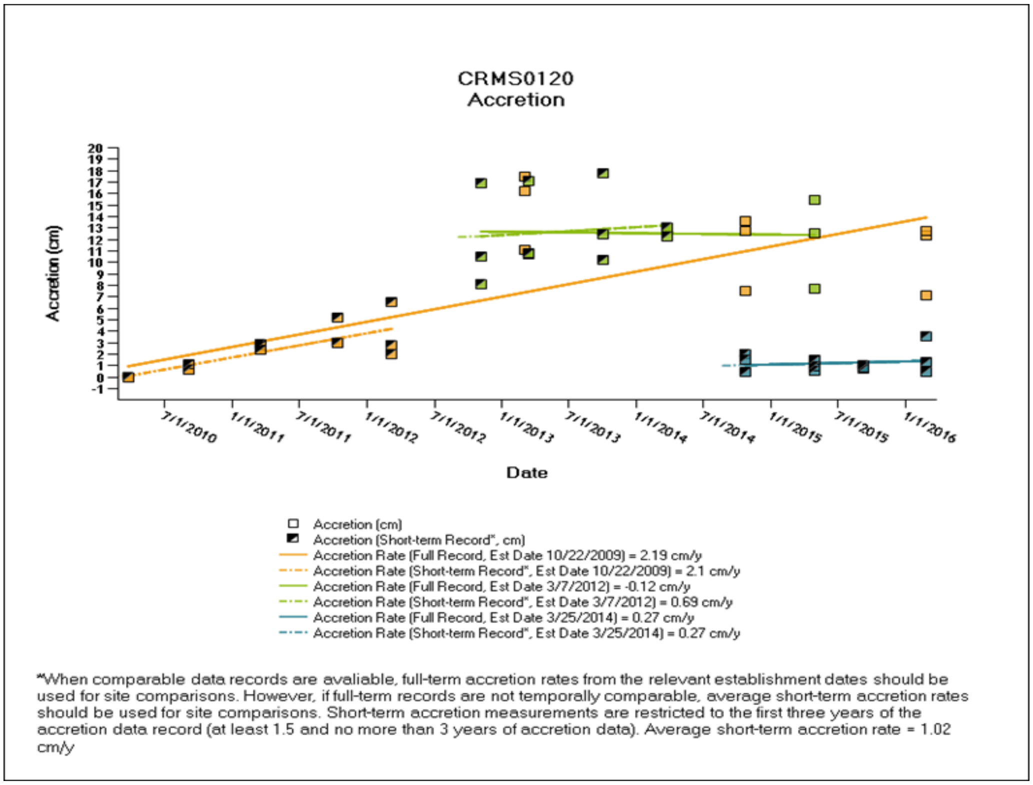

Figure 27d. Accretion rate at CRMS0120 in reference stratum 5R at the Caernarvon Diversion Outfall Management (BS-03a) project for the 2009–2016 surveys.

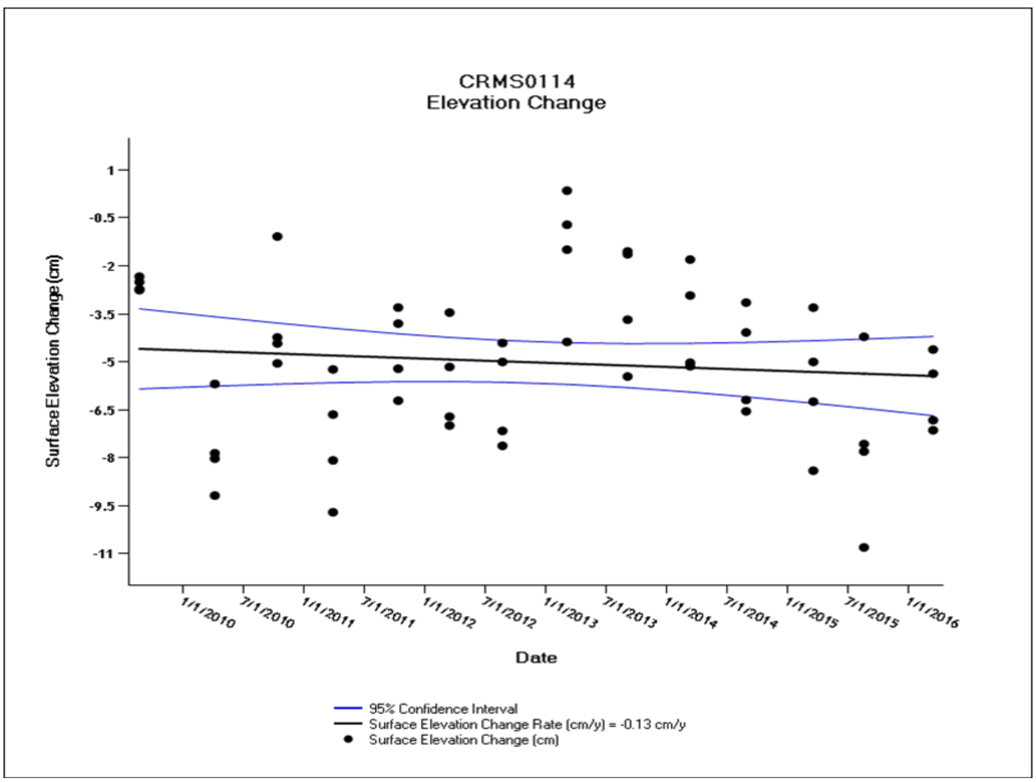

Figure 28a. Surface elevation change at CRMS0114 in reference stratum 6R at the Caernarvon Diversion Outfall Management (BS-03a) project for the 2009–2016 surveys.

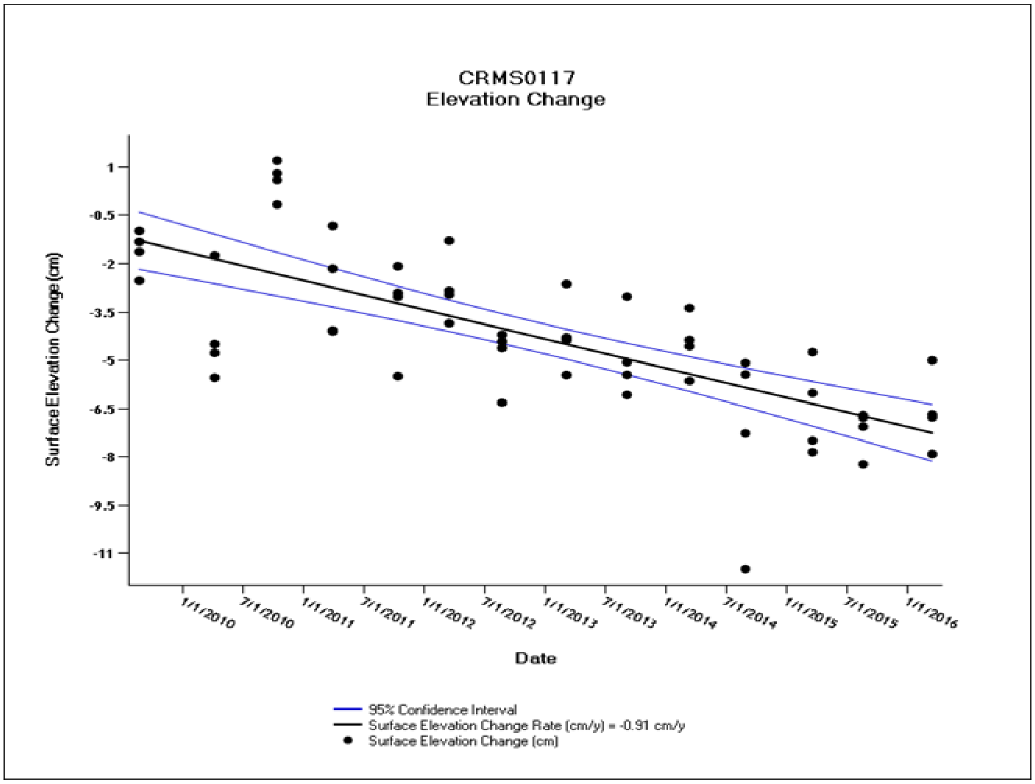

Figure 28b. Surface elevation change at CRMS0117 in stratum 2 at the Caernarvon Diversion Outfall Management (BS-03a) project for the 2009−2016 surveys.

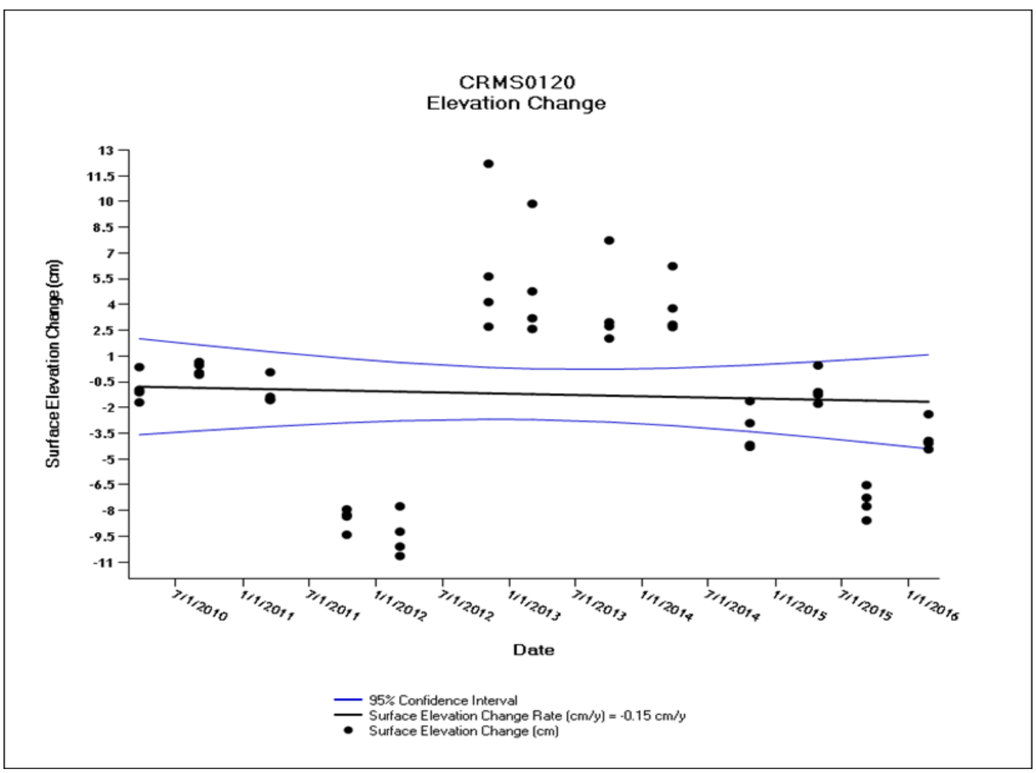

Figure 28c. Surface elevation change at CRMS0120 in reference stratum 5R at the Caernarvon Diversion Outfall Management (BS-03a) project for the 2009−2016 surveys.

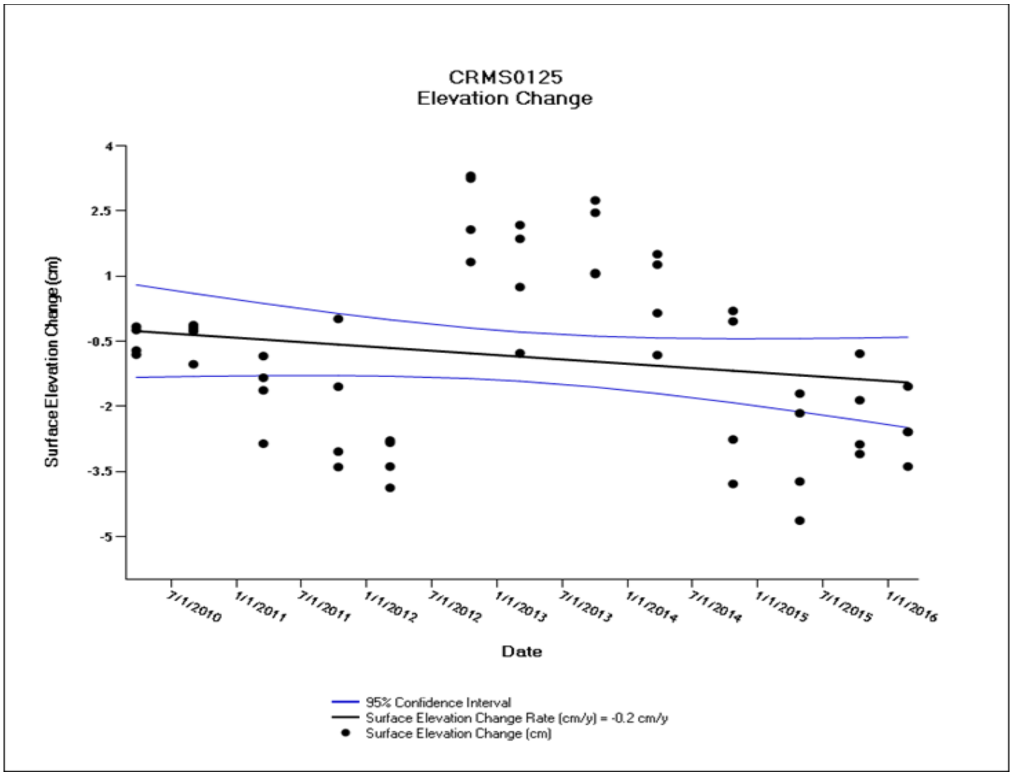

Figure 28d. Surface elevation change at CRMS0125 in stratum 4 at the Caernarvon Diversion Outfall Management (BS-03a) project for the 2009–2016 surveys.

d. Discussion

Prior to Hurricane Katrina, a salinity gradient existed within the basin with lower salinities closest to the diversion structure and increasing further from the structure. Mean daily salinities in strata 1, 2, 3, and 5R, were fresh, ranging from an average of <0.4 ppt to an average of 0.5 ppt. Strata 4 and 6R had slightly higher salinity levels, with mean daily salinities of around 0.7 ppt and 1.2 ppt, respectively. Following the storm, however, this gradient was disrupted, especially in the upper strata, due to factors including blocked canals, spoil bank degradation, and marsh rearrangement. An overall increase in salinity was observed following Hurricane Katrina. The salinity continued to fluctuate in response to tropical storm events and increased flow of freshwater from the diversion. However, after 2012, the salinity increased and remained about .5 ppt higher in almost all strata. This timeframe is consistent with a shift in Caernarvon Diversion Operations to a salinity range based operational regime, which resulted in fewer opportunities to flow the diversion. In addition, levee work in the immediate outfall area further prevented operating the diversion to its full potential.

Water levels within the project area increased within all project strata, except stratum 1, during the post-construction period. At low flow operations, strata 2 and 4 experienced increases in water level, indicating a greater retention of water within those strata. Whether this increase is a result of the project features is uncertain due to drought conditions that prevailed during the pre-construction period. Post-Katrina water levels decreased compared to the immediate post-construction period in most strata most likely due to damage to the project structures, marsh, and spoil banks which allowed water to flow unimpeded rather than being detained within hydrologic units. CRMS0125, located in stratum 4 at the southwestern boundary of the project area, does not appear to be influenced by the diversion. Salinity and water level appear to be more influenced by water exchange through the canal on which it is located.

Vegetation data was the only monitoring element collected in 2005 after Hurricane Katrina. The survey was conducted in November due to the storm-related problems associated with accessing the area, both by car and boat. Although this is two months later than the ideal sampling period, winter senescence was not the cause for the lack of vegetation observed. Only 10 of 28 stations surveyed had recordable live vegetation with most resulting in total covers of less than 15%. One plot had 80% cover of *Spartina patens* but the personnel conducting the sampling noted “clumps, 2-3ft marsh moguls” on the data sheet. The vegetation sampled was uprooted from another location and deposited near this plot, which was likely the source for most vegetation sampled during this period.

Accretion and elevation data, though not an explicit goal of the project, has been collected consistently since 2009. These data can provide information on whether the project is building land within the project area via diverted sediments. Although there has been positive accretion of sediment at the four sites monitored, there has also been an overall decrease in surface elevation at all four sites. Although sediment has been accumulating, additional factors such as subsidence, sea-level rise, and erosion, appear to have a larger, negative impact on the land, resulting in a net loss. This overall decrease in surface elevation is a consistent trend seen at CRMS sites throughout the Breton Sound basin.

V. Conclusions

a. Project Effectiveness

The effectiveness of the BS-03a project, features, and hydrologic units was heavily reliant on the natural landscape at the time of construction. Unfortunately, due to a number of factors including sea level rise, subsidence, and storm events, the current landscape has undergone a high degree of change. These changes to the landscape and hydrology of the area have impacted the effectiveness of the project features, and have made it difficult to assess any impacts due to the project versus natural events. Maintaining naturally occurring hydrologic barriers was not included in the original intent or maintenance plan of the project; therefore, restoring these barriers to the as-constructed state was not within the scope of the BS-03a project and budget.

The first monitoring goal of the Caernarvon Diversion Outfall Management project was to reduce marsh loss rates. This assessment cannot be made in this report due to the lack of aerial photography to compare pre- and post-construction. The 2006 post-construction photography could not be analyzed due to the damage to the project area from Hurricane Katrina. Aerial photography will be taken in 2018 and land-water percentages will be compared to the 2000 values. A separate analysis of land-water change between the fall of 2004 and 2005 (pre- and post-Katrina) by USGS showed water area increase by 40.9 square miles, but the water was still elevated from the recent storm. Given the severity and extent of storm impacts, it would be difficult to attribute any land/water changes to the project.

The second monitoring goal of this project was to reduce salinity variation in the interior marshes. Stratum 4 showed a reduction in salinity variance during the post-construction period. However, this decrease in salinity variance was also associated with a slightly higher mean salinity for the post-construction period. In the post-Katrina period, salinity variance increased in all strata, likely due to the rearrangement of the topography and hydrology of the project area. Structures intended to retain diverted waters within the project strata were rendered ineffective by breaches from surge forces, which allowed multiple points of water exchange. Likewise, canals that transported diversion waters to the far eastern and western ends of the upper basin were clogged with displaced marsh sediments. These landscape-level storm impacts to the project's hydrologic units resulted in higher variances than anticipated by initial project goals.

The third monitoring goal was to increase the occurrence and abundance of fresh/intermediate marsh type plant species. The percent cover of vegetation increased in all strata except reference stratum 6R between 2000 and 2003. However, the 2000 survey occurred during a drought, and the increase in cover may reflect the community recovering from drought conditions. Hurricane Katrina caused significant damage to the vegetation community in the project area. One noticeable and continuing effect to the community post-Katrina has been a decrease in *S. patens*, an intermediate-brackish species, in most strata. This species is seen more often now than immediately after Katrina, but it does not dominate the community as it did before Katrina. There has also been a post-Katrina increase in *P. punctatum*, a fresh-intermediate species that typically dominates permanently flooded locations in low marsh areas and in channels. Overall, there has also been a slight decrease in FQI across all strata. This can be attributed to more fresh species being present which are assigned a lower CC score than more saline species such as *S. patens*. Significant damage to the marsh and to some of the structural features of the BS-03a project makes it difficult to accurately assess the response of the vegetation community to the outfall management project. Additionally, the location of vegetation monitoring stations changed from project-specific stations to CRMS stations in 2008. While CRMS stations are located within each stratum, their locations within the strata are different from the project-specific stations, complicating the ability to compare vegetation changes before and after 2008.

The fourth goal of the project was to increase the occurrence of submerged aquatic vegetation (SAV) in shallow open-water areas. SAV was sampled during the spring of 2000 (pre-construction) and 2003 (post-construction); however, sampling has been discontinued due to the destructive effects of Hurricane Katrina on the marsh ponds used for sampling. This monitoring goal is no longer assessed.

Overall, it appeared the project was benefiting the area prior to Hurricane Katrina, even though the drought during the pre-construction data collection period made it difficult to determine the extent of these benefits. The hydrologic blockages resulting from Hurricane Katrina have subsequently been cleared. The Delacroix Canal which runs across the southern end of Big Mar was dredged immediately after Hurricane Katrina to allow access to gas wells on the western side of the project area. This dredged material was placed on the southern bank of the Delacroix Canal resulting in a small levee being created. Two small gaps were created along the length of this spoil placement to allow water to enter the now mostly open water area south of Big Mar (stratum 2). Prior to the storm, diverted water would overtop the entire length of this southern bank and sheet flow across the marsh. However, with the dredged material stacked to the south, most diverted water now travels east from Big Mar down Bayou Mandeville to Lake Lery. Stratum 4 lies west of this obstruction and receives little, if any, diversion input.

b. Recommended Improvements

Evaluating and re-directing Caernarvon Diversion flow by hydrologically altering the outfall area to better carry flow into the Outfall project area would be of great benefit to the project area, although the feasibility of this recommendation is uncertain. The current BS-03a project will continue to monitor recovery, attempt to re-establish flows and distribution to pre-Katrina conditions, and apply adaptive management concepts. The increased amount of open water in the project area leaves the remaining marsh susceptible to erosion from wave action. Because much of the diversion flow is lost out of Bayou Mandeville into Lake Lery, additional marsh creation and terracing sites in the area could provide some mitigation via wave abatement and sediment trapping. This concept is under discussion as part of a new project, BS-24, Terracing and Marsh Creation South of Big Mar, and some benefits may be realized from the recently completed BS-16 South Lake Lery Shoreline and Marsh Restoration project.

c. Lessons Learned

The most important lesson for the selection and design of future outfall management projects is to properly consider the structural integrity of existing topographic features, i.e., spoil banks, cheniers, etc., that the project structures will depend on to function. Proper consideration should be given to the maintenance efforts and costs necessary to maintain the landscape in the event that it is compromised through subsidence, increased water velocity, tropical weather events, or erosion during the 20-year life of the project, and these costs should be included in the selection criteria. Diversions also have a natural tendency to channelize, and periodic monitoring, adaptive management and/or maintenance events should be considered to maintain hydrologic connection to outfall project features that depend upon flows reaching intended areas. As diversion flow rates increase from no flow to high flow, a reduction in salinity is seen within the project area. However, the distribution and retention of diversion waters is most effective at lower flow rates.

The project area is susceptible to storm surge, and freshwater marshes are particularly susceptible to damage from storm surge. The majority of marsh that remained in the project area post-Katrina was adjacent to spoil banks that had woody vegetation growing on them. Ridges with trees may be a highly beneficial restoration technique in freshwater marshes to retain the displaced marsh. Storm surges can also significantly increase salinity in the basin. The diversion and outfall structures could be utilized following a storm surge to flush saltwater from interior marshes more quickly and efficiently, helping to protect fresh and intermediate marsh areas.

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APPENDIX A
Photographs

Photo No. 1, Site 13

Photo No. 2, Site 13

Photo No. 3, Site 13

Photo No. 4, Site 26

Photo No. 5, Site 26

Photo No. 6, Site 40

Photo No. 7, Site 40

Photo No. 8, Site 50

Photo No. 9, Site 50

Photo No. 10, Site 50

Photo No. 11, Site 51

Photo No. 12, Site 52

Photo No. 13, Site 52

Photo No. 14, Site 52

Photo No. 15, Site 54

Photo No. 16, Site 54

Photo No. 17, Site 56

Photo No. 18, Site 56

Photo No. 19, Site 58

Photo No. 20, Site 60

Photo No, 21, Site 60

Photo No. 21, Site 60

Appendix B
Three-Year Operations & Maintenance Budgets

Caernarvon Outfall Management (BS-03a)

Federal Sponsor: NRCS

Construction Completed : September 10, 2002

Current Approved O&M Budget July 2016	Year 0 FY03	Year - 1 FY 04	Year -2 FY05	Year -3 FY06	Year -4 FY07	Year -5 FY08	Year -6 FY09	Year -7 FY10	Year -8 FY11	Year -9 FY12	Year -10 FY13	Year -11 FY14	Year -12 FY15	Year -13 FY16	*Year -14 FY17*	*Year -15 FY18*	*Year -16 FY19*	Year - 17 FY20	Year -18 FY21	Year -19 FY22	OCPR Project Estimate Project Life Budget	CWPPRA Allocated Money Currently Funded (Sum YR 0 to YR 19)
State O&M	$3,870	$3,971	$4,074	$4,180	$265,424	$4,400	$4,514	$4,632	$4,752	$301,775	$5,002	$5,133	$5,266	$5,403	$343,113	$5,687	$5,835	$5,987	$6,143	$56,773	$1,045,934	$1,045,934
Corps Admin																					$0	$0
Federal S&A																					$0	$0
Total																					$1,045,934	$1,045,934

Projected O&M Expenditures	Year 0 FY03	Year - 1 FY 04	Year -2 FY05	Year -3 FY06	Year -4 FY07	Year -5 FY08	Year -6 FY09	Year -7 FY10	Year -8 FY11	Year -9 FY12	Year -10 FY13	Year -11 FY14	Year -12 FY15	Year -13 FY16	*Year -14 FY17*	*Year -15 FY18*	*Year -16 FY19*	Year - 17 FY20	Year -18 FY21	Year -19 FY22	Remaining Project Life	***Current 3 year Request (FY17, 18, 19)***
Maintenance Inspection									$4,752	$4,876	$5,002	$5,133	$5,266	$5,403	$5,543	$5,687	$5,835	$5,987	$6,143	$6,302	$35,497	$17,065
General Maintenance																					$0	$0
Structure Operation									$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$300,000	$150,000
Federal S&A									$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$30,000	$15,000
State S&A									$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$60,000	$30,000
E&D									$10,000												$0	$0
Surveys									$15,000												$0	$0
Construction									$265,000												$0	$0
Construction Oversight									$5,000												$0	$0
Total					$0	$0	$0	$0	$364,752	$69,876	$70,002	$70,133	$70,266	$70,403	$70,543	$70,687	$70,835	$70,987	$71,143	$71,302	$425,497	$212,065

Total O&M Expenditures from COE Report (Inception to present)	$679,761.27	LanaReport Mar2016
State O&M Expenditures not submitted for in-kind credit	$0	
Federal Sponsor MIPRs (if applicable) (REQUESTED MONEY)	$0	
Total Estimated O&M Expenditures (as of March 2016)	**$679,761.27**	

Current O&M Budget less COE Admin *(State O&M Currently Funded + Fed S&A Currently Funded)*	$1,045,934	
Remaining Available O&M Budget *(Current O&M - Total Est. O&M Expenditures)*	$366,173	
Incremental Funding Request Amount FY17-FY19	**$ (154,107.73)**	3 year surplus

Current Project Life Budget less COE Admin *(State O&M Project Life Budget + Fed S&A Project Life Budget)*	$1,045,934
Total Projected Project Life Budget *(Remaining Project Life + Total Estimated O&M Expenditures)*	$1,105,258
Project Life Budget Request Amount	**$59,324**

Notes:

1. The year-by-year figures for the current Approved O&M Budget are based on the BEAST approved at the 6/3/09 Task Force meeting. This spreadsheet was a correction to the BEAST submitted for the Fall 2008 funding requests.

Previous O&M Funding Requests	Baseline Approved Funding	2014	2015	Currently Funded
State O&M				$0
Corps Admin				$0
Federal S&A				$0
Total	$0	$0	$0	$0

Appendix C
Field Inspection Form

FIELD INSPECTION CHECK SHEET

Project No. / Name:	Caernarvon Outfall Management BS-03a	Date of Inspection:	7/5/2016 Time: 10:30 AM
Structure No.	**See Report Section III**	Inspector(s):	CPRA: David Chambers, Erin Plitsch, Kathleen Eubanks NRCS: Loland Broussard
Structure Description:	See Report Section III	Water Level:	Marsh: -0.5 NAVD88 River: +3.40 NAVD88
Type of Inspection:	2016 Annual Inspection	Weather Conditions:	Cloudy and Warm, Wind Calm (0 cfs Diversion)

Item	Condition	Physical Damage	Corrosion	Photo	Observations and Remarks
CMP Culverts Earthen / Rock Embankment	Good	Minor	None	Appendix B	Culverts appear to be clear. Water surface elevations were mostly at the crest of the structures. Scale of scouring at tie-ins needs to be reviewed and level of severity determined. **Breach of about 20-25 feet wide is present at site #52.**
Water Control Gates	Good	None	Moderate	Appendix B	All water Control Gates appear to be in good condition. The O&M contractor has been reportedly lubricating, cleaning, and operating all gates on a scheduled basis. Gears on the gates are clean. Bolts holding gearbox to the gate structure are stainless steel.
Rock Canal Closures	Good	See Remarks	N/A	Appendix B	One of the warning signs at structure #56 is leaning lseverly and needs to be cleaned.
Timber Piling at Culverts	Good	None	None	Appendix B	Structure #13 is tilting as the timber piles settle unevenly. All other timber pilings are in good condition.
Timber walkways at Culverts	Good	See Remarks	N/A	Appendix B	Structure #50 has a wood plank that is detached from structure on one end. Minor damage consists of bowing deck boards.
Spoilbank Restoration	Fair	Minor	N/A	Appendix B	Vegetation (grasses, shrubs, and trees) has flourished along the banks. Moderate scouring is evident at shoreline/water surface interface due to increased boat traffic.
Flow Meters	N/A	N/A	N/A	Appendix B	Flow meters installed at structures No. 26, 40, and 54 were removed in 2011 and 2014 due to damage and not replaced.