Coastal Protection and Restoration Authority of Louisiana
Office of Coastal Protection and Restoration

2008 Operations, Maintenance, and Monitoring Report

for

Caernarvon Diversion Outfall Management

State Project Number BS-03a
Priority Project List 2

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Plaquemines Parish

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Preface

The 2008 OM&M Report format is a streamlined approach which combines the Operations and Maintenance annual project inspection information with the Monitoring data and analyses on a project-specific basis. This new reporting format for 2008 includes monitoring data collected through December 2007, and annual Maintenance Inspections through June 2008. Monitoring data collected in 2008 and maintenance inspections conducted between July 2008 and June 2009 will be presented in the next OM&M Report.

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 project is located in Plaquemines Parish, Louisiana, and lies to the south and west of Big Mar, a failed agricultural impoundment. The project area totals 18,200 acres (7,365 ha; 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 (Dunbar et al. 1992). Land loss rates peaked between 1958 and 1974, exceeding 270 acres/yr (109 ha/yr). The number of oil and gas pipeline canals increased dramatically during this time period, significantly increasing saltwater intrusion into the upper reaches of the basin. Most erosion occurred in the western portion of the project area, near the intersection of the Reggio and DP canals (figure 1). In another area west of Tigers Ridge, forested wetlands were once the dominant habitat. In 1965 however, Hurricane Betsy struck the Louisiana coast, and oil and gas canals allowed gulf waters brought in by the storm surge to penetrate into the upper reaches of the basin. Salt water was trapped behind the ridge, and ultimately the entire swamp became salt-stressed and was killed. 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 (U. S. Department of Agriculture/Natural Resources Conservation Service [USDA/NRCS] 1996).

The increasing effects of saltwater intrusion have 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* (marshhay cordgrass) to be the dominant vegetation in brackish communities. Less dominant species included *Baccharis halimifolia* (baccharis), *Scirpus olyneyi* (Olney 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 quadalupensis* (Southern naiad), *Myriophyllum spicatum* (Eurasian water-milfoil), and *Ruppia maritima* (widgeon grass).

The intent of the project is to maximize benefits from the Caernarvon Freshwater Diversion Project to the marshes immediately south and west of Big Mar (figure 1). The Caernarvon diversion structure was constructed between 1988 and 1991 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, because of several contributing factors, the annual discharge has been much less than anticipated. The contributing factors include oyster suits, above normal rainfall that adds to the natural freshness of the basin, and a shrimping industry that does not allow excessive amounts of fresh water in the spring. As some of these factors are resolved, it is anticipated that the annual average discharge will increase considerably.

Once diversion waters enter Big Mar, 66% of those waters exit to the southeast via Bayou Mandeville and flow into Lake Lery and ultimately Bayou Terre aux Boeufs. Another 33% flows to the southwest and out through the Delacroix Canal, while theremaining 1% of Caernarvon discharge flows westward through the Forty Arpent Canal. With only 34% of structure discharge going to the south and west, it is critical to optimally manage the structure's outfall in these regions. The purpose of the Caernarvon Outfall Management Project is to improve the utilization of fresh water, sediments, and nutrients from the Mississippi River by interior marshes south and west of Big Mar during low Caernarvon diversion flows before the discharge is conveyed to the lower reaches of the basin by channelized flow through bayous and canals. This was accomplished by installing culverts with interior flap gates or exterior sluice gates into existing plugs and spoil banks. Once diversion waters are in the interior marshes, increased retention time is needed to facilitate distribution of the fresh water, deposition of suspended sediments, and assimilation of nutrients by the vegetation communities. This goal was attained by enhancing existing spoil banks and installing plugs in key locations where introduced diversion waters once discharged from the interior marshes back into bayous and canals. Specifically, the following project features were completed in August 2002:

1. Two 48-inch culverts with exterior (Caernarvon Diversion side) sluice gates were installed in the earth fill core plugs protected with rock riprap at sites 25, 40, and 54. At site 26 the number of 48-inch culverts with exterior sluice gates was increased to four. These structures allow controlled introduction of Caernarvon flows into the west and southwest portions of the project area (figure 2). Incremental spoil degradation on the south bank of Promised Land Canal west of site 54 was employed to allow distribution of diverted river water from the site 54 culverts into interior marshes to the south and southeast of that site.

2. Automatic flapgated culverts were incorporated into the existing plugs at sites 13, 50, 52, and 60. All structures were constructed using a earth fill core with a rock riprap armor for protection. Sites 13 and 50 each have one 48-inch culvert with a combination-gate on the interior side (distal to Caernarvon discharge) and sites 52 and 60 each have two 36-inch culverts with interior combination-gates. Sites 13 and 50 were built to replace existing structures on the west bank of Bayou Mandeville. Sites 52 and 60 are located adjacent to breached openings in the south spoilbank of DP Canal and the north spoilbank of Reggio Canal, respectively. These structures permit continuous, unimpeded inflows of Caernarvon

Figure 1. Upper Breton Sound Basin, with Caernarvon Outfall Management (BS-03a) project and reference areas.

Diversion waters into interior marshes when water levels on the outside are greater. Additionally, these structures prohibit dewatering of interior marshes during periods of lower exterior water level, thus increasing retention time of Caernarvon Diversion waters in those interior marshes (figure 2).

3. Rock-filled plugs were installed in the channel connecting Lake Lery to Le Blanc Bayou at site 32 and across the mouth of the oilfield canal at site 56. Those plugs increase retention time of diversion waters within the interior marshes (figure 2). There exists an armored rock plug at site 51. With two water control structures immediately below and hydrologically connected to site 51, it is imperative the plug at this site be maintained throughout the life of the project.

   Several openings exist around the perimeter of the project area that will remain unobstructed. This will provide continued, unimpeded access for local marine traffic and fishery resources.

4. Approximately 5,320 ft of spoil bank on the west side of Bayou Mandeville was improved (site 58) to ensure that diversion waters entering the marsh through structures at sites 13 and 50 distribute throughout the interior, rather than simply breaching the historically low spoil bank and draining into Bayou Mandeville. The spoil bank along the west side of Reggio Canal, between sites 40 and 54, had numerous breaches. To ensure that Caernarvon Diversion water introduced at sites 40, 26, and 54 did not simply re-enter Reggio Canal and bypass project area wetlands to the south, 5,398 ft of spoil bank was restored (site 57). The settled height of the embankments is approximatley 2.5 ft above average marsh elevation (figure 2).

Each of the project features influence one of four distinct polygons that are bound by high ridges or spoil banks within the project area, and therefore the project area was subdivided into four strata (figure 3). 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. A 6,000-ft section of the western spoil bank between sites 40 and 54 was restored to help retain the water that area receives.

Because different regions of the project area are under the influence of 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. To account for this variation, a stratified design will be employed. Each region will serve as a stratum, and the factor, “strata”, will serve as a blocking factor in the ensuing data analysis.

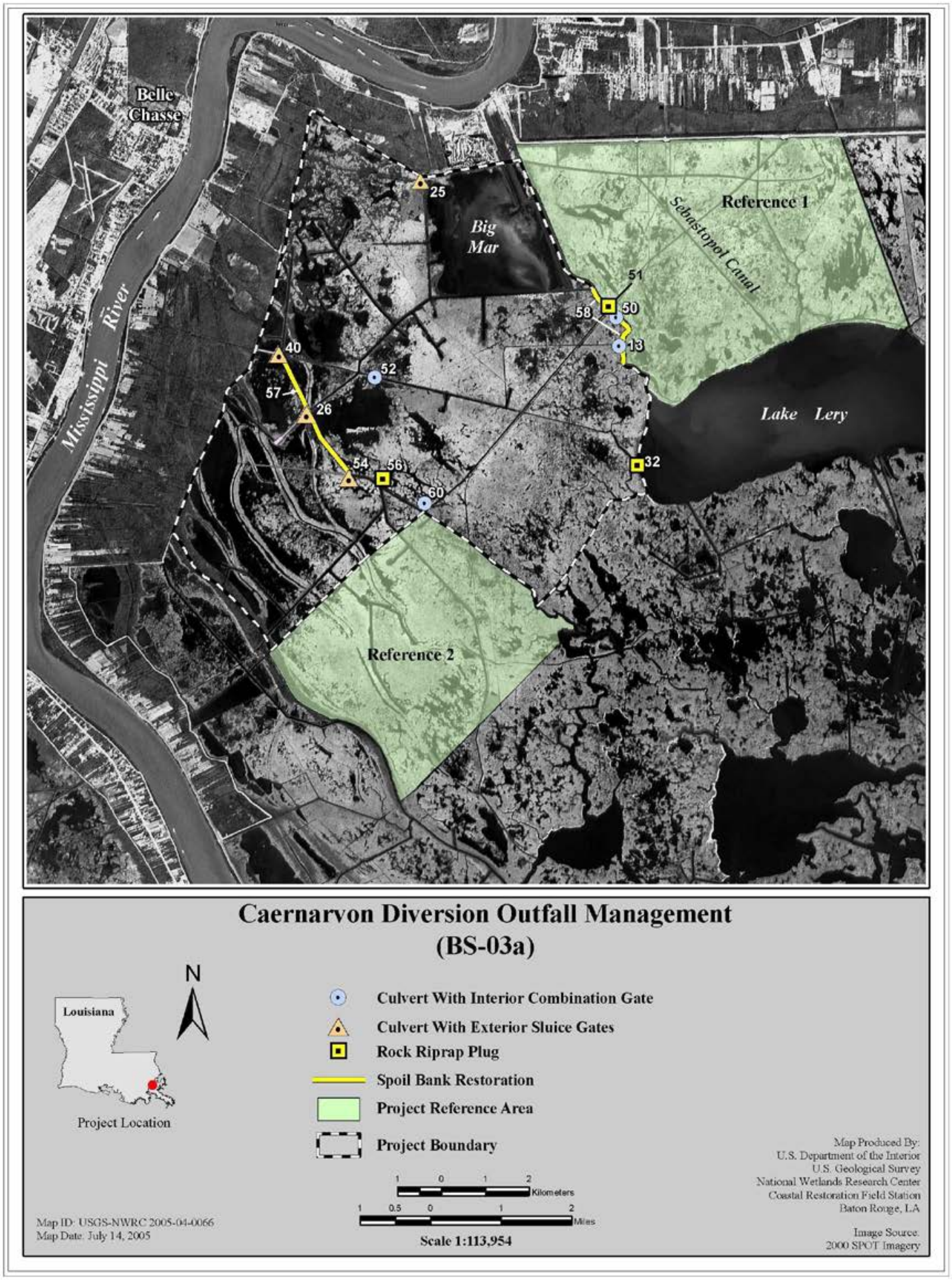

Figure 2. Caernarvon Outfall Management (BS-03a) project features. North Reference Area is stratum 5R and South Reference Area is stratum 6R.

II. Maintenance Activity

a. Project Feature Inspection Procedures

An inspection of the project area was conducted on on March 4, 2008 on a clear to partly cloudy and cold day with winds NW 20 to 25 mph. At the time of the inspection all 5 gates of the diversion structure were open with a flow of 7,100 cubic feet per second. The Marsh Gage reading was +2.5 feet NGVD and the River Gage reading was +9.5 feet NGVD. In attendance were Tom Bernard, Barry Richard, of OCPR; and Loland Broussard and Michael Trusclair of NRCS. Due to canal blockages from Katrina, the team was unable to reach the entire project using one launch site. Therefore; the team left the Scarsdale boat launch at 9:30 am to inspect the west portion of the project and later left the Delacroix Corporation boat launch in Caernarvon at noon to inspect the east portion of the project. Extreme windy conditions prohibited the use of air boats during this inspection. Photographs were taken at each project site reached and a field inspection form was completed in the field to record measurements and deficiencies (Bernard 2008).

b. Inspection Results

Much of the marsh debris that was deposited throughout the area as a result of Hurricane Katrina has been cleared making the project accessible for this years' inspection. The main blockage, approx. 1,000 ft., still remains in the Delacroix Canal just east of structure #26. At the time of the inspection, water levels were high due to high diversion flows over a long period of time causing most of the marsh to be flooded. The water levels were only four to six inches from the bottom of the structure walkways and well above the tops of the culverts. Due to the fact that the entire outfall area had been flooded for a long period of time and strong SE winds and tides had pushed much water over the spoil-banks into the marshes, there was evidence of water flowing out of the marsh into the canals, both over the banks and through the culverts. While the flow was high 7,100 cfs during the inspection, the strong NW winds was pushing much of the diverted water southward over and out the marsh and through the main channels.

Site/Structure # 13 - The gate was in the open position at the time of the inspection. Water flow was visibly going out, possibly due to a sufficient differential head. It was evident that not much (if any) blockage remains due to storm debris. Water was rushing out of the interior where it appeared that a few rocks were displaced on the north end of the closure accented by some scouring of the embankment at the tie-in. The timber walkway has separated from its support beam at one end.

Site/Structure # 25 The structure remains covered with small amounts of marsh debris from the storm. The gates were padlocked closed at the time of the inspection but plans are in place to open these gates in the near future. It was not evident how much (if any) blockage remains due to storm debris. Note: The structure could be accessed due to water hyacinth and debris obstructions in the N-C canal.

Site/Structure # 26 - The structure is still has some storm debris deposits in spots. The gates were in the open position at the time of the inspection. Water flow was slightly visible, possibly due to a lack of sufficient differential head. It was evident that not much (if any) blockage remains due to storm debris. Padlocks on all 4 gates were non-functional. Delacroix Canal is completed plugged with storm-related debris thereby eliminating a substantial portion of freshwater flow from the diversion towards this portion of the project area.

Site/Structure # 32 - Overall condition was good with the exception of the area that was vandalized in early 2003. That area was partially repaired by the 2003 inspection team; however, that repair was again vandalized to the original depth. The condition of the closure appears not to have changed; most of the storm debris is gone. This structure was constructed to keep diversion water from entering Lake Leary from the western lake rim; the storm devastated that portion of the lake rim rendering this structure ineffective. Nothing needs to be done until the Lake Lery shoreline is re-built.

Site/ Structure # 40 - The structure is just slightly covered with storm debris. The gates were in the open position at the time of the inspection. Water flow was somewhat visible, possibly due to a lack of a large differential head. The culverts at this site was flushed out since the last inspection. The interior channel that leads to the site was relatively clear of debris and hyacinths. Padlocks on both gates were non-functional.

Site/Structure # 50 – The gate was in the open position at the time of the inspection. The outfall water elevations were so high that flow was visible over the entire closure, as well as through the culvert. The timber walkway is slightly bowed. Padlock on the gate was non-functional.

Site/Structure #52 – The gates were in the open position at the time of the inspection. There appeared to be a vortex on the water surface near the inlet of the north culvert indicating some water flow. It was evident that much blockage remains due to storm debris in the north culvert. There is a tree ball located at the end of the combination gate that keeps it from operating. There was a moderate breach of the spoil bank to the right and left of the plug allowing some flow from the canal to the marsh. It is estimated that the canal water level was from 9 to 12 inches higher than the interior, which allowed much water to flow over the spoil-bank into the marsh. The padlock on the gate was non-functional.

Site/Structure # 54 – The structure has been cleared of all storm debris. The gates were in the open position at the time of the inspection. Water flow was not visible, due to a lack of sufficient differential head therefore it was not evident how much blockage remains due to storm debris. The culverts at this site were flushed out since the last inspection.

Site/ Structure # 56 - No subsidence was noted in this rock structure since the last inspection. Some storm debris remains on the entire rock closure. The warning signs that were damaged during the storm have been reset. The middle section of the plug is approx. 0.5' lower than the sides.

Site # 57 - It appears that the vegetation on the spoil bank along the sides of the Reggio Canal that was damaged by the storm is recovering well although many sparse areas remain. There are small breaches in the spoil-bank between structure nos. 26 and 40. One large cut (~15' wide) exists in the spoil-bank east of structure no. 54.

Site # 58 - The vegetation on the spoil bank along the sides of the Bayou Mandeville that was damaged by the storm is recovering although many sparse areas remain.

Site/Structure # 60 – The gate structure is completely cleared from any storm debris. The gates were in the open position at the time of the inspection. Water flow was slightly visible; therefore, not much blockage remains due to storm debris. The culverts at this site were flushed out since the last annual inspection. The high water stage makes the rock closure on the east wing-wall appear to have subsided since the last inspection; however, the closure still is functioning as designed.

c. Maintenance Recommendations

i. Immediate/ Emergency Repairs

No repairs are suggested at this time.

ii. Programmatic/Routine Repairs

Areas of the outfall project show good signs of recovery from the Katrina Storm event. This recovery appears to be due to a steady moderate to high flow of river water through the diversion. Many structures may still be slightly blocked by storm debris, but are slowly being cleaned out by water exchange through the culverts. Completed repair operations to the levee breaches that occurred behind Braithwaite and Scarsdale now allow the diversion structure to be operated above 5,000 cfs without fear of further flooding the east bank of Plaquemines Parish. OCPR and NRCS have tentatively agreed to pursue a 404 permit to clear approx. 1200 lf of Delacroix Canal west of DP Canal to re-establish channel capacity and freshwater flows to the SW portion of the project area.

It is OCPR's conclusion that, the outfall project may never be restored to its original condition. The entire complexion of the project has been changed. It will take clearing of the channels, clearing of the remaining debris from and around some culverts, and repair all the washed out embankments that formed the perimeter affected by each individual structure. It will also be necessary to repair the entire west and north lake rim of Lake Leary that was damaged, so as not to allow diversion water to enter the lake from those sides.

OCPR suggests that we continue to aggressively operate the diversion structure with hopes that much of the marsh debris that was deposited by the storm will be displaced from the project area. It is also thought that by operating the structure aggressively, will allow more desirable vegetation to take over and expand where it did exist before the storm. The Delacroix Corp. has recently received a marsh management permit that will allow them to repair much of the spoil-banks and holding areas that contributed to the success of this project. That work should commence very soon. In the interim, we will continue to divert fresh water into the South and West section of the outfall area.

OCPR would also like to suggest that the State and NRCS continue to work together to make the necessary changes, to the original project, that were brought on by the following post design and construction events:

a. Resolution of the oyster litigation that for so long influenced the operational plan for the diversion.
b. Severe storm damage from Katrina that dramatically changed the complexion of the entire outfall landscape.
c. Legislation resulting from the storm damage that granted the project $10.1 million by the 4th supplemental appropriation. These funds will be used to modify the Caernarvon Freshwater Diversion Project by restoring the surrounding wetlands to reverse wetland losses and modification of the main structure operations.
d. Under that supplemental appropriation, the COE will look to re-authorize the project in order to maximize freshwater diversion to the Breton Sound Basin.

All of these events will influence the effectiveness of the Caernarvon Outfall Project as we now see it. It is anticipated that the low flows that initially were an integral part of the yearly operational plan will be a thing of the past. We are now looking at a more aggressive flow plan and, if the project is re-authorized, and given the demand for introduction of more freshwater into the marshes, we could enter into a pattern that would approach maximum flow (8,000 cfs) whenever the river stage will allow.

III. Operation Activity

a. Operation Plan

The operations schedule depicts the water control structures to be minimally operated year round. The structures are gated to allow flexibility in regulating water flow, if necessary. Initially, all sluice-gated structures will be fully opened to allow maximum inflow of available river water. Flap-gated structures at Sites 52 and 60 will be operated such that the gates will be locked open, except during waterfowl season, when they may be closed at the discretion of the landowner. Remaining flap-gated structures will be allowed to operate automatically throughout the year. Temporary changes in the normal mode of operation may occur during special conditions, such as storm surges, extremes in precipitation, or in 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 this past year. All gates have been left in the open position to allow fresh water in all the marsh areas except Structure 25, which was closed to minimize flow to the area behind Braithwaite, where emergency levee restoration was being constructed by the USACE. Plans are to now open that structure and operate it as outlined in the O & M Plan. In 2008, when the contract for operation of the main diversion structure is re-bid, the O & M of the outfall structures will be included. A monthly maintenance plan will be drafted for the contractor to follow. That contract will go into affect on July 1, 2008.

IV. Monitoring Activity

This is a comprehensive report and includes all data collected from the pre-construction period and the post-construction period through August 8, 2005. Hurricane Katrina destroyed all monitoring stations on August 29, 2005 and the data from the one recorder that was found was unrecoverable. Since the Coast-wide Reference Monitoring System (CRMS) project stations were to replace the hydrologic stations in the project area, no new stations were constructed from project funds. Due to programmatic difficulties with the CRMS project, the CRMS stations in the project area did not start collecting hydrographic data until late 2007.

Katrina completely rearranged the topography and hydrology of the area. Large areas of land were torn up and deposited towards the north and west extent of the Breton Basin. Spoil banks which held diverted waters within stratums were ripped open. Canals were turned to marsh, and marsh areas to open water with just sporadic clumps of marsh dotting the surface. All canals in the project area were filled with chunks of marsh, with the main canals being dredged to allow passage. However, many canals in the area are still blocked. The Delacroix canal is blocked at its intersection with the DP canal preventing water from reaching the west side of the project area. The 40-arpent canal to the east is also clogged with marsh. Most diverted water now exits Big Mar to the east and flows to Lake Lery through Bayou Mandeville.

a. Monitoring Goals

The objective of the Caernarvon Outfall Management Project is to increase freshwater and nutrient dispersion into interior marshes that are currently isolated from Caernarvon Diversion flow during low discharge periods, and promote better retention 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. Increase occurrence and abundance of fresh/intermediate marsh type plant species.
3. Increase the occurrence of submerged aquatic vegetation (SAV) in shallow open-water areas.
4. Reduce salinity variation in the interior marshes.

Due to the damage the project features sustained from Hurricane Katrina goals are hard to meet much less evaluate. Monitoring in the Caernarvon outfall area has taken the role of assessing marsh conditions instead of determining whether the project's objectives are being met.

b. Monitoring Elements

Habitat Mapping

To determine ratios of marsh to open water, land loss rates, and changes in vegetation community structure, color-infrared aerial photography (1:24,000 scale, with ground control markers) will be obtained for each stratum in the project area and each reference area. The photography will be georectified, photo interpreted, mapped, ground-truthed, and analyzed with Geographic Information Systems (GIS) by NWRC personnel using techniques described in Steyer et al. (1995). 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 at one station inside each project area stratum and at one station in each reference stratum with continuous recorders from 2000 - 2005 (figure 3). In addition to those 6 continuous recorder stations, 12 stations in the project area and 6 stations in the reference areas were established and salinity at those stations were measured monthly to help spatially characterize project-induced changes. Due to programmatic changes in monitoring efforts, Coast-wide Reference Monitoring System (CRMS) stations were used in place of the project-specific recorders to document salinity in each of the six strata (LDNR/CRD 2002). CRMS stations were not established in the project area until late 2007, consequently, there is a gap in data from the time project stations were destroyed by Katrina and the deployment of CRMS stations. Discrete salinity stations were discontinued after 2004.

Water Level

To assist in determining if the project objective of increased freshwater dispersion into and retention within interior marshes is being met, hourly water level data were collected at the same six sites as where hourly salinity data were taken with the same continuous recorders. Within the vicinity of each recorder, average marsh elevation was determined, and all recorders are surveyed to the North American Vertical Datum (NAVD 88). This enables assessment of frequency, duration, and depth of marsh inundation.

Vegetation

Vegetation was surveyed in the project and reference areas using a modified Braun-Blanquet method (Steyer et al. 1995). Six plots ($4m^2$ each) were located in each sampling stratum of the project area, and six additional plots were established 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). In the near future, project-specific sites will be discontinued and vegetation will only be surveyed at CRMS stations within each stratum. Those data will also be supplemented with Chabreck and Linscombe habitat classification data.

Due to the loss and rearrangement of marsh from hurricane Katrina, navigation in the area has completely changed.

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 (figure 5). SAV was sampled during the spring of 2000 (pre-construction) and 2003 (post-construction). SAV sampling has been discontinued due to the effects of hurricane Katrina on the marsh ponds used for sampling.

Accretion
Although not an explicit goal of the outfall management project, vertical accretion and subsequent surface elevation change is an important response to 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 6). Feldspar marker horizon stations were established at the same locations as the SET's to monitor vertical accretion and sediment deposition. These stations were sampled in 2001(pre-construction), and in 2002, 2003, and 2004. However, with the implementation of CRMS, project-specific stations were discontinued in favor of the CRMS stations located in each stratum.

Flow Rate
Flow meters were installed in March 2004 on single pipes at structures 26, 40, and 54. Although not part of the project specific monitoring, flow measurements were added to quantify conveyance of water to strata 4 after the canals behind these structures were blocked with marsh mats from the storms of 2002. This data will be used to determine whether the canals should be dredged to promote flow of water into the area. These stations were also destroyed by Katrina. Two recorders were lost and one damaged, no data was recoverable.

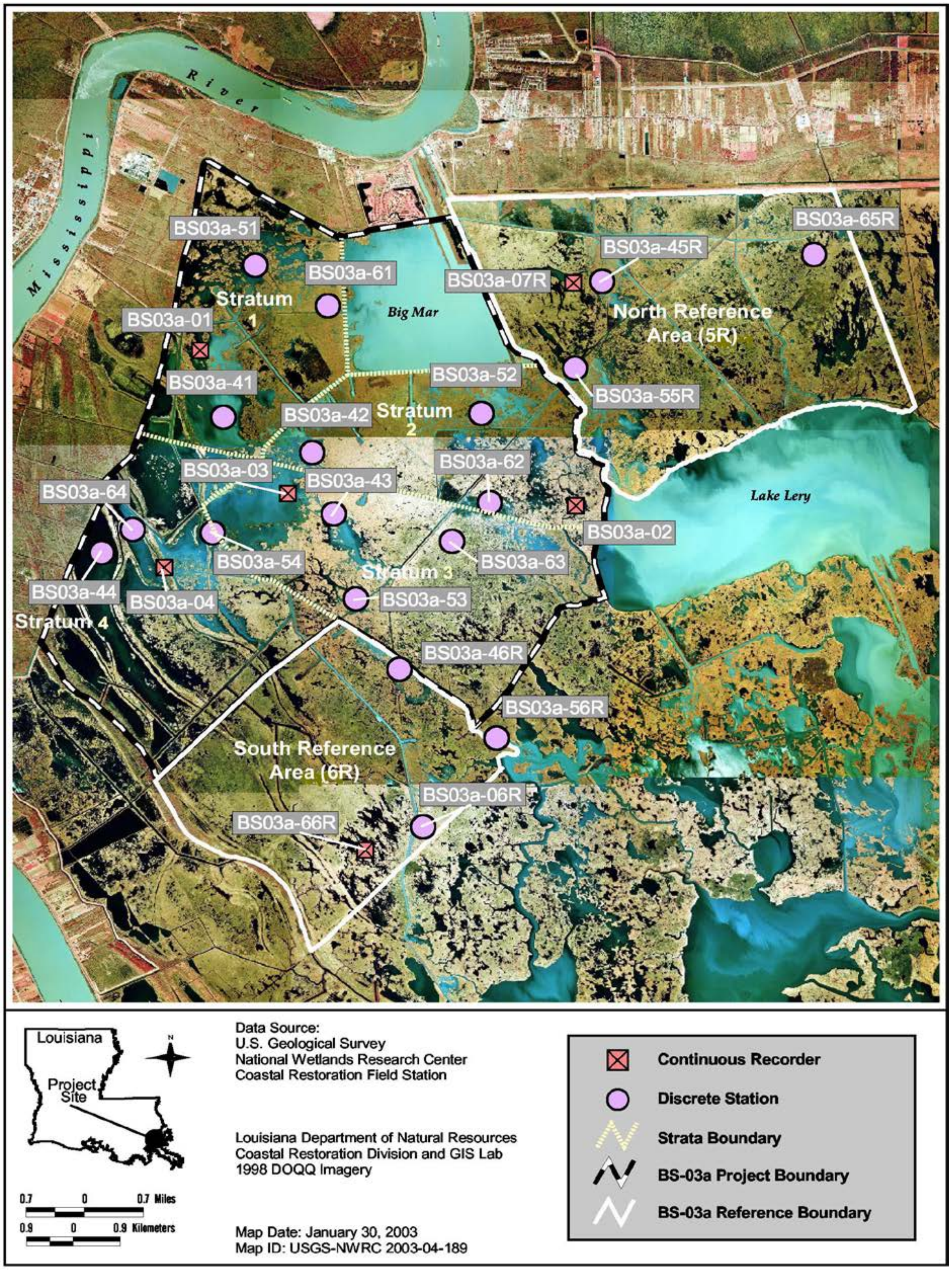

Figure 3. Location of continuous recorder and discrete stations for the Caernarvon Outfall Management (BS-03a) project .

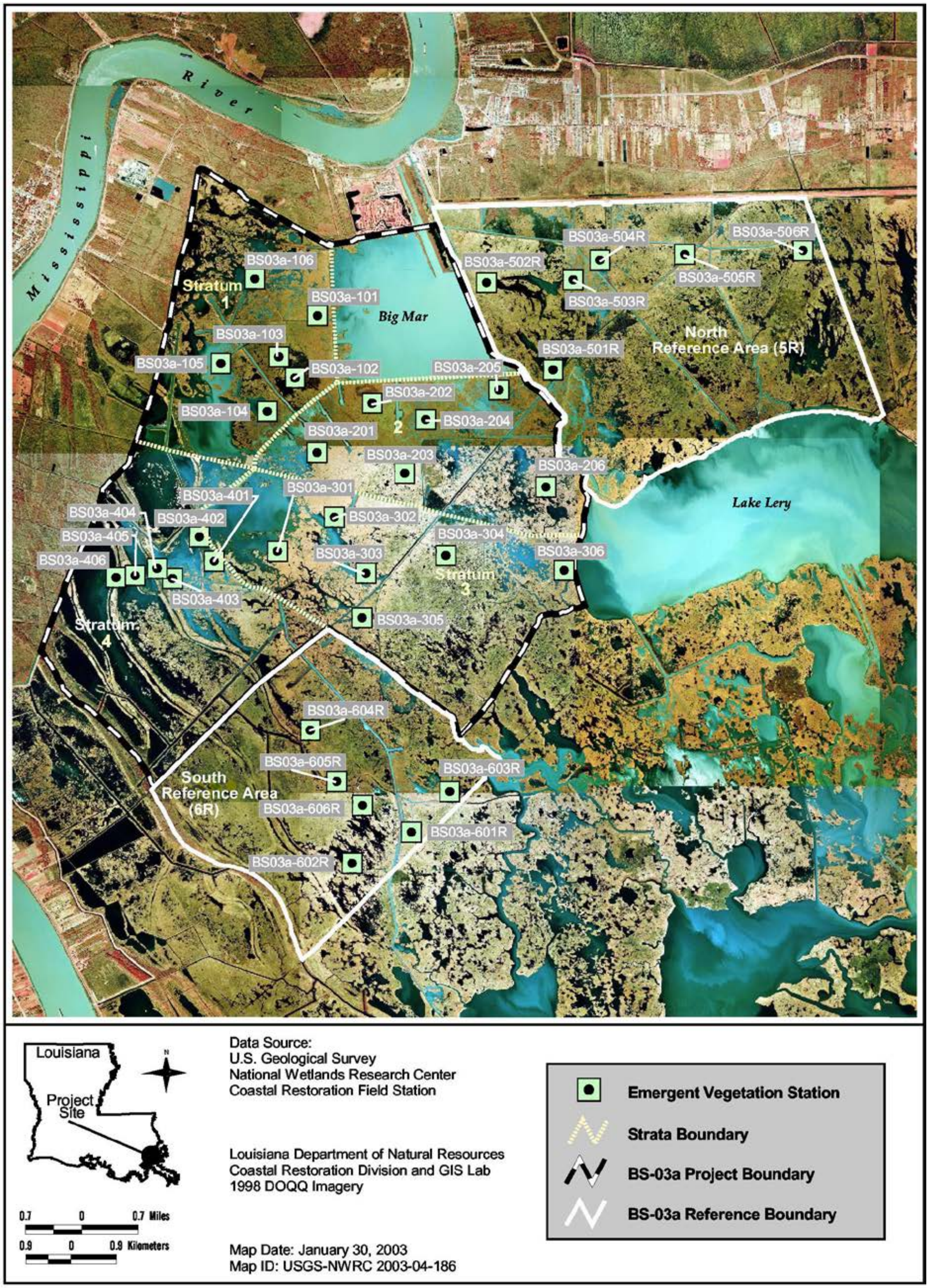

Figure 4. Caernarvon Outfall Management (BS-03a) vegetation sampling station locations.

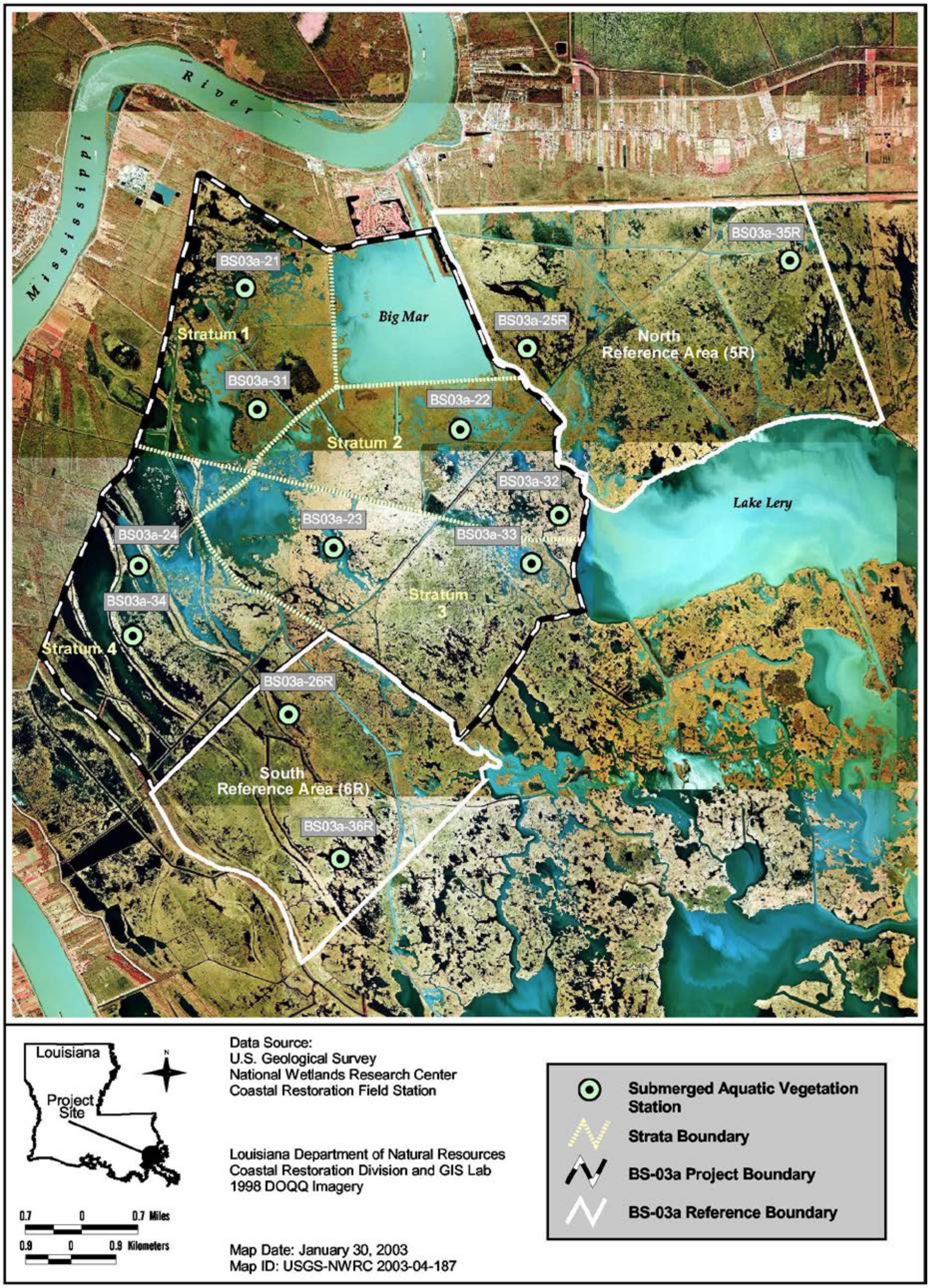

Figure 5. Caernarvon Outfall Management (BS-03a) SAV sampling stations.

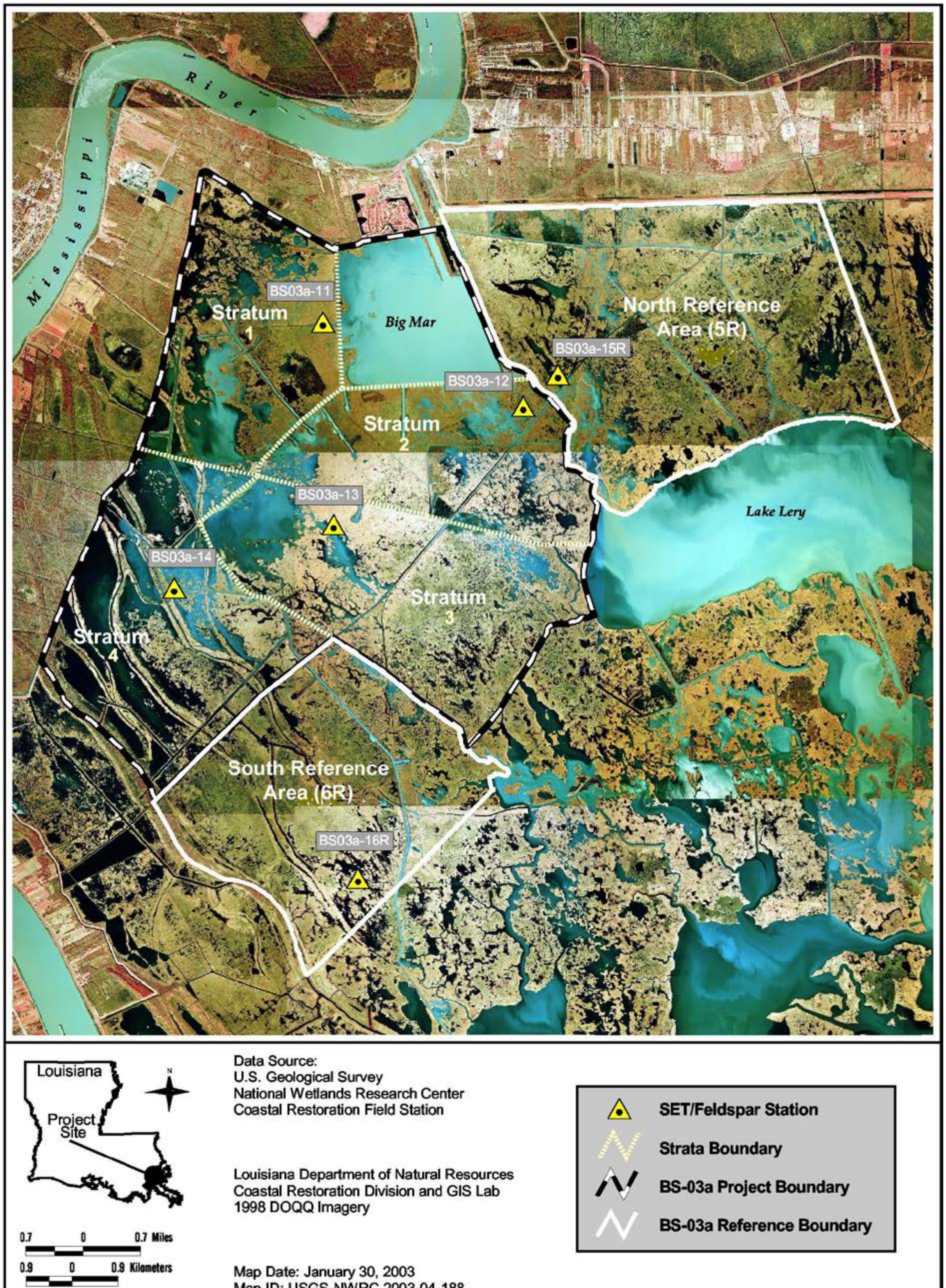

Figure 6. Location of Caernarvon Outfall Management (BS-03a) project accretion sampling stations.

IV. Monitoring Activity (continued)

c. Preliminary Monitoring Results and Discussion

Habitat Mapping

Aerial photography obtained in 2000 (pre-construction) has been analyzed and is presented in figure 7. The 2006 photography has been acquired but due to the extent of damage from Katrina analysis is impossible. It is hoped that analysis will be possible with the next round of photography. To show the affects of Hurricane Katrina around the Caernarvon area, satellite imagery was acquired a week after the storm by the United States Geological Survey (USGS) and compared to a pre-storm image from 2004 (figure 8). The amount of marsh loss is astounding, although water levels were still elevated at the time of the photo acquisition. However, even with water levels still high, the massive disturbance the wetlands received can still be observed. 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 (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.

Salinity

The initial deployment of the Caernarvon Outfall Management (BS-03a) project continuous recorders occurred in the middle of a drought, which affected southeast Louisiana from August 1999 to December 2000. To show the droughts affect on salinity prior to deployment of the BS-03a recorders, data from station DCPBS06 (Reggio Canal) is presented in figure 9. This station is located in Reggio Canal near its intersection with Manuel's Canal, and was established in January of 1999 (LDNR/CRD 2003). Salinities normally remain below 2 ppt, but approached 7 ppt during the drought (figure 9). However, during the drought salinity levels were suppressed by diversion waters when the river stage and operational plan allowed (figure 9). This flushing effect can also be seen after tropical storm events when diversion waters dilute and remove more saline waters associated with storm surges. Project and reference strata seem to follow the same general trend of the Reggio Canal DCP, with rises and falls in salinity in relation to diversion flow (figures 10 and 11). 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 interior marshes.

Yearly mean salinities for project and reference strata have averaged less than 1 ppt since the inception of data collection in 2000. Exceptions were strata 4 during 2004 when mean salinity increased to greater than 1 ppt and reference stratum 6 where means were between 1 and 1.8 ppt for all years (figure 12). Mean salinity increased, however, for all strata in 2004. The decrease in mean salinitiy from 2000 to 2001 across all strata may have resulted from the previously mentioned drought (figure 12). The salinity increase in 2004 represents the susceptibility of the area to storm surges, even from tropical events not directly impacting the area. If the recorder stations would have survived the surge from hurricane Katrina 2005 salinities would have likely exceeded those of 2004.

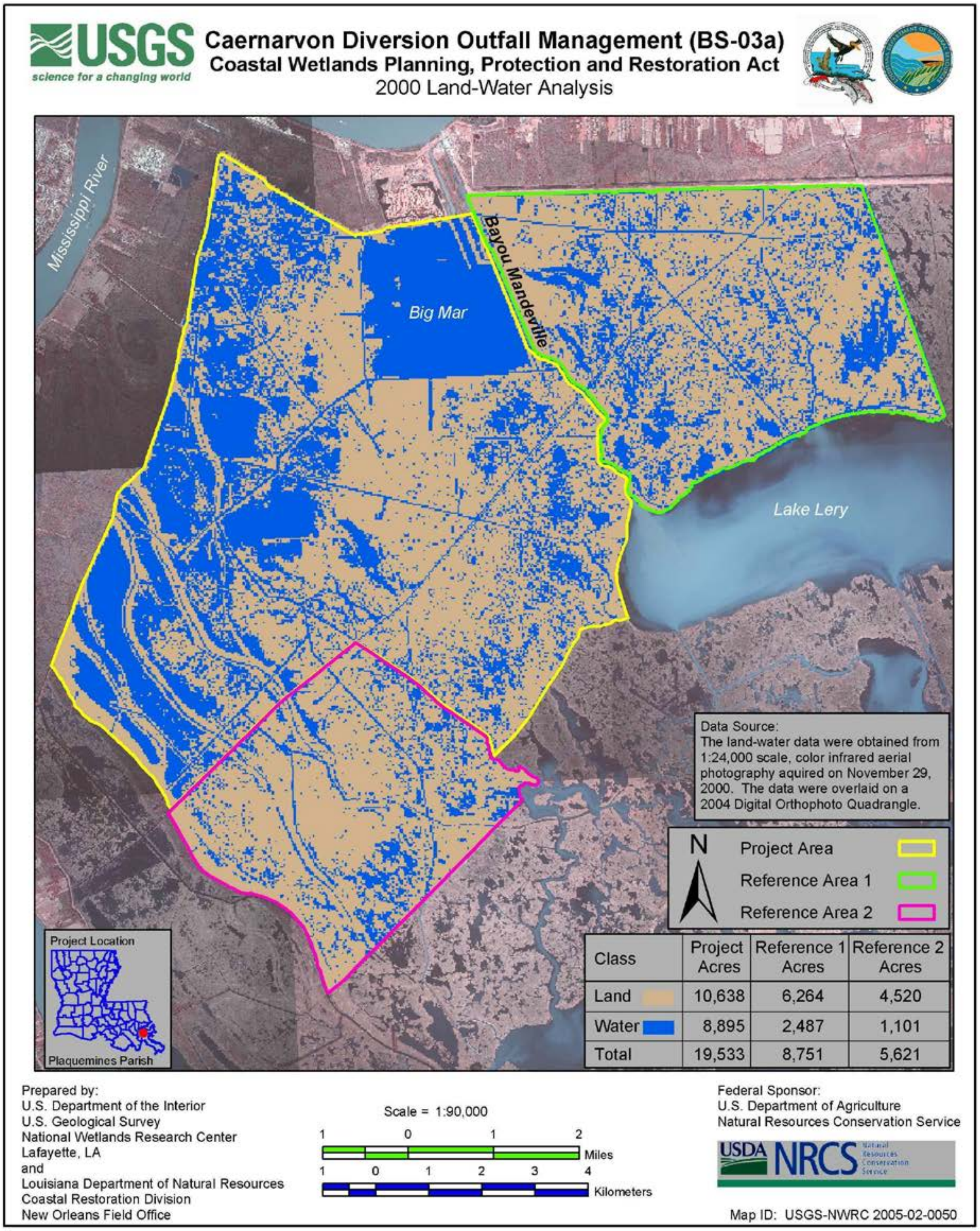

Figure 7. 2000 Land water analysis for the Caernarvon Diversion Outfall Management (BS-03a) project.

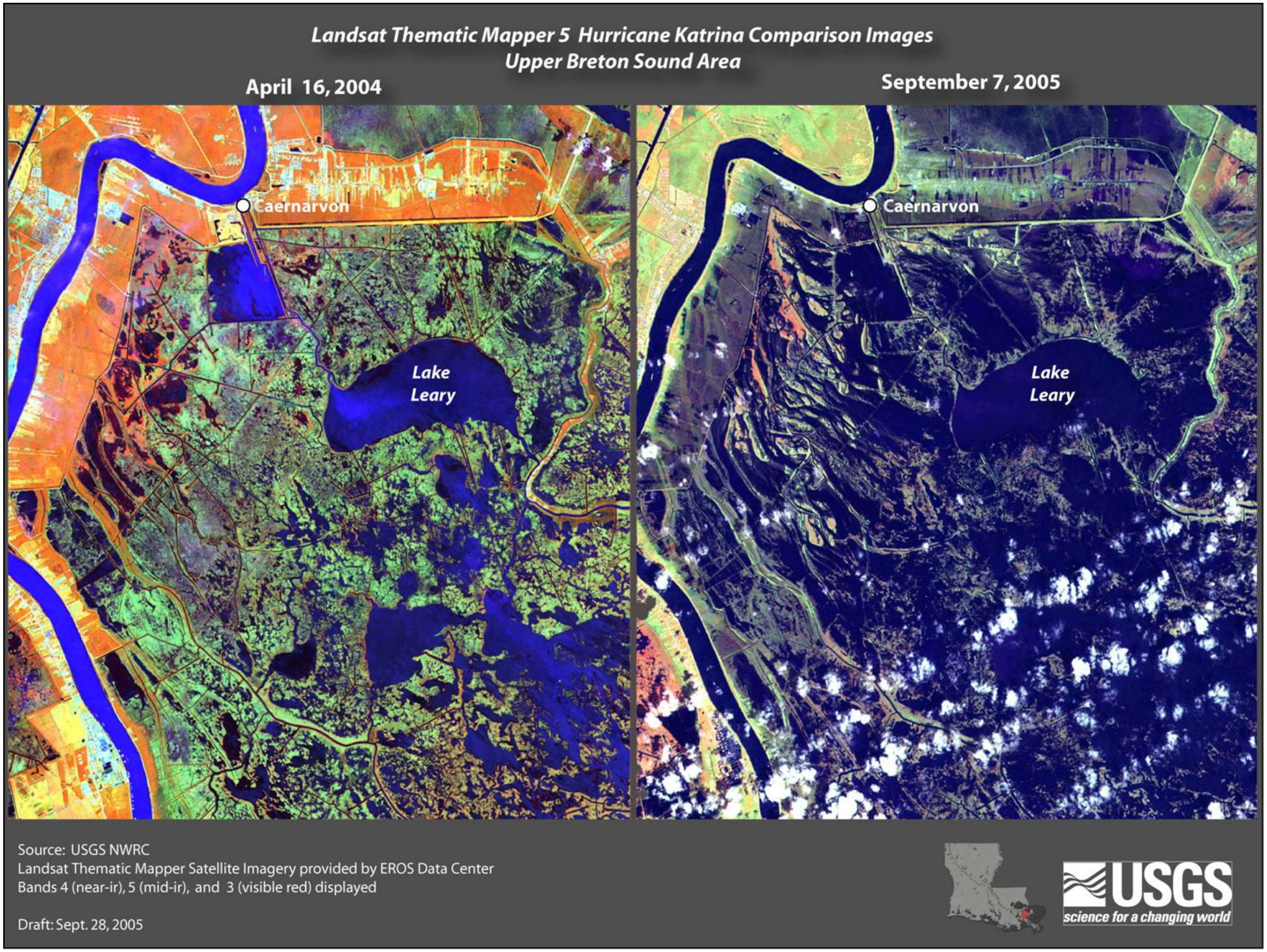

Figure 8. Pre and Post Katrina satellite imagery showing changes to the Caernarvon area from the storm.

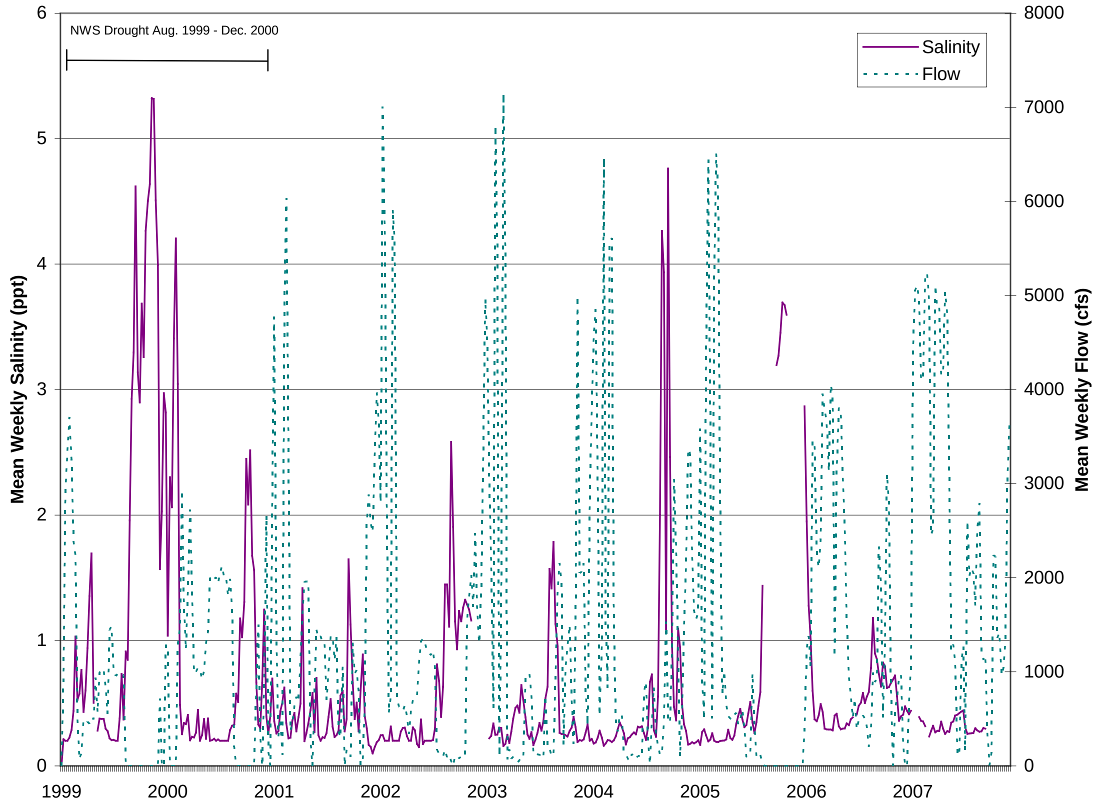

Figure 9. Mean weekly salinity for the Reggio Canal DCP, located within the Caernarvon Outfall Management (BS-03a) project, and mean weekly flow rates for the Caernarvon Diversion, 1999 - 2007.

Even with mean salinities below 1ppt diversion benefits are still realized with a reduction in mean salinity as flow rates increase from no flow within the project area (figure 13). However, salinities are so low throughout the area that brief salinity incursions (Holm and Sasser 2001) such as storms or persistent east and southerly winds, may skew estimates of average salinities. This was likely the case with stratum 2 & 3 because of back-to-back tropical events that hit the area in late September and early October 2002. Salinities rose to a maximum of 2.5 ppt and stayed above 1 ppt until November 2002 (figure 10). The area received a similar back-to-back hit in September 2004 from a single tropical system, Ivan. Salinities rose above 2 ppt again and lingered, particularly in strata 4 (figures 10 and 11). These tropical weather events were probably responsible for the increase in mean salinity values from the pre-construction period to the post-construction period (figure 14).

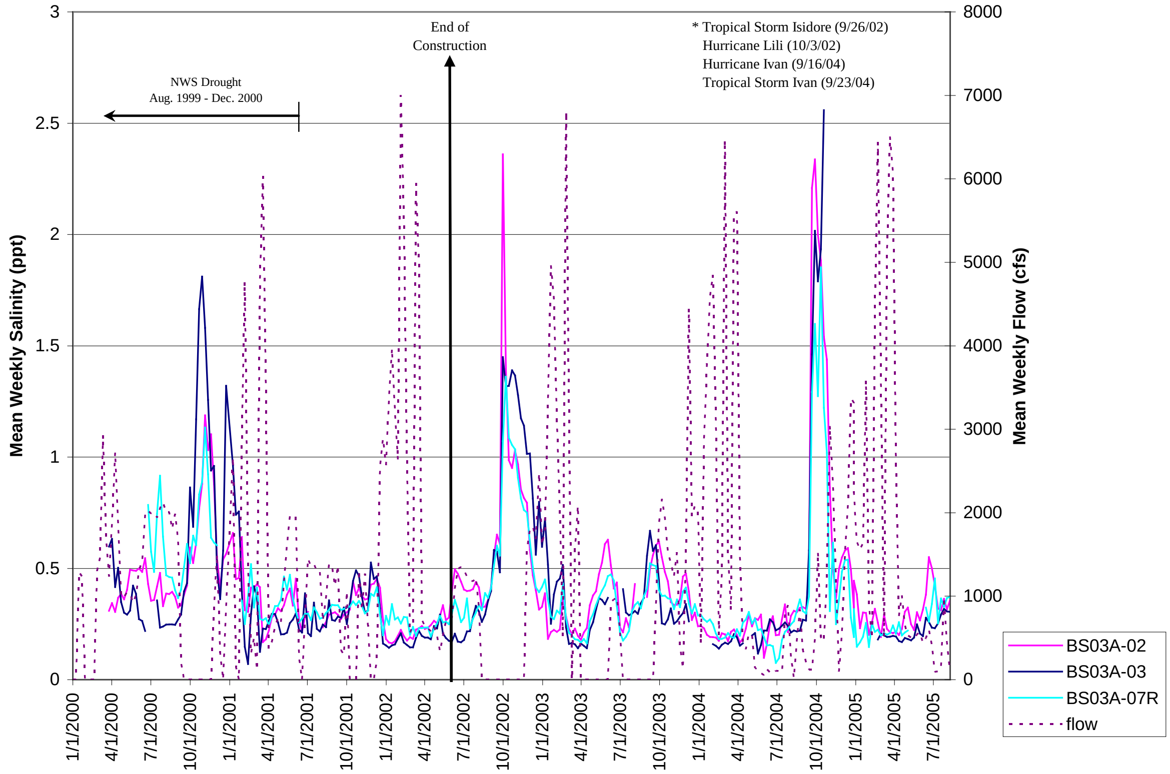

Figure 10. Mean weekly salinity for project stations BS03a-02 & 03 and reference station BS03a-07R for the Caernarvon Outfall Management (BS-03a) project, along with flow rates for the Caernarvon Diversion 2000 - 2005. Station BS03a-01, located in stratum 1, was not presented because it shows little variation over the course of record.

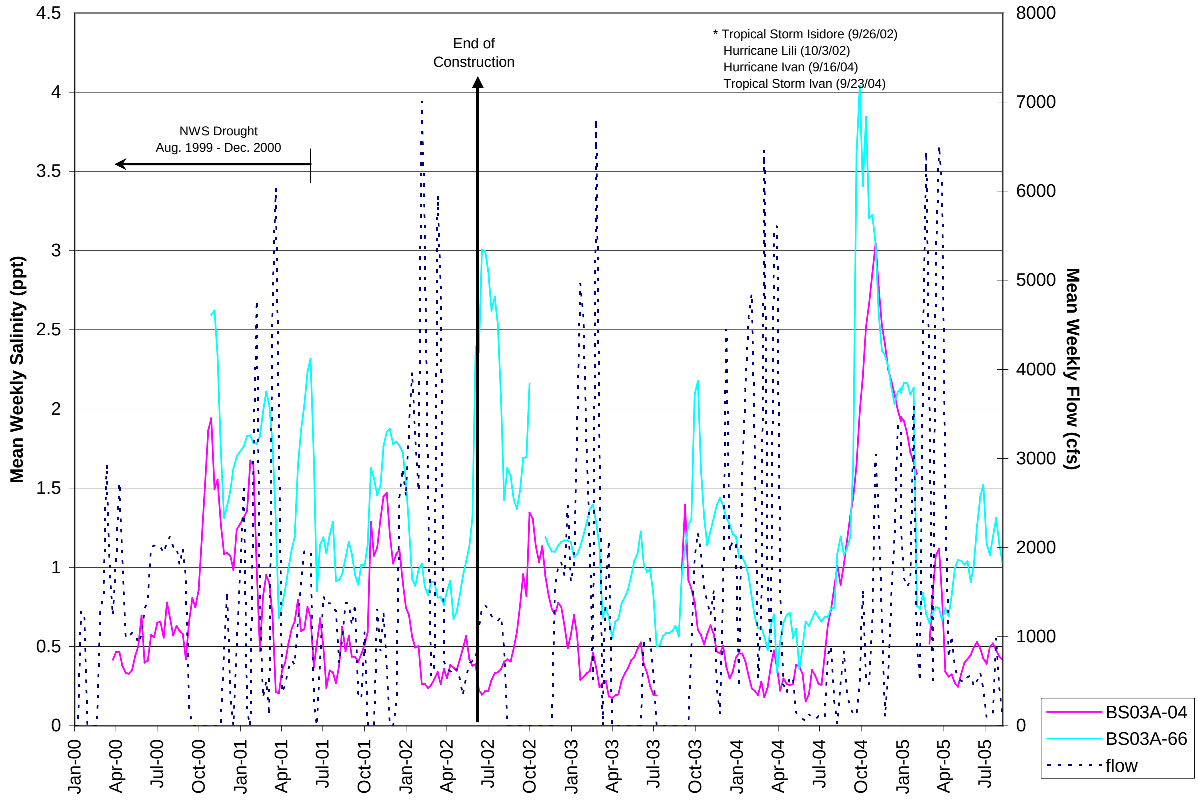

Figure 11. Mean weekly salinity for project station BS03a-04 and reference station BS03a-66R for the Caernarvon Outfall Management (BS-03a) project, along with flow rates for the Caernarvon Diversion 2000 - 2005.

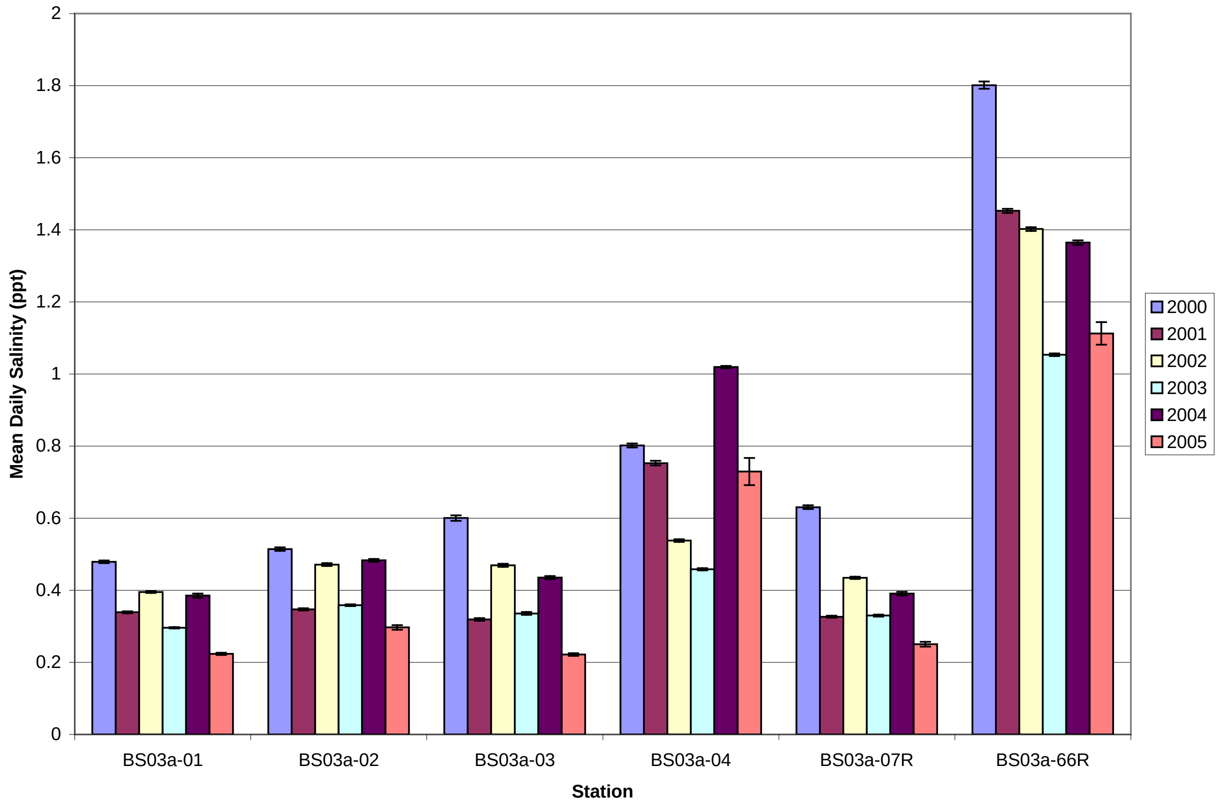

Figure 12. Yearly mean salinity for the Caernarvon Outfall Management (BS-03a) project.

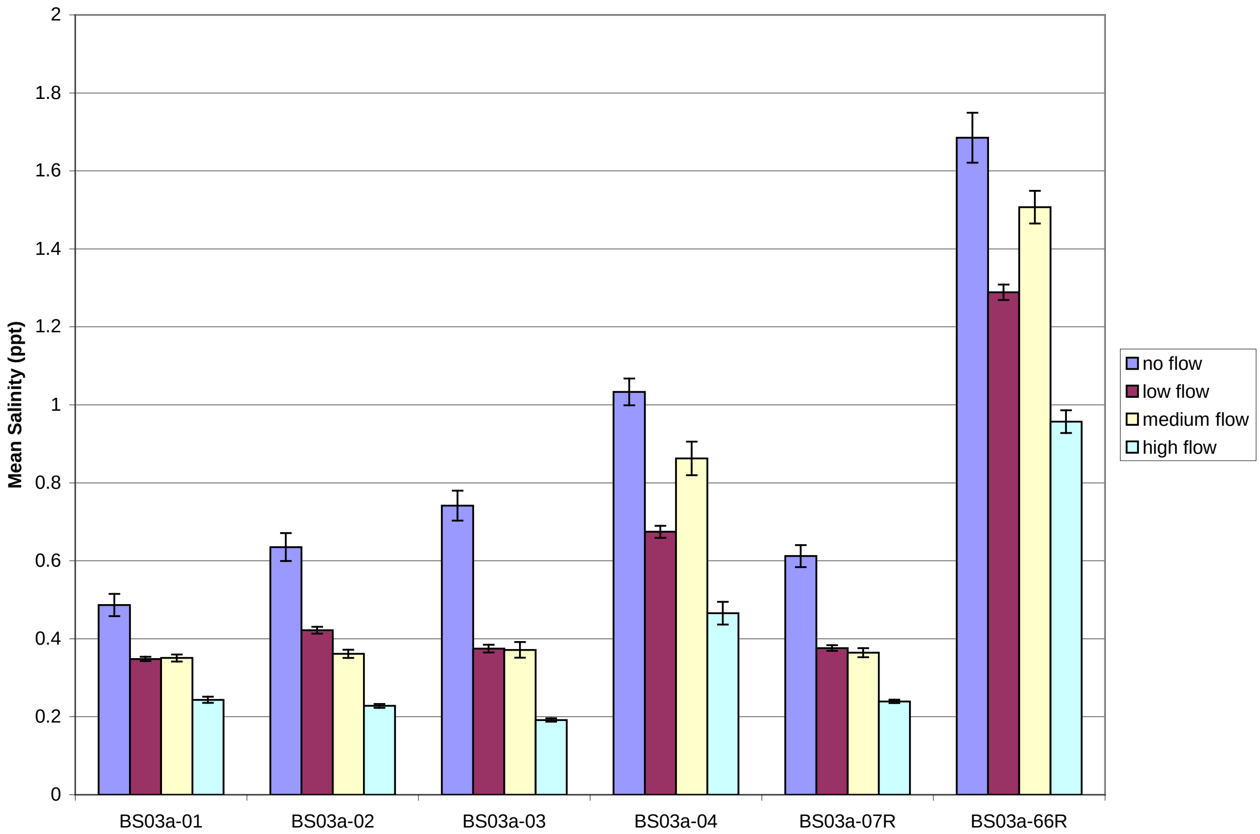

Figure 13. Mean (± SE) salinity for the period 2000 – 2005 at YSI continuous recorder stations during 4 operational categories [Low = 0 – 2000 cfs, Medium= 2000 – 4000 cfs, High= >4000 cfs] for the Caernarvon Outfall Management (BS-03a) project and reference stations.

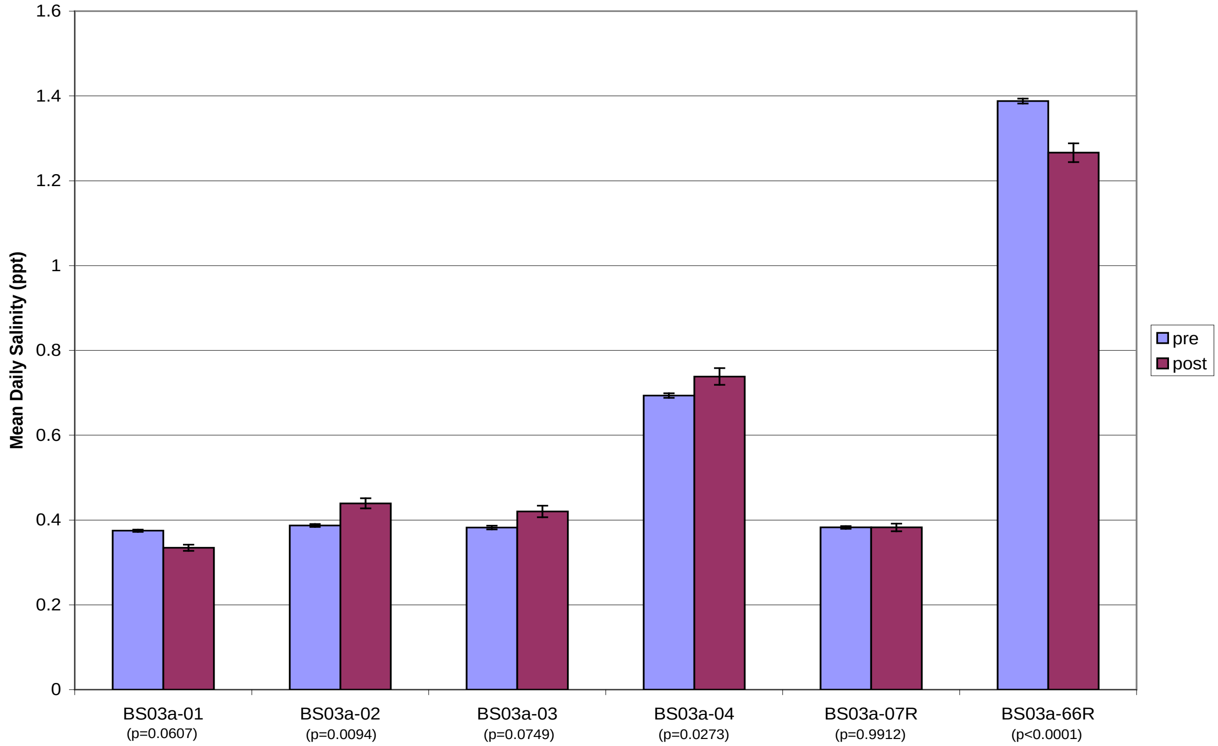

Figure 14 Mean daily (±SE) salinity at YSI continuous recorder stations for the Caernarvon Outfall Management (BS-03a) project and reference areas during pre- (3/27/2000 - 6/14/2002) and post-construction (6/15/2002 – 8/09/2005) periods.

One goal of the project was to reduce salinity variation within the interior marshes. Visual observation of monthly salinity variance over the entire data collection period seems to show a general trend of decreasing variance after construction, with the exception of the periods surrounding tropical weather events (figure 15). However, a statistical comparison of pre- and post-construction showed increasing variance for all but strata 4. Stratum 1 and 5 were the only strata that increased significantly (figure 16). The large increase in variance in strata 2 and 3 was likely attributable to the tropical weather events of 2002 and 2004. These two strata were probably 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 with Lake Lery and has repeatedly been vandalized in order to allow boats through. Strata 2 and 3 share a common boundary, the DP canal, which connects to Lake Lery through LeBlanc Bayou.

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 *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, with stratum 1 (BS03a-01) having the lowest salinity and reference stratum 6 (BS03a-66R) the highest, albeit a small difference between the two (figure 12).

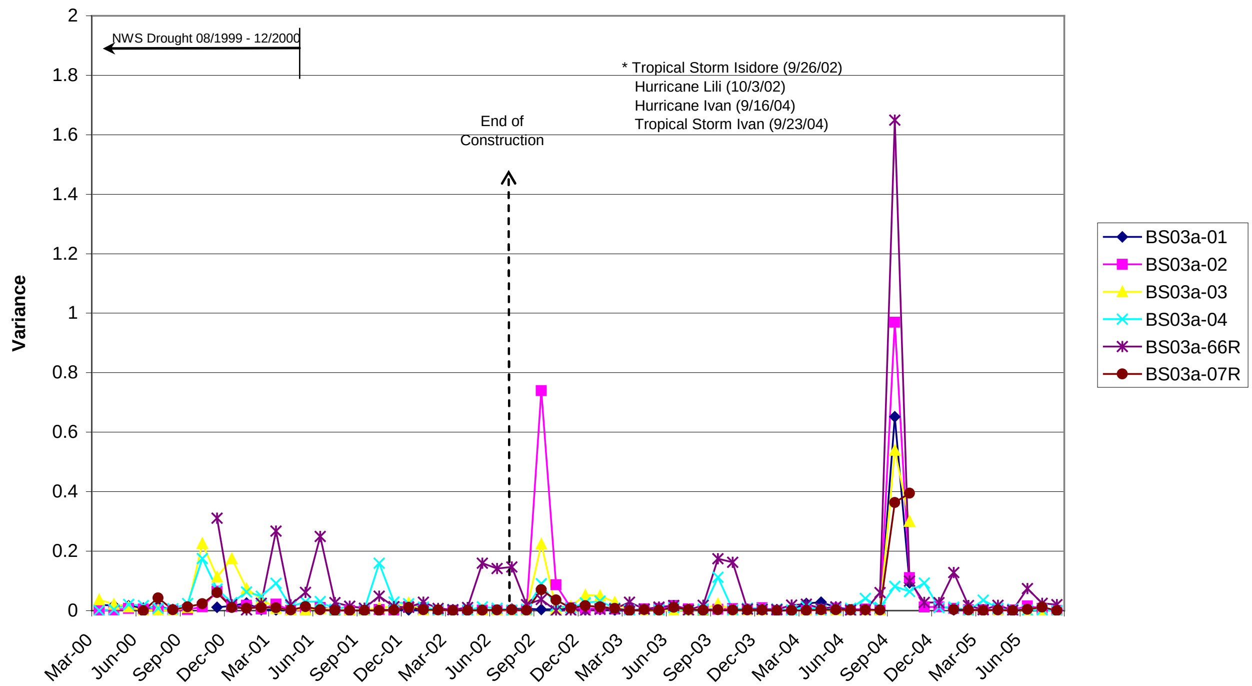

Figure 15. Mean monthly salinity variance at YSI continuous recorder stations for the Caernarvon Outfall Management (BS-03a) project and reference areas, for the period 2000 - 2005.

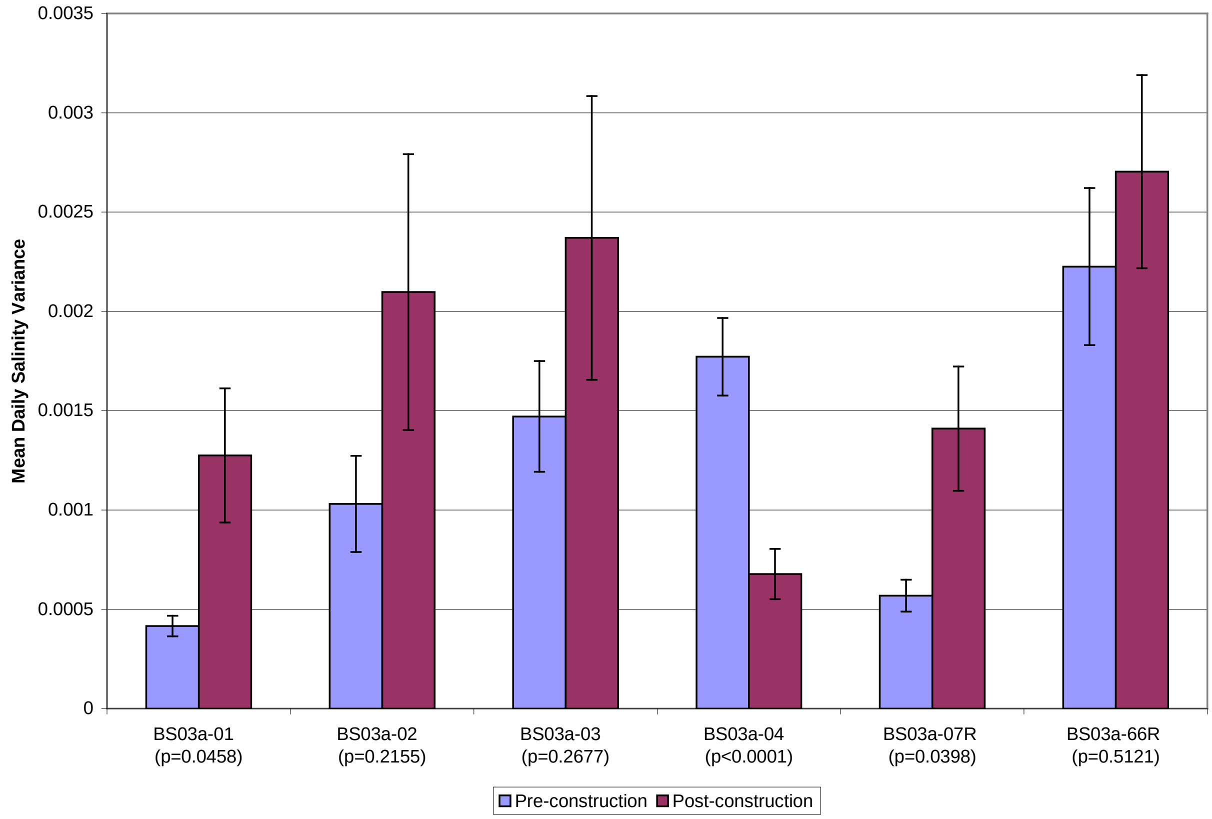

Figure 16. Mean daily salinity variance at YSI continuous recorder stations for the Caernarvon Outfall Management (BS-03a) project and reference areas during the pre- (3/27/2000 - 6/14/2002) and post-construction (6/15/2002 – 8/09/2005) periods.

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 consist of two, two-week high flow (6,500 cfs) periods, immediately followed by two-week low flow (500 cfs) periods, in the early spring each year. 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. *unpublished*). 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.

Water Elevation

Mean daily water level increased for the post-construction period in all strata except stratum 1; with only stratum 3 being non-significant (figure 17). Stratum 4 showed 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 of 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. If the continuous recorders would have survived Hurricane Katrina, post-construction water levels would have been bolstered by the estimated 18-foot storm surge that impacted the area.

Water level was compared during different flows for the pre- and post-construction periods and showed a significant increase during the post-construction period for low flow operations (0 – 2000 cfs) in strata 2, 4, and both reference strata (figures 17 - 22). Benefits from low flow operations were part of the primary objective of the project, but the effect of the drought on the pre-construction data and the effects of tropical events on the post-construction data should be taken into consideration. At medium (2000 – 4000 cfs) and high flow (>4000 cfs) operations, two strata showed a decrease in water level for the post-construction period while the other two showed increases, although not all proved significant. Stratum 4 showed significant increases for both high and medium flow rates while stratum 3 showed a significant decrease for the high flow category. The decrease is probably a result of the project confining water to only a certain few entry points. Before the project features were constructed, at medium and high flow operations water would move overbanks or through openings to reach the interior marshes within each stratum. After construction but before Katrina, entry points are confined to culverts through higher spoil banks and it takes longer to get that volume of water into the marshes. Unfortunately, fewer entry points means fewer exit points and water introduced into the marsh during storms may not regress quickly. During the no flow periods, water levels were significantly higher during the post-construction period for all strata. The low water levels associated with a drought pre-construction combined with elevated water levels during tropical events post-construction make associating this effect with project success difficult.

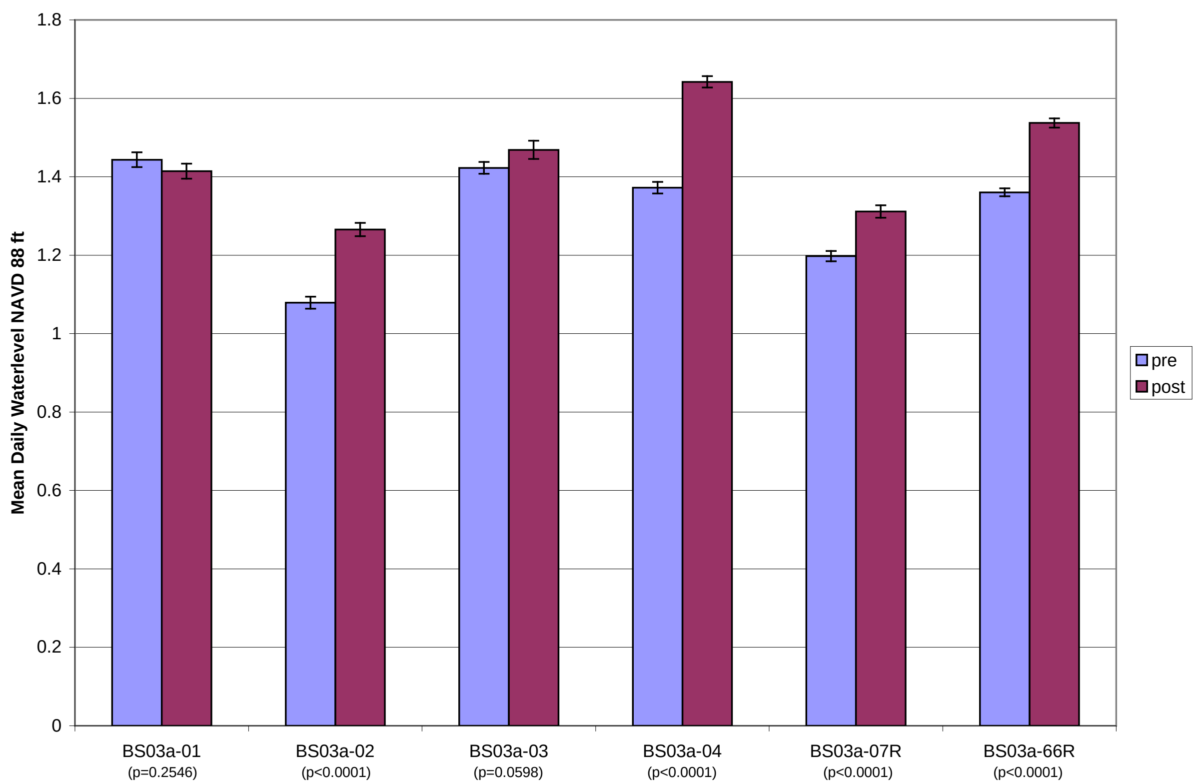

Figure 17. Mean daily (SE) water level NAVD 88 at YSI continuous recorder stations for the Caernarvon Outfall Management (BS-03a) project and reference areas during the pre- (3/2000 - 6/14/2002) and post-construction (6/15/2002 – 8/09/2005) period.

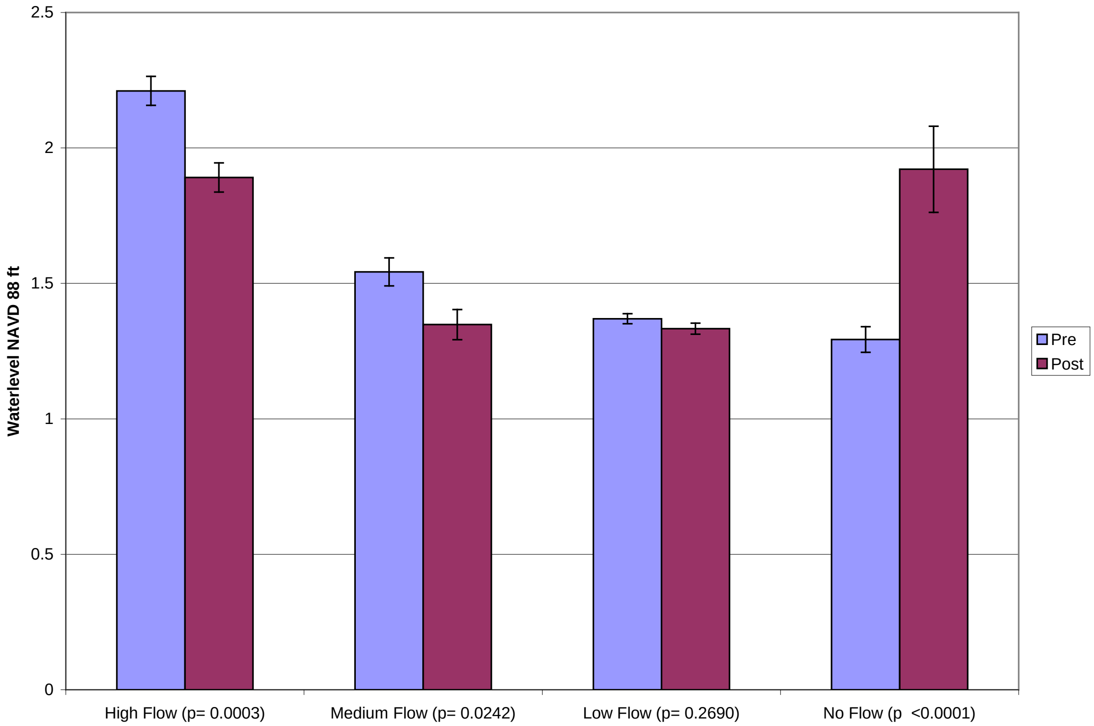

Figure 18. Mean water level NAVD 88 at the YSI continuous recorder station for stratum 1 of the Caernarvon Outfall Management (BS-03a) project during the the pre- (3/2000 - 6/14/2002) and post-construction (6/15/2002 – 8/09/2005) period.

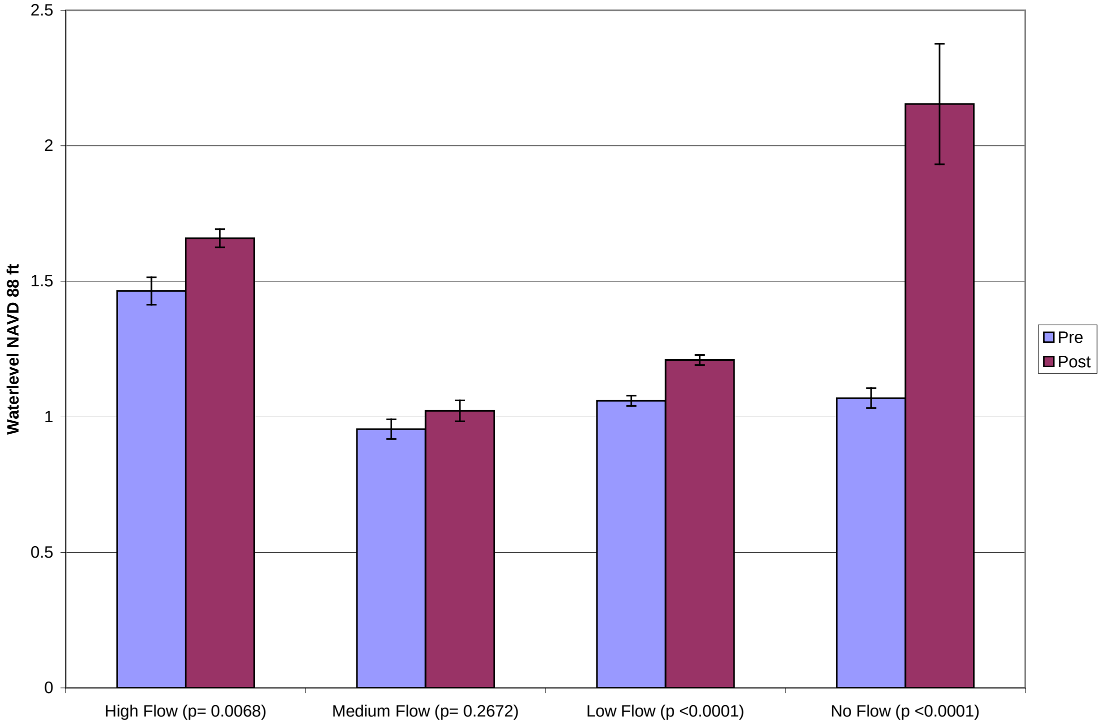

Figure 19. Mean water level NAVD 88 at the YSI continuous recorder station for stratum 2 of the Caernarvon Outfall Management (BS-03a) project during the pre- (3/2000 - 6/14/2002) and post-construction (6/15/2002 – 8/09/2005) period.

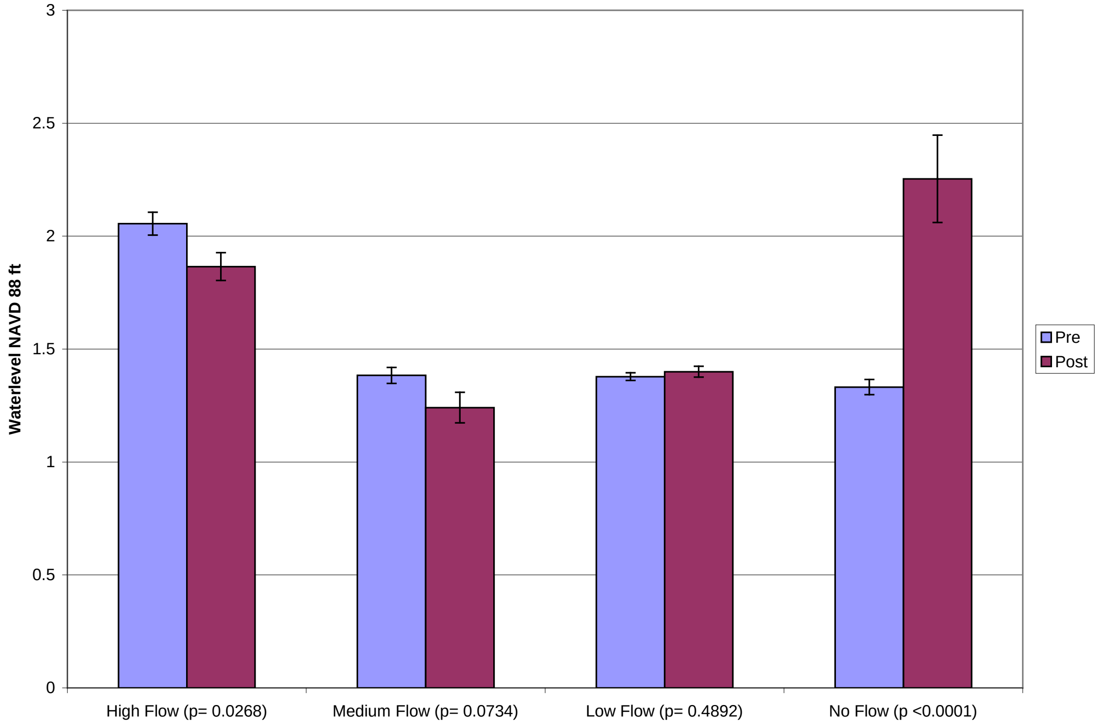

Figure 20. Mean water level NAVD 88 at the YSI continuous recorder station for stratum 3 of the Caernarvon Outfall Management (BS-03a) project during the pre- (3/2000 - 6/14/2002) and post-construction (6/15/2002 – 8/09/2005) period.

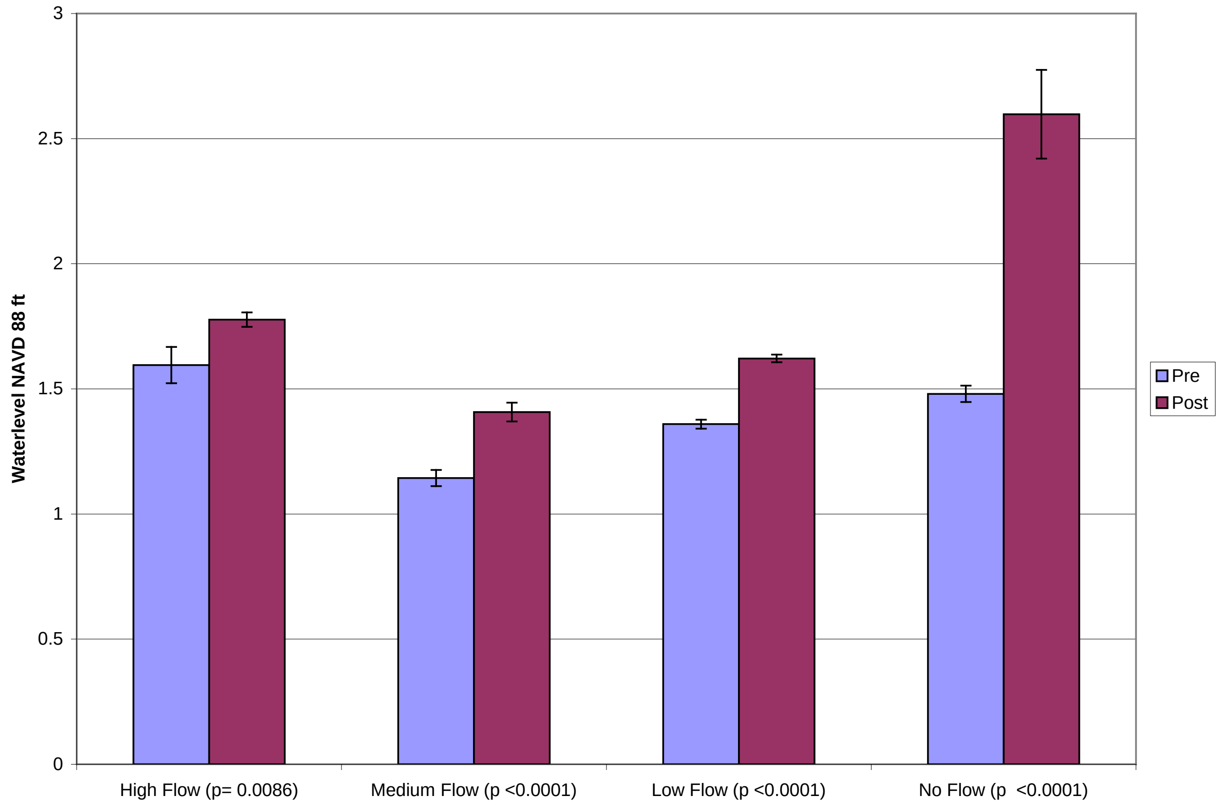

Figure 21. Mean water level NAVD 88 at the YSI continuous recorder station for stratum 4 of the Caernarvon Outfall Management (BS-03a) project during the pre- (3/2000 - 6/14/2002) and post-construction (6/15/2002 – 8/09/2005) period.

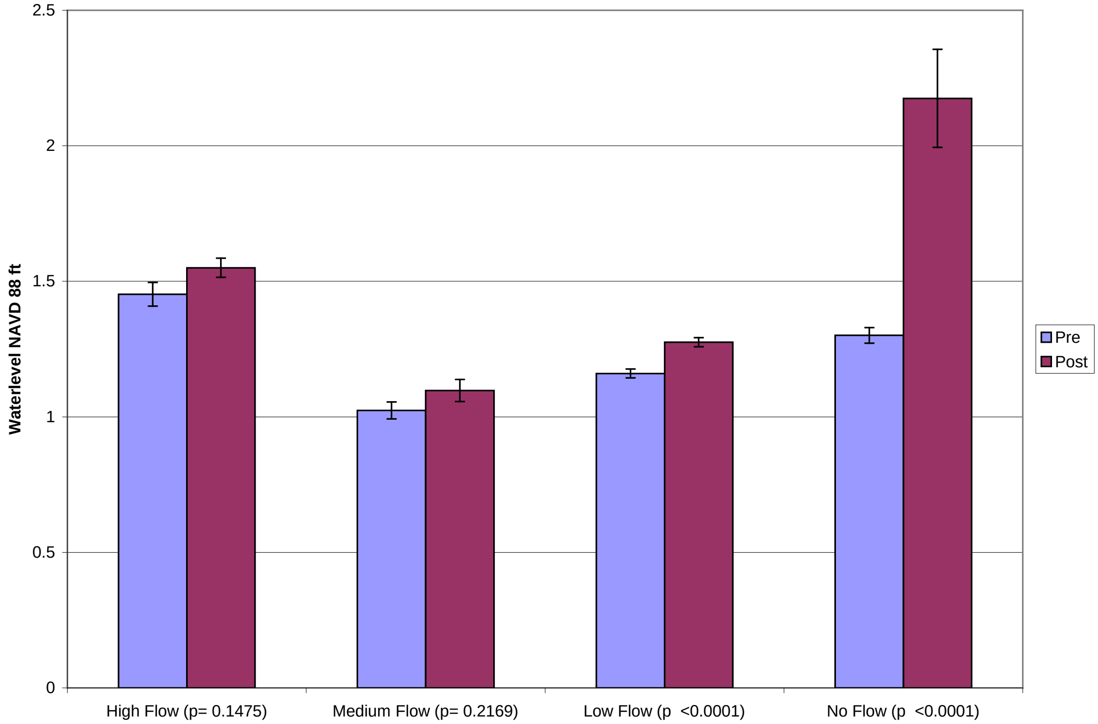

Figure 22. Mean water level NAVD 88 at the YSI continuous recorder station for stratum 5R of the Caernarvon Outfall Management (BS-03a) project during the pre- (3/2000 - 6/14/2002) and post-construction (6/15/2002 – 8/09/2005) period.

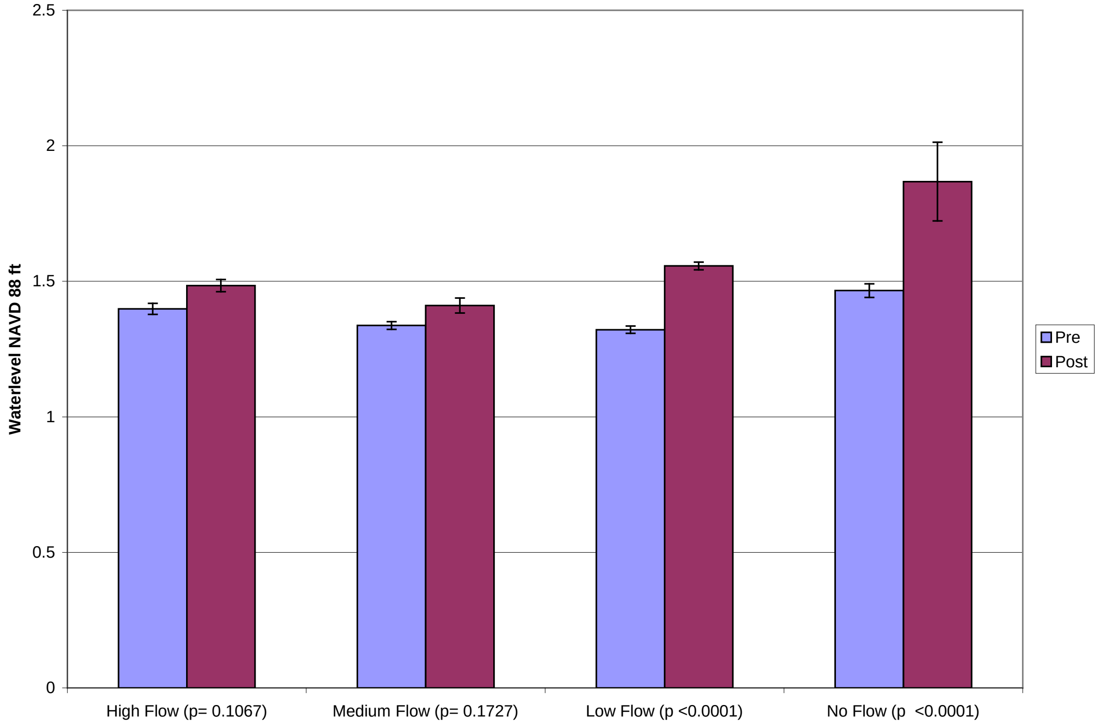

Figure 23. Mean water level NAVD 88 at the YSI continuous recorder station for stratum 6R of the Caernarvon Outfall Management (BS-03a) project during the pre- (3/2000 - 6/14/2002) and post-construction (6/15/2002 – 8/09/2005) period.

All strata showed an increase in the number of flood events from the pre-construction period (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) period. Stratum 3 had a period where water levels fluctuated above and below marsh elevations, resulting in the high number of flood events. These fluctuations along with the tropical weather of 2002 and 2004 are the reason for the high variance associated with stratum 3 (figure 23). Strata 2 and 5 also show high variance which is likely attributable to their bordering Lake Lery and being affected by the storm surge. 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 24 & 25). The PULSES project also contributed to the increased duration of flooding post-construction. All strata showed increases in depth of flooding between the pre- and post-construction periods, which is likely attributable to project features.

Table 1. Frequency, depth and duration of flooding for Caernarvon Outfall Management (BS-03a) project and reference strata during the pre- and post-construction period

Strata	Pre	Post
1		
# of Flood Events	45	61
Mean Duration (days)	18.7571	56.214
Mean Depth (ft)	0.4479	0.5412
2		
# of Flood Events	84	91
Mean Duration (days)	17.1268	31.7451
Mean Depth (ft)	0.4500	0.6107
3		
# of Flood Events	78	184
Mean Duration (days)	12.5502	21.7310
Mean Depth (ft)	0.3762	0.5890
4		
# of Flood Events	58	87
Mean Duration (days)	5.9735	15.1875
Mean Depth (ft)	0.2543	0.4143
5R		
# of Flood Events	81	81
Mean Duration (days)	27.0940	30.8284
Mean Depth (ft)	0.3953	0.5636
6R		
# of Flood Events	32	44
Mean Duration (days)	50.2297	62.8737
Mean Depth (ft)	0.2347	0.3791

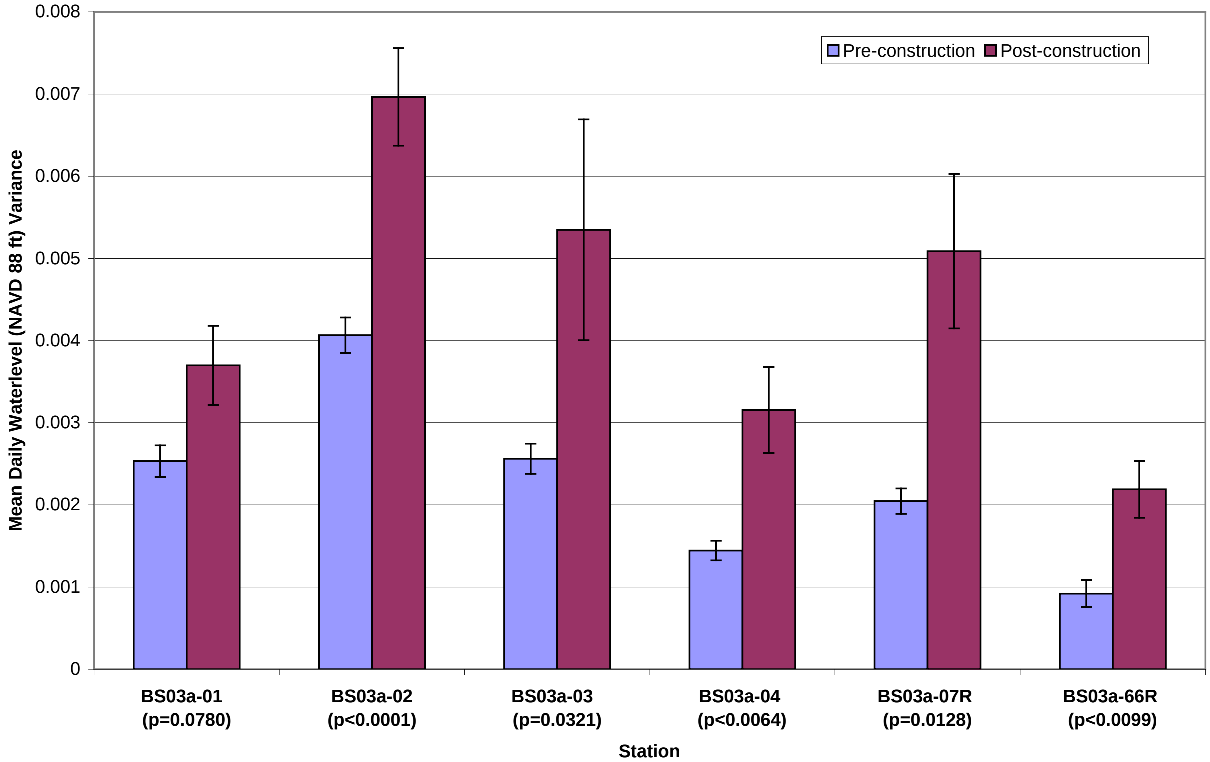

Figure 24. Mean daily water level variance at YSI continuous recorder stations for the Caernarvon Outfall Management (BS-03a) project and reference areas during the pre- (3/2000 - 6/14/2002) and post-construction (6/15/2002 – 8/09/2005) period.

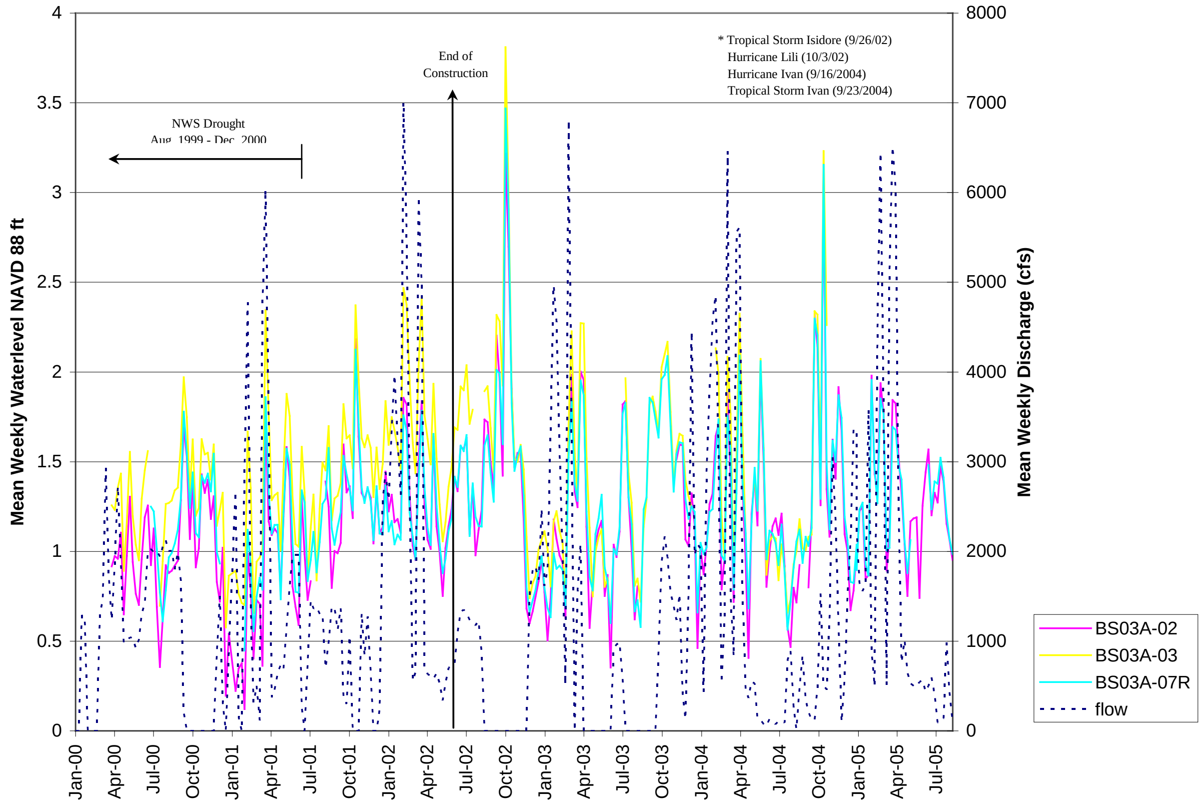

Figure 25. Mean weekly water levels at YSI continuous recorder stations for Caernarvon Outfall Management (BS-03a) project stations 02 & 03 and reference station 07R along with Caernarvon diversion flow for the period 2000 - 2005.

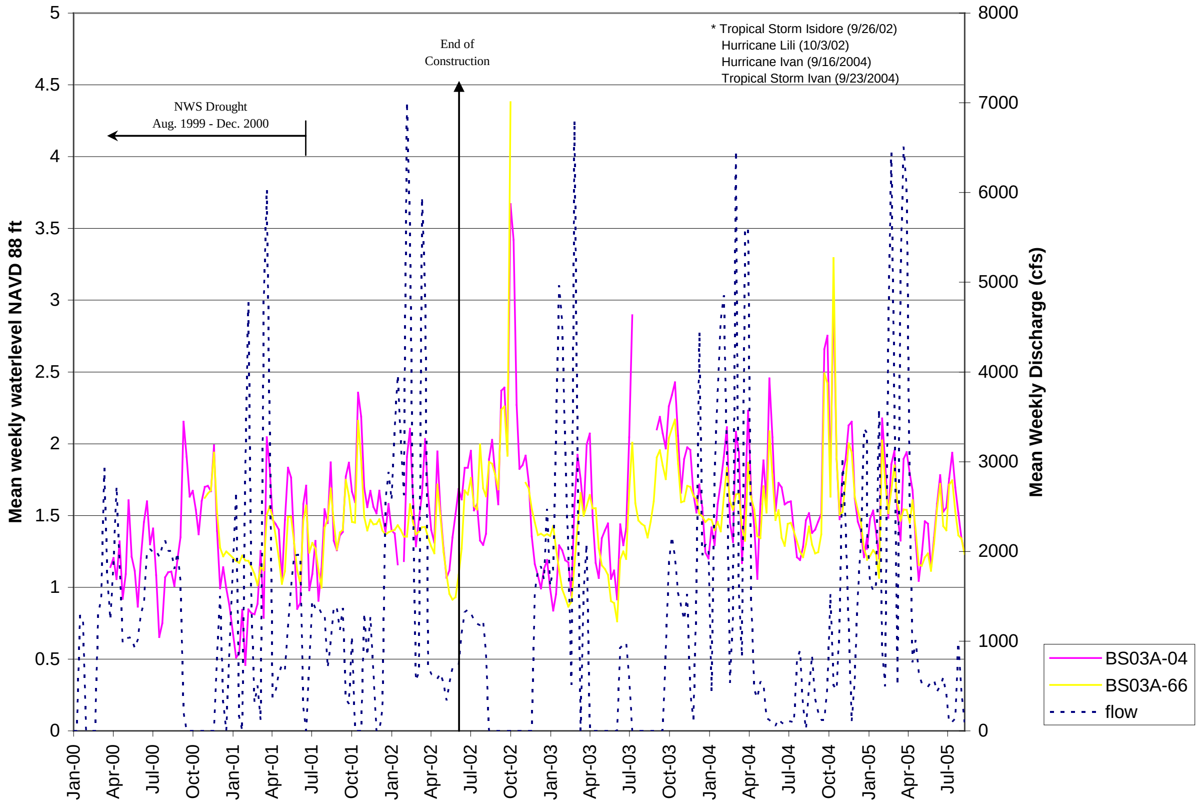

Figure 25. Mean weekly water levels at YSI continuous recorder stations for Caernarvon Outfall Management (BS-03a) project station 04 and reference station 66R along with Caernarvon diversion flow for the period 2000 - 2005.

Vegetation

Spartina patens was dominant in all strata in 2000 and in 2003 it was dominant in all, except stratum four (figures 26-31, tables 2 &3). *Spartina p*. was again dominant in all strata in 2005 after hurricane Katrina, except reference stratum 5. However, in 2005 8 of the 36 stations were inaccessible and of the 28 reached 18 were located in open water. For the 2006 survey, new stations were established at the closest vegetation adjacent to the stations determined to be open water in 2005. This resulted in 30 stations being monitored in 2006. *Polygonum sp.* was dominant in three strata, *Ludwigia* in two strata, and *Vigna* in stratum 3. However, *Vigna* is a vine supported by emergent vegetation, making *Ludwigia* the dominant emergent species in stratum 3 for 2006. In 2007, 29 stations were surveyed, as one station became inaccessible from the previous year. Dominant species recorded in 2006 were replaced in all strata, except for *Polygonum sp*. in stratum 4. The number of species observed in 2006 in all strata increased from 2005 and rivaled that of 2003 (table 4). However, species richness declined in all strata for 2007, except stratum 2 which remained the same. This is likely due to the area becoming more stable two years after the massive disturbance caused by Katrina.

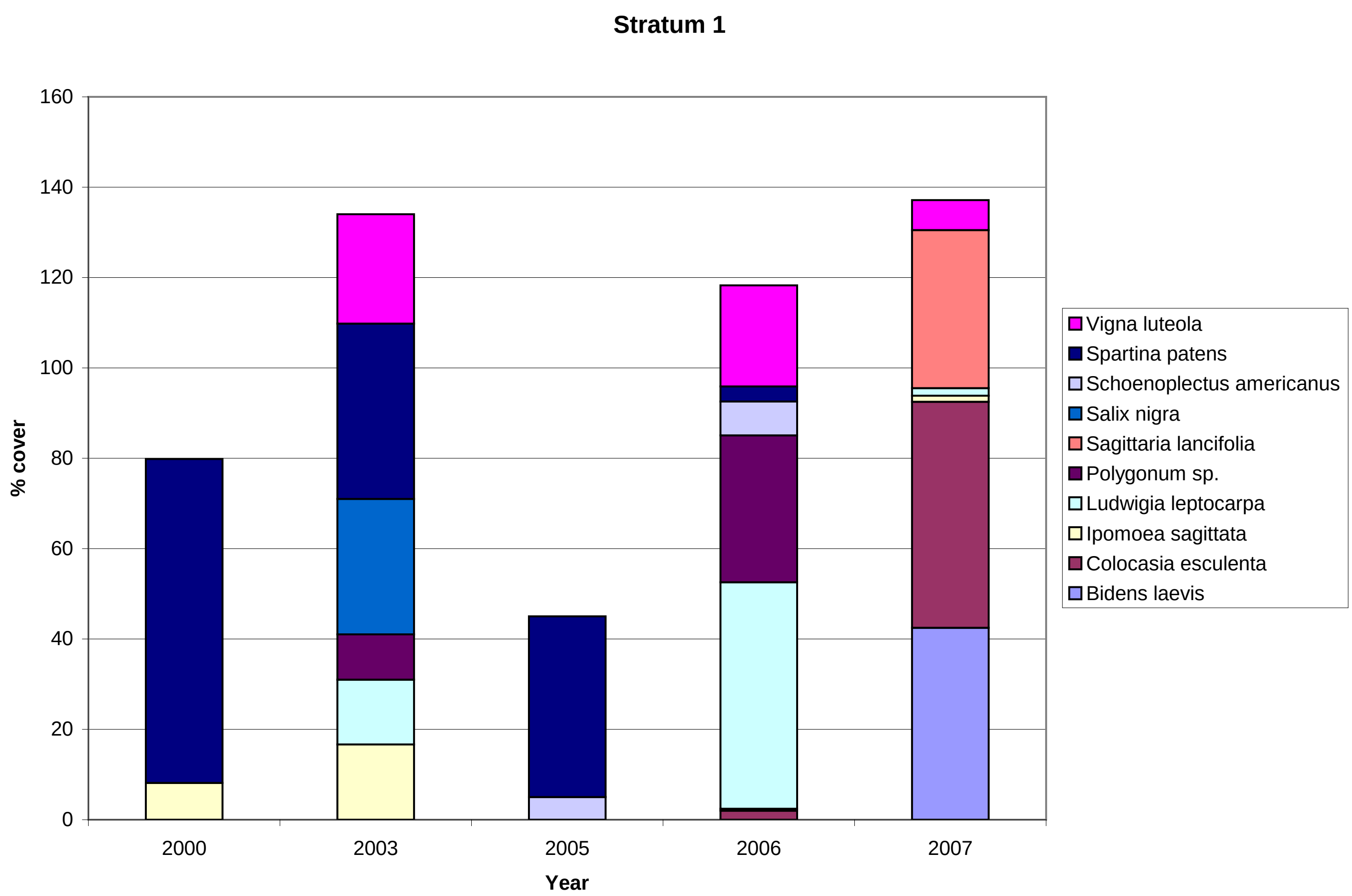

Figure 26. Mean % cover of dominant vegetative species across all 4m^2 plots from vegetation surveys for stratum 1 of the Caernarvon Outfall Management (BS-03a) project.

Stratum 2

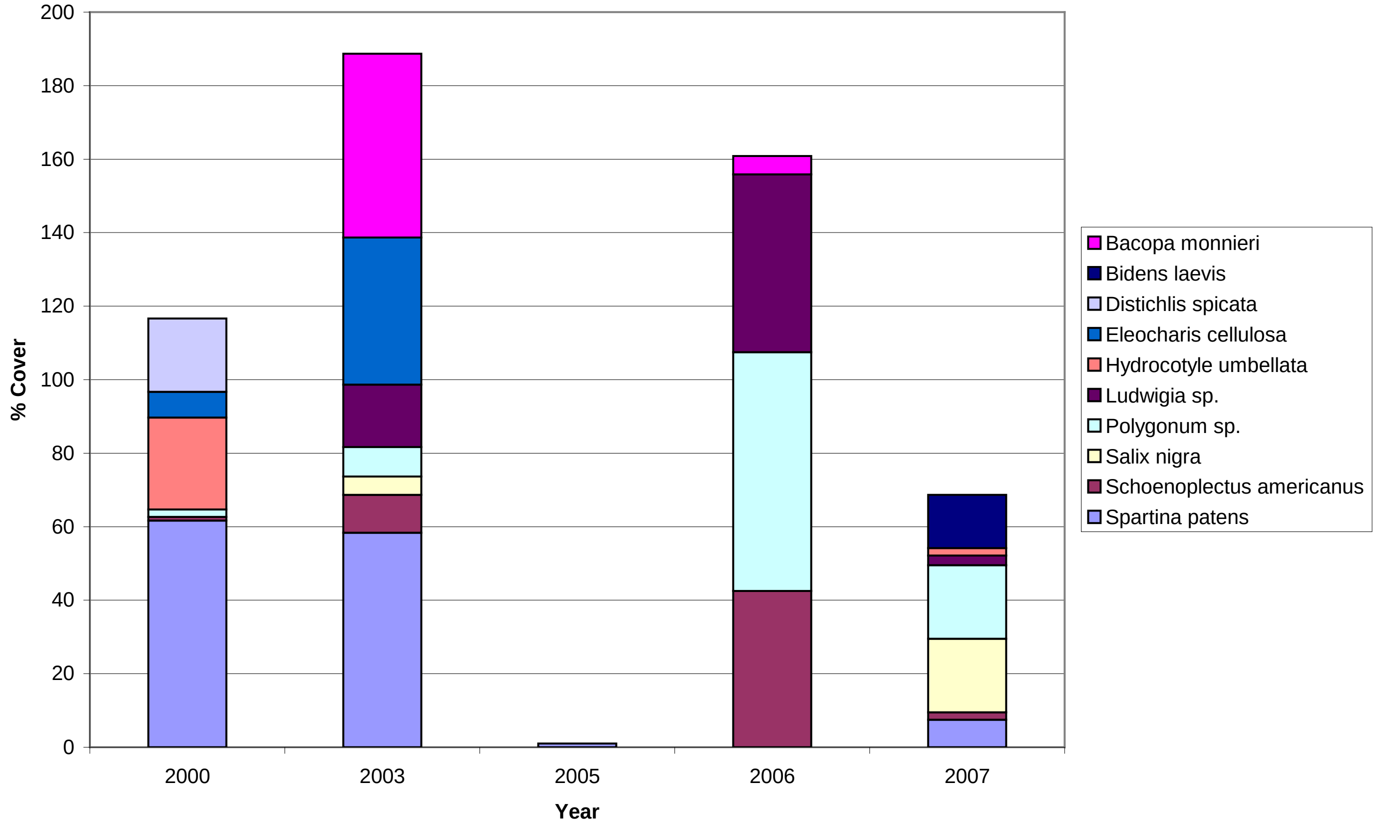

Figure 27. Mean % cover of dominant vegetative species across all $4m^2$ plots from vegetation surveys for stratum 2 of the Caernarvon Outfall Management (BS-03a) project.

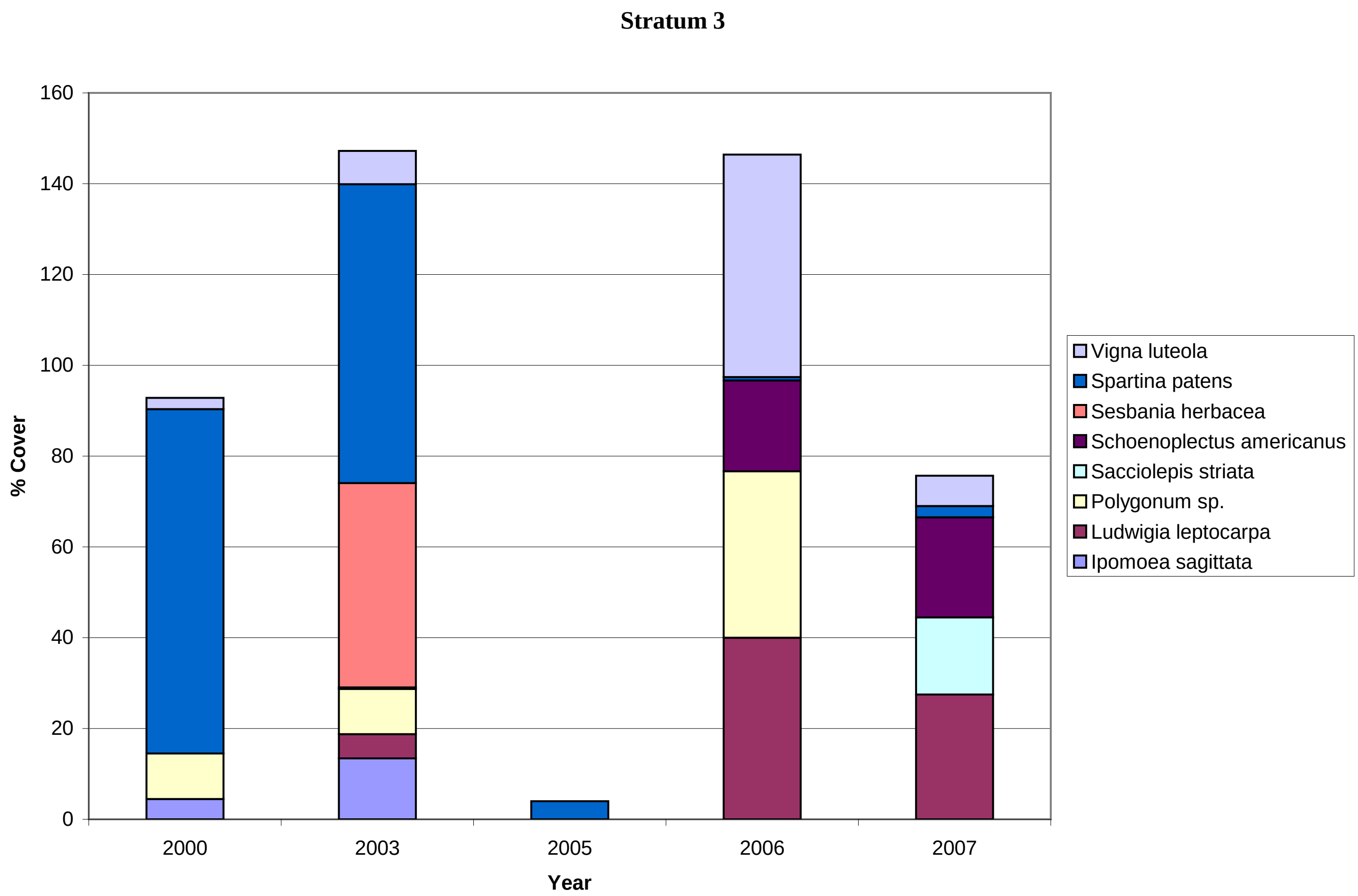

Figure 28. Mean % cover of dominant vegetative species across all 4m^2 plots from vegetation surveys for stratum 3 of the Caernarvon Outfall Management (BS-03a) project.

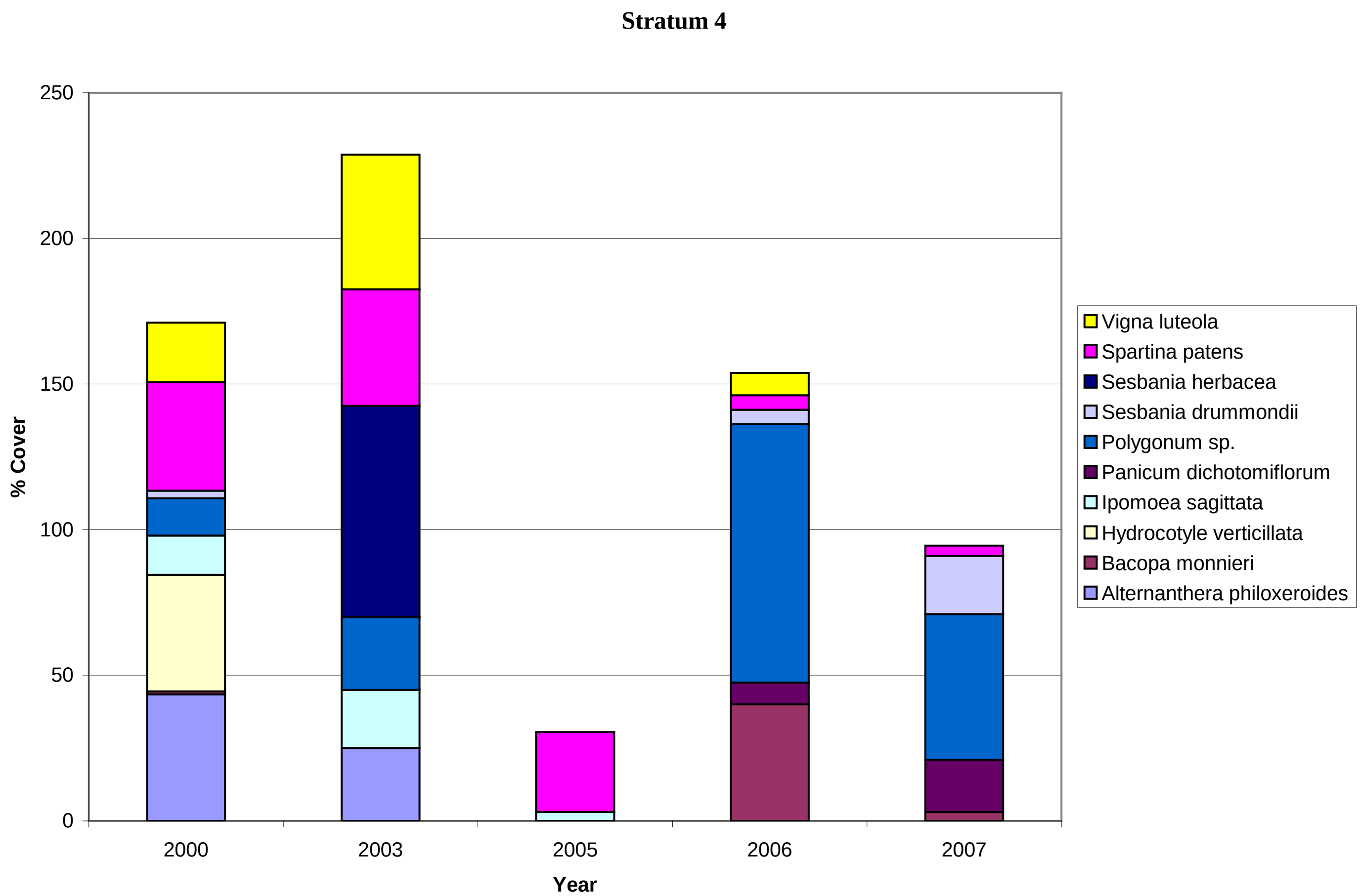

Figure 29. Mean % cover of dominant vegetative species across all $4m^2$ plots from vegetation surveys for stratum 4 of the Caernarvon Outfall Management (BS-03a) project.

Stratum 5

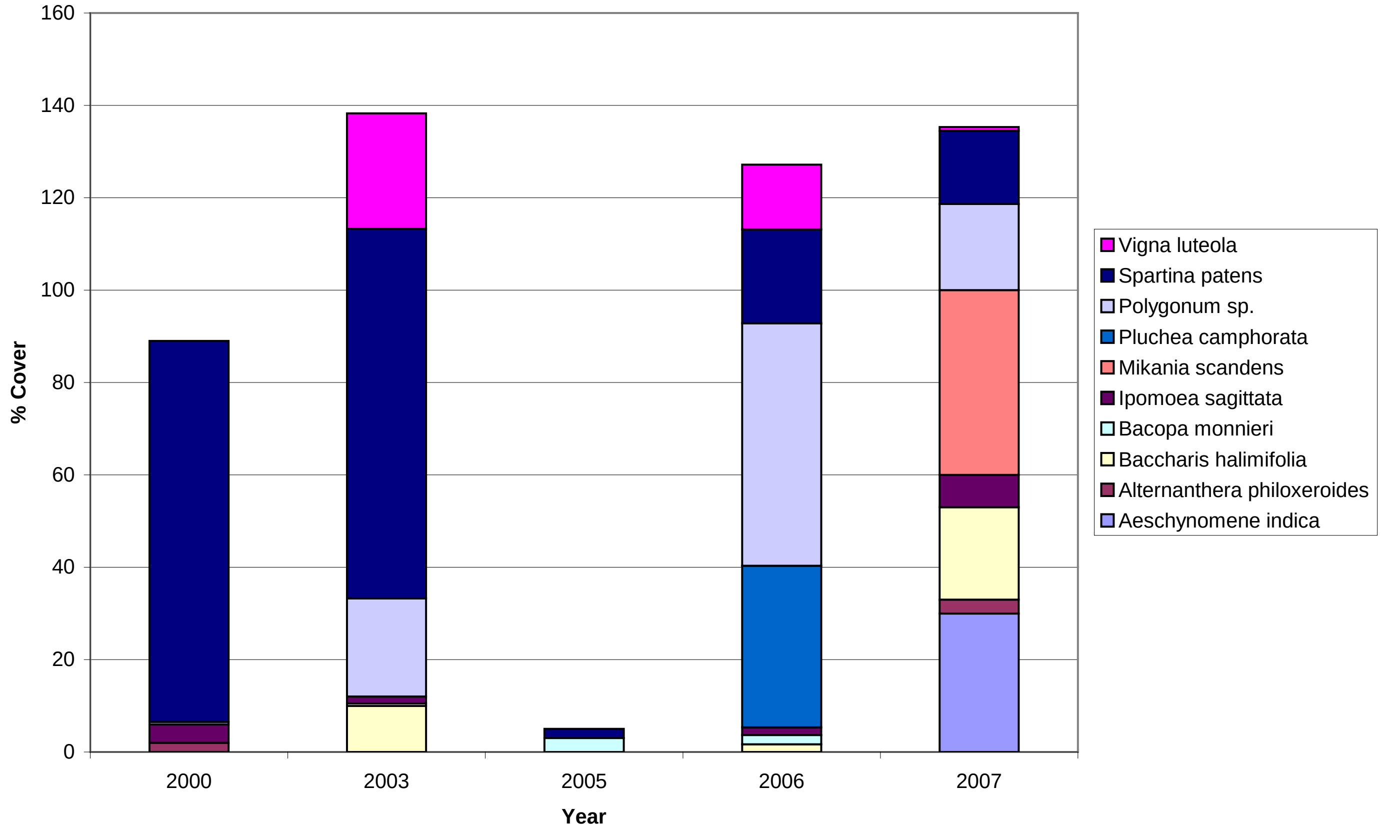

Figure 30. Mean % cover of dominant vegetative species across all 4m^2 plots from vegetation surveys for stratum 5R of the Caernarvon Outfall Management (BS-03a) project.

Stratum 6

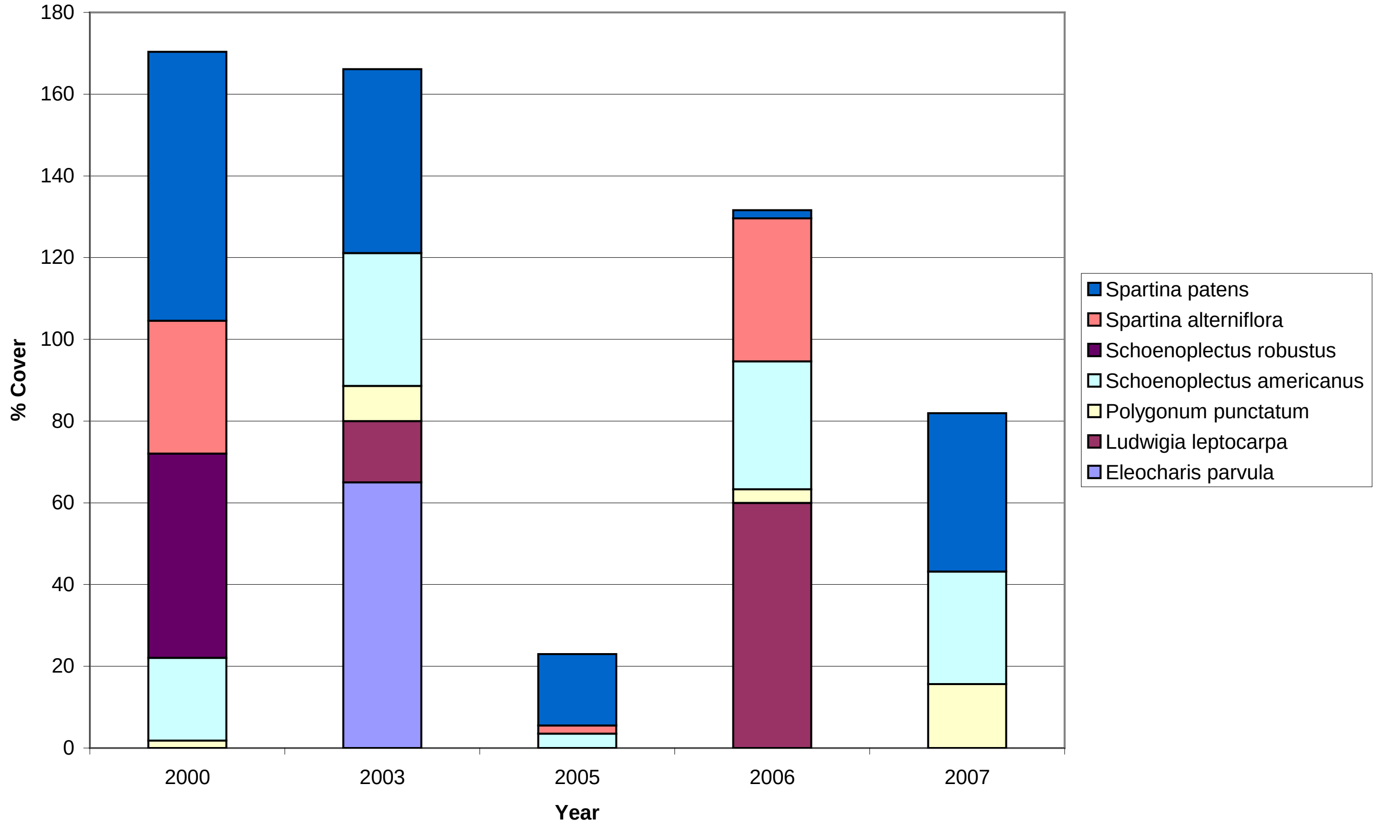

Figure 31. Mean % cover of dominant vegetative species across all $4m^2$ plots from vegetation surveys for stratum 6R of the Caernarvon Outfall Management (BS-03a) project.

Table 4. Species richness by stratum for all species found within 4-m^2 plots of the Caernarvon Outfall Management (BS-03a) project and reference areas during 2000, 2003, 2005, 2006, and .

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*

Submerged Aquatic Vegetation (SAV)

Relative frequency of SAV increased dramatically across all strata, except 5R, from the sampling period in 2000 to the sampling period of 2003 (figure 32). All project area strata had empty sample percentages less than 10, and strata 6R showed a decrease of 19% occurrence of empty samples (table 5). All strata showed an increase in species diversity with at least one species of plant being observed in all strata that was not present in the 2000 survey. As was seen with emergent vegetation data, the dramatic increase of SAV may not be fully attributable to project effects because pre-construction data were taken during a drought.

Strata 5R is located east of the diversion and is bordered on the west by Bayou Mandeville, which carries 66% of total diversion flow south to Lake Lery. The two ponds in which SAV sampling occurs are located on the extreme western (BS03a-25R) and eastern (BS03a-35R) boundaries of the strata. The two transects located at station BS03a-25R resulted in 100% occurrence of SAV (90% in 2000) compared to 24.3% (53% in 2000) for the two transects at BS03a-35R during the 2003 surveys. It appears that freshwater from diversion operations buffered salinities in the area bordering Bayou Mandeville, but the areas within stratum 5R detached from diversion waters were affected by the drought. This suggests that drought effects can be overcome with the addition of freshwater.

Accretion

Accretion data was collected in 2001, 2002, 2003, and 2004. However, the stations used for accretion monitoring were constructed on flotant marsh, and therefore cannot be used to quantify elevation changes. The stations were constructed during the drought when water levels were suppressed giving the marsh the feel of being attached.

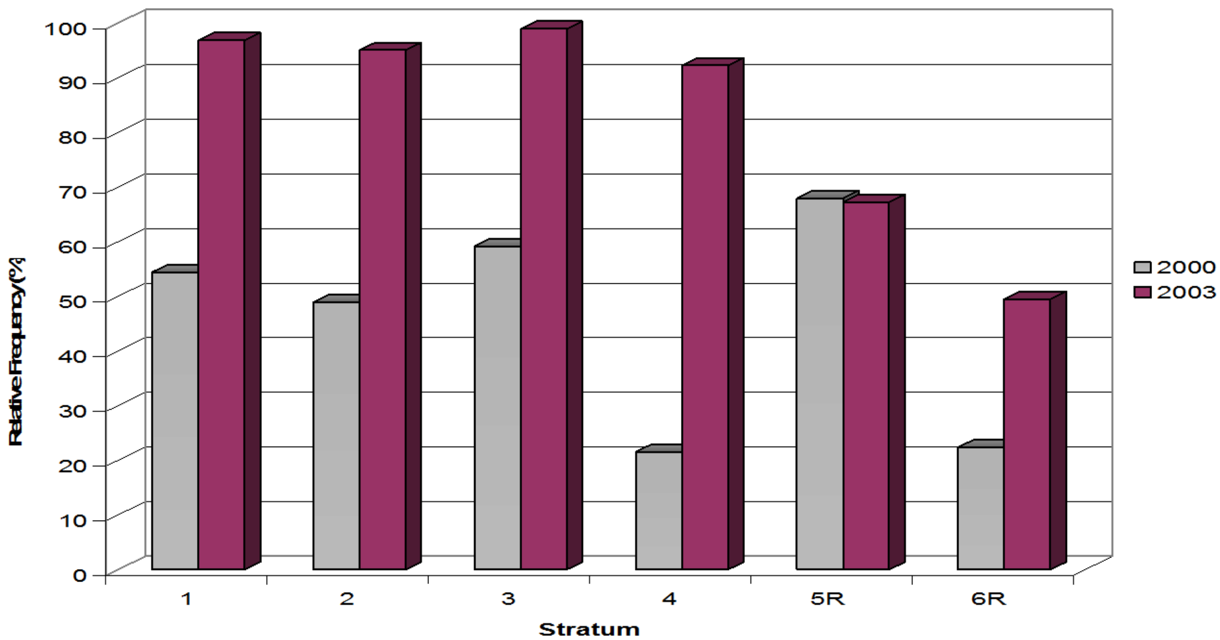

Figure 32. Relative frequency (%) of all submerged aquatic vegetation species combined across two transects within two ponds per stratum of the Caernarvon Diversion Outfall Management (BS-03a) project and reference areas in April 2000 and 2003.

Table 5. Relative frequency (%) of submerged aquatic vegetation species combined across two transects within two ponds for Caernarvon Outfall Management (BS-03a) project and reference strata.

	Stratum 1		Stratum 2		Stratum 3		Stratum 4		Stratum 5R		Stratum6R	
	Frequency (%)		Frequency (%)		Frequency (%)		Frequency (%)		Frequency (%)		Frequency (%)	
	2000	2003	2000	2003	2000	2003	2000	2003	2000	2003	2000	2003
Empty Sample	34.16	4.19	46.35	4.93	40.30	1.03	23.04	7.73	32.02	32.75	69.96	50.47
Cabomba caroliniana	5.45		0.52				4.41					
Ceratophyllum demersum	27.72	59.16	41.67	46.80	16.92	75.26	2.94	28.99	56.16	33.92		22.64
Myriophyllum spicatum	6.93	8.90	22.40	20.69	10.45	46.39	0.49	17.39				
Najas guadalupensis	25.74	13.09	41.67	37.93	46.77	60.82	19.12	49.28	43.35	12.87	22.42	13.21
Ruppia maritima		71.73		79.80		80.93		72.95		60.23		39.15
Chara sp.		5.24		5.42		1.03				1.20		0.47
Hydrilla verticillata		4.19										
Heteranthera dubia				6.40								
Vallisneria americana						1.03		0.97				

V. Conclusions

a. Project Effectiveness

Pre-Katrina

Salinities in the project area are fresh, and have been since the beginning of data collection. Seasonal events have the biggest effect on mean salinities within the project area and were likely the cause for post-construction means being greater than pre-construction means. However, these differences were less than 0.5 ppt and likely had no ecological affect on the area. Although there was a drought during the pre-construction period, diversion operations seemed to dilute its effects. This is further supported by the suppression of salinities during high flow diversion operations associated with the PULSES project. Stratum 4, which was of particular interest to this project, seemed to have benefited from this project showing a significant 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 is a result of the projects' effectiveness at retaining more water, both diverted and from storm surge, within the marsh.

Water levels within the project area have 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 on 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, can be seen by the increase in depth and duration of flooding events since project construction. While depth and duration of flooding have increased, it appears to be within the limits of tolerance of the vegetation community, as can be seen by the increase in species richness and occurrence of fresh marsh vegetation species.

Since construction of the outfall management project, an increase in fresher species of vegetation and a reduction of brackish species percent cover has been observed. This was likely a result of increased diversion water input for a greater duration due to project features, but may also be attributed to the drought effect on the 2000 data. Submerged aquatic vegetation also increased in both frequency and diversity since project construction, but the pre-construction surveys to which it was compared may not represent conditions had there not been a drought during the survey year. Thus, the determination of project effectiveness on vegetation in the Caernarvon Outfall Management project was confounded by the drought.

Post-Katrina

As discussed above, it appeared the project was benefiting the area prior to August 29, 2005, even though the drought during the pre-construction data collection period made it difficult to determine the extent of these benefits. It was hoped that after a couple more years of data collection the actual benefits could be quantified. However, after this date, Katrina made it so we will never know how beneficial the project could have been to the area over time. Katrina completely rearranged 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 created by surge force allowing multiple points of water exchange. Canals that carried diversion waters to the far eastern and western ends of the upper basin were completely clogged with marsh. The Delacroix canal which runs across the southern end of Big Mar was dredged immediately after 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. Big Mar was a shallow lake with three small forested islands before the storm, now the western half is filled with displaced marsh and the eastern side is littered with marsh as well. This blockage in the western half of Big Mar along with the dredge material stacked to the south results in most diverted water traveling east from Big Mar down bayou Mandeville to Lake Lery. The little water that does travel west encounters another blockage at the intersection of the DP canal and Delcaroix canal which forces it south down the DP canal where it enters Lake Lery through cuts in the lakeshore created by Katrina. Stratum 4 lies west of this blockage and receives little, if any, diversion input now.

Vegetation sampling was the only monitoring element collected after Katrina. The 2005 sampling 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 36 stations 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. In 2006 stations located in open water were moved to the closest vegetation from the original plot. The number of species observed and the percent covers in 2006 were much higher than the year prior and rivaled those from the last sampling conducted before the storm in 2003. This was likely a result of competition among the plant community responding to the massive disturbance to the area and was possibly helped along by diversion operations. Dominant species in 2003 and 2005 were replaced in all strata according to the 2006 data. Species richness decreased for all but stratum 2 in 2007. This could be a sign that the plant community is stabilizing with the more aggressive plants taking hold. Percent covers of the more dominant species in each project stratum were reduced in 2007 in all project strata except stratum 1. This could be the affect of competition for resources of the plant species left, or that the area is further degrading. The later may be supported by the fact that 8 stations that had recordable vegetation in 2006 had converted to open water in 2007.

b. Recommended Improvements

As of 2008, the outfall project was not functioning as designed due to the extreme disturbance caused by Katrina. Even if the project features remained in tact or were rebuilt, the marsh they were designed to enhance and protect is no longer there. There is 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 even begin to regain what was lost. Terraces created in some of the larger ponds could also help with wave abatement to try and keep what is left. Although the feasibility of the two aforementioned recommendations is uncertain, they represent a way of restoring what was loss 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.

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.

Freshwater marshes do not fair well in 18-foot storm surges. The majority of marsh that remained in the project area was adjacent to spoil banks which had woody vegetation growing on them. Ridges with trees may be the best restoration technique in freshwater marshes, to hold or at least capture the adjacent marsh.

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