State of Louisiana
Coastal Protection and Restoration Authority

2011 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 2011 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 December 2010, and annual maintenance inspections through July 2011. The 2011 Caernarvon Diversion Outfall Management OM&M report is the 3rd in a series of reports. For additional information on lessons learned, recommendations and project effectiveness please refer to the 2004 and 2008 OM&M reports on the CPRA Resources web site.

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 another 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 had 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). Submersed 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).

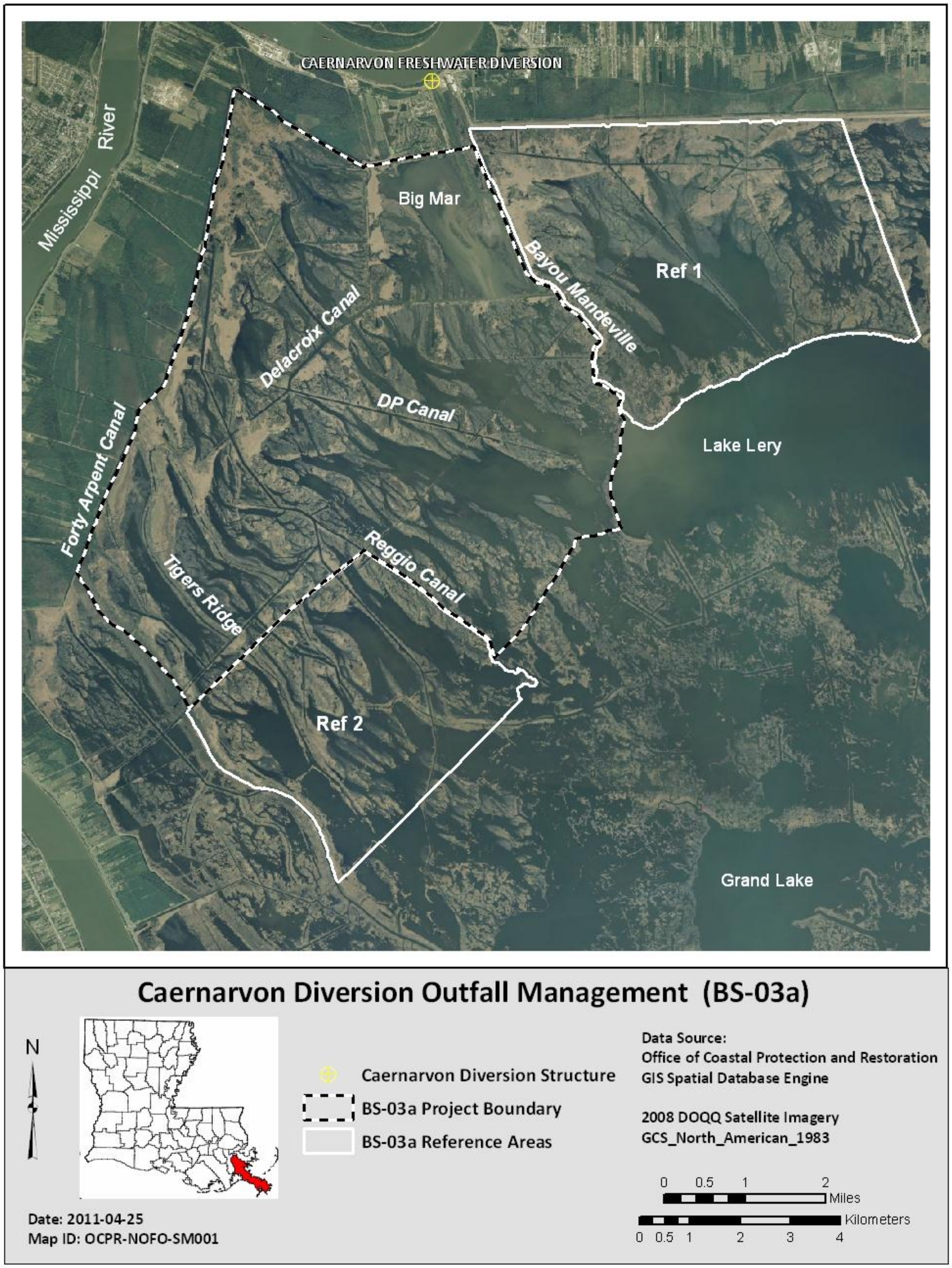

Figure 1. Caernarvon Diversion Outfall Management (BS-03a) project and reference areas.

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 discharge has been much less than anticipated due to several contributing factors. These factors include oyster industry lawsuits, above normal rainfall that adds to the natural freshness of the basin, and a shrimping industry that prefers to not allow excessive amounts of fresh water in the spring. 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 Caernarvon Diversion structure. Prior to the BS-03a project, man-made spoilbanks and plugs routed much of the water to the lower southwest reaches of the basin and did not inundate the 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, deposition of suspended sediments, and assimilation of nutrients by the vegetation communities. This goal was approached by enhancing existing spoil banks and installing plugs and water control structures in key locations 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 Caernarvon Diversion Outfall Management 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 feet 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 are bound by high ridges or spoil banks within the project area; 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 different regions of the project area 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.

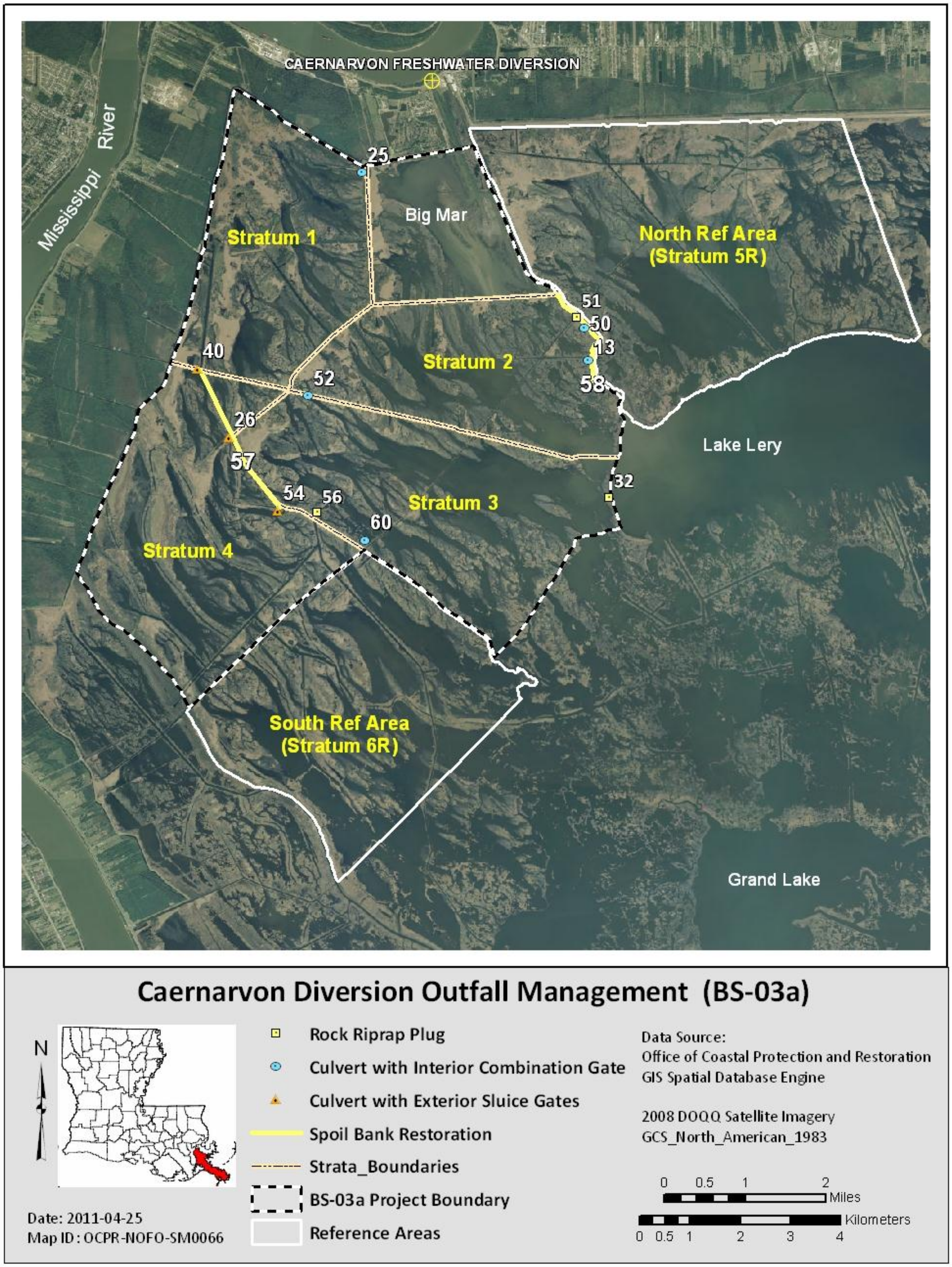

Figure 2. Caernarvon Diversion Outfall Management project (BS-03a) boundaries and features. A combination of culverts, plugs and spoil bank restoration allows water from the channels to flow into the marsh interior and be retained in the marsh for a longer period of time.

Once diversion water enters Big Mar, an estimated 80% of the water currently exits southeast to Lake Lery via Bayou Mandeville, with only 20% 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 a greater percentage 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 north and west 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. 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

The O & M contractor was given a maintenance schedule designed to ensure the project features operate as designed. O & M tasks for the gates and culverts include the lubrication and periodic operation of each structure, cleaning of 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.

In July 2011, three flow meters were re-installed by the O & M contractor at structures #26, 40, and 54. The contractor will monitor the flow of fresh water into the interior marshes to determine if the operation of the sluice gates on the water control structures is providing optimum flow and when maintenance dredging of associated channels may be necessary.

Note: Simon & Delany is the O & M contractor for the diversion structure and the outfall project. They are often called upon to conduct specific inspections and maintenance items between annual inspections.

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, and 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 (O & M Plan; May 15, 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 was conducted on May 5, 2011 by Tom Bernard and Kyle Breaux from CPRA and Mike Trusclair from NRCS (Bernard 2011). On the day of the inspection, the diversion structure was flowing at 525 cubic feet per second. The marsh gauge reading was +0.82 feet NAVD, and the river gauge reading was +16.48 feet NAVD. All photographs taken at the time of the inspection are included in Appendix A.

b. Inspection Results

After Hurricane Katrina, most of the length of the Delacroix Canal was blocked by debris. The Delacroix Corp. excavated a floatation route through this blockage to allow mobilization of their floating plant to access their marsh management areas. Only 500 ft. of that severe blockage remained prior to a dredging contract that was completed on June 28, 2011. The dredging was in progress at the time of the 2011 inspection. Water now flows freely through the Delacroix Canal and into the Reggio Canal, which feeds the western side of the outfall area. Structures #25 and #32 are only accessible by air boat during the inspection due to clogging of the access channel from water hyacinth and siltation, respectively.

A. Site/Structure #13 – Water is moving into the marsh. It appears that scouring has formed a breach in the south side of the closure at the structure tie-in. This 2-3 foot gap in the closure is allowing water to flow freely in and out of the project area. The combination gate was in the up/open operating position to allow maximum uninterrupted tidal exchange into the marsh. The combination gates will be closed to allow the flap gates to function as designed. The timber walkway is still separated from its support beam at one end (Photos 1 & 2).

B. Site/Structure #25 – Water hyacinth blocked the canal and prevented inspection of the structure; however, that structure was inspected by the O & M Contractor by airboat. The Forty Arpent Canal was clear leading to the structure.

C. Site/Structure #26 – The gates were in the open position allowing unimpeded flow. Massive blooms of water hyacinth have carpeted the Reggio Canal surface. There is seasonal vegetation covering the earthen/rock closures that house the culverts (Photos 3 & 4).

D. Site/Structure #32 – The area was partially repaired by the 2003 inspection team; however, that repair was again vandalized. The canal closure still functions even during high flows. This structure was constructed to keep diversion water in Bayou LeBlanc from entering Lake Lery through a breach in the western lake rim. Hurricane Katrina devastated that portion of the lake rim rendering this structure ineffective until the lake rim is repaired (USFWS Lake Lery Shoreline Restoration and Marsh Creation CWPPRA Project (BS-16)).

E. Site/ Structure #40 – The gates remain in the open position, and the culverts remain clean. The interior channel that leads to the site was blanketed by water hyacinths (Photos 5 & 6).

F. Site/Structure #50 – The combination gate was in the up/open position. The gate will be completely lowered to allow the flap gate to function as designed. A small amount of water movement was noticed through the structure to the interior marsh. The timber walkway remains bowed. The next maintenance contract for the Caernarvon Outfall will include a work item for repair of this breach. (Photos 7 & 8)

G. **Site/Structure #51 –** This plug is heavily vegetated. Maintenance is not required for this structure.

H. **Site/Structure #52 –** The two combination gates were in the up/open position. The combination gates will be closed to allow the flap gates to function as designed. A 10-15 foot wide breach was plugged in June 2011 by the Delacroix Canal dredging contractor. The photo in the appendix shows the breach prior to the repair. (Photos 9 & 10)

I. **Site/Structure #54 –** The gates remain in the open position. Water flow indicated that the culverts are clear. The channel leading to the earthen/rock closure has growth of water hyacinth (Photo 11).

J. **Site/ Structure #56 –** No additional subsidence was noted in this rock structure since the last inspection. Small amounts of vegetation remain on the entire rock closure. Soon after construction, the middle section of the plug subsided approximately 0.5 feet more than the sides. The warning signs that were damaged during the storm were previously reset; however, one of the signs is leaning and partially submerged (Photo 12).

K. **Site #57 –** Vegetation on the spoil bank along the sides of the Reggio Canal includes grasses and shrubs. There are small breaches in the spoil-bank between structure #26 and #40 (Photos 13 & 14).

L. **Site #58 –** The vegetation on the spoil bank along the sides of Bayou Mandeville includes grasses, shrubs, and trees. The 2012 inspection will determine whether the spoil bank elevation is effectively separating the hydrology of the interior marsh and Bayou Mandeville. (Photo 15)

M. **Site/Structure #60 –** At the time of the inspection, the two combination gates were in the up/open position but will be closed to allow the flap gate to control the marsh water levels. Water flow indicated that the culverts remain clear. Vegetation has covered the canal closure and the majority of the earthen/rock closure that houses the culverts (Photo 16).

Areas of the outfall project have recovered since Hurricanes Katrina, Gustav, and Ike. A steady, moderate-to-high flow of river water through the diversion aids this recovery. All structures are functioning as required.

c. Maintenance Recommendations

i. Immediate/ Emergency Repairs

No repairs are suggested at this time.

ii. Programmatic/Routine Repairs

The CPRA concludes that the outfall project will slowly be restored to its original condition; however, the dynamics of the project have been changed because storms have reduced the amount of diverted water that flows west. Channels need to be cleared and washed-out marsh perimeter embankments need to be repaired. High flows through the diversion structure should assist in flushing out these channels. Repairing the entire hurricane-damaged west and south rim of Lake Lery would help prevent diversion water from entering the lake from those sides. USFWS Lake Lery Shoreline Restoration and Marsh Creation CWPPRA Project (BS-16) is in the final design stage to mitigate the damage in this same area. This project, when construction funding is obtained, is expected to take approximately 1 year to complete.

The CPRA suggests that the State and NRCS continue to work together to address the following challenges that arose post-design and construction of the diversion and outfall management projects: 1) Oyster litigation that continues to influence the operational plan for the diversion and 2) Severe storm damage from the three storms that dramatically changed the dynamics of the entire outfall landscape. Also, the CPRA recommends continued aggressive operation of the diversion structure to divert more freshwater to the western side of the project. The Delacroix Corp. received a marsh management permit that will allow them to repair the spoil-banks and holding areas that contributed to the success of this project.

Legislation resulting from storm damage granted $10.1 million towards a project identified by the 4th supplemental appropriation. The CPRA encourages collaboration between the State, NRCS, and USACE to best utilize these funds for restoration of the surrounding wetlands through modifications of the Caernarvon Freshwater Diversion project and main structure operations. Under the supplemental appropriation, the USACE will look to re-authorize the project in order to maximize freshwater diverted to the Breton Sound Basin. If the project is re-authorized, the demand for introduction of more freshwater into the marshes could reach the maximum flow (8,000 cfs) whenever the river stage would allow.

III. Operation Activity

a. Operation Plan

The gated structures 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, none of the structures were operated in 2010, and all gates were in the open position to allow fresh water in all the marsh areas. At the conclusion of the 2011 inspection, Simon and Delany were instructed to lower all combination gates. The contractor continues to perform periodic O & M of each of the gated structures. This includes cleaning and maintaining the timber platforms and periodic inspections as directed by the CPRA. In early 2008, the contract was re-bid for operation of the main diversion structure, including the operation and maintenance of the outfall structures. That contract went into effect on July 1, 2008, and was renewed in 2009, 2010, and 2011. On July 1, 2011, Simon and Delany was awarded the contract for the entire BS-03a project.

IV. Monitoring Activity

This OM&M report includes all data collected from March 2000 through December 2010. In August 2005, Hurricane Katrina destroyed all 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.

b. Monitoring Elements

<u>Habitat Mapping</u>
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 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. CRMS0115 and CRMS0120 were converted from marsh well stations to typical monitoring surface water stations at their respective start dates. Adjusted salinity data were available through the end dates shown below.

CRMS Station Monitoring Dates – Salinity		
Stratum 1	CRMS0128	10/29/2007−12/31/2010
Stratum 2	CRMS0117	Well data
Stratum 3	CRMS0115	04/09/2009−12/07/2010
Stratum 4	CRMS0125	01/21/2008−10/14/2010
Stratum 5R	CRMS0120 CRMS4355	08/18/2009−12/13/2010
Stratum 6R	CRMS0144 CRMS0114	Well data

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 six CRMS sites (post-Katrina). Average marsh elevation (NAVD 88) was determined at each site, enabling the assessment of frequency, duration, and depth of marsh inundation. Adjusted water level data were available through the end dates shown below.

CRMS Station Monitoring Dates - Water Level		
Stratum 1	CRMS0128	10/29/2007−12/31/2010
Stratum 2	CRMS0117	10/29/2007−11/08/2010
Stratum 3	CRMS0115	10/29/2007−12/07/2010
Stratum 4	CRMS0125	01/21/2008−10/14/2010
Stratum 5R	CRMS0120	10/29/2007−12/13/2010
Stratum 6R	CRMS0114	10/29/2007−12/31/2010

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. 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 has been discontinued 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 floating marsh. The stations were built during the drought when water levels were low and the marsh was not identified as flotant. Accretion data was collected at CRMS stations in 2009 and 2010 and will be analyzed in the 2014 OM&M report.

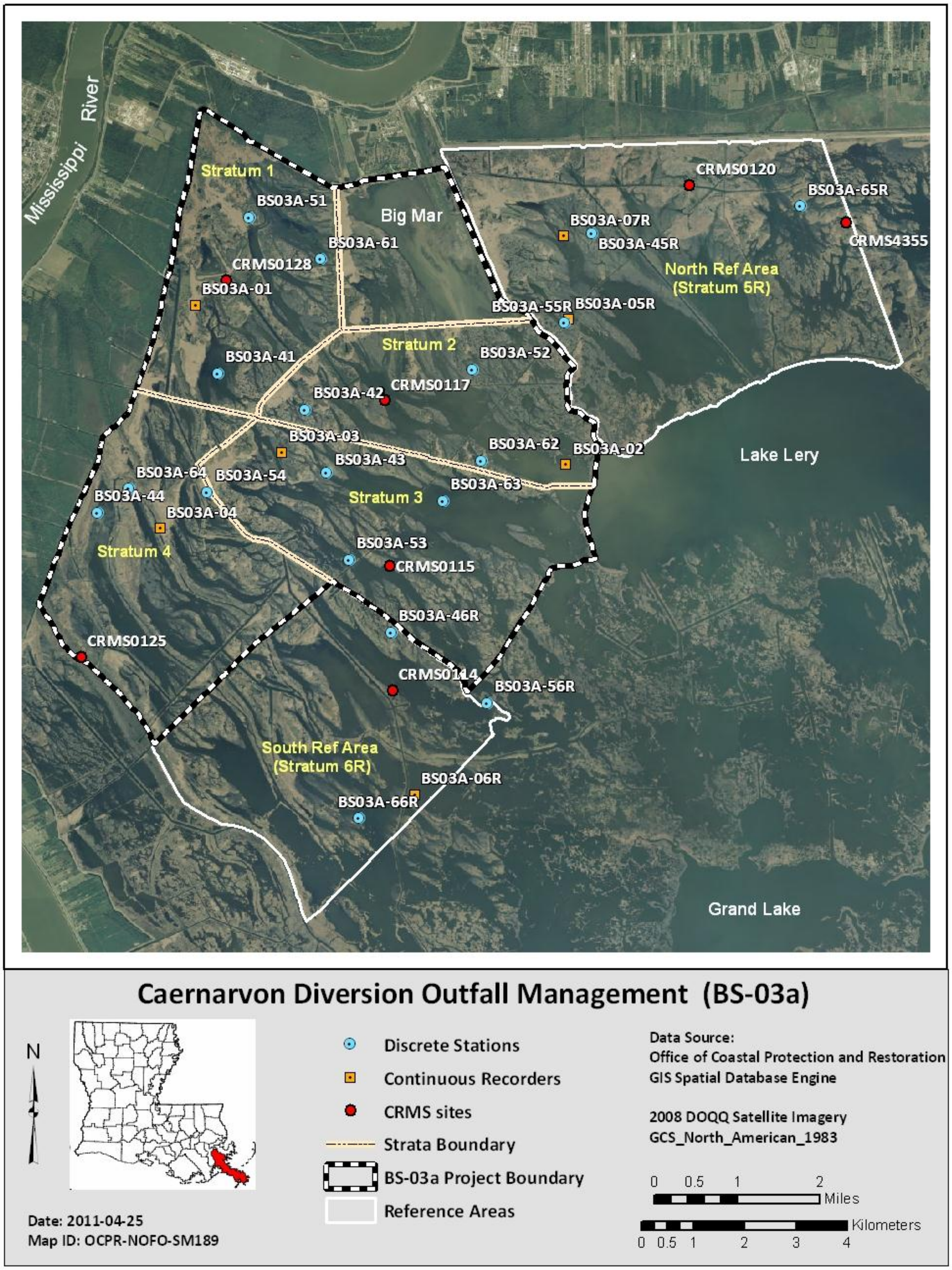

Figure 3. Location of Caernarvon Diversion Outfall Management Project (BS-03a) project-specific and CRMS hydrologic stations. All project-specific continuous and discrete monitoring stations were rendered inoperable by Hurricane Katrina in 2005. CRMS sites have been used for data collection since 2007.

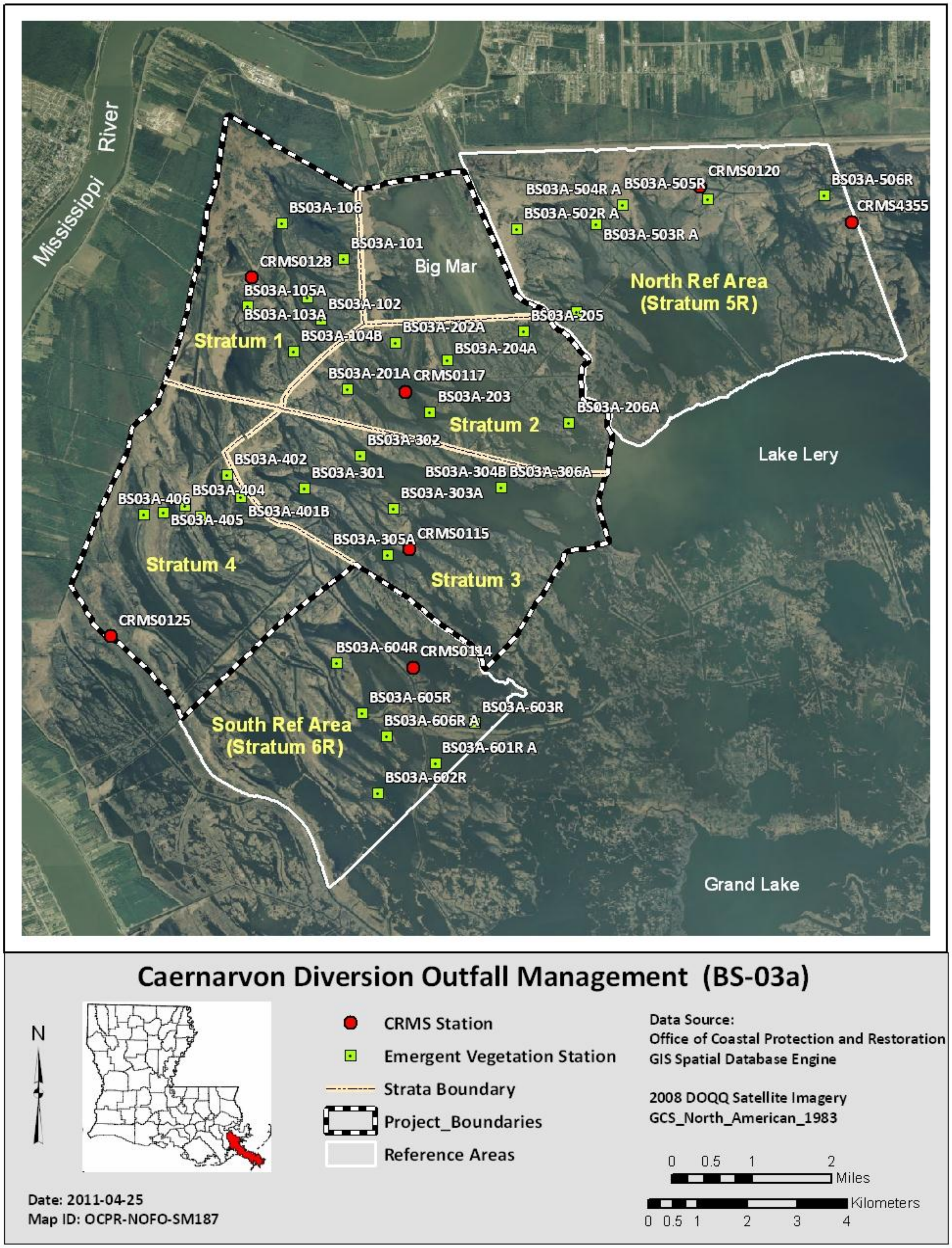

Figure 4. Location of Caernarvon Diversion Outfall Management (BS-03a) project-specific and CRMS vegetation stations. Species composition and relative abundance were documented at project-specific sites in 2000, 2003, 2005, 2006 and 2007; however, these sites were discontinued after 2007. Since 2008,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

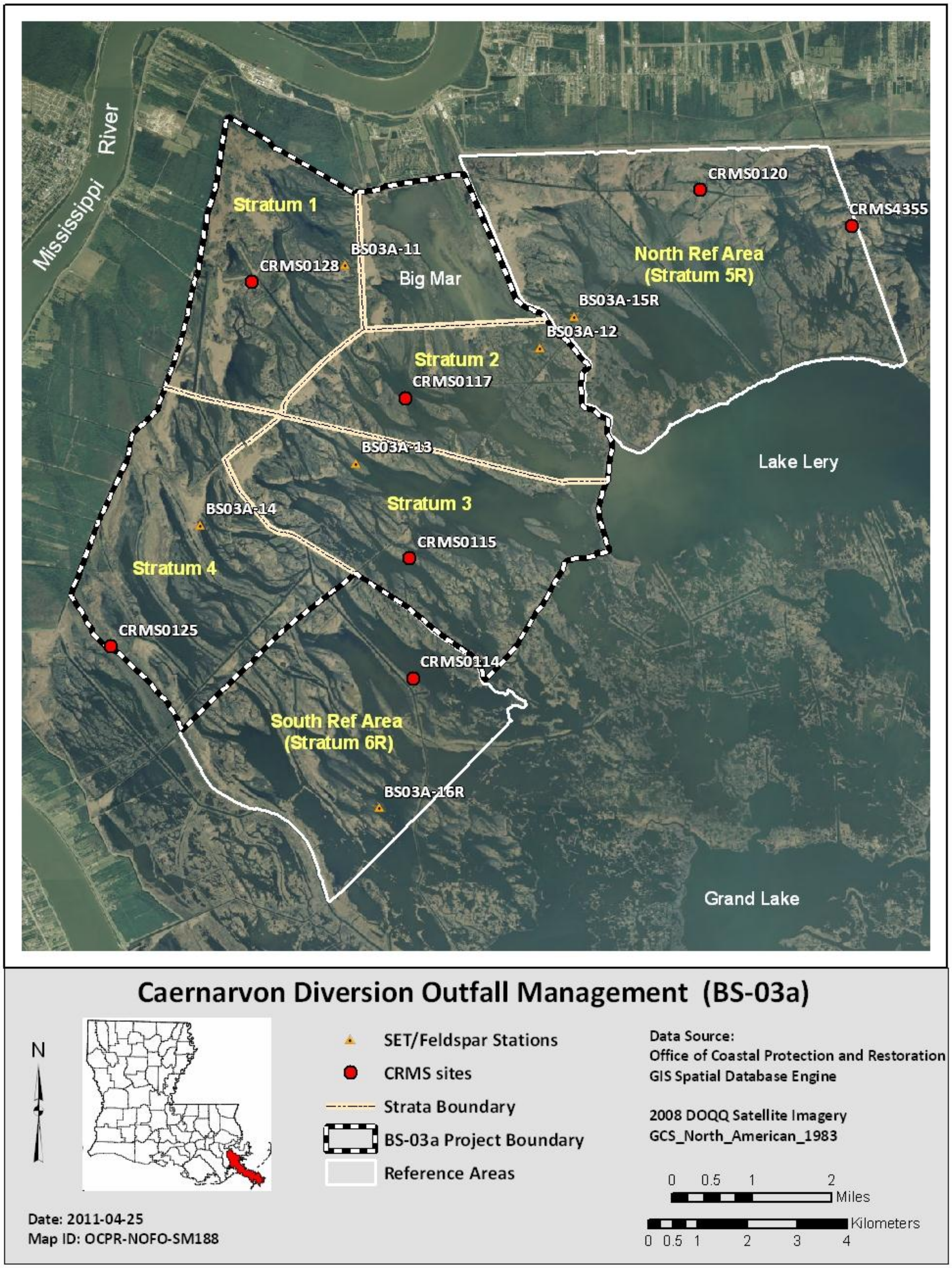

Figure 5. Location of Caernarvon Diversion Outfall Management (BS-03a) project-specific and CRMS accretion sampling stations.

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, there are no post-construction land-water analysis data to compare to pre-construction data. The next round of aerial photography will be taken in 2018.

To show the effects of Hurricane Katrina in the Caernarvon area, satellite imagery was acquired a week after the hurricane by the USGS and compared to a pre-storm image from 2004 (Figure 7). The amount of marsh loss is considerable, although it must be taken into consideration that water levels were still elevated at the time of the photo acquisition. Analysis of land-water change between the fall of 2004 and 2005 by USGS scientists using Landsat 5 Thematic Mapper imagery showed the Breton Sound basin's water area increased by 40.9 square miles. This one-year loss estimate 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.

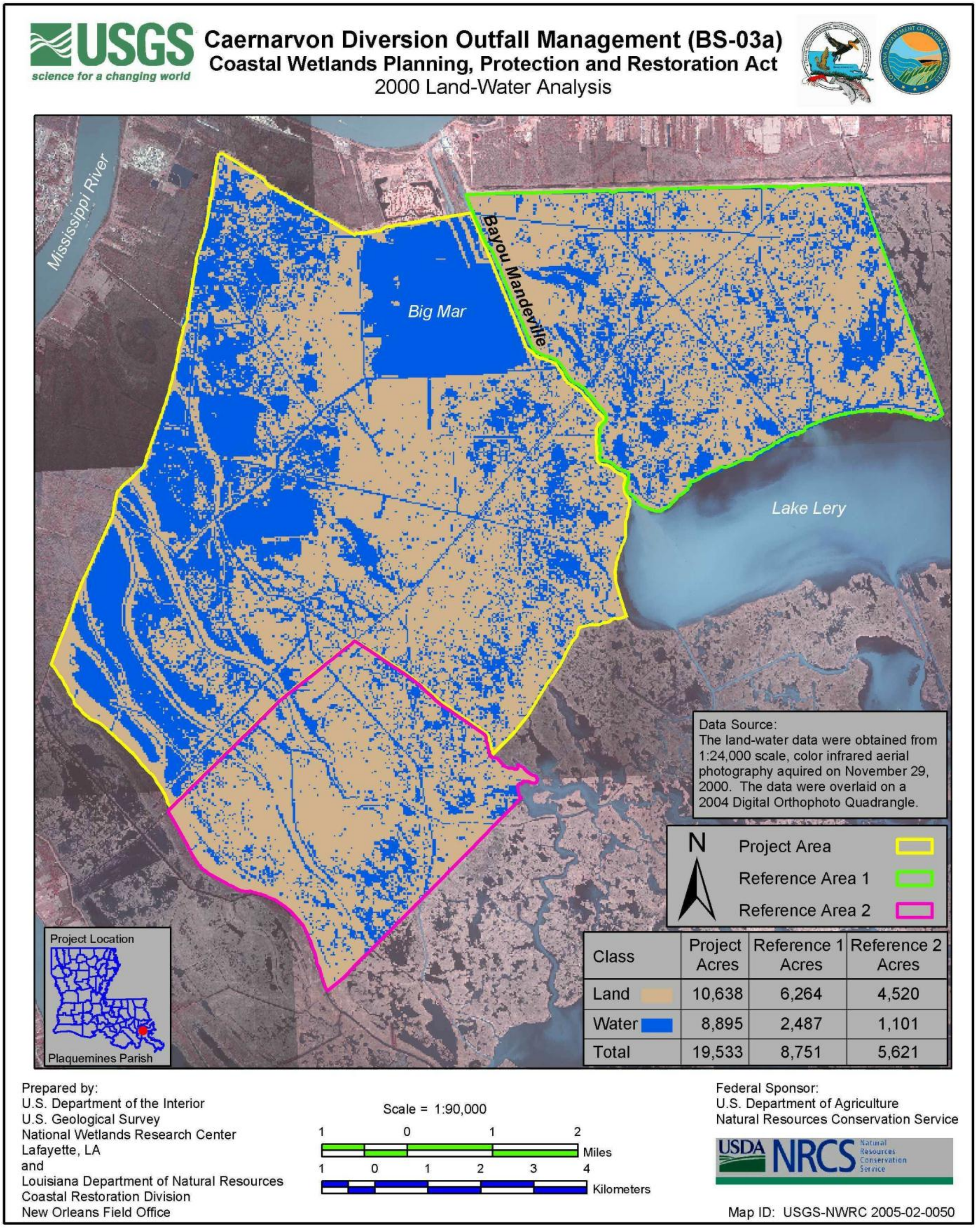

Figure 6. 2000 Land-water analysis for the Caernarvon Diversion Outfall Management (BS-03a) project.

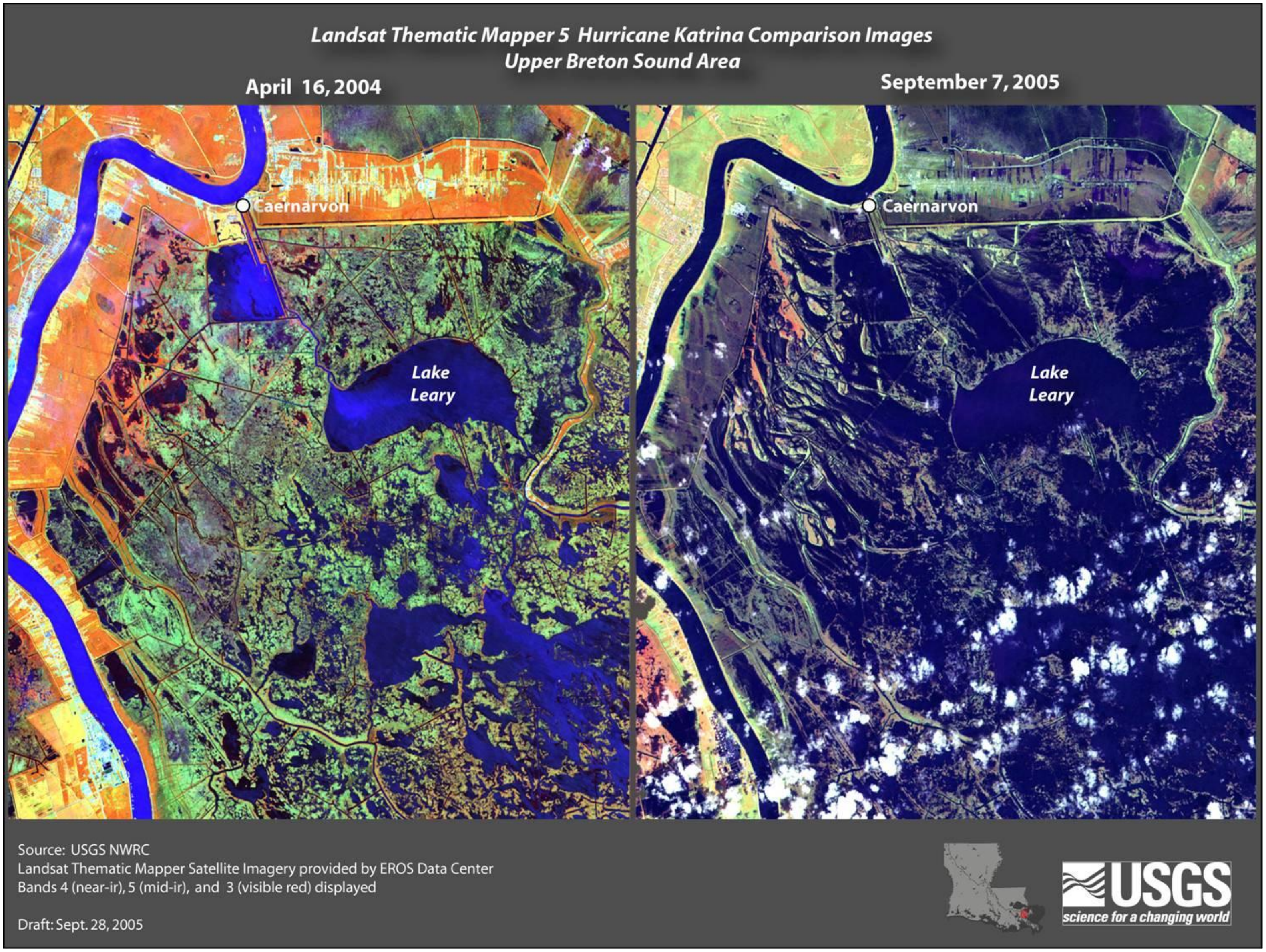

Figure 7. Pre- and post-Katrina satellite imagery showing changes to the Caernarvon area from the storm.

ii. Salinity

The initial deployment of the Caernarvon Diversion Outfall Management project-specific continuous recorders occurred in the middle of 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). 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). This flushing effect can also be seen after tropical storm events when diversion waters dilute and displace more saline waters associated with storm surges. Both project-specific (2000-2005) and CRMS data (2007-2010) 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). 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. Flow data for all analyses are from USGS station DCPBS09, located at the Caernarvon Outfall Channel.

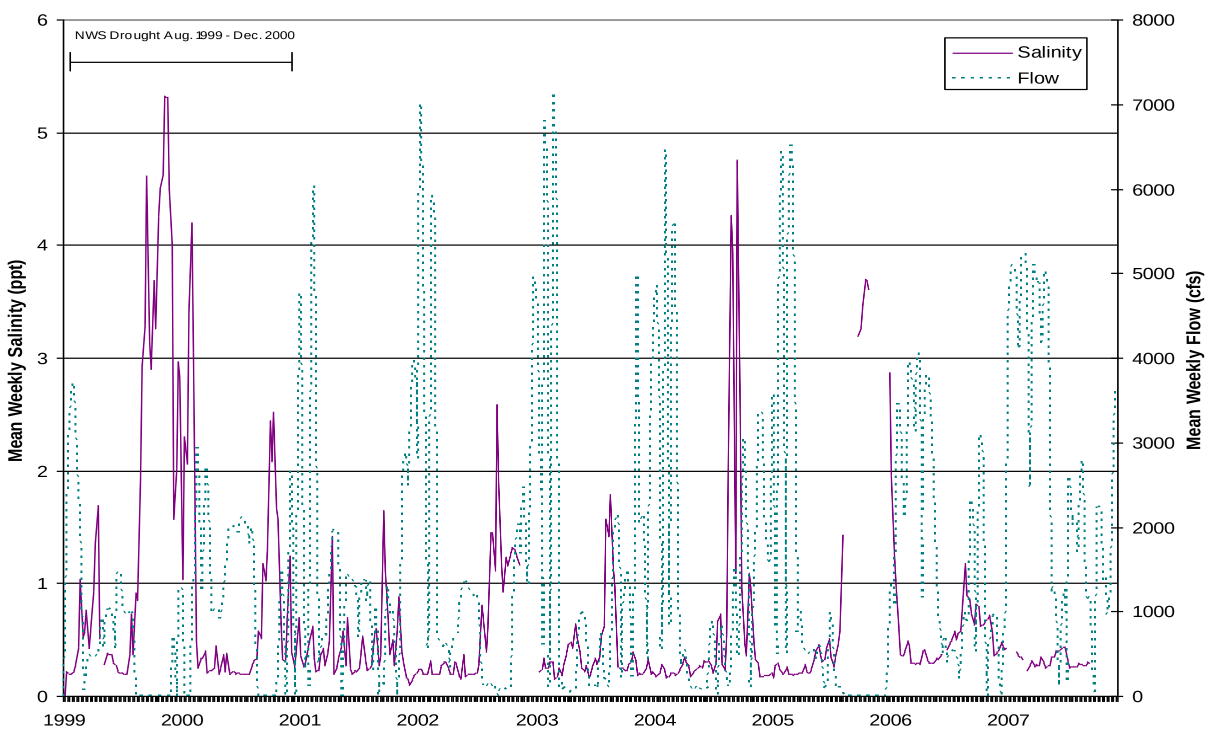

Figure 8. Mean weekly salinity at the Reggio Canal station (DCPBS06), located within the Caernarvon Diversion Outfall Management (BS-03a) project area, and mean weekly flow rates for the Caernarvon Diversion (DCPBS09), 1999−2007.

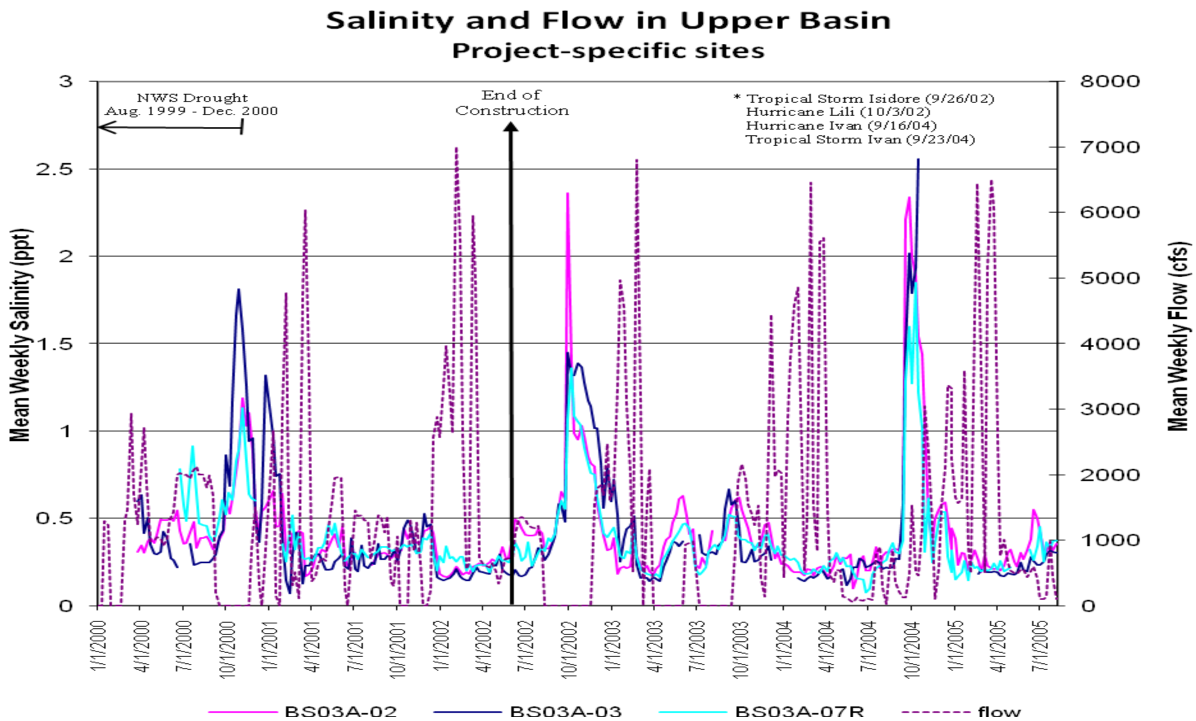

Figure 9a. Mean weekly salinity for stations BS03a-02 & 03 and reference station BS03a-07R within the Caernarvon Diversion Outfall Management (BS-03a) upper basin, along with flow rates through the Caernarvon Diversion (DCPBS09), 2000−2005. Station BS03a-01, located in stratum 1, was not presented because it shows little variation over the course of record.

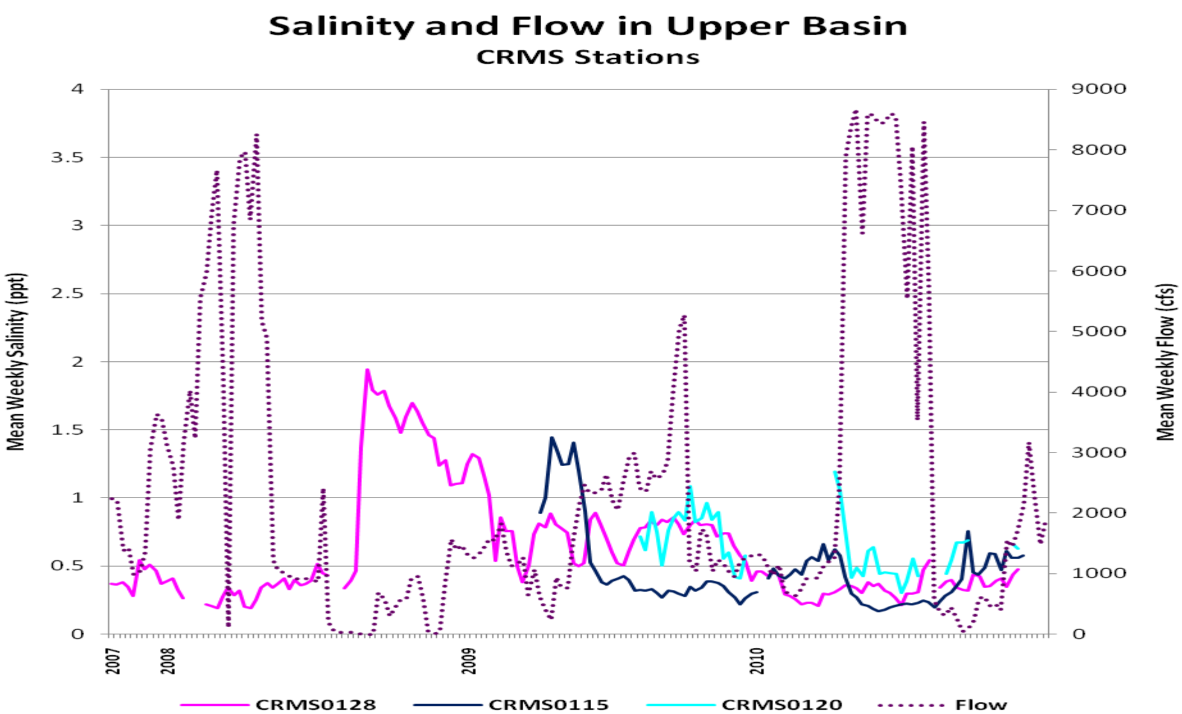

Figure 9b. Mean weekly salinity for CRMS0128 & CRMS0115 and reference station CRMS0120 within the Caernarvon Diversion Outfall Management (BS-03a) upper basin (Oct 2007−Dec 2010), along with flow rates through the Caernarvon Diversion (DCPBS09).

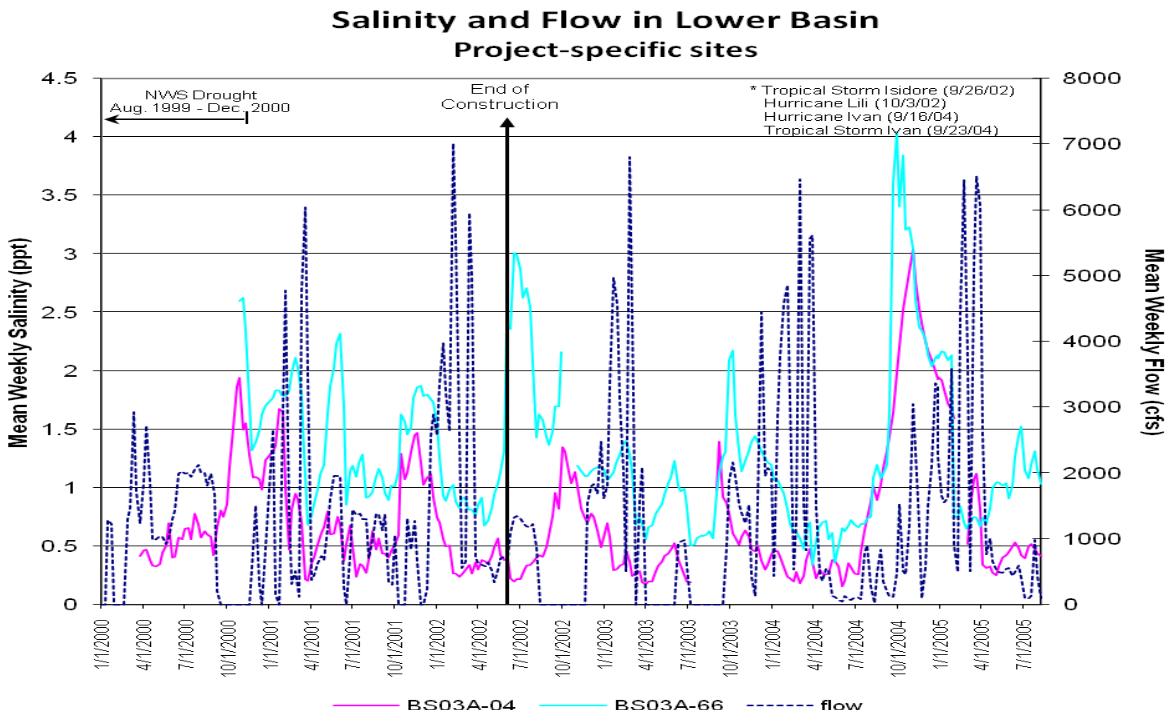

Figure 10a. Mean weekly salinity for project station BS03a-04 and reference station BS03a-66R within the Caernarvon Diversion Outfall Management Project (BS-03a) lower basin, along with flow rates through the Caernarvon Diversion (DCPBS09), 2000−2005.

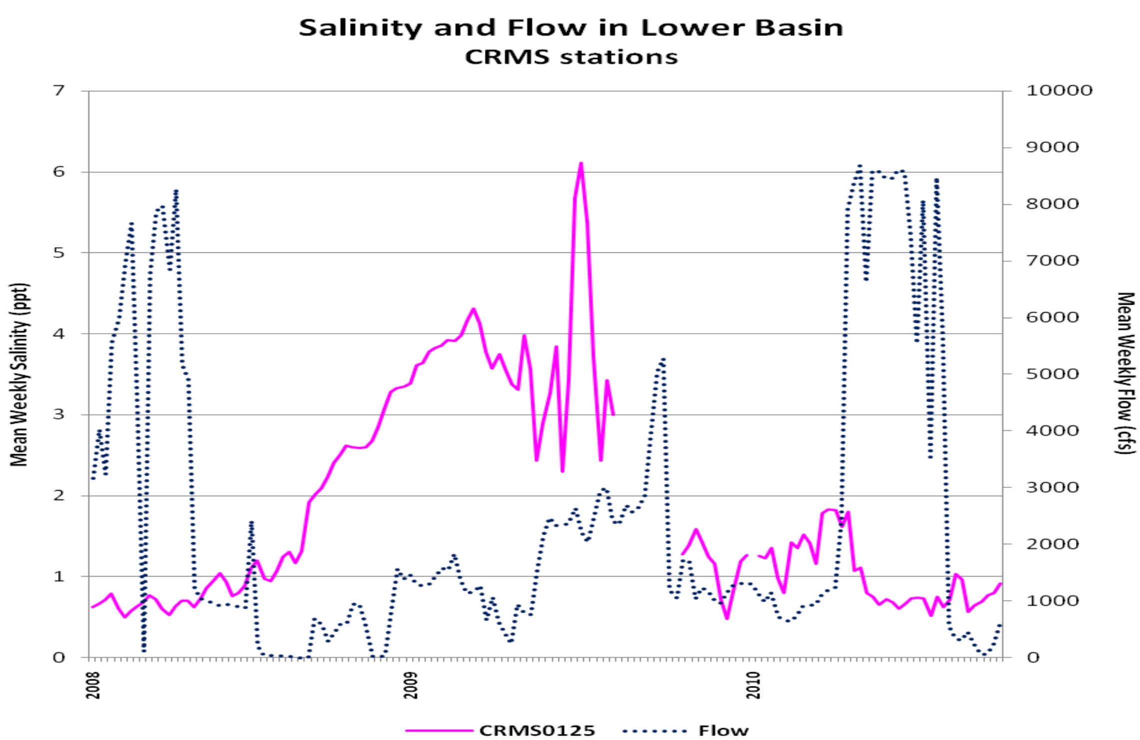

Figure 10b. Mean weekly salinity for CRMS0125 within the Caernarvon Diversion Outfall Management Project (BS-03a) lower basin, along with flow rates through the Caernarvon Diversion (DCPBS09), Jan 2008−Oct 2010.

Yearly mean salinities for project and reference strata have averaged <1 ppt since data collection began from 2000 to 2005 for project specific data (Figures 11a) and from 2007 to 2010 for CRMS data (Figure 11b). Exceptions include stratum 6 (southern reference area) where mean yearly salinity was between 1 and 1.8 ppt during 2000-2005 and stratum 4 where mean yearly salinity was between 1 and 2.97 during 2008-2009. Salinity increase was evident in all strata during the 2000 drought and the elevated tropical activity in September 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, even those not passing directly over the area. As Ivan traversed the Gulf in September, 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 ppt in nearly all strata. Storm surge from Hurricanes Gustav and Ike in 2008 also increased salinity in the project area (Figure 11b). Salinity is not available for strata 2 and 6 between 2007−2010, as these recorders were installed within marsh well stations. In addition, salinity data in 2008 were only available in strata 1 and 4.

Even with mean salinities of < 1 ppt, diversion benefits are still realized with a reduction in mean salinity as flow rates increase from no flow to high flow within the project area from 2000 – 2005 (Figures 12a) and 2007 -2010 (Figure 12b). However, salinities are so low throughout the area that 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 back-to-back events such as Tropical Storm Isidore (09/2002) and Hurricane Lili (10/2002), as well as Hurricane Ivan (09/16/2004) and Tropical Storm Ivan (09/23/2004). Salinities rose to a maximum of >2.5 ppt and stayed above 1 ppt until diversion waters were once again at a moderate to high flow (see Figure 9a). These tropical weather events were also probably 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. A portion of salinity data in this stratum was also removed from the analysis due to recorder malfunction, which may have also affected the results.

Data for the Caernarvon Diversion (BS-08) project has been collected since the structure was opened in 1991. Rainfall, wind data, Caernarvon operational rates, basin-wide salinity data, and fish and wildlife data are presented in the *Caernarvon Freshwater Diversion Project Annual Report 2005* (LDNR 2005). 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 stratum 1 (BS03a-01) having the lowest salinity and reference stratum 6 (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.

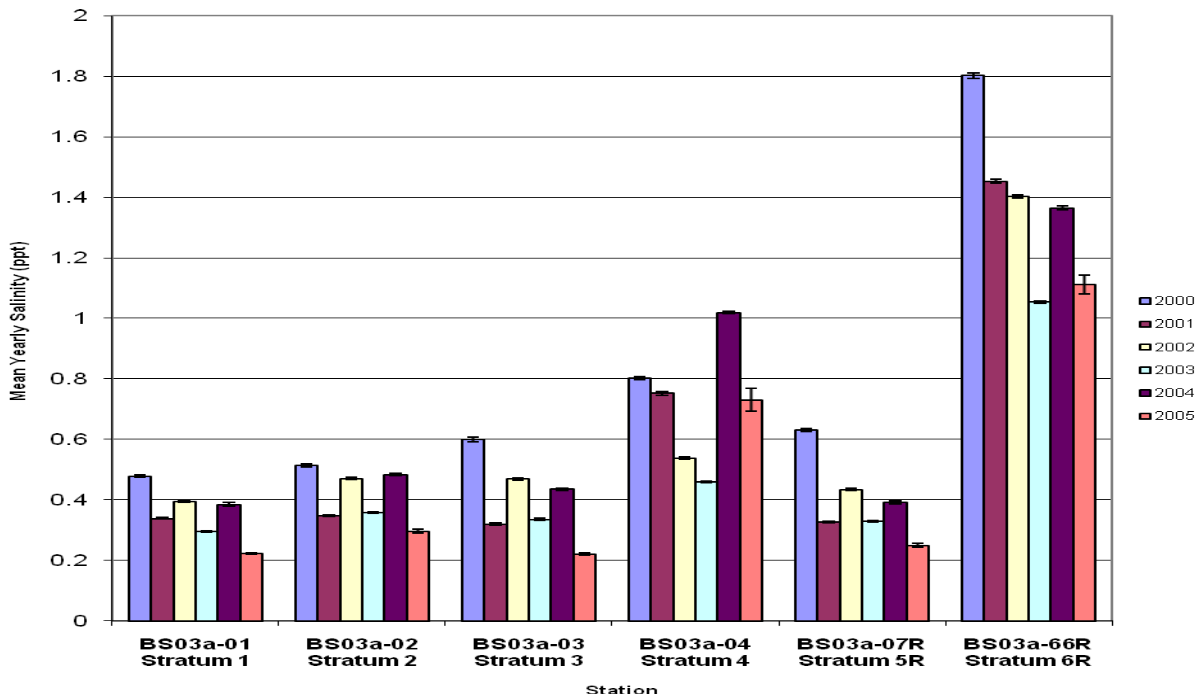

Figure 11a. Yearly mean salinity (±SE) for the project-specific sites in the BS-03a project area, 2000−2005.

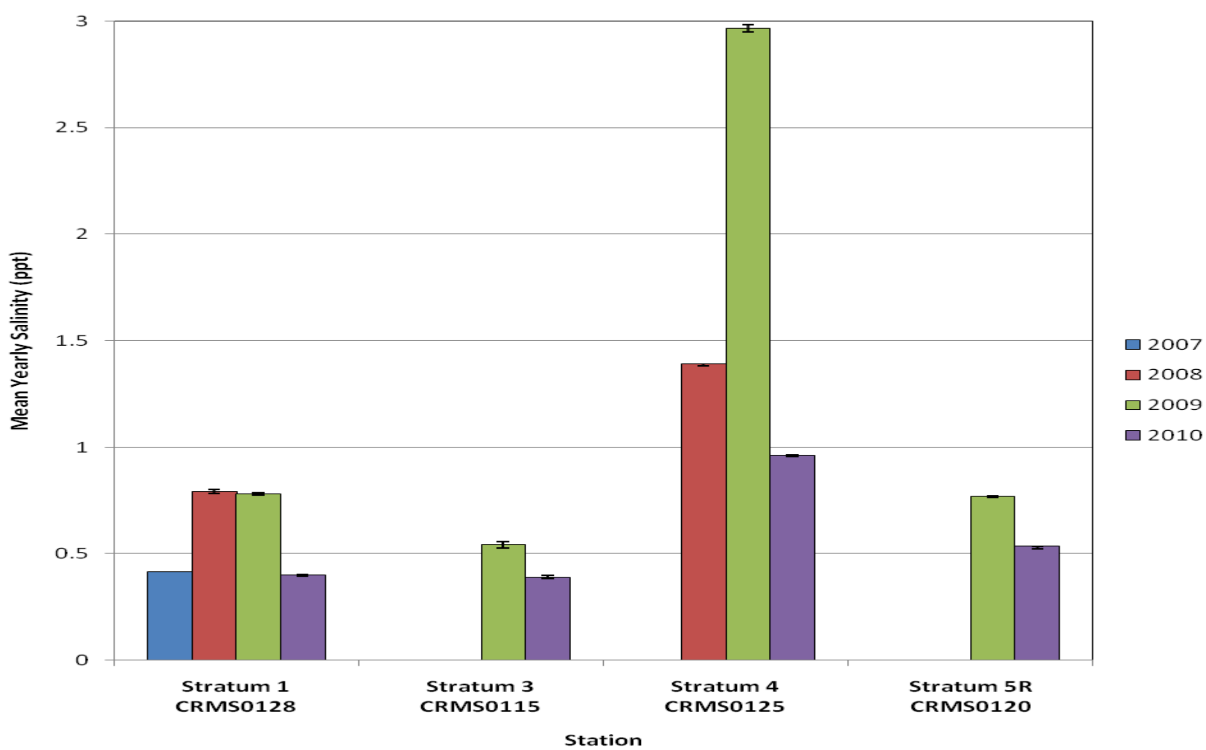

Figure 11b. Yearly mean salinity (±SE) for the CRMS sites in the BS-03a project area, 2007−2010.

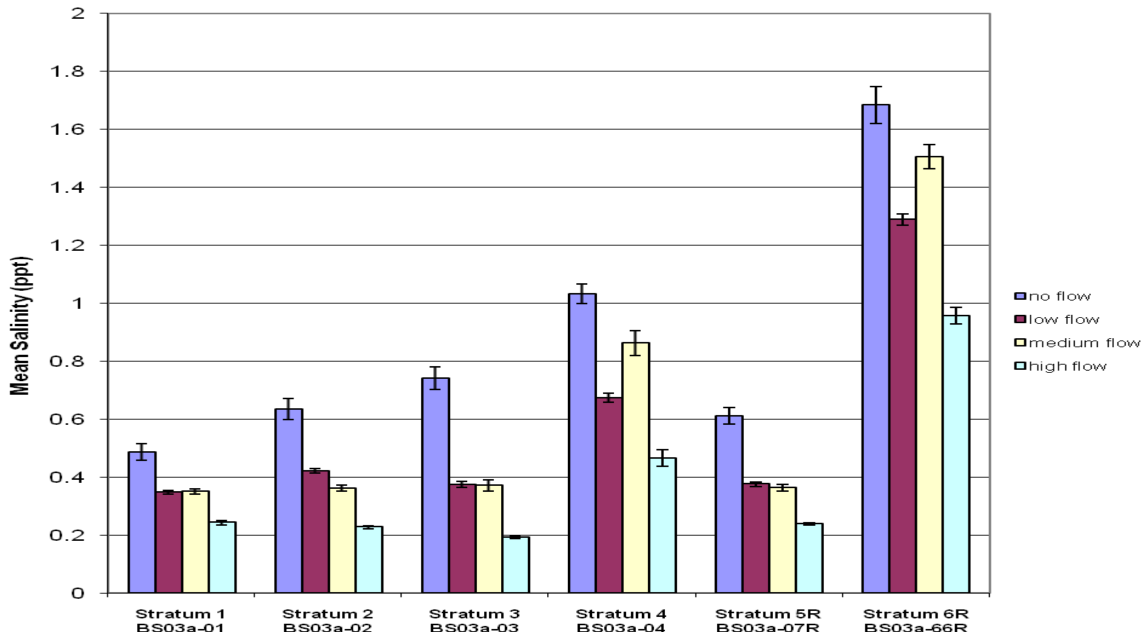

Figure 12a. Mean salinity (±SE) for the period 2000–2005 at continuous recorder stations during 4 operational categories [Low = 1–2000 cfs, Medium= 2000–4000 cfs, High= >4000 cfs] for the Caernarvon Diversion Outfall Management (BS-03a) project area.

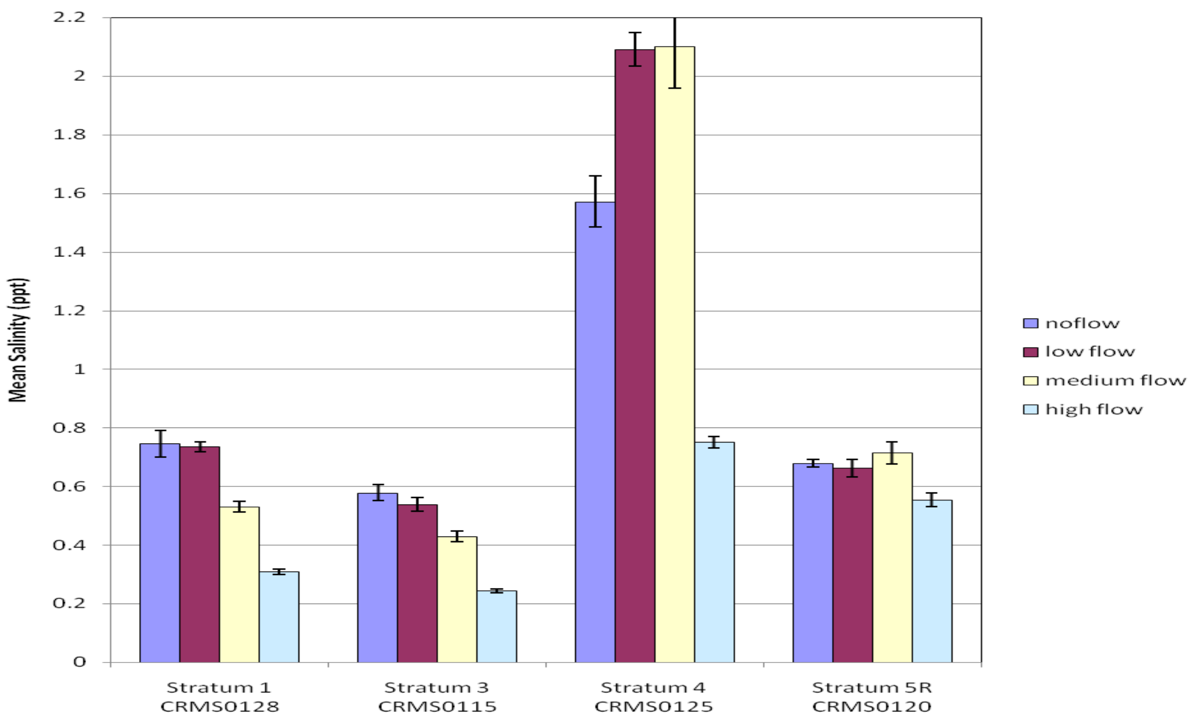

Figure 12b. Mean salinity (± SE) for the period 2007–2010 at CRMS stations during 4 operational categories [Low = 1–2000 cfs, Medium= 2000–4000 cfs, High= >4000 cfs] for the Caernarvon Diversion Outfall Management (BS-03a) project area.

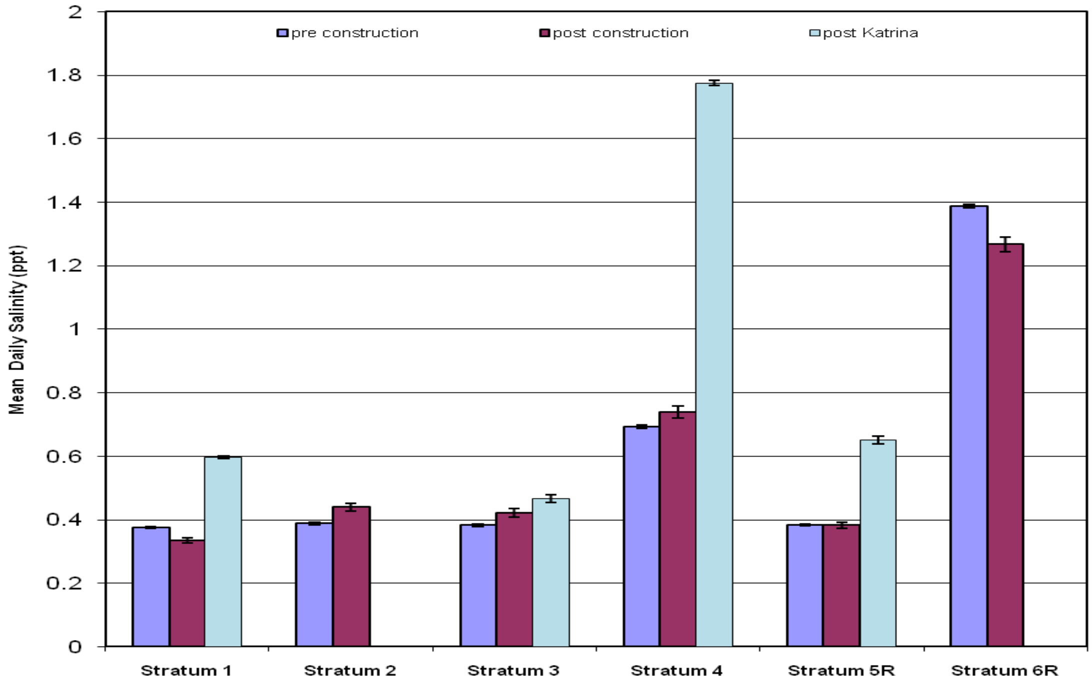

Figure 13. Mean daily salinity (±SE) at project-specific continuous recorders and CRMS stations for the Caernarvon Diversion Outfall Management (BS-03a) project and reference areas during pre-construction (3/27/2000−6/14/2002), post-construction (6/15/2002−8/09/2005) and post-Katrina (Oct 2007−2010) periods.

One goal of the BS-03a project is to reduce salinity variation within the interior marshes. However, mean daily salinity variance increased at three of the six strata in the post-construction period (Figure 14). The large increase in variance in strata 2 and 3 between the pre- and post-construction period was likely attributable to the tropical weather events of 2002 and 2004. These two strata were likely affected more by the storms than the other strata due to their close proximity to Lake Lery and vandalism of structure 32. Structure 32, a rock dike, is located at the intersection of LeBlanc Bayou and Lake Lery, and has repeatedly been vandalized in order to allow boat passage. Strata 2 and 3 share a common boundary, the DP Canal, which connects to Lake Lery through LeBlanc Bayou. The large increase in variance in the post-Katrina period, particularly in strata 4, is likely attributable to the storm events during the 2007 and 2008 hurricane seasons, as well as the previously mentioned anomaly at CRMS0125 (Strata 4) in 2009. In addition, Hurricane Katrina caused significant damage to the marsh in the upper basin. 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.

In 2001, a multi-investigator PULSES project was begun 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.

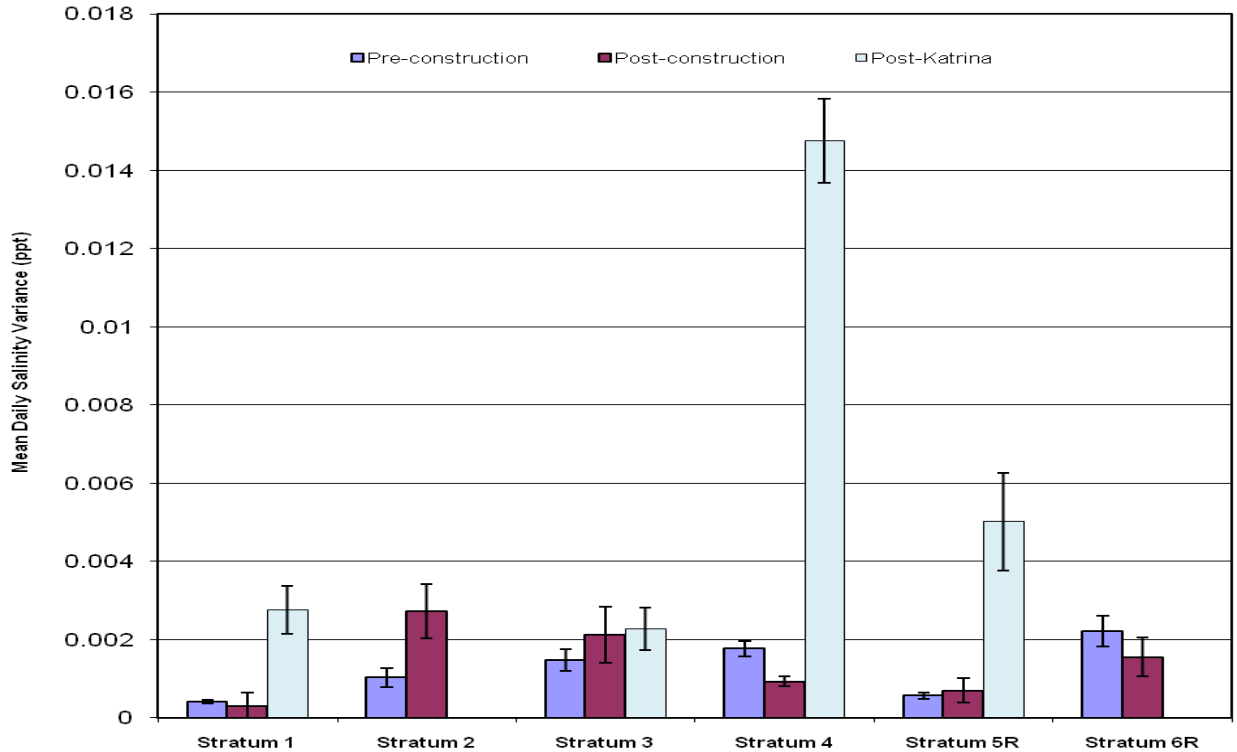

Figure 14. Mean daily salinity variance (±SE) for the Caernarvon Diversion Outfall Management (BS-03a) project and reference areas during pre-construction (3/27/2000−6/14/2002), post-construction (6/15/2002−8/09/2005) and post-Katrina (Oct 2007−2010) periods.

iii. <u>Water Elevation</u>

Mean daily water level increased for the post-construction period in all strata except stratum 1 (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 stratum 2 and reference stratum 5R. From this trend, it would appear that project features are performing as intended in the area immediately south of the diversion structure, but not retaining or supplying water in all other strata. Due to the Scarsdale levee repair after Hurricane Katrina, the diversion was not allowed to discharge above 500 cfs for many months and Delacroix Canal was severely blocked during this same period. Strata 2 and 5R are in the “immediate” outfall of the diversion and therefore experienced increased water levels. Also, the structures at sites 26, 40, &54 were blocked with post-Katrina debris for over 2 years. Reference stratum 5R appears to be benefiting from the disproportionate amount of water that flows to the east from the diversion.

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

2007−2010) periods. Post-construction water level increased in strata 2, 4, and both reference strata during low flow (0−2000 cfs), medium flow (2000−4000 cfs), and high flow (>4,000 cfs) operations (Figure 16). However, water level decreased post-construction in stratum 1 during all flow regimes and decreased in strata 3 during high and medium flow operations. The decrease in stratum 3 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 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. Unfortunately, this restricted flow may also contribute to a delayed regression of water that is introduced into the marsh during storms. During no flow periods, water levels were higher during the post-construction period for all strata. Due to the drought during the pre-construction period and the elevated water levels during tropical events post-construction, associating this effect with project success is difficult.

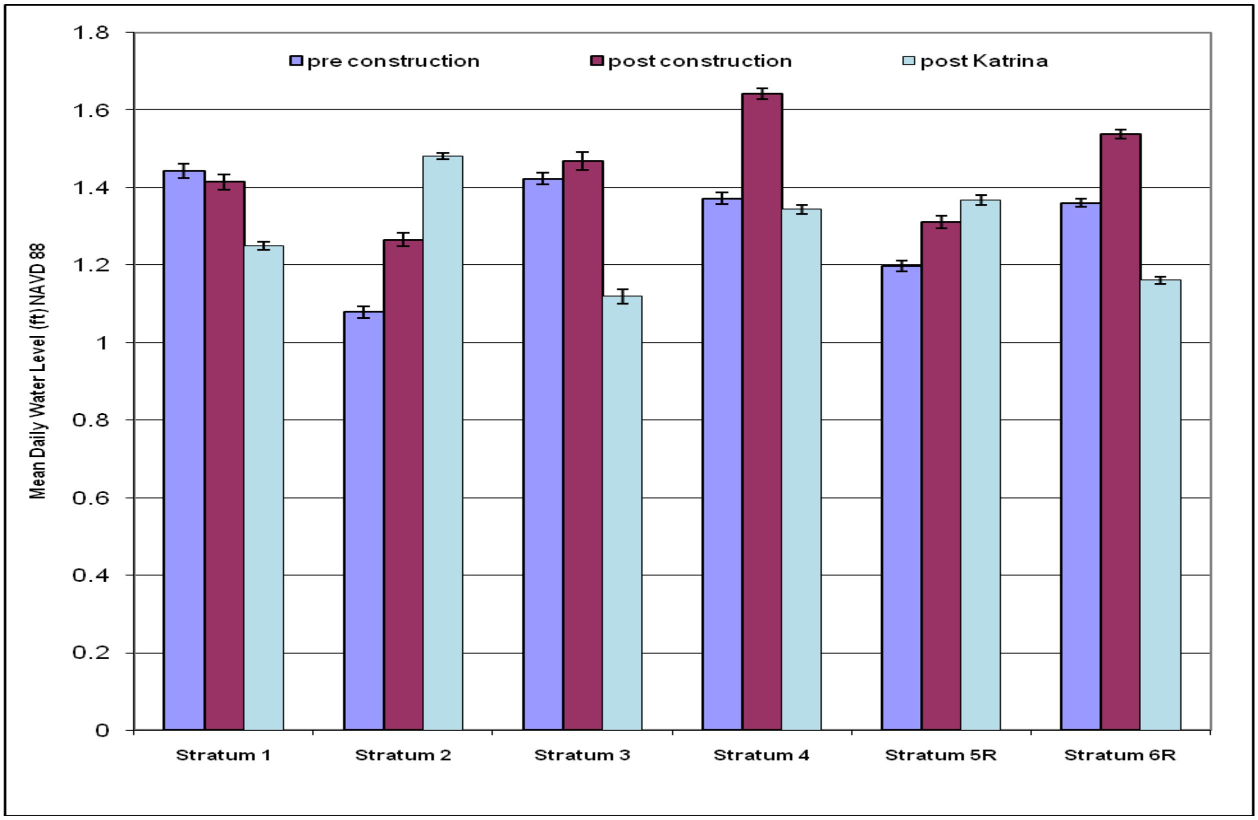

Figure 15. Mean daily water level (±SE) at project-specific continuous recorder and CRMS stations for the Caernarvon Diversion Outfall Management (BS-03a) project and reference areas during the pre-construction (3/2000−6/14/2002), post-construction (6/15/2002−8/09/2005) and post-Katrina (Oct 2007−2010) periods.

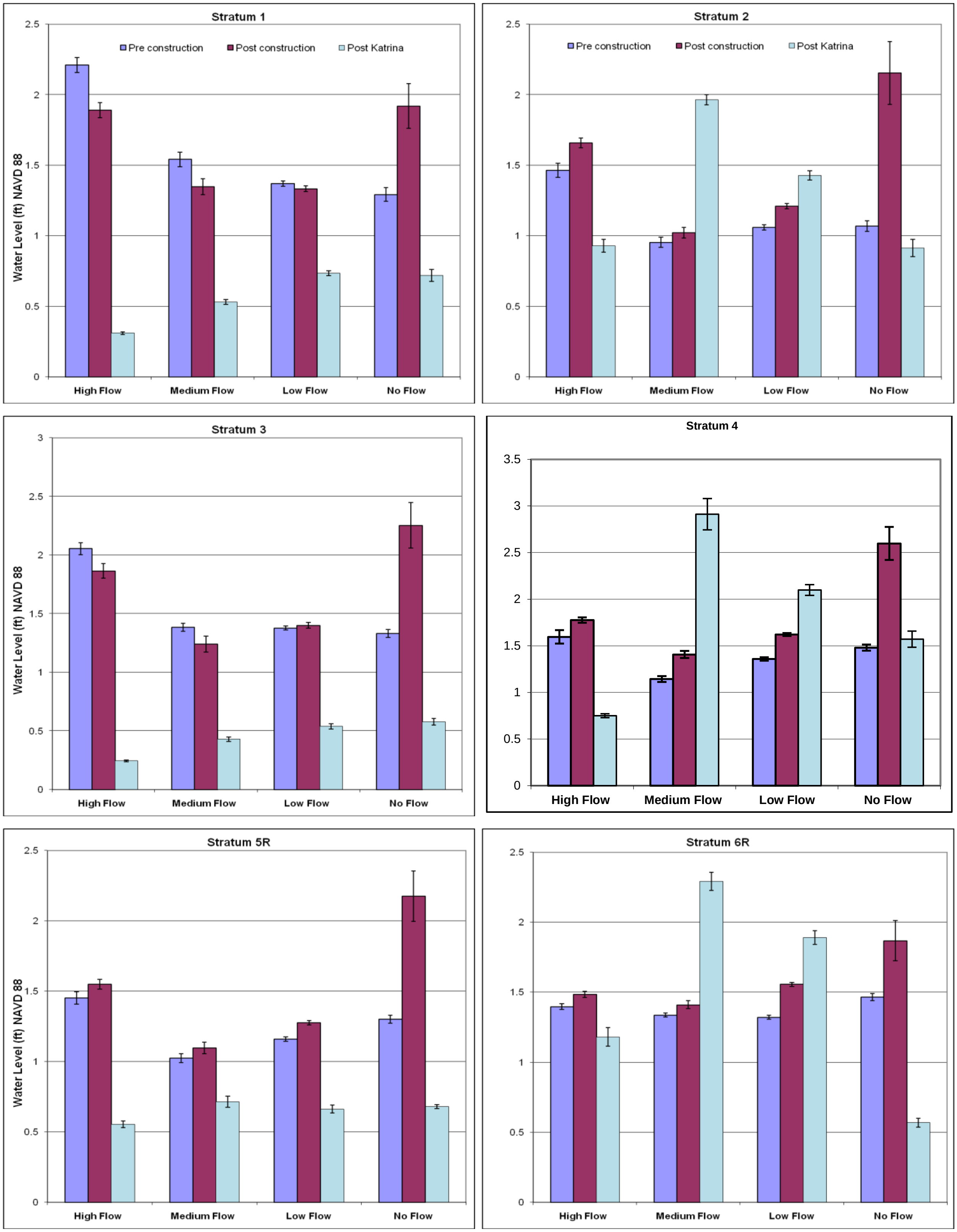

Figure 16. Mean daily water level (±SE) at continuous recorder project-specific and CRMS stations for the BS-03a project under different flow rates during the pre-construction (3/2000−6/14/2002), post-construction (6/15/2002−8/09/2005) and post-Katrina (Oct 2007−2010) periods.

Water level decreased in strata 1, 3 and reference stratum 5R during all operational flows from the post-construction to the post-Katrina period. Water level between these periods also decreased in strata 2, 4, and 6R during high flow, but increased during medium and low flow. Within the post-Katrina time period, a trend of increasing water elevation with decreasing flow occurred in strata 1 and 3. A similar trend was seen in strata 2, 4 and 6R, with water level increasing from high flow to low flow; however, water level in these strata was highest during medium flow conditions. 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 was an intention of the project design.

All strata increased in the number of flood events from the pre-construction to the post-construction period, with the exception of reference stratum 5R, which exhibited the same number of flood events pre- and post-construction (Table 1). However, the data stream for the pre-construction (n=809 days) period is shorter than that of the post-construction (n=1148 days). From November 2002 to March 2003, water levels in stratum 3 fluctuated above and below marsh elevations, resulting in the high number of flood events for the post-construction period. Strata 2 saw similar trends Post-Katrina with water levels fluctuating above and below marsh level from November 2007 to May 2008. These fluctuations are mainly due to the location of the strata immediately south of the diversion. All strata increased in depth of flooding between the pre- and post-construction periods (Table 1). This is likely attributable to project features. With the shift to CRMS sites for hydrologic data collection, a direct correlation is not possible between pre- and post-construction and post-Katrina periods due to data collection locations changing and the large disturbance that occurred between station setup. All strata appear to have been influenced by tropical events in 2008 when considering depth and duration of flooding.

All strata post-Katrina had greater water level variance than the pre- and post-construction periods, with the exception of stratum 2 (Figure 17). This increase in variance can likely be attributed to marsh loss and a subsequent increase in open-water area resulting from that occurred as a result of Hurricane Katrina and tropical events in 2008. The use of the diversion in 2010 to combat the infiltration of oil in the lower basin from the Mississippi Canyon 252 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 18a,b & 19a,b).

Table 1. Frequency, depth and duration of flooding for the Caernarvon Diversion Outfall Management (BS-03a) project and reference strata during the pre-construction (3/2000−6/14/2002), post-construction (6/15/2002−8/09/2005) and post-Katrina (Oct 2007−2010) periods.

Strata - CRMS Site	Pre	Post	Post Katrina			
1 - CRMS0128			**2007**	**2008**	**2009**	**2010**
# of Flood Events	45	61	Flotant Station - No marsh elevation for flooding measurements.			
Mean Duration (days)	18.76	56.21				
Mean Depth (ft)	0.45	0.54				
2 - CRMS0117						
# of Flood Events	84	91	4	15	24	19
Mean Duration (days)	17.13	31.75	4.86	39.62	25.41	45.17
Mean Depth (ft)	0.45	0.61	0.22	0.71	0.38	0.78
3 - CRMS0115						
# of Flood Events	78	184		8	64	18
Mean Duration (days)	12.55	21.73		18.34	2.02	5.00
Mean Depth (ft)	0.38	0.59		0.52	0.35	0.39
4 - CRMS0125						
# of Flood Events	58	87		18	26	21
Mean Duration (days)	5.97	15.19		28.99	12.22	11.15
Mean Depth (ft)	0.25	0.41		0.61	0.54	0.53
5R - CRMS0120						
# of Flood Events	81	81		7	27	15
Mean Duration (days)	27.09	30.83		5.21	0.75	2.09
Mean Depth (ft)	0.40	0.56		0.73	0.26	0.36
6R - CRMS0114						
# of Flood Events	32	44	1	15	39	26
Mean Duration (days)	50.23	62.87	0.65	16.57	3.53	4.71
Mean Depth (ft)	0.23	0.38	0.09	0.58	0.37	0.40

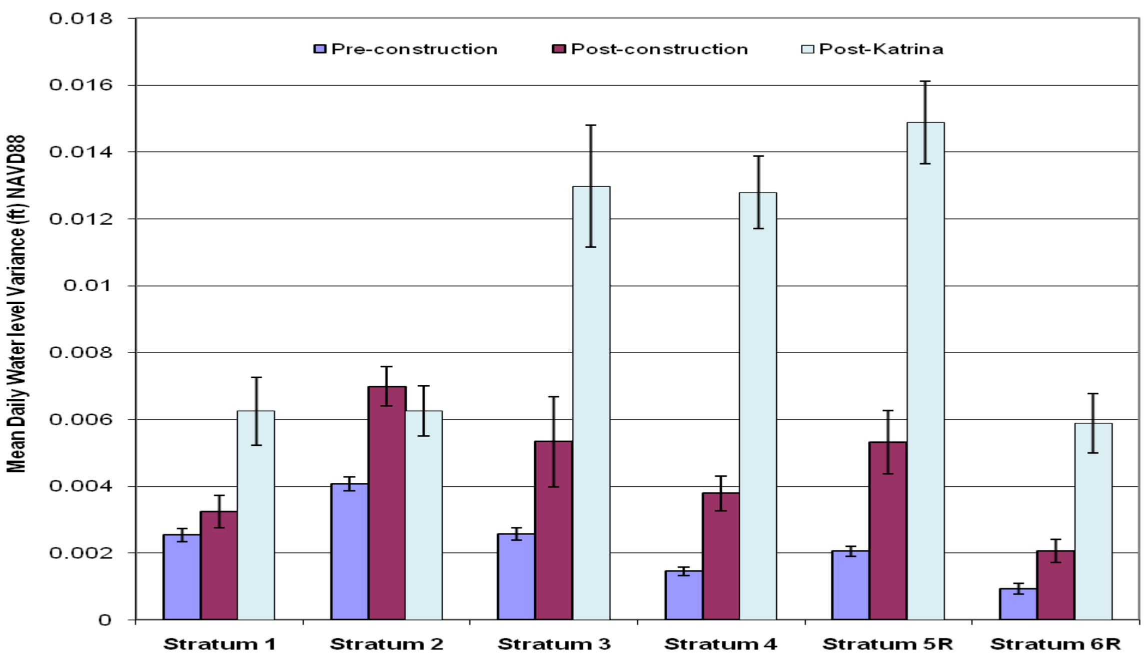

Figure 17. Mean daily water level variance (±SE) at YSI continuous recorder and CRMS stations for the Caernarvon Diversion Outfall Management Project (BS-03a) and reference areas during the pre-construction (3/2000−6/14/2002), post-construction (6/15/2002−8/09/2005) and post-Katrina (Oct 2007−2010) periods.

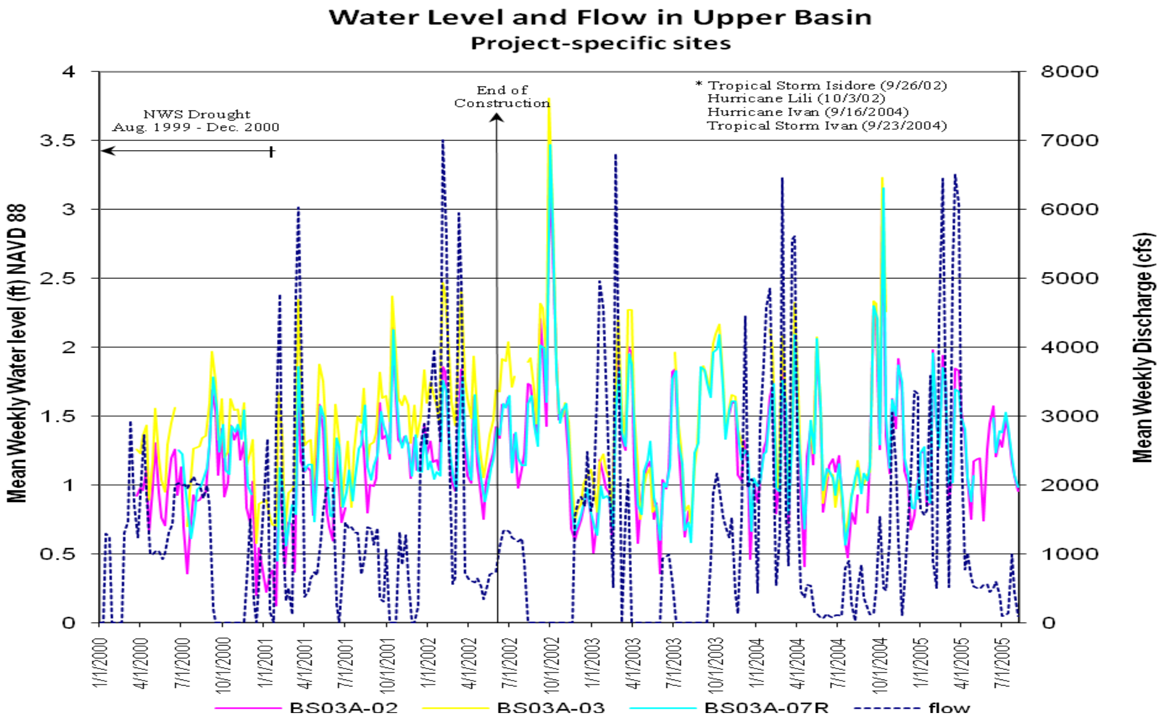

Figure 18a. Mean weekly water level for project stations BS03a-02 & 03 and reference station BS03a-07R within the Caernarvon Diversion Outfall Management (BS-03a) project upper basin, along with flow rates for the Caernarvon Diversion (DCPBS09), 2000 −2005.

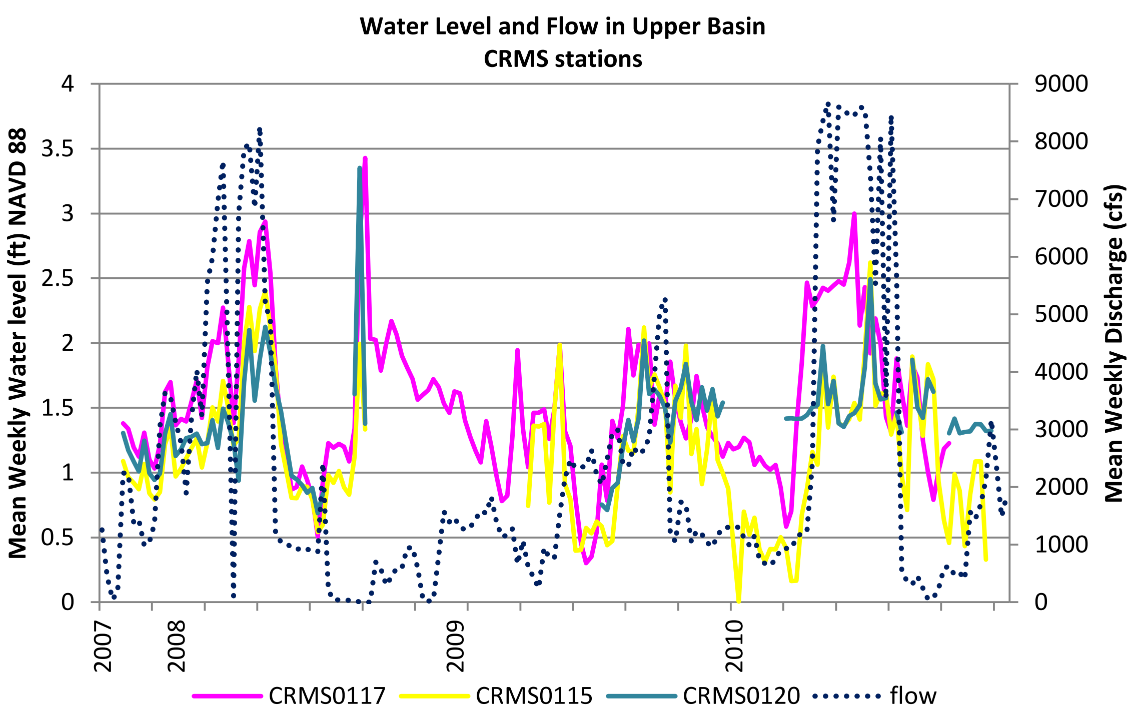

Figure 18b. Mean weekly water levels for CRMS stations 0115 & 0117 and reference station CRMS0120 within the Caernarvon Diversion Outfall Management (BS-03a) project upper basin, along with flow rates for the Caernarvon Diversion (DCPBS09), Oct 2007−2010.

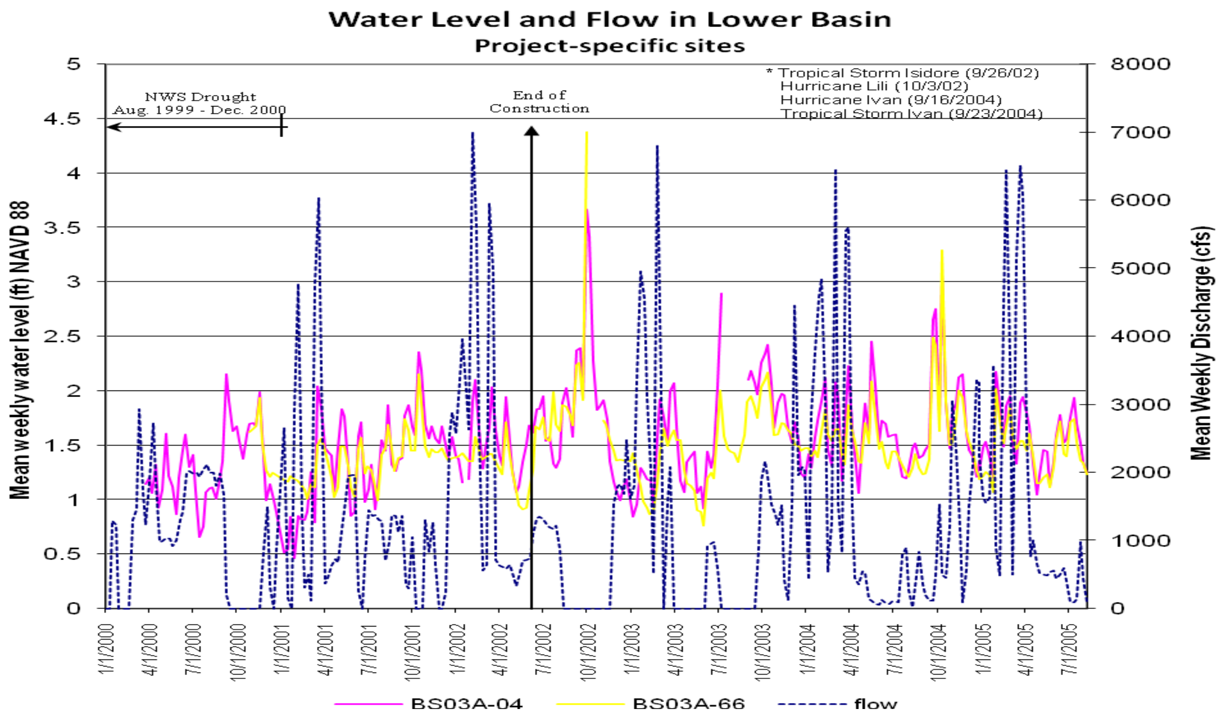

Figure 19a. Mean weekly water levels for project station BS03a-04 and reference station BS03a-66R within the Caernarvon Diversion Outfall Management (BS-03a) project lower basin, along with flow rates for the Caernarvon Diversion (DCPBS09), 2000−2005**.**

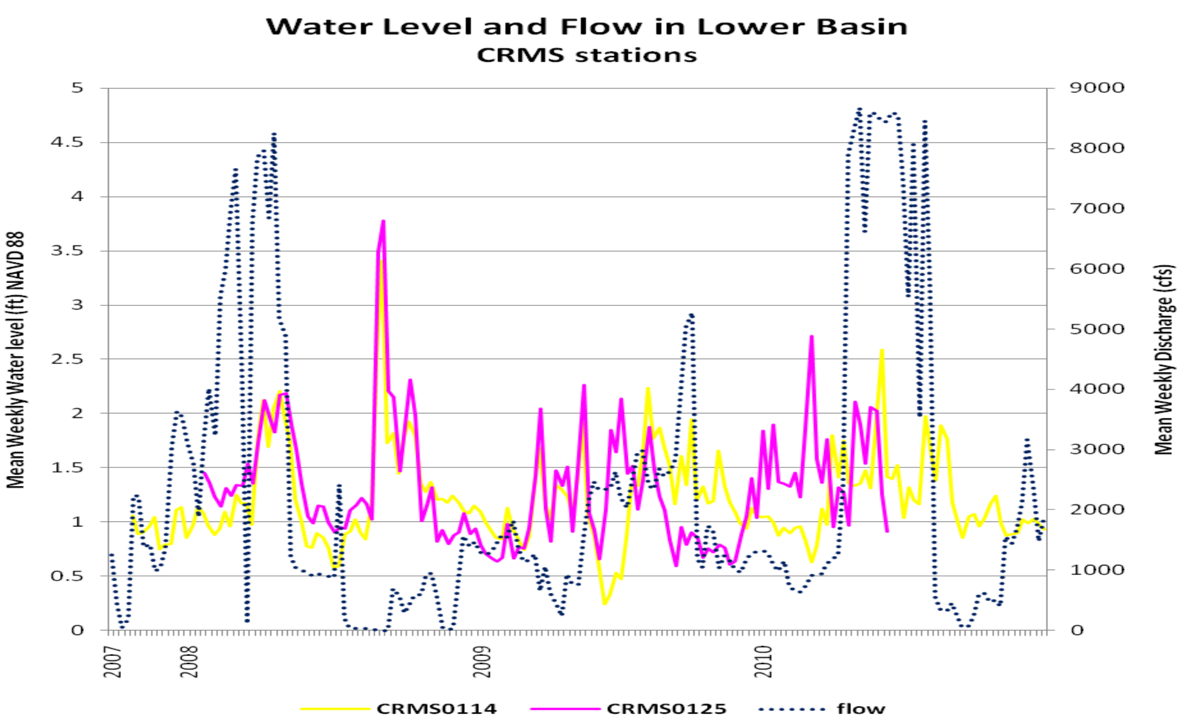

Figure 19b. Mean weekly water levels for CRMS station 0125 and reference station CRMS0114 within the Caernarvon Diversion Outfall Management (BS-03a) project lower basin, along with flow rates for the Caernarvon Diversion (DCPBS09), Oct 2007−2010.

iv. **Vegetation**

Spartina patens (saltmeadow cordgrass) had the greatest percent 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 20−25). In 2005, 8 of the 36 vegetation stations were inaccessible and of the 28 reached, 18 were located in open water. 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 percent cover and in 2006, was dominant in strata 2, 4 and 5R, while the percent cover of *S. patens* declined in all strata except 5R.

Vegetation surveys were conducted for BS-03a 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 notable increase in percent cover for *Polygonum punctatum* (dotted smartweed) and a decrease in species diversity. In 2010, *P. punctatum* was the dominant species in all strata except stratum 4, where *Echinochloa walteri* (coast cockspur grass) had a slightly greater percent cover.

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.

FQI declined sharply at all vegetation stations in 2005 (Figures 20−25). The 2005 vegetation survey was conducted in November, less than three months after Hurricanes Katrina and Rita, and the decrease in percent cover and FQI demonstrates the effects that the hurricanes had on the marsh. 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 continuing 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). CRMS vegetation surveys for 2007−2010 have continued to show the same general downward trend for FQI as the project-specific plots.

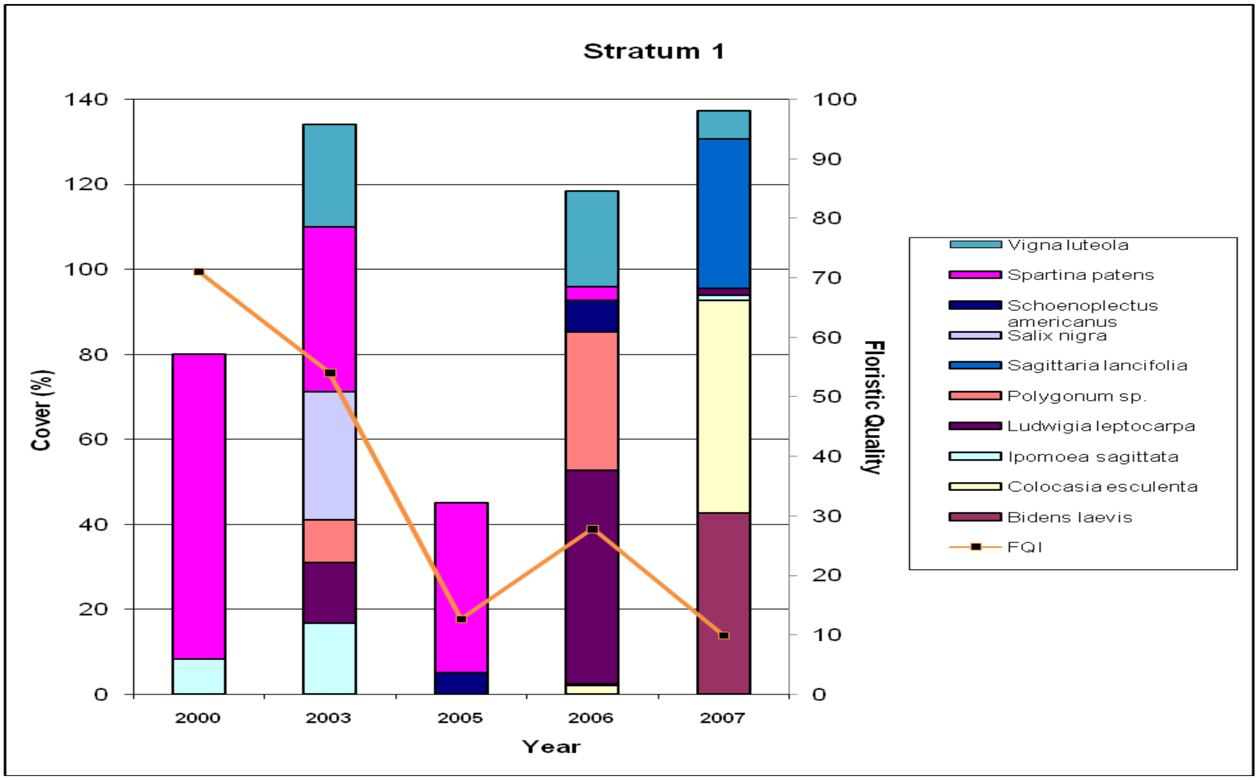

Figure 20a. Mean vegetation % cover and FQI for dominant species at project-specific stations in stratum 1 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2000–2007 surveys.

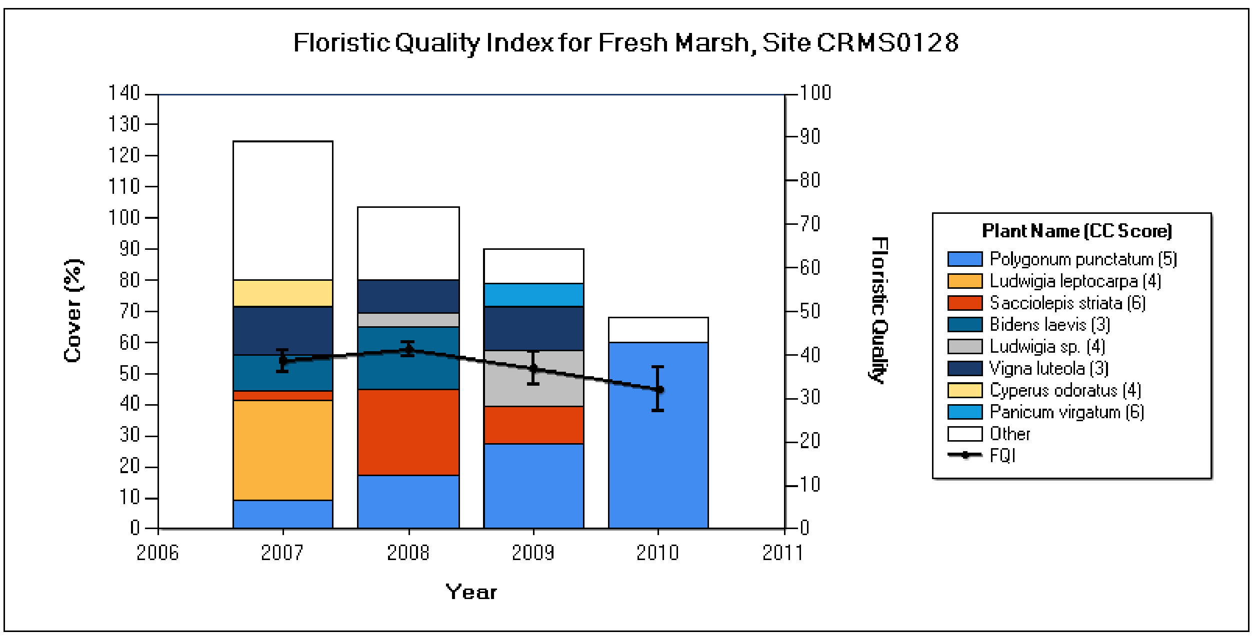

Figure 20b. Mean vegetation % cover and FQI at CRMS0128 in stratum 1 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2007–2010 surveys.

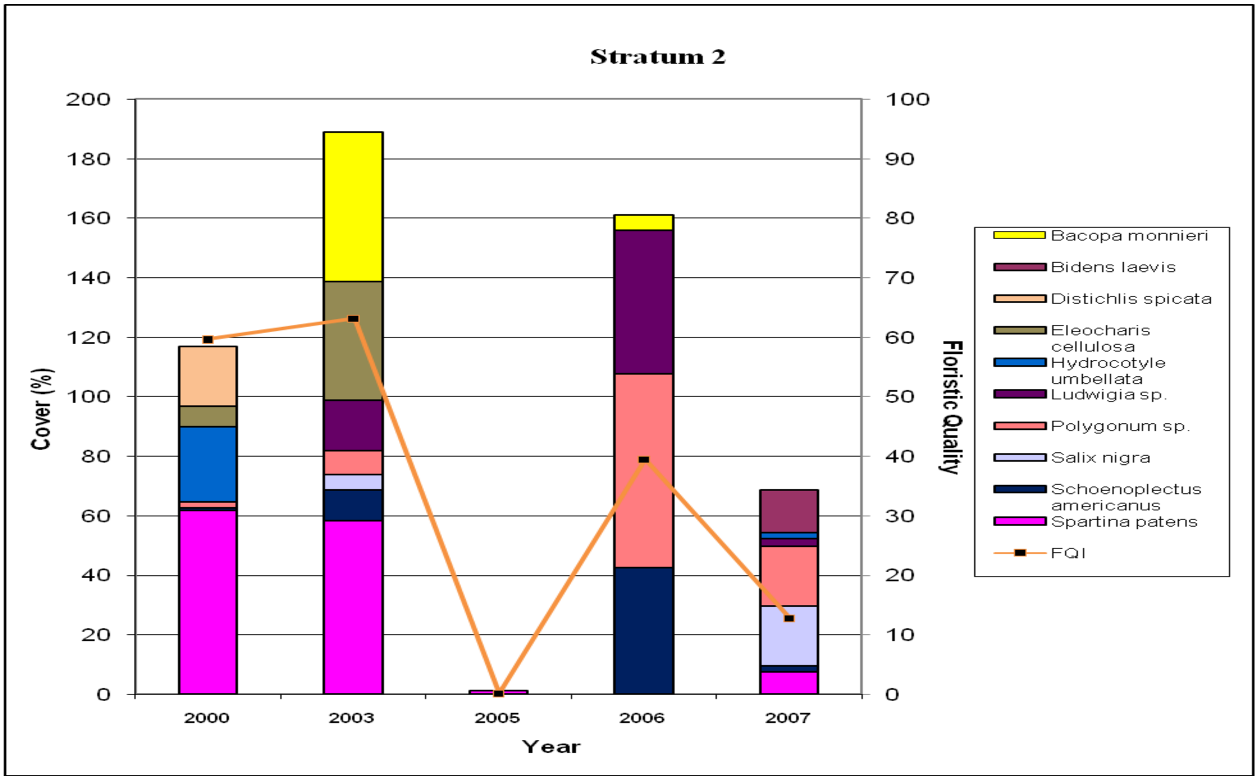

Figure 21a. Mean vegetation % cover and FQI for dominant species at project-specific stations in stratum 2 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2000−2007 surveys.

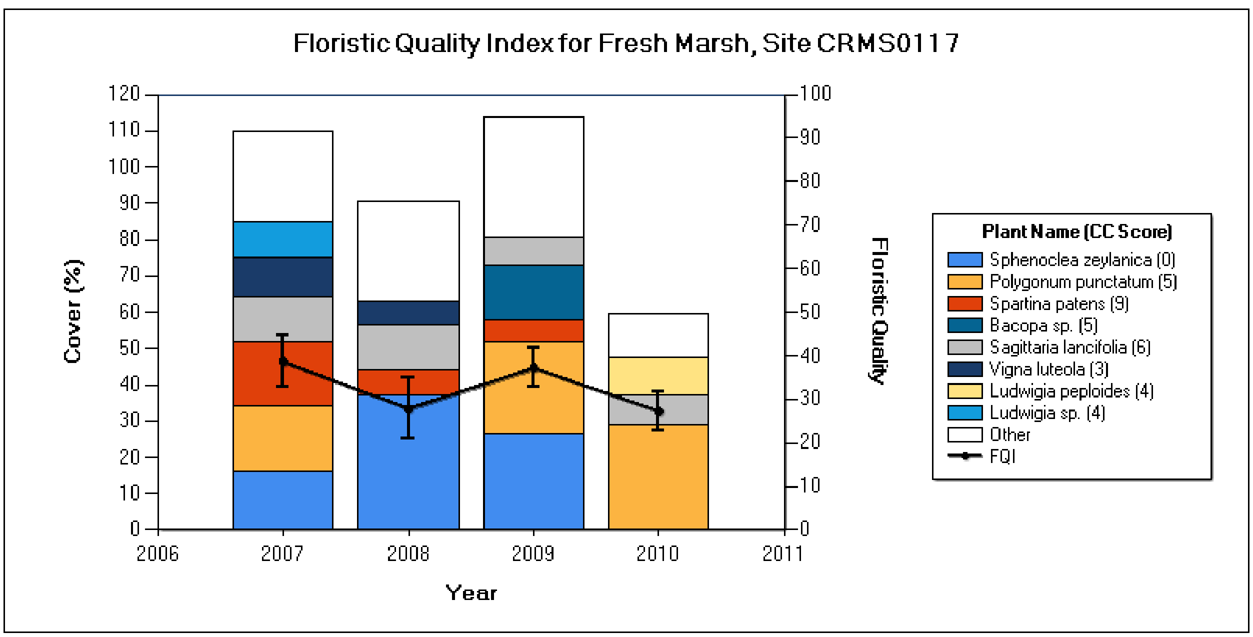

Figure 21b. Mean vegetation % cover and FQI at CRMS0117 in stratum 2 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2007−2010 surveys.

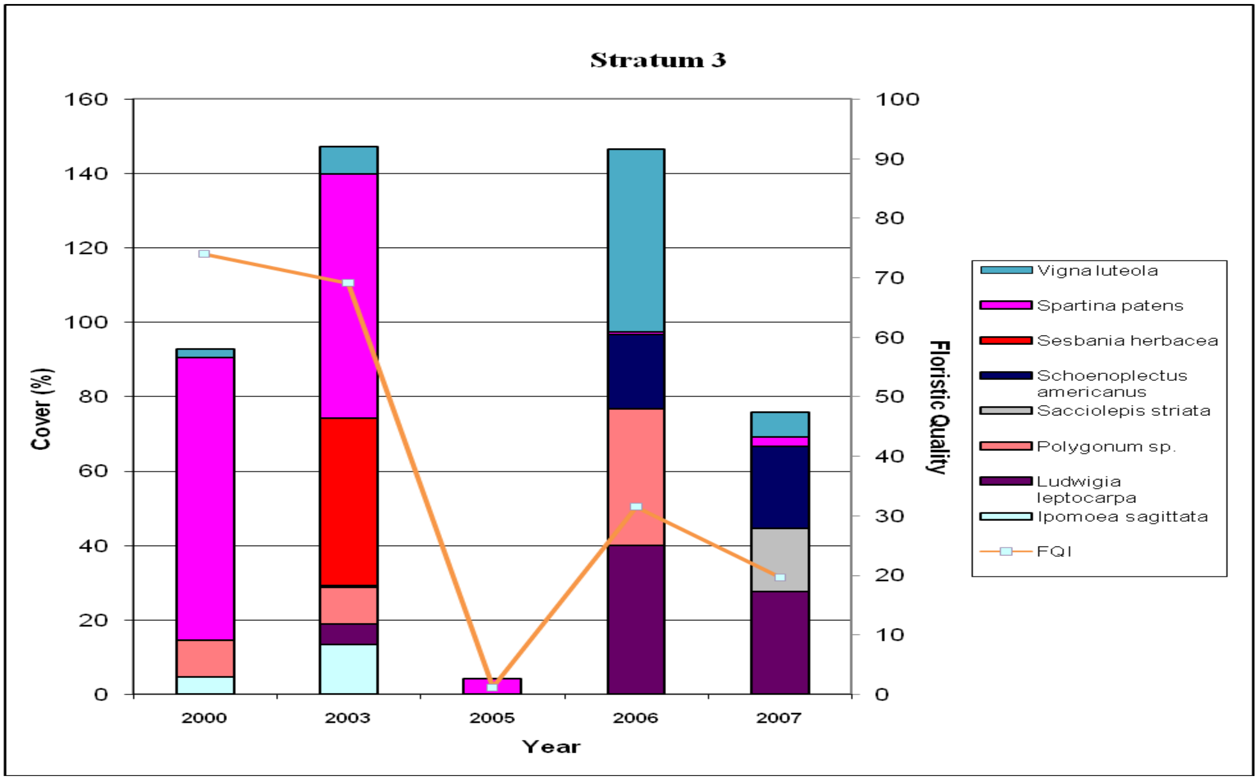

Figure 22a. Mean vegetation % cover and FQI for dominant species at project-specific stations in stratum 3 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2000–2007 surveys.

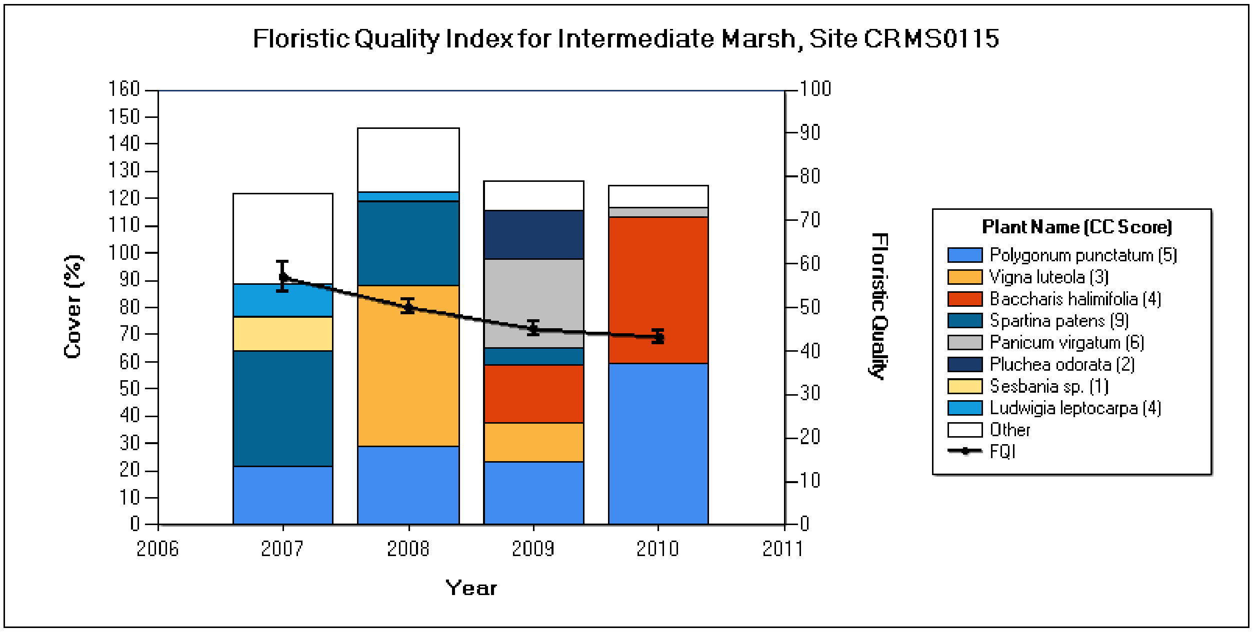

Figure 22b. Mean vegetation % cover and FQI at CRMS0115 in stratum 3 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2007–2010 surveys.

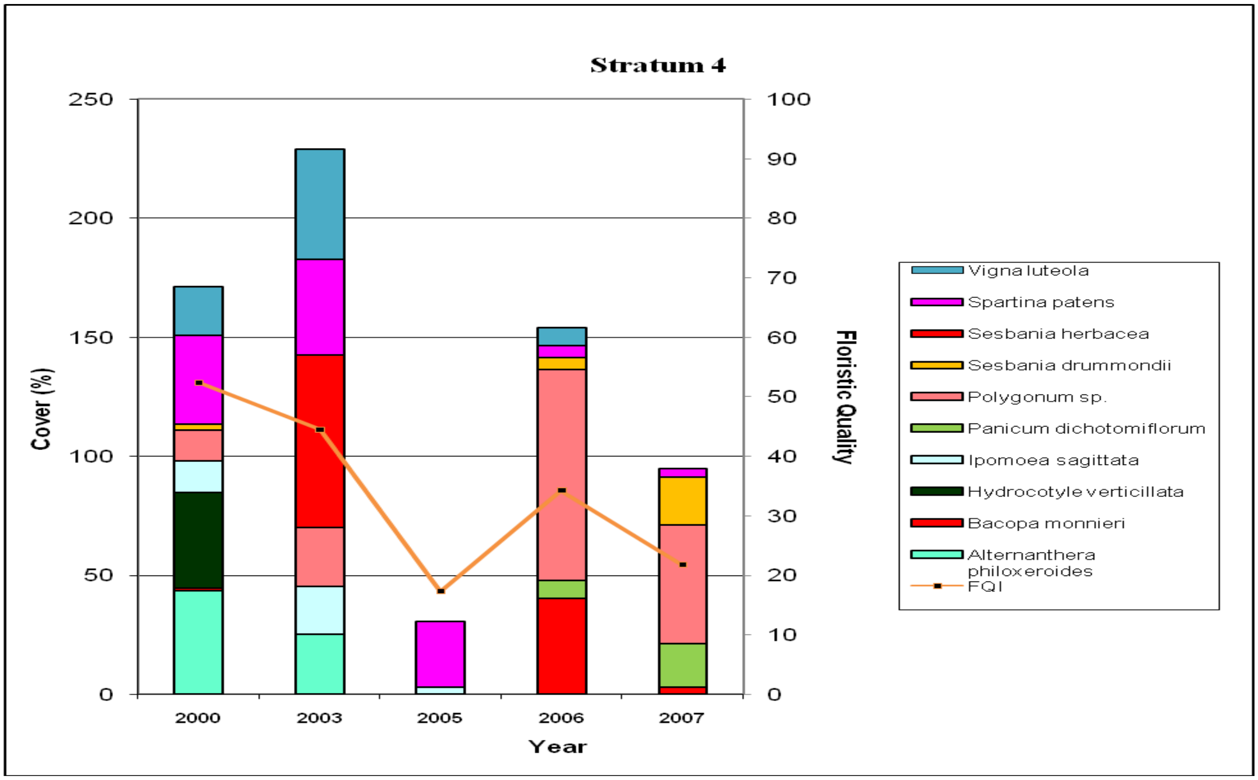

Figure 23a. Mean vegetation % cover and FQI for dominant species at project-specific stations in stratum 4 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2000–2007 surveys.

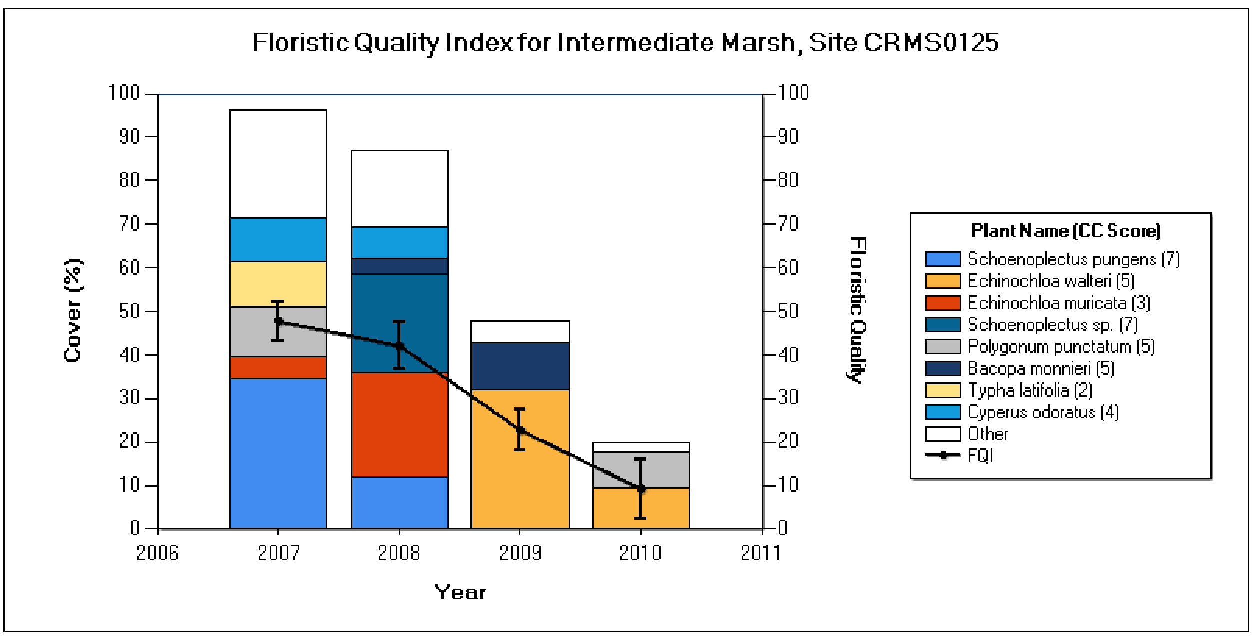

Figure 23b. Mean vegetation % cover and FQI at CRMS0125 in stratum 4 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2007–2010 surveys.

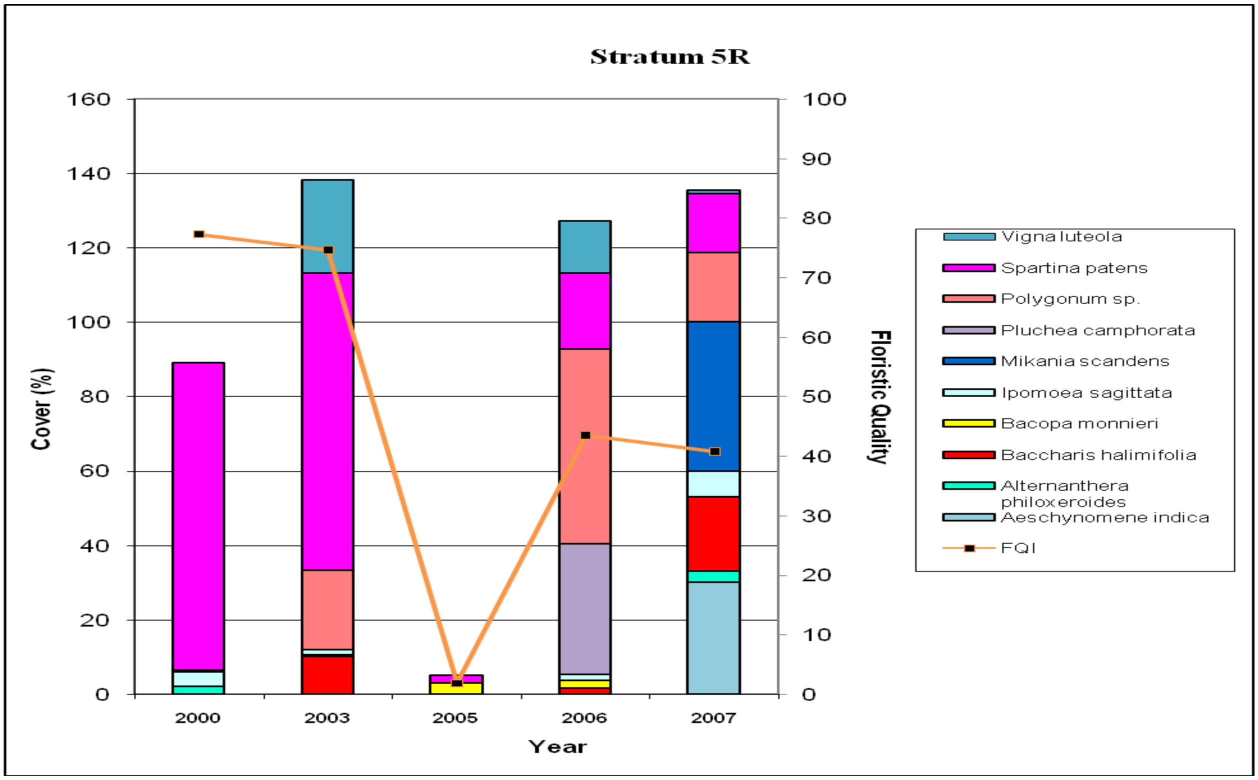

Figure 24a. Mean vegetation % cover and FQI for dominant species at project-specific stations in stratum 5 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2000–2007 surveys.

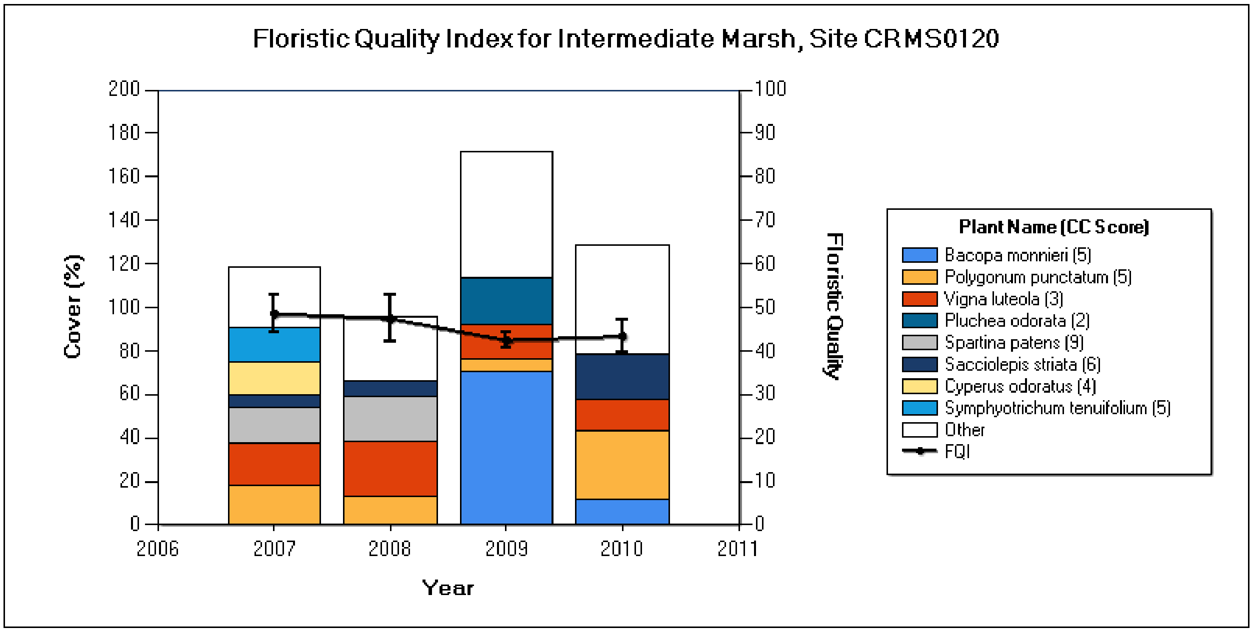

Figure 24b. Mean vegetation % cover and FQI at CRMS0120 in stratum 5 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2007–2010 surveys.

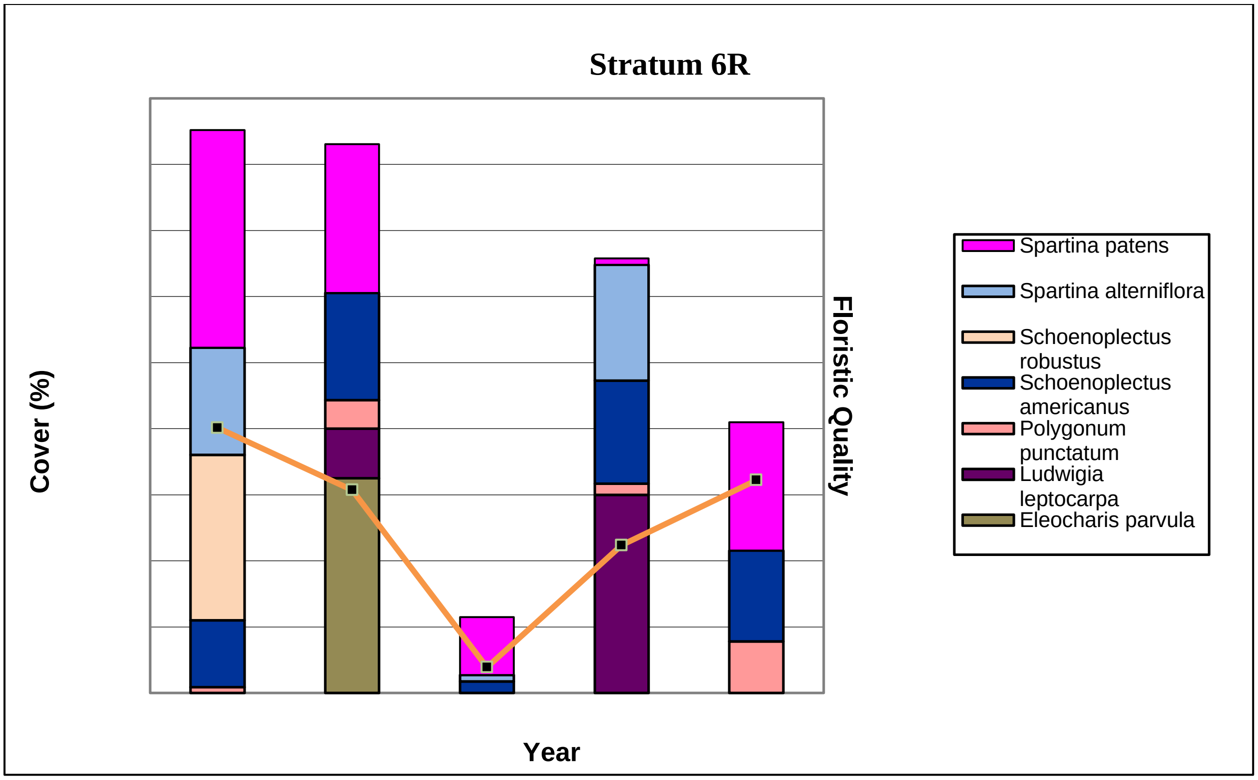

Figure 25a. Mean vegetation % cover and FQI for dominant species at project-specific stations in stratum 6 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2000–2007 surveys.

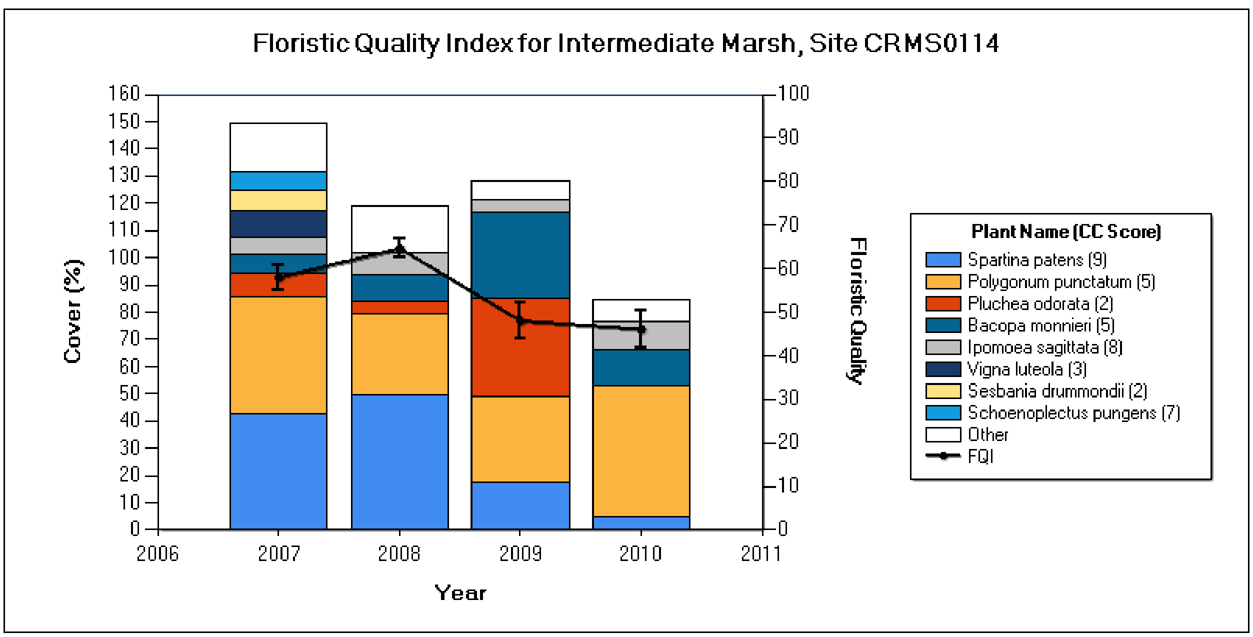

Figure 25b. Mean vegetation % cover and FQI at CRMS0114 in stratum 6 of the Caernarvon Diversion Outfall Management (BS-03a) project for the 2007–2010 surveys.

Between the 2000 and 2003 vegetation surveys, species richness increased in all strata except strata 4; however, it declined for the 2005 vegetation survey, which was conducted in November after Hurricanes Katrina and Rita (Table 2). 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.

Table 2. 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, 2003, 2005, 2006, and 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*

V. Discussion

Prior to Hurricane Katrina, a salinity gradient existed within the basin with lower salinities closest to the diversion structure and increasing values further from it. Mean daily salinities in strata 1 and 5R, the northern most strata, were <0.4 ppt, while strata 2 and 3 to the south averaged between 0.4 and 0.5 ppt. Stratum 4 had a mean daily salinity around 0.7 ppt, and stratum 6R, the southernmost stratum, maintained salinities >1.2 ppt. After the storm, however, this gradient was disrupted, especially in the upper strata. Many factors, including blocked canals and spoil bank degradation, contribute to this non-conformity.

Vegetation sampling 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.

Water levels within the project area increased for all project strata, except stratum 1, during the post construction period. At low flow operations, strata 2 and 4 experienced significant increases in water level, indicating a greater retention of water within those strata. Whether this increase is a result of the project features in the area is uncertain due to drought conditions that prevailed during the pre-construction period and the tropical storm events with associated high water levels. Although the project appears to limit water access at the higher flow categories, the benefits of confining water access points, and thus exit points, were seen by the increase in depth and duration of flooding events since project construction.

VI. Conclusions

a. Project Effectiveness

The first monitoring goal of the Caernarvon Diversion Outfall Management project is 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.

The second monitoring goal of this project is to reduce salinity variation in the interior marshes. Strata 1, 4 and 6R showed a reduction in salinity variance during the post-construction period. However, the decrease in salinity variance is associated with a higher mean salinity for the post-construction period. This may be a result of the project's effectiveness at retaining more water, both diverted and from storm surge, within the marsh. The increased salinity variance in all strata post-Katrina was likely due to the rearrangement of the topography and hydrology of the project area. Structures placed to hold diverted waters in the wetlands of the project strata were made ineffective by breaches from surge forces and allowed multiple points of water exchange. Likewise, canals that carried diversion waters to the far eastern and western ends of the upper basin were completely clogged with marsh.

The third monitoring goal is to increase the occurrence and abundance of fresh/intermediate marsh type plant species. The percent cover of vegetation increased is 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 fact, this one-dominant species was only detected in reference stratum 6R in 2010. 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.

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, vegetation monitoring was converted 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 monitor vegetation changes through 2010.

The fourth goal of the project is 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.

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. Most of the hydrologic blockages resulting from Hurricane Katrina have subsequently been cleared, but some still remain. 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. Another main blockage just east of structure #26 has also mostly been cleared. However, the lesser amount of water that travels this path west from Big Mar encounters remaining blockages in the Delacroix Canal and massive water hyacinth blooms located all along the Reggio Canal, forcing water to preferentially flow east toward Lake Lery, especially at high flow. Stratum 4 lies west of this obstruction and receives little, if any, diversion input. The re-installation of flow meters at sites 26, 40 & 54 will help to more accurately monitor the volume of water accessing this stratum in comparison to the discharge at the diversion.

b. Recommended Improvements

As of 2011, there is still an alarming amount of open water in the project area, which leaves the remaining marsh susceptible to erosion from wave action. Sediment needs to be brought in to fill these open areas because the diversion does not carry enough mineral material to regain what was lost. The creation of terraces in some of the larger ponds could also help with wave abatement and sediment trapping. Although the feasibility of the two aforementioned recommendations is uncertain, they represent a way of restoring what was lost and protecting what is left. For now, we will continue to monitor recovery, re-establish flows to pre-Katrina conditions, and apply adaptive management concepts.

The inability to collect surface salinity data at well monitoring sites poses great difficulty in assessing project goals and effectiveness. It is recommended that sites CRMS0114 and CRMS0117 be converted to surface water stations. In addition, CRMS0125, located 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. To more accurately depict the effects of diversion water in this stratum, it would be more beneficial to relocate this station on the northern side of Tigers Ridge.

c. Lessons Learned

The most important lesson to remember in 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 our project structures will depend on to function. In the event that they may be compromised through subsidence, increased water velocity, or erosion during the 20-year life of the project, then proper consideration should be given to the maintenance efforts and costs and these costs should be included in the selection criteria. In addition, project design for future freshwater diversions should anticipate the potential impacts of emergent invasive species, such as water hyacinth promulgated by a lower salinity environment, and incorporate resources into the budget for the control of these occurrences.

Freshwater marshes do not fare well in an 18-foot 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 hold, or at least capture, the adjacent marsh.

The project area is susceptible to storm surge, which can significantly increase salinity in the basin. 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. It would appear that at high flow, project features in all strata are retaining little to no water, as intended.

VII. References

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APPENDIX A
Photographs

Photo No. 1, Site 13

Photo No. 2, Site 13

Photo No. 3, Site 26

Photo No. 4, Site 26

Photo No. 5, Site 40

Photo No. 6, Site 40

Photo No. 7, Site 50

Photo No. 8, Site 50

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Photo No. 9, Site 52

Photo No. 10, Site 52

Photo No. 11, Site 54

Photo No. 12, Site 56

Photo No. 13, Site 57

Photo No. 14, Site 57

Photo No. 15, Site 58

Photo No. 16, Site 60

Appendix B
Three-Year Operations & Maintenance Budgets

Caernarvon Outfall Management (BS-03a)
Federal Sponsor: NRCS
Construction Completed : September 10, 2002

rent Approved O&M Buc	Year 0	Year - 1	Year -2	Year -3	Year -4	Year -5	Year -6	Year -7	Year -8	***Year -9***	***Year -10***	***Year -11***
June 2009	FY03	FY 04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	***FY12***	***FY13***	***FY14***
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
Corps Admin												
Federal S&A												
Total												
Projected O&M Expenditures												
Maintenance Inspection									$4,752	$4,876	$5,002	$5,133
General Maintenance												
Structure Operation									$50,000	$50,000	$50,000	$50,000
Federal S&A									$5,000	$5,000	$5,000	$5,000
State S&A									$10,000	$10,000	$10,000	$10,000
E&D									$10,000			
Surveys									$15,000			
Construction									$265,000			
Construction Oversight									$5,000			
Total					$0	$0	$0	$0	$364,752	$69,876	$70,002	$70,133

rent Approved O&M Buc	Year -12	Year -13	Year -14	Year -15	Year -16	Year - 17	Year -18	Year -19	OCPR Project Estimate Project Life	CWPPRA Allocated Currently Funded
June 2009	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Budget	(Sum YR 0 to YR 19)
State O&M	$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
									Remaining	***Current 3 year***
Projected O&M Expenditures									Project Life	***Request (FY12,***
Maintenance Inspection	$5,266	$5,403	$5,543	$5,687	$5,835	$5,987	$6,143	$6,302	$65,929	$14,630
General Maintenance									$0	$0
Structure Operation	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$600,000	$150,000
Federal S&A	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$60,000	$15,000
State S&A	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$120,000	$30,000
E&D									$10,000	$10,000
Surveys									$15,000	$15,000
Construction									$265,000	$265,000
Construction Oversight									$5,000	$5,000
Total	$70,266	$70,403	$70,543	$70,687	$70,835	$70,987	$71,143	$71,302	$1,140,929	$504,630

Total O&M Expenditures from COE Report (Inception to p	$368,497.78	
State O&M Expenditures not submitted for in-kind credit	$0	From 5/23/11
Federal Sponsor MIPRs (if applicable) (REQUESTED MONEY)		
Total Estimated O&M Expenditures (as of April 2011)	**$368,497.78**	

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)*	$677,436	
Incremental Funding Request Amount FY12-FY14	$ (172,806.22)	3 year surplus

Current Project Life Budget less COE Admin *(State O&M Porject Life Budget + Fed S&A Project Life Budg*	$1,045,934
Total Projected Project Life Budget *(Remaining Project Life + Total Estimated O&M Expenditur*	$1,509,427
Project Life Budget Request Amount	**$463,493**

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	2008	2009	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:	5/5/2011 Time: 10:00 AM
Structure No.	**See Report Section II**	Inspector(s):	OCPR: Tom Bernard, Kyle Breaux----NRCS: Mike Trusclair
Structure Description:	See Report Section II	Water Level:	Marsh: +0.82 NGVD River: +16.48 NGVD
Type of Inspection:	2011 Annual Inspection	Weather Conditions:	Clear and Cool, Wind ENE 6-10 mph (525 cfs Diversion)

Item	Condition	Physical Damage	Corrosion	Photo	Observations and Remarks
CMP Culverts Earthen / Rock Embankment	Good	Minor	None	Appendix B	Some of the culverts that had previously rotated slightly with the differential settlement of the rock structure remain that way today. Culverts are clear. Most all rock embankment has remained in place with some earthen material scoured at the tie-in points. Breaches are present at sites #13 & #50.
Water Control Gates	Good	None	Moderate	Appendix B	All water Control Gates appear to be in good condition. The O&M contractor has been lubricating, cleaning, and operating all gates on a scheduled basis. A small section of DC Canal has been dredged and cleared by the Delacroix Corp for acces to their property within the outfall area
Rock Canal Closures	Good	See Remarks	N/A	Appendix B	The overall condition of the canal closures is good with small areas of erosion where the rock meets the earthen embankment. The vandalism to site #32 remains that way. However; it does not appear to affect the function of the closure. We will try to include that site in the earthen dike closure in the upcoming project (BS-16).
Timber Piling at Culverts	Very Good	None	None	Appendix B	All of the timber piling are in very good condition. Some of the rock structures have settled as well as the culvert themselves causing some slight rotation in the culverts.
Timber walkways at Culverts	Good	See Remarks	N/A	Appendix B	Some of the 4 X 4 timber support posts for the timber walkways settled excessively causing the timber walkway to bend and twist slightly.
Spoilbank Restoration	Fair	Minor	N/A	Appendix B	Vegetation (grasses, shrubs, and some trees) has flourished along the banks. Minor scouring is evident at shoreline/water surface interface. Some areas have been repaired by the Delacroix Corp.
Flow Meters	N/A	N/A	N/A	N/A	New flow meters will be installed at structures No. 26, 40, and 54 to monitor the flow of water going into the interior marsh . The meters should be succesfully installed by July 1st, 2011.