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Department of Natural Resources
Coastal Restoration Division and
Coastal Engineering Division

2004 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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For
Caernarvon Outfall Management (BS-03a)

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Preface

The 2004 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 2004 includes monitoring data collected through December 2003, and annual Maintenance Inspections through June 2004. Monitoring data collected in 2004 and maintenance inspections conducted between July 2004 and June 2005 will be presented in the 2005 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 the remaining 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 rock fill core plugs protected with rock riprap at sites 25, 40, and 54. At site 26 the core of the plug was earth material protected with rock riprap and 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 rock fill core with a rock riprap armor for protection. Sites 13 and 50 each have one 48-inch culvert with a flapgate on the interior side (distal to Caernarvon discharge) and sites 52 and 60 each have two 36-inch culverts with interior flapgates. 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-armored 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 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 culverts. 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.

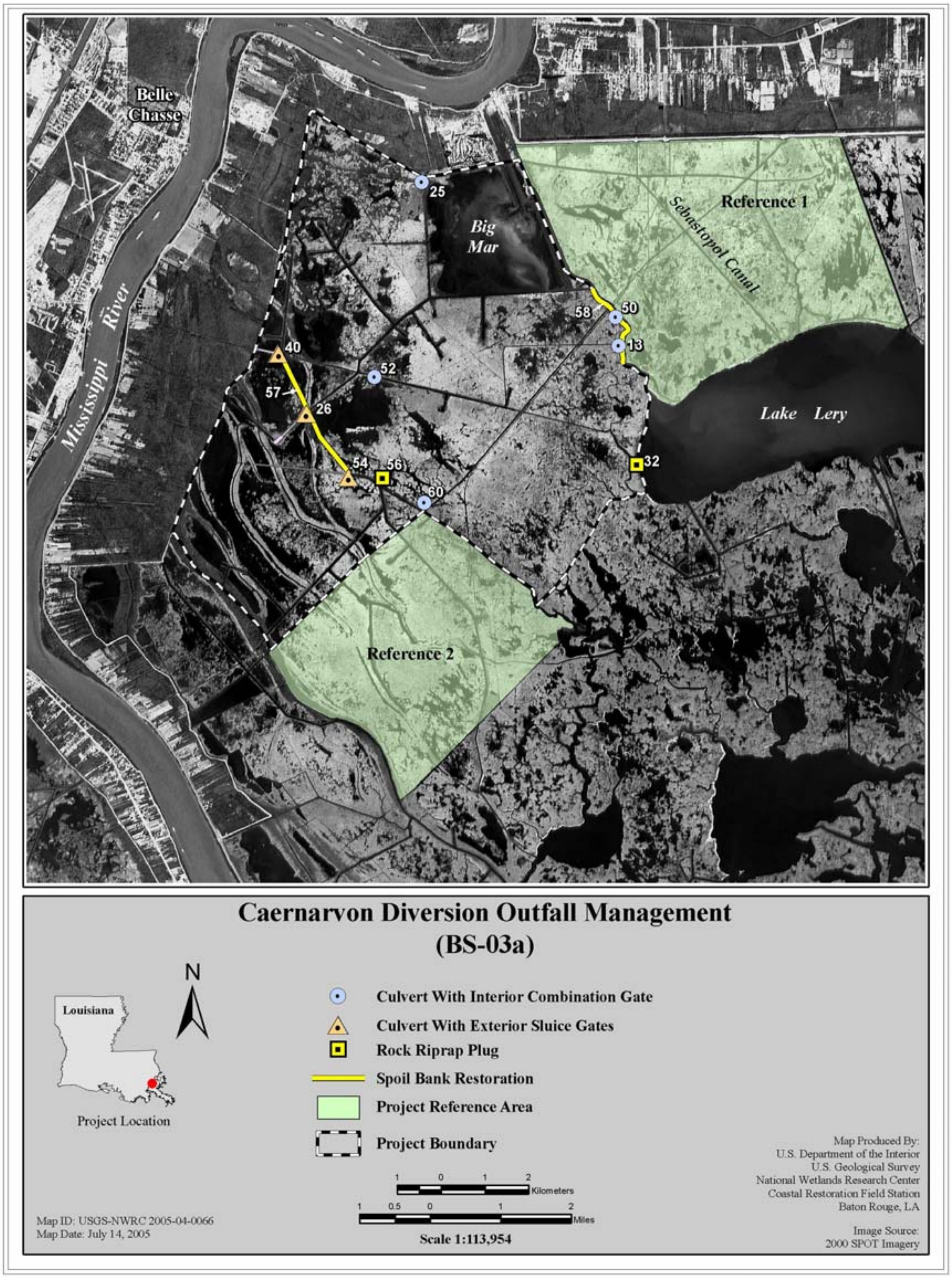

Figure 2. Caernarvon Outfall Management (BS-03a) project features and project area strata. North Reference Area is stratum 5R and South Reference Area is stratum 6R.

II. Maintenance Activity

a. Project Feature Inspection Procedures

An inspection of the project area was conducted on April 16, 2003 by Tom Bernard, Paul Gremillion, Maury Chatelier from LDNR and Dale Garber, Allen Bolotte, and Brad Sticker of NRCS. The field inspection included a complete visual inspection of each of the project's structure sites. Photographs were taken at each project site and a field inspection form was completed in the field to record measurements and deficiencies (Cook and Bernard 2004).

b. Inspection Results

Site/Structure # 13 - Overall condition was excellent. The single pipe had rotated slightly, and there was slight settlement of the rock on sides of pipe. Regarding the walkway, one board had popped up on the end next to the plug and there was more settlement of walkway at the 4 x 4 inch supports.

Site/Structure # 25 Overall condition was excellent. Some corrosion was observed on the valve stem fittings. It may be desirable to install stem covers on the gate.

Site/Structure # 26 - Excellent condition. Water was observed to be flowing into project area.

Site/Structure # 32 - Overall condition was good with the exception that vandals had removed enough rock to create a breach in the plug whereby boats could be pulled through to bypass the plug (picture 1). The inspectors on the present inspection trip filled (by hand labor) approximately 50 % of breach with rock. The remainder of the breach will be filled by LDNR during the periodic trips that are made to the project.

Picture1. Site #32 looking west, showing the breach in the rock closure caused by vandals, possibly trappers, in the area.

Site/ Structure # 40 - Overall condition was good. Part of earthen embankment has eroded at the toe. There is some settlement on the ends of the rockfill.

Site/Structure # 50 – Overall condition is excellent. Slight settlement in rock on either side of pipe = 0.5 ft.

Site/Structure #52 – Overall condition is excellent. Slight settlement of rock on sides of pipe.

Site/Structure # 54 – Overall condition is excellent. One pipe gate was slightly rotated.

Site/ Structure # 56 - Overall condition is excellent.

Site # 57 - Overall condition of embankment is excellent. Slight erosion at the toe of the embankment near the north end.

Site # 58 - Selective erosion. Several hundred feet of slope has eroded back to crown. Remainder of embankment has not eroded significantly.

Site/Structure # 60 – Condition is good. Gates need locks.

c. Maintenance Recommendations

i. Immediate/ Emergency Repairs

No immediate repairs are suggested. However, during the inspection field trip a breach created by vandals at site 32 was repaired by the inspection team. Approximately 50% of the breach was repaired, with the remainder to be addressed by LDNR/CED during the periodic trips made to the project. There was a presence of water hyacinths throughout the outfall area. This could possibly be a problem in the future. It may be necessary to address control of these hyacinths, not only on the present diversions but on future projects.

ii. Programmatic/Routine Repairs

- Monitor/Repair walkways and piers around structures.
- Install stem covers on the gate valves.
- Monitor the erosion of embankment at sites 57 and 58.
- Periodic checks on distributary channels (Delacroix and Reggio Canals) to determine if adequate flow is permissible to the south and west outfall area.

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

None of the structures were operated since the completion of construction. All structures remain in the open position allowing free flowage of water into the marshes and ponds. LDNR is in the process of investigating the possibility of modifying the landrights agreement so that the landowner will have the capability of operating the structures.

IV. Monitoring Activity

This is a comprehensive report and includes all data collected from the pre-construction period and the post-construction period through December 2003.

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.

b. Monitoring Elements

Habitat Mapping

To determine ratios of marsh to open water and land loss rates, and also 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 will be collected in 2006 and 2018.

Salinity
Salinity has been measured hourly at one station inside each project area stratum and at one station in each reference stratum with continuous recorders using techniques described in Steyer et al. (1995) from 2000 - 2003 (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 are measured monthly to help spatially characterize project-induced changes. Due to programmatic changes in monitoring efforts, Coast-wide Reference Monitoring System (CRMS) stations will be used in place of the project-specific recorders to document salinity in each of the six strata (LDNR/CRD 2002). With the inception of CRMS, discrete salinity stations will be 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 are collected at the same six sites as where hourly salinity data are 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 intensity of marsh inundation. CRMS will also affect water level collection, see salinity section above.

Vegetation
Vegetation was surveyed in the project and reference areas using techniques described in Steyer et al. (1995) (figure 4). Specifically, a modification of the Braun-Blanquet method (Mueller-Dombois and Ellenberg 1974) was used. 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. Species composition and relative abundance of vegetation were documented in 2000 (pre-construction) and 2003 (post-construction) and will be evaluated again in 2006. After the 2006 survey, 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.

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). CRMS will not affect SAV sampling, which will be collected in the spring on a 3-year interval until 2021.

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

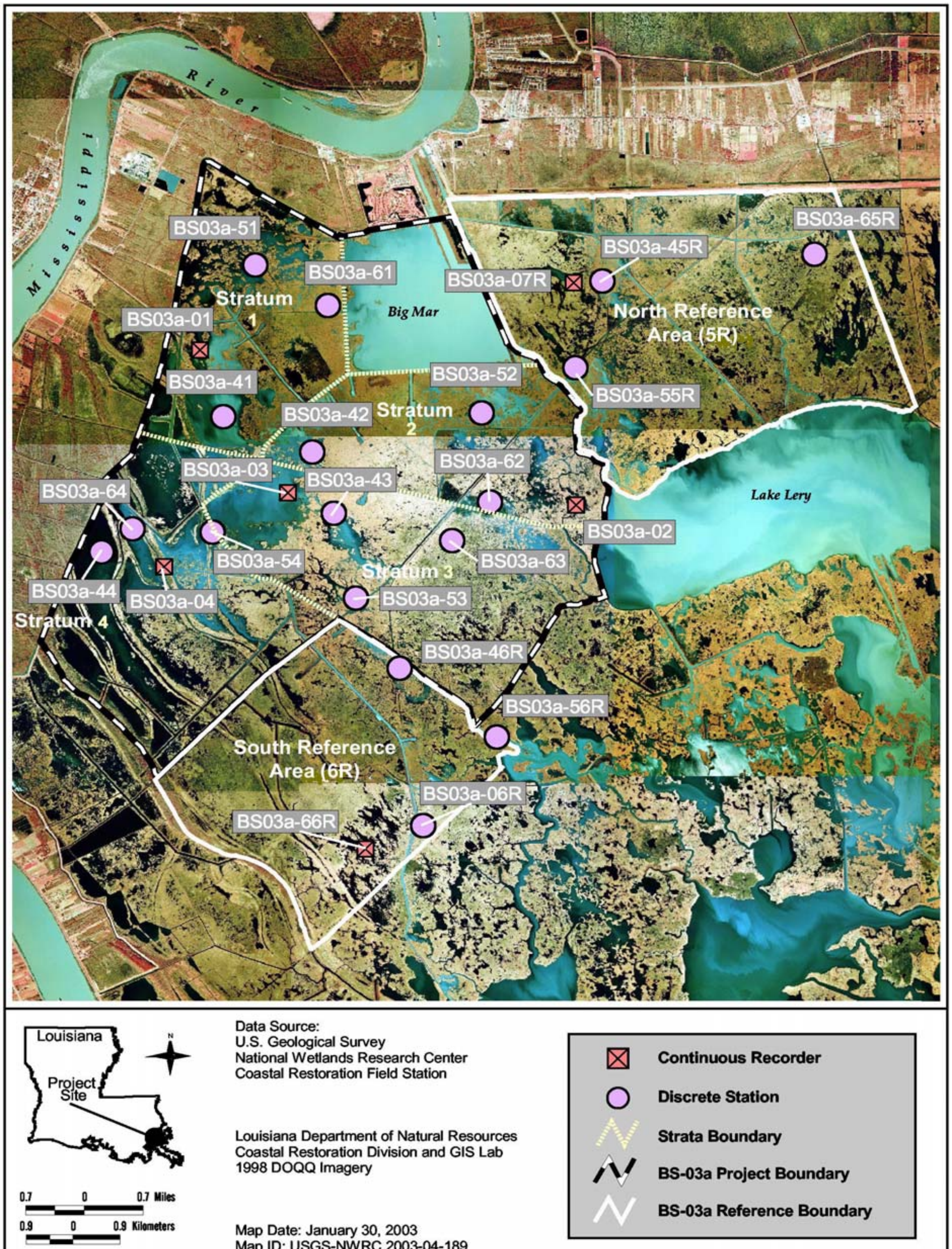

Figure 3. Location of continuous recorder and discrete stations for the Caernarvon Outfall Management (BS-03a) project .

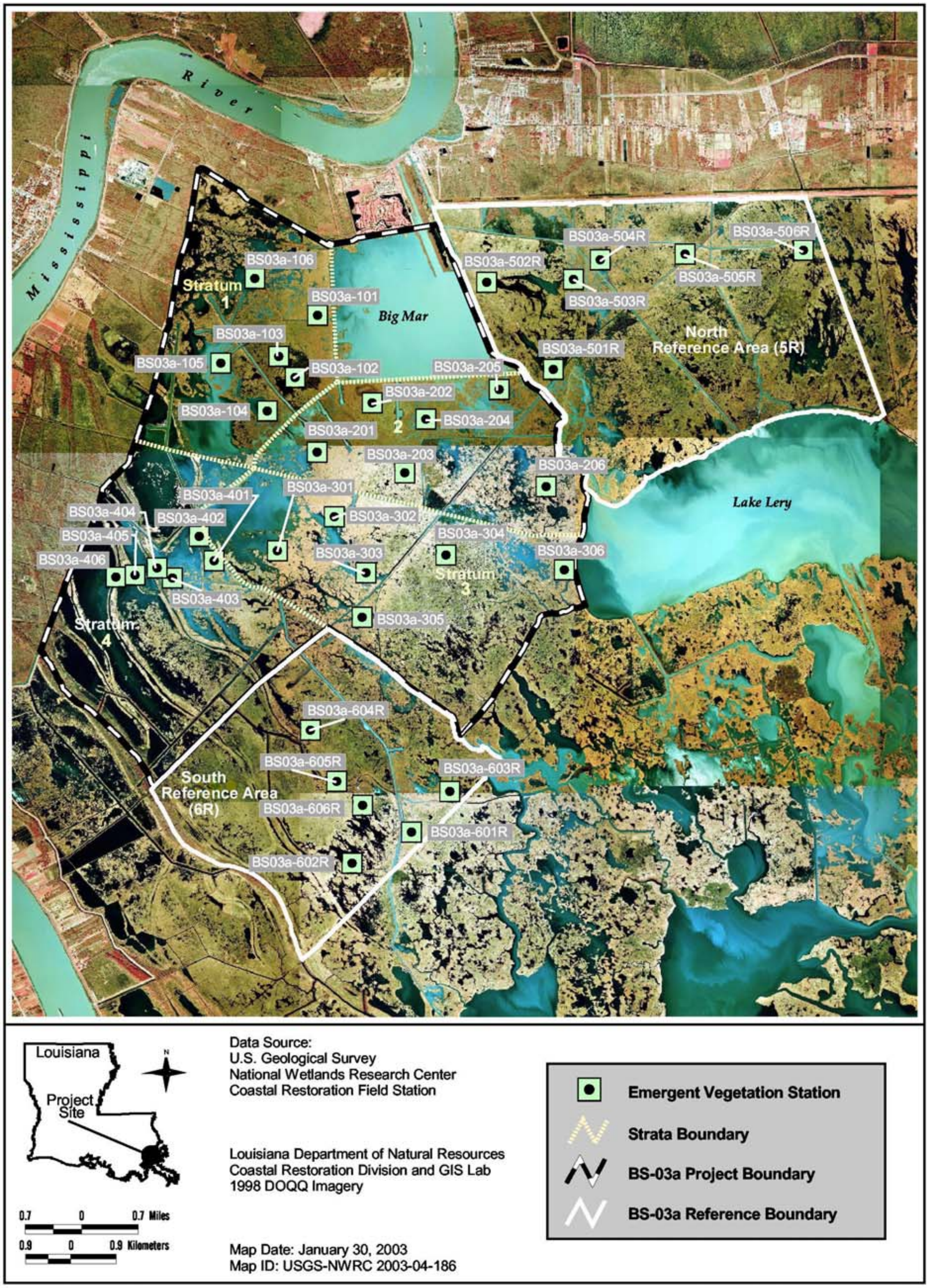

Figure 4. Caernarvon Outfall Management (BS-03a) vegetation sampling station locations.

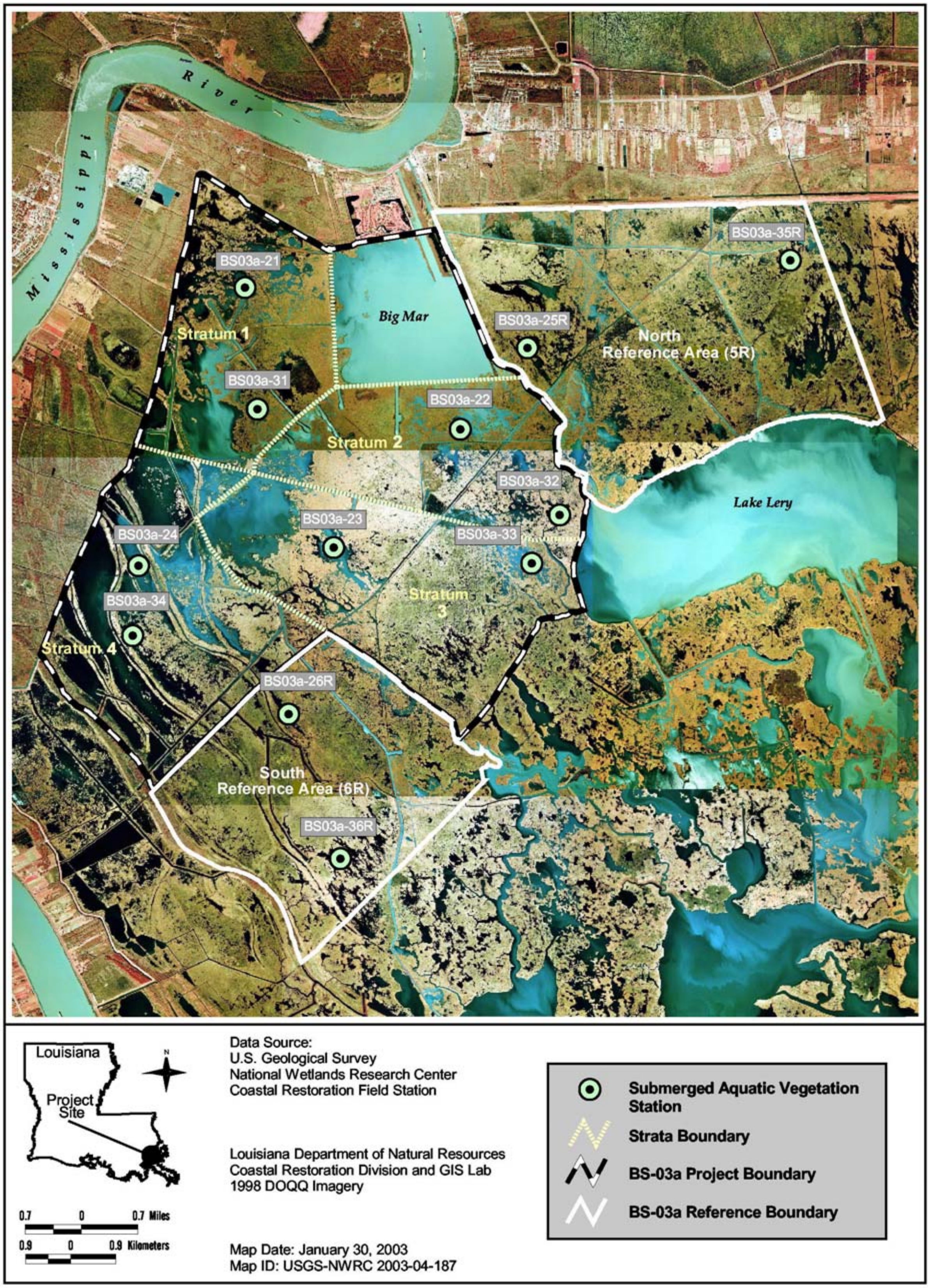

Figure 5. Caernarvon Outfall Management (BS-03a) SAV sampling stations.

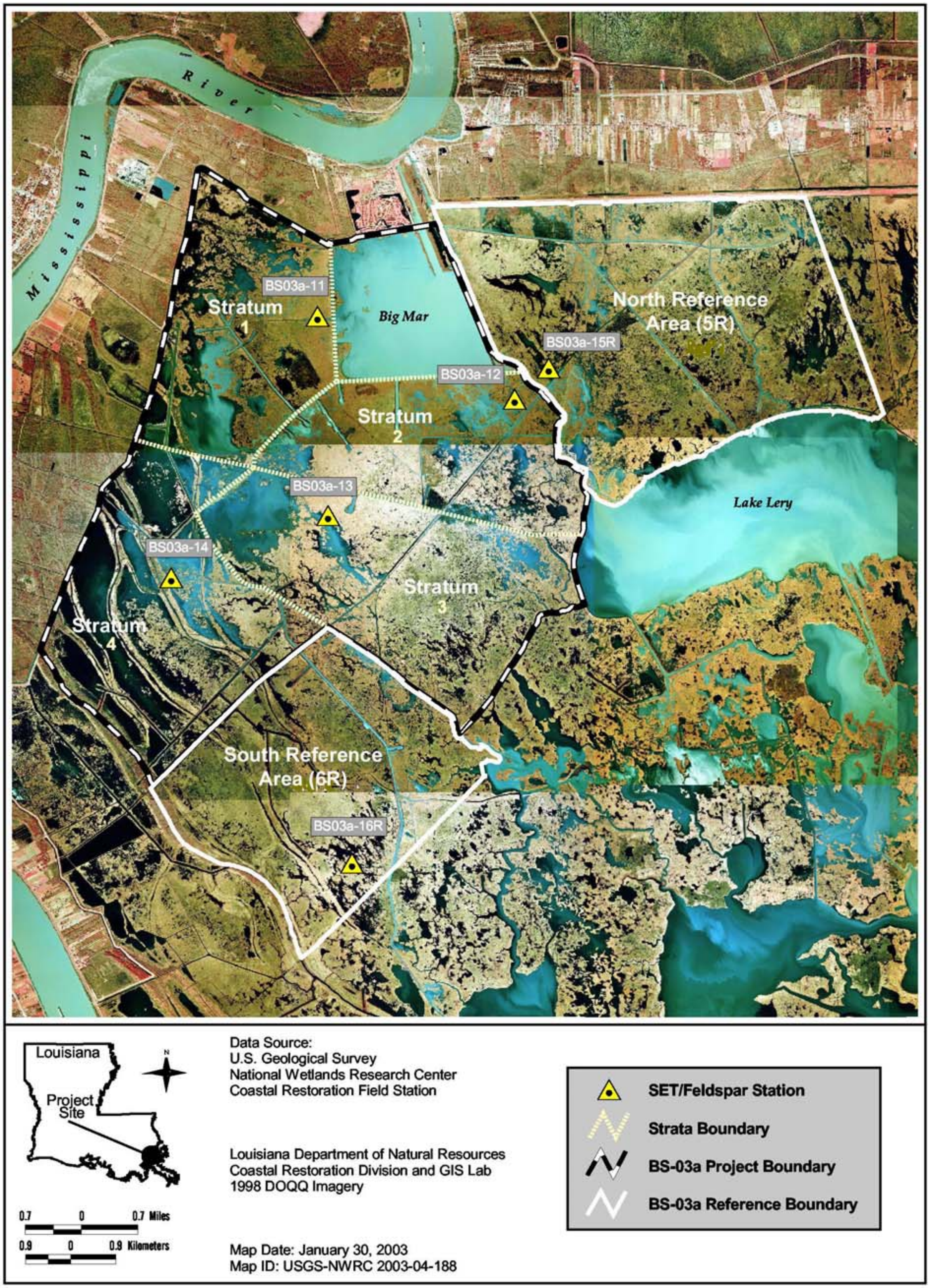

Figure 6. Location of Caernarvon Outfall Management (BS-03a) project accretion sampling stations.

(pre-construction), and in 2002 and 2003. However, with the inception of CRMS, project-specific stations will be discontinued in favor of the CRMS stations located in each stratum.

IV. Monitoring Activity (continued)

c. Preliminary Monitoring Results and Discussion

Habitat Mapping

The aerial photography obtained in 2000 (pre-construction) is currently being analyzed, and was not available for this report.

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 7. 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

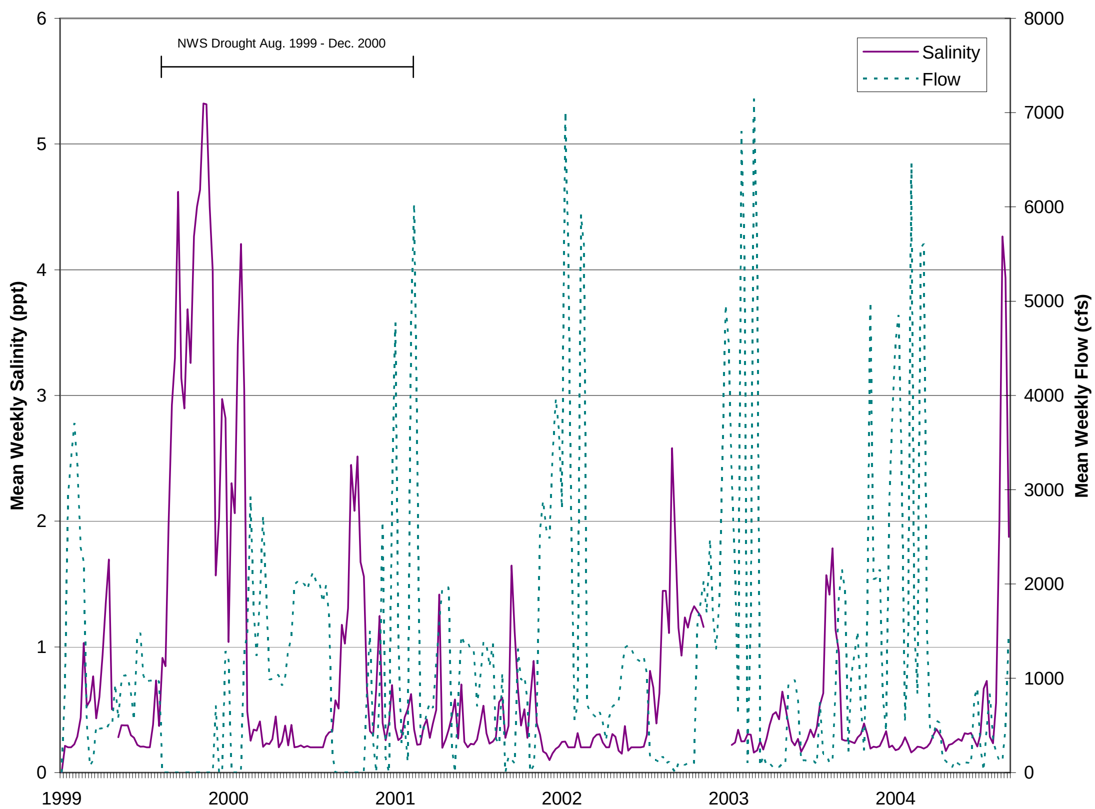

Figure 7. Mean weekly salinity for the Reggio Canal DCP, located within the Caernarvon Outfall Management (BS-03a) project, and mean weekly flow rates for the Caernarvon Diversion, 1999 - 2003.

ppt during the drought (figure 7). However, during the drought salinity levels were suppressed by diversion waters, when the river stage and operational plan allowed (figure 7). 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 8 and 9). 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, with the exception of reference stratum 6 whose means were between 1 and 1.8 ppt for all years (figure 10). The decrease in yearly mean salinities for all strata from the 2000 yearly means, possibly identifies the effect of the drought on the area (figure 10). Even with mean salinities below 1ppt diversion operations are still realized with a reduction in mean salinity as flow rates increase from no flow within the project area (figure 11). However, being that salinities are so low throughout the area, brief salinity incursions (Holm and Sasser 2001), such as with storms or persistent east and southerly winds, may skew estimates of average salinities. This was likely the case for stratum 2 & 3, when in late September and early October 2002 back-to-back tropical events hit the area. Salinities rose to a maximum of 2.5 ppt and stayed above 1 ppt until November 2002 (figure 8). This coupled with a shorter post-construction data stream, possibly resulted in mean salinity values, compared pre- and post-construction, to show an increase in the post-construction period for the 2 strata (figure 12).

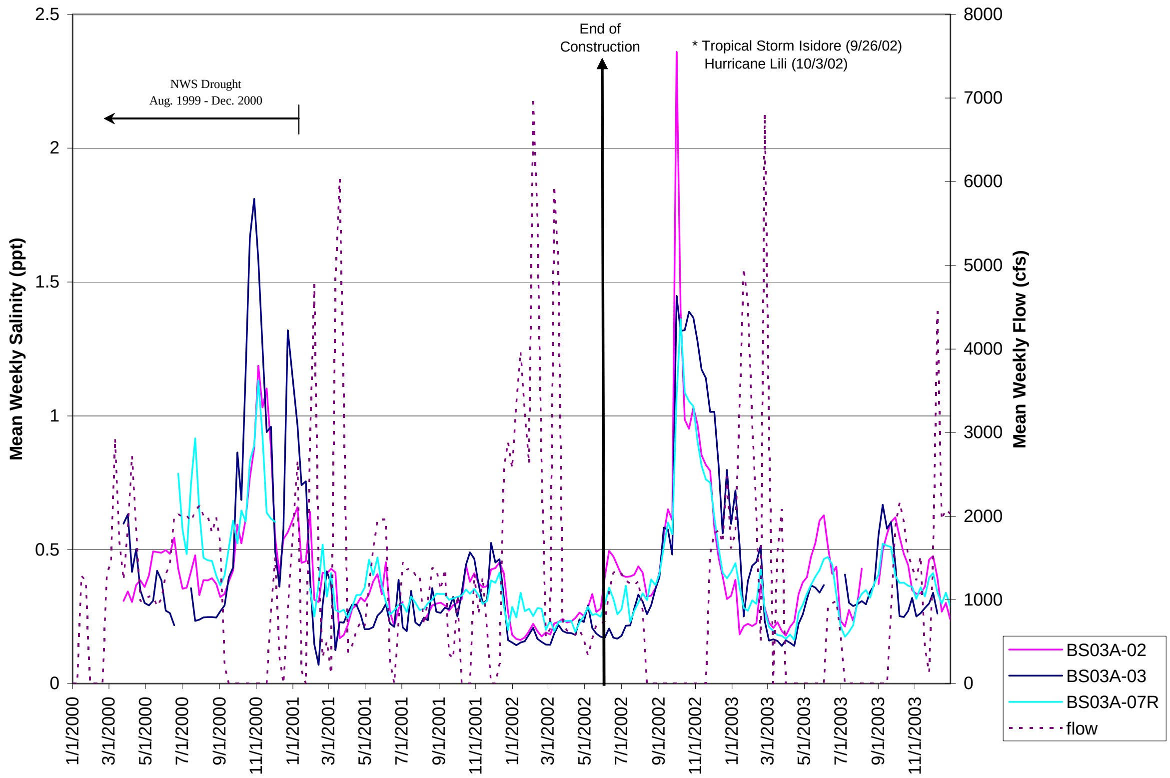

Figure 8. Mean weekly salinity for project stations BS03a-02 & 03 and reference station BS03a-07R for the Caernarvon Outfall Management (BS-03a) project, along with flow rates for the Caernarvon Diversion 2000 - 2003. Station BS03a-01, located in stratum 1, was not presented because it shows little variation over the course of record.

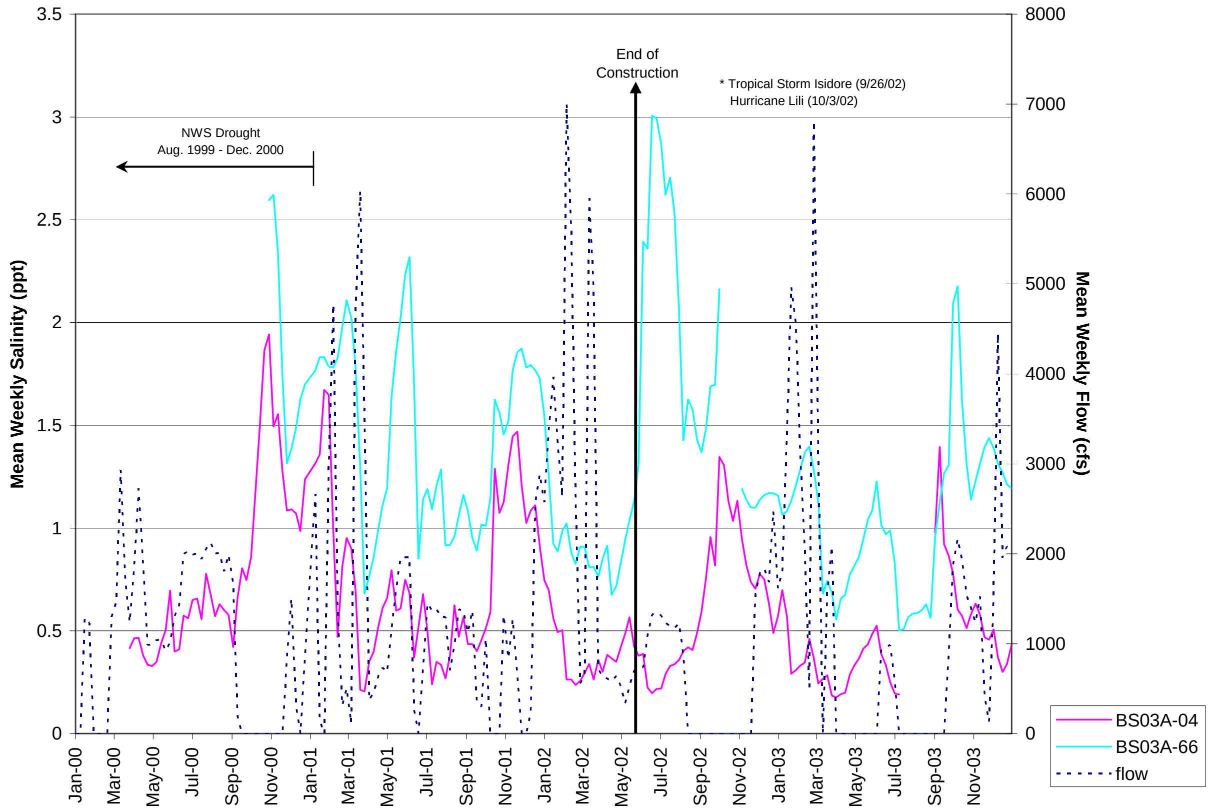

Figure 9. Mean weekly salinity for project station BS03a-04 and reference station BS03a-66R for the Caernarvon Outfall Management (BS-03a) project, along with flow rates for the Caernarvon Diversion 2000 - 2003.

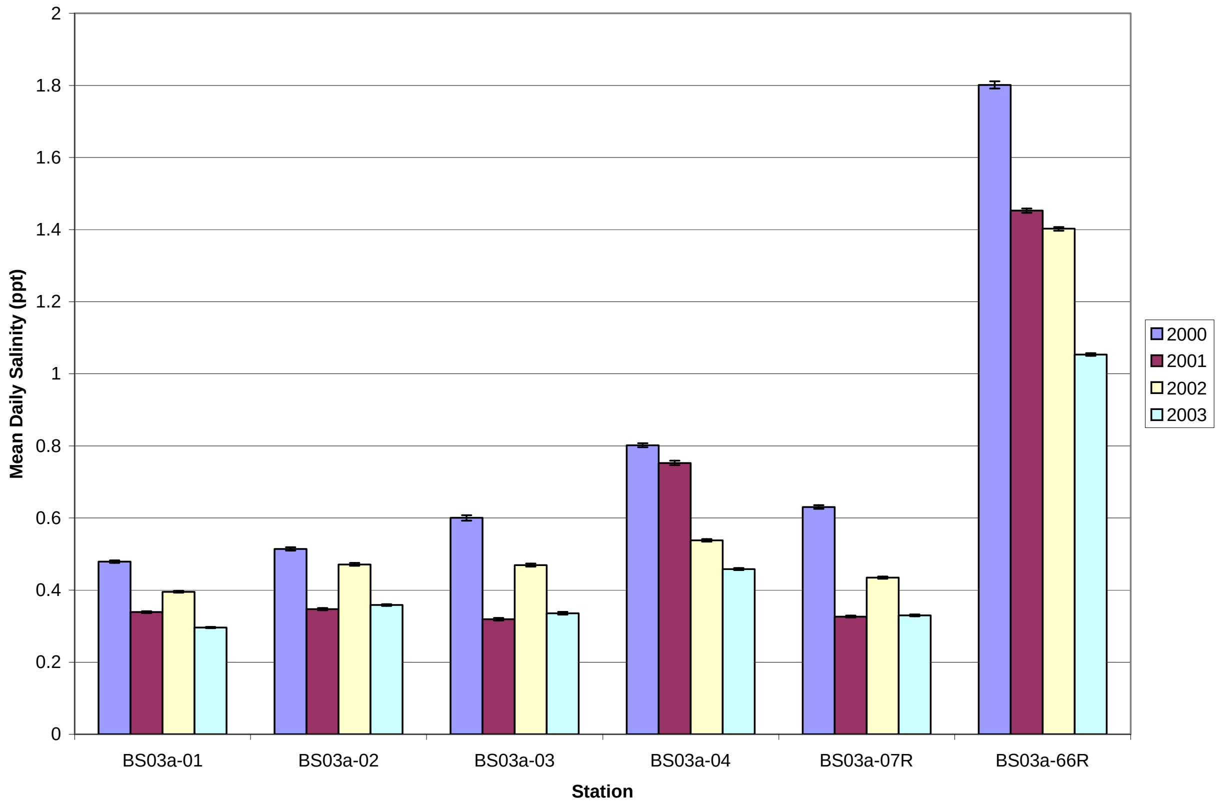

Figure 10. Mean daily salinity by year for the Caernarvon Outfall Management (BS-03a) project.

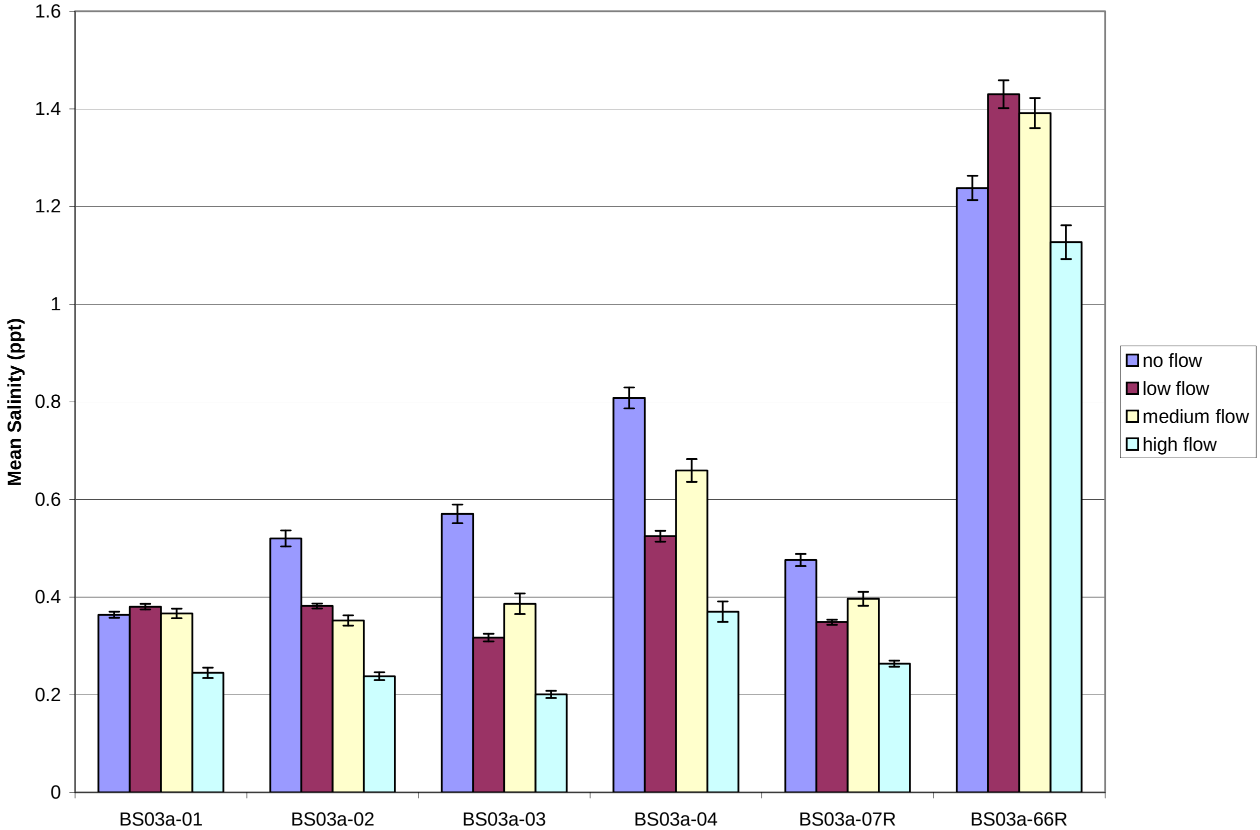

Figure 11. Mean (± SE) salinity for the period 2000 – 2003 at YSI continuous recorder stations during 4 operational categories [Low = 0 – 2000 cfs, Medium= 2000 – 4000 cfs, High= >4000 cfs] for the Caernarvon Outfall Management (BS-03a) project and reference stations.

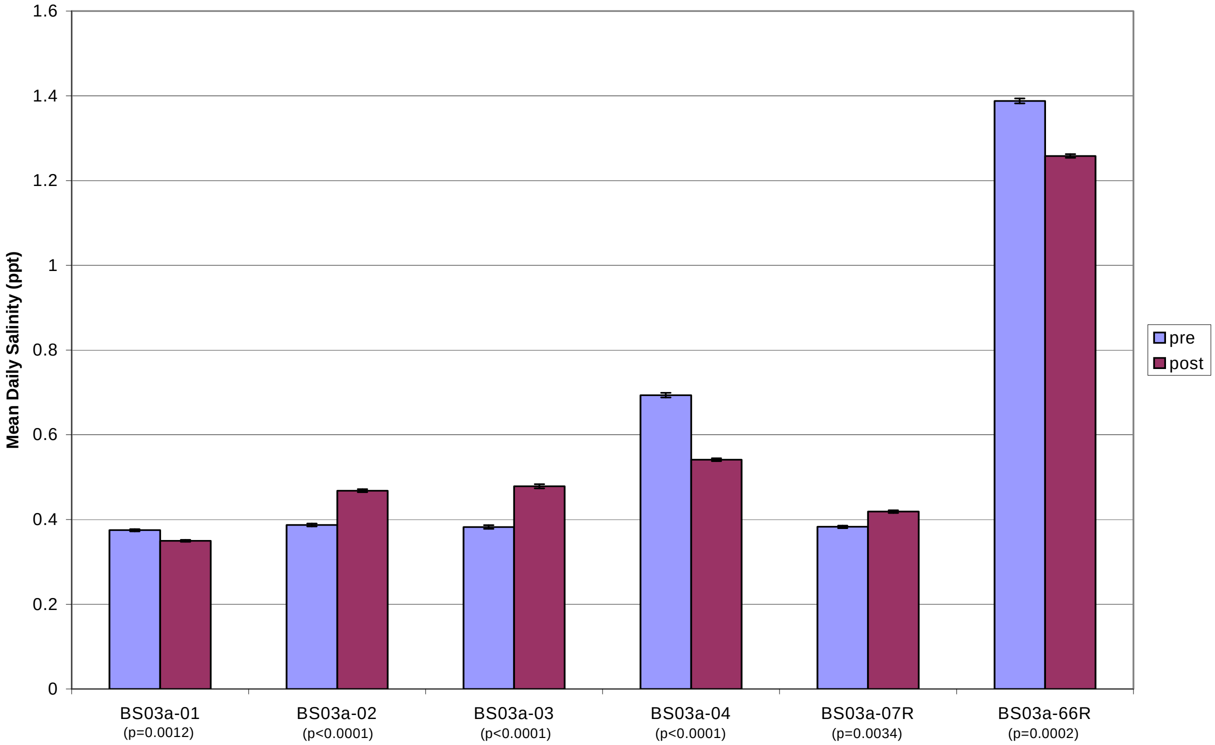

Figure 12 Mean daily (±SE) salinity at YSI continuous recorder stations for the Caernarvon Outfall Management (BS-03a) project and reference areas during pre- (3/27/2000 - 6/14/2002) and post-construction (6/15/2002 – 12/31/2003) periods.

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 variances lessening after the end of construction, with the exception of the tropical weather events in September and October of 2002 (figure 13). However, mean daily salinity variance comparisons between the pre- and post-construction period proved non-significant for all project and reference strata, except for stratum 4 ($p<0.0053$, figure 14). The large increase in variance realized for strata 2 and 3 was likely attributable to the tropical weather events of 2002. 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 boat traffic 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 2003* (LDNR 2003). 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 having the lowest salinity and associated variance and reference stratum 6 the highest, albeit a small difference between the two (figure 10).

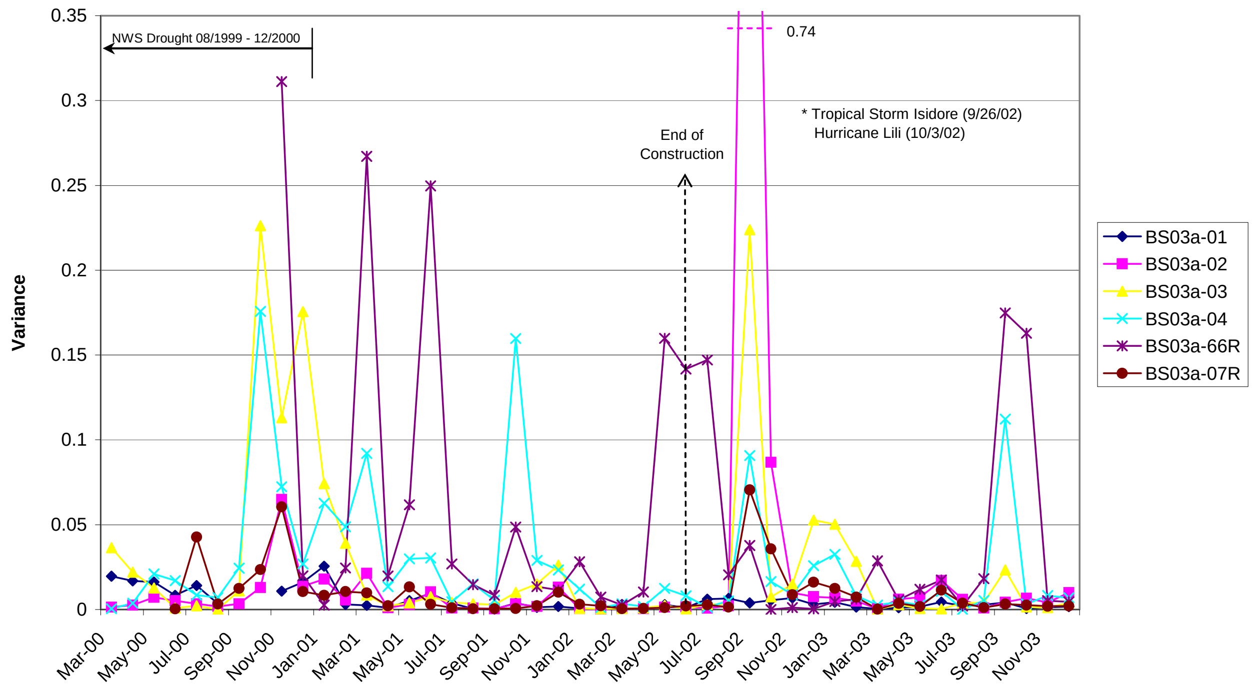

Figure 13. Mean monthly salinity variance at YSI continuous recorder stations for the Caernarvon Outfall Management (BS-03a) project and reference areas, for the period 2000 - 2003.

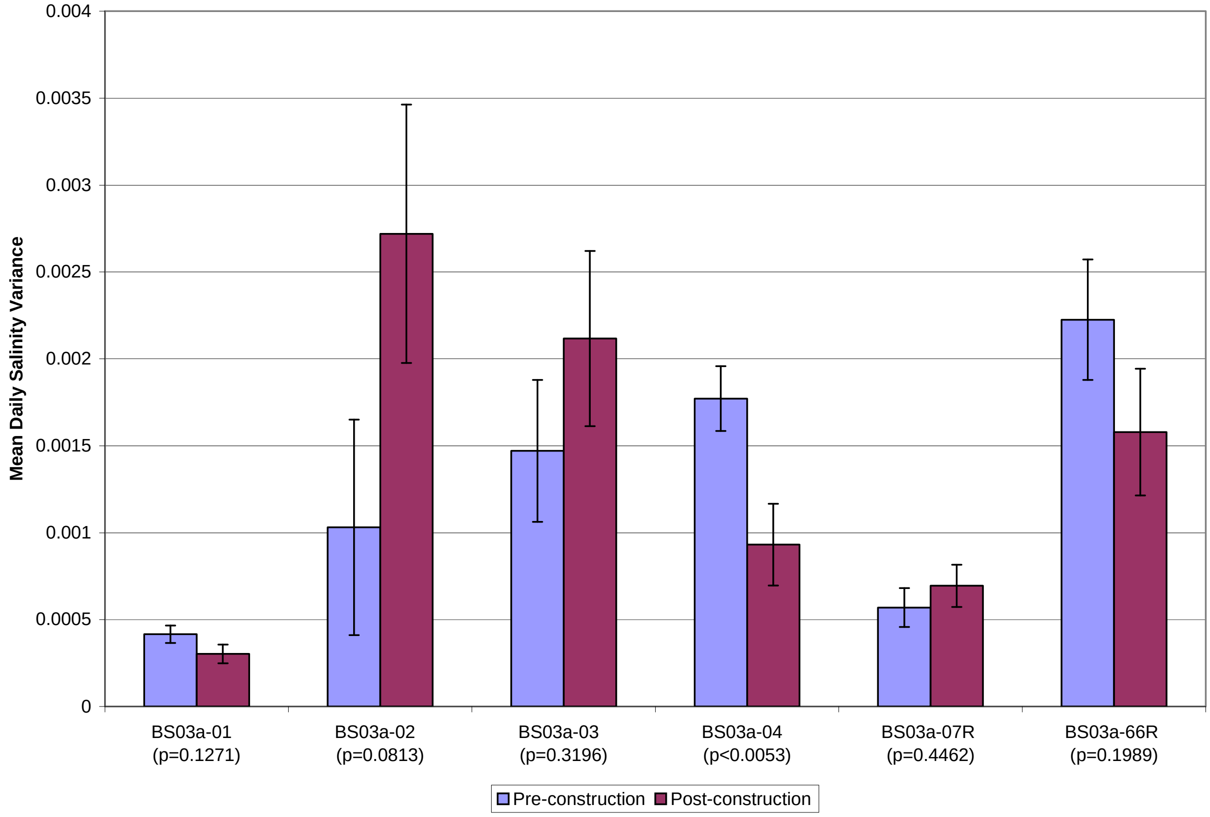

Figure 14. Mean daily salinity variance at YSI continuous recorder stations for the Caernarvon Outfall Management (BS-03a) project and reference areas during the pre- and post-construction periods.

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. 2003). 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, with only stratum 2 being non-significant (figure 15). Stratum 4 showed the highest increase (0.28 ft), while stratum 2 had the smallest change (0.05 ft). This across strata increase, however, could be a function of tropical weather events of 2002, 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.

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 all strata (figures 16 - 21). 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 should

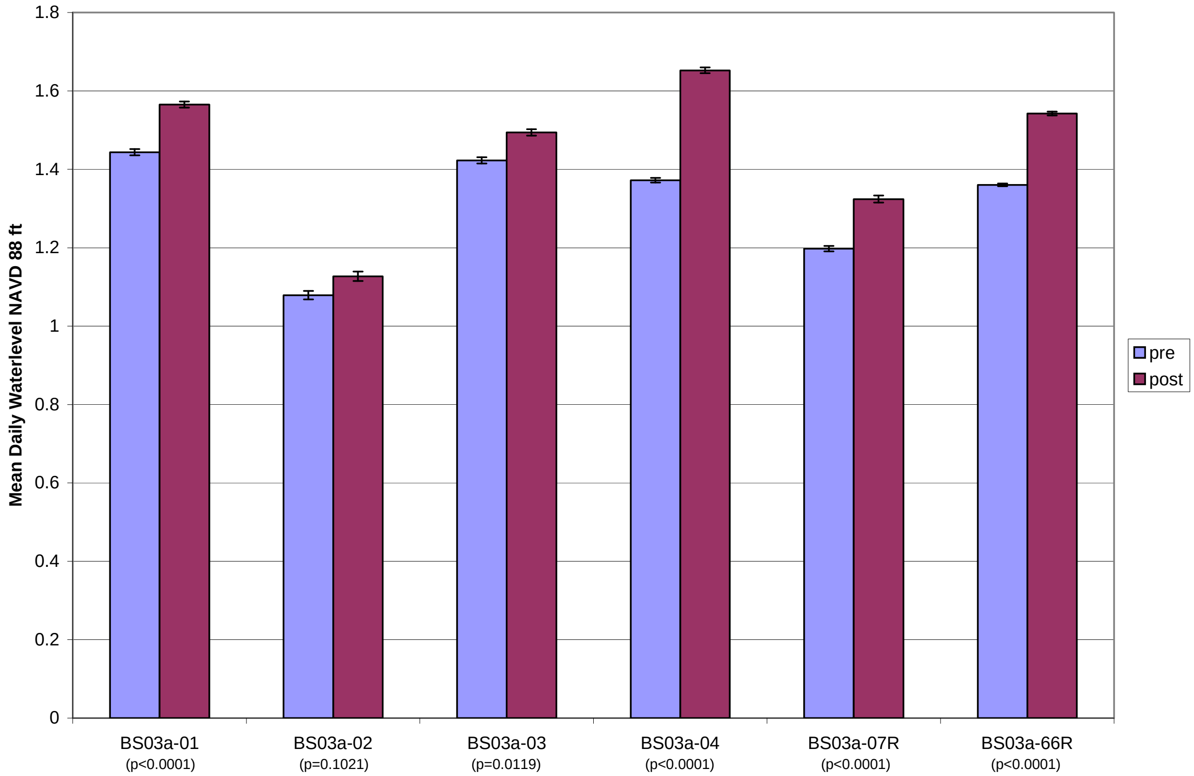

Figure 15. Mean daily (SE) water level NAVD 88 at YSI continuous recorder stations for the Caernarvon Outfall Management (BS-03a) project and reference areas during the pre- (3/2000 - 6/14/2002) and post-construction (6/15/2002 – 12/31/2003) period.

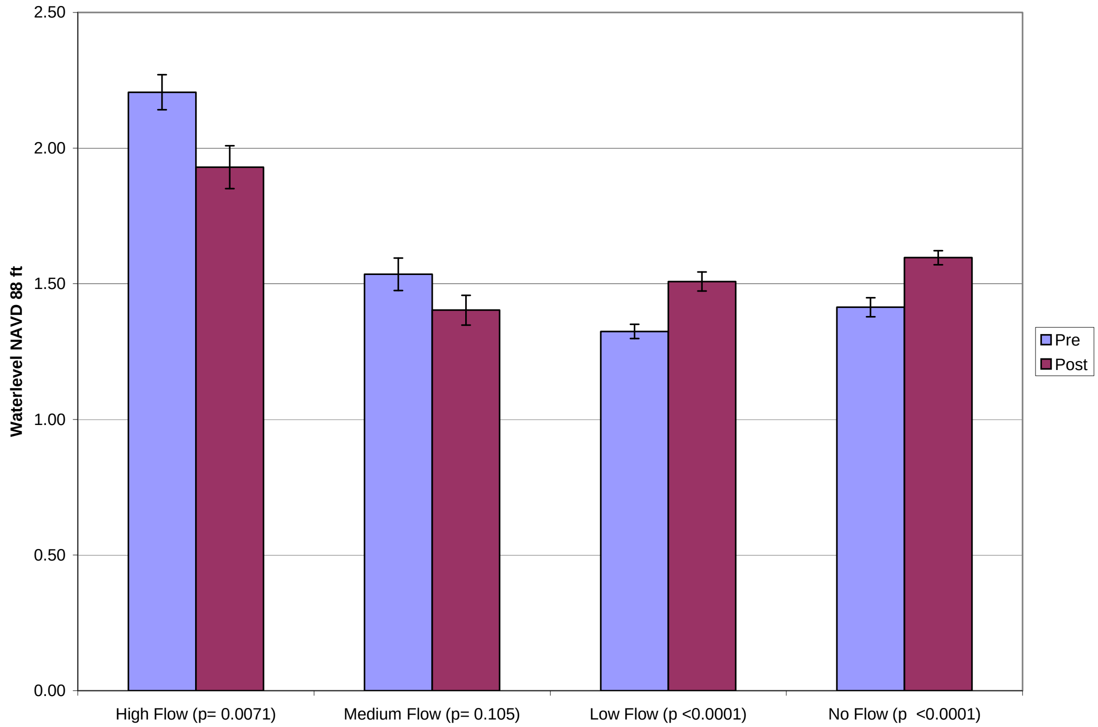

Figure 16. Mean water level NAVD 88 at the YSI continuous recorder station for stratum 1 of the Caernarvon Outfall Management (BS-03a) project during the pre- and post-construction period.

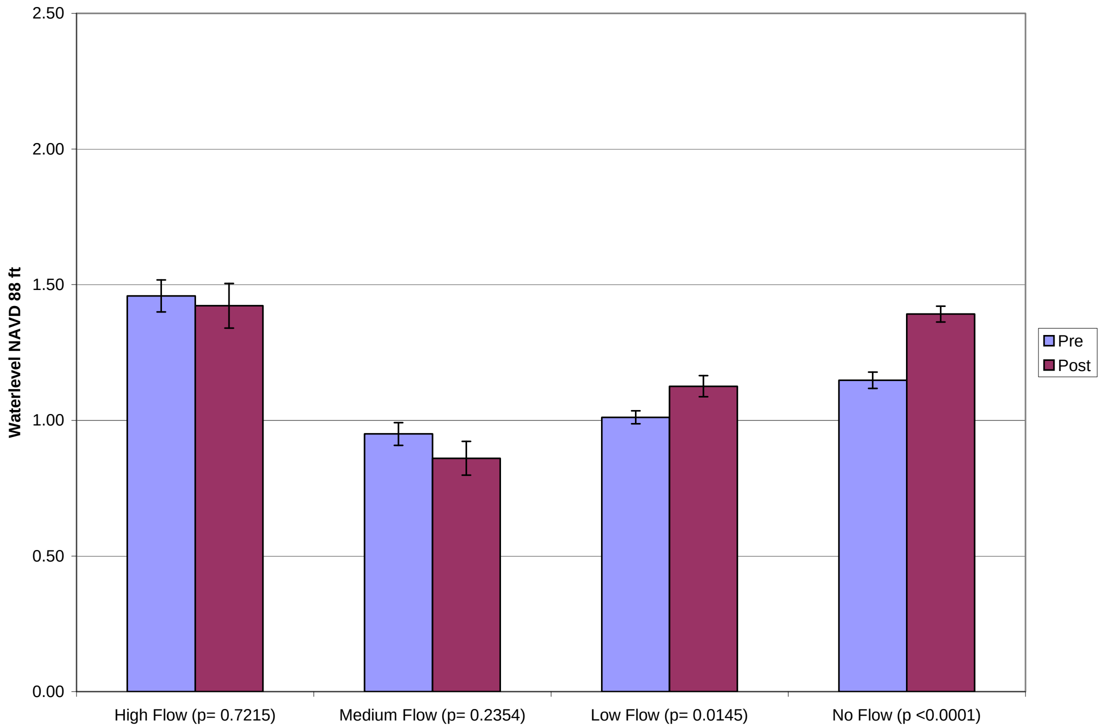

Figure 17. Mean water level NAVD 88 at the YSI continuous recorder station for stratum 2 of the Caernarvon Outfall Management (BS-03a) project during the pre- and post-construction period.

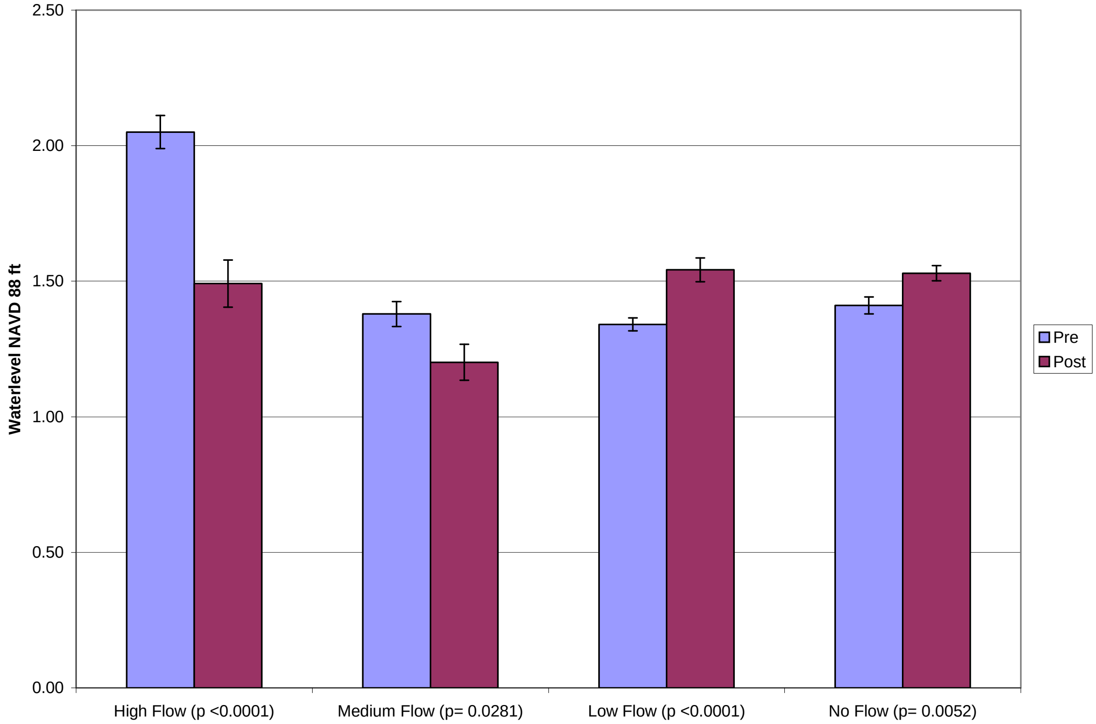

Figure 18. Mean water level NAVD 88 at the YSI continuous recorder station for stratum 3 of the Caernarvon Outfall Management (BS-03a) project during the pre- and post-construction period.

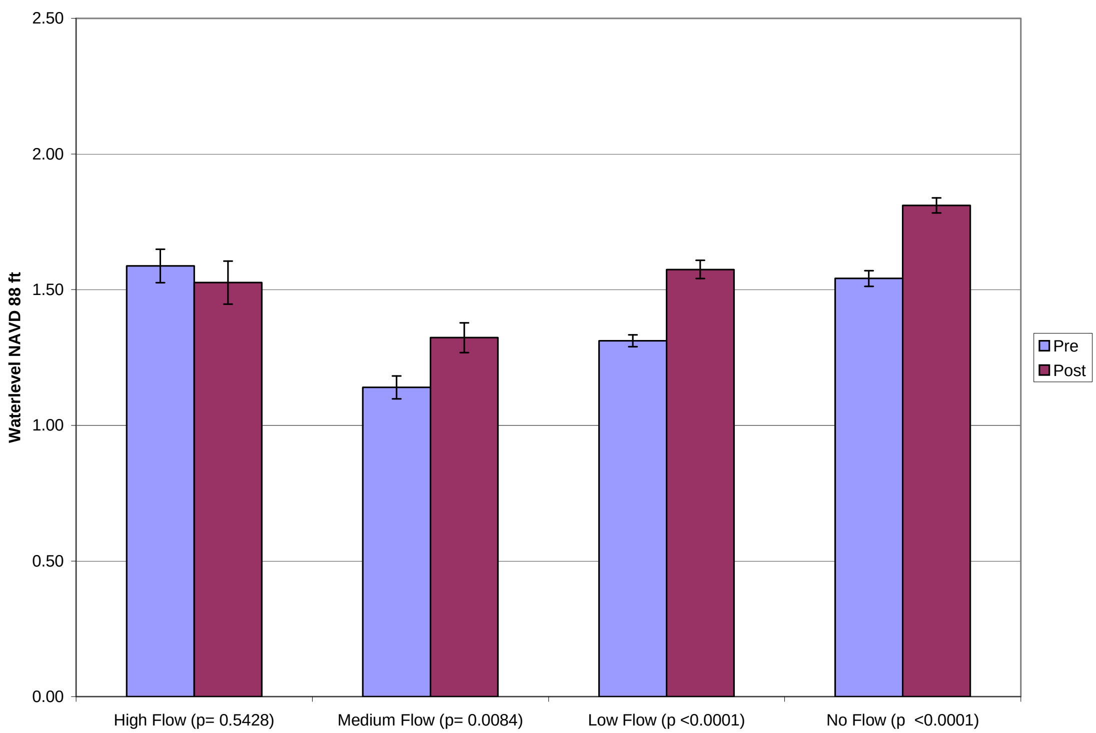

Figure 19. Mean water level NAVD 88 at the YSI continuous recorder station for stratum 4 of the Caernarvon Outfall Management (BS-03a) project during the pre- and post-construction period.

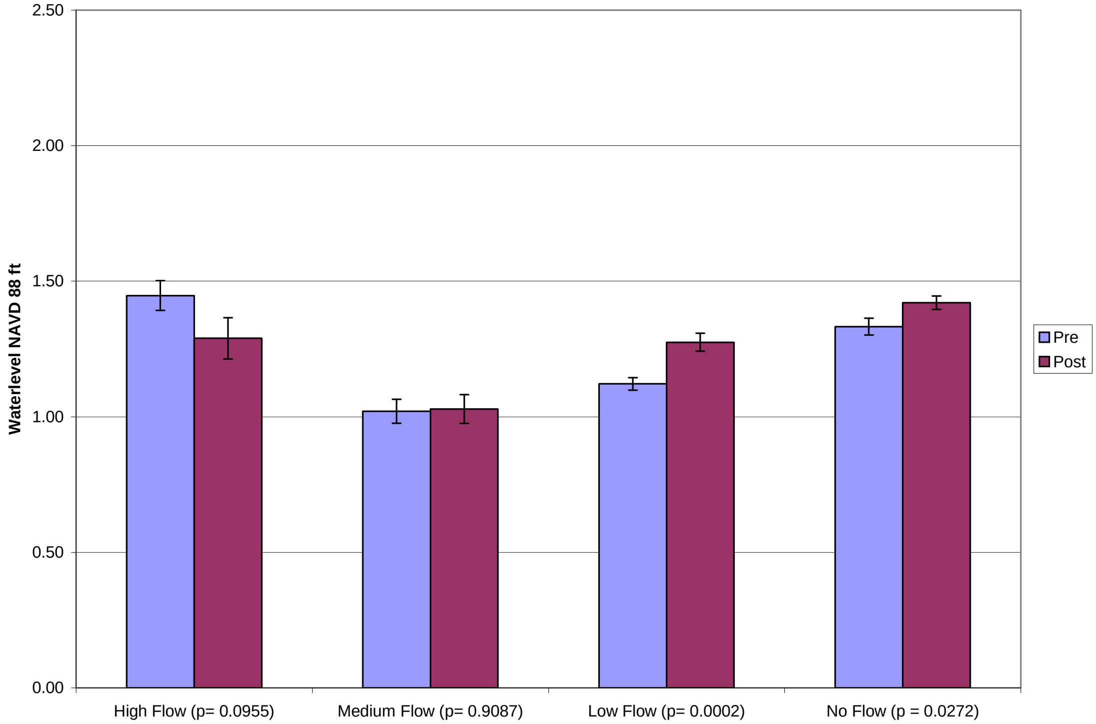

Figure 20. Mean water level NAVD 88 at the YSI continuous recorder station for stratum 5R of the Caernarvon Outfall Management (BS-03a) project during the pre- and post-construction period.

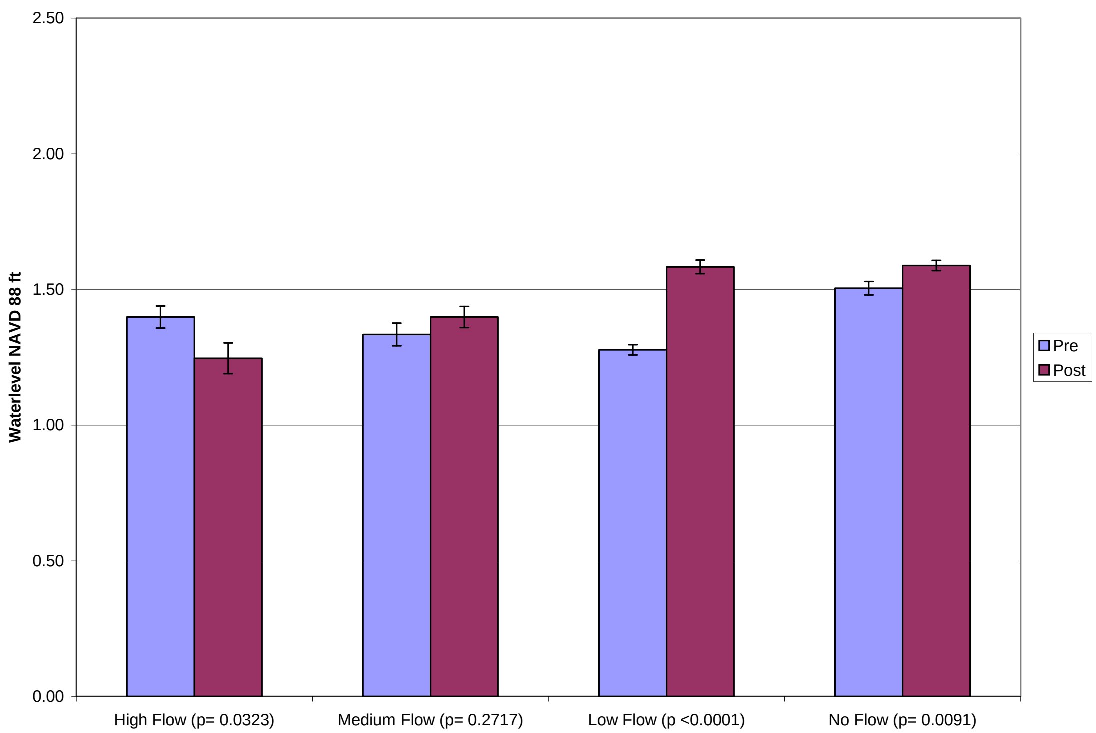

Figure 21. Mean water level NAVD 88 at the YSI continuous recorder station for stratum 6R of the Caernarvon Outfall Management (BS-03a) project during the pre- and post-construction period

be taken into consideration. However, at medium (2000 – 4000 cfs) and high flow (>4000 cfs) operations all strata (except 4 during medium flow) showed a decrease in water level for the post-construction period. This was probably a result of the project on confining the 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. Now with entry points confined to culverts through higher spoil banks it takes longer to get that volume of water into the marshes. During the no flow periods, water levels were 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.

All strata, except stratum 3, realized a decrease in the number of flood events from the pre-construction period (table 1). However, the data stream for the post-construction (n=564 days) period is shorter than that of the pre-construction (n=809 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 are the reason for the high variance associated with stratum 3 (figure 22). 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 when most strata stayed flooded for more than 2 months (figures 23 & 24). All strata showed increases in depth of flooding between the pre- and post-construction periods, and 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	34
Mean Duration (days)	18.7571	37.6135
Mean Depth (ft)	0.4479	0.5410
2		
# of Flood Events	65	36
Mean Duration (days)	5.3934	15.9486
Mean Depth (ft)	0.2929	0.4978
3		
# of Flood Events	78	177
Mean Duration (days)	12.5494	25.8835
Mean Depth (ft)	0.3762	0.5411
4		
# of Flood Events	58	26
Mean Duration (days)	5.9735	22.1129
Mean Depth (ft)	0.2543	0.4688
5R		
# of Flood Events	78	43
Mean Duration (days)	27.1519	41.4393
Mean Depth (ft)	0.3953	0.6063
6R		
# of Flood Events	32	13
Mean Duration (days)	50.2297	68.1140
Mean Depth (ft)	0.2347	0.4020

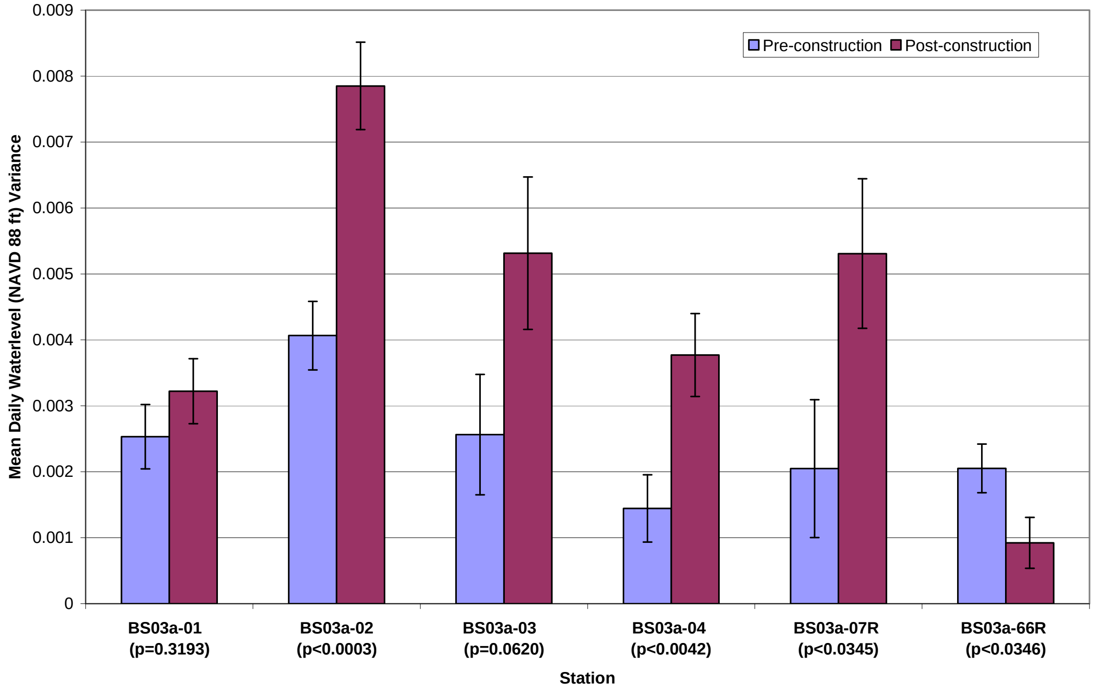

Figure 22. Mean daily water level variance at YSI continuous recorder stations for the Caernarvon Outfall Management (BS-03a) project and reference areas during the pre- and post-construction periods.

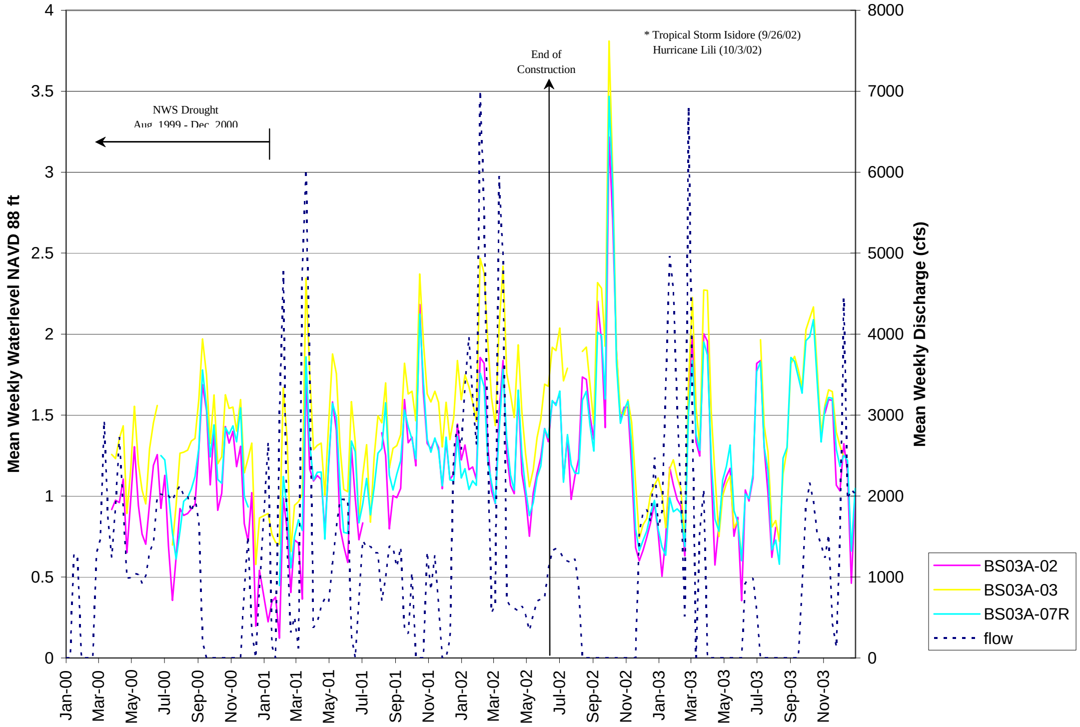

Figure 23. Mean weekly water levels at YSI continuous recorder stations for Caernarvon Outfall Management (BS-03a) project stations 02 & 03 and reference station 07R along with Caernarvon diversion flow for the period 2000 - 2003.

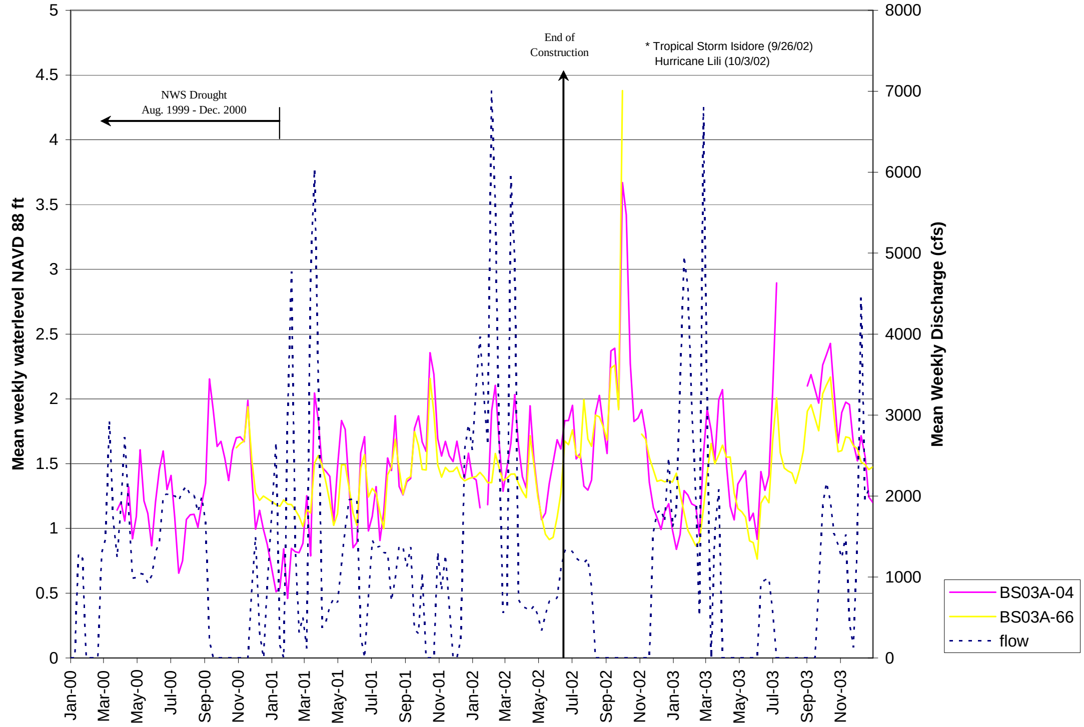

Figure 24. Mean weekly water levels at YSI continuous recorder stations for Caernarvon Outfall Management (BS-03a) project station 04 and reference station 66R along with Caernarvon diversion flow for the period 2000 - 2003.

Vegetation

Spartina patens was dominant in all strata in 2000, and in 2003 it was dominant in all, except stratum four (figures 24-29, tables 2 &3). However, mean cover of *S. patens* was reduced across all strata from the 2000 survey, with an increase of species richness for all strata, except for strata 4, realized from the 2003 survey (table 4). Even though *Vigna luteola* was considered dominant by both occurrence and percent total cover in stratum four, it is a vine supported by emergent vegetation. The dominant non-vine vegetation was *Sesbania herbacea* followed by *Spartina patens* in stratum four.

The decrease of *S. patens* and the increase in species richness for most strata probably indicate a recovery of the vegetation community from the drought and do not necessarily equate to project effectiveness. More data (e.g. 2006 survey) will be needed to determine project effects, as the post-construction survey in 2003 was little more than a year after project construction. However, vegetation type mapping show the area becoming increasingly fresher since diversion operations began (Chabreck and Linscombe 2001).

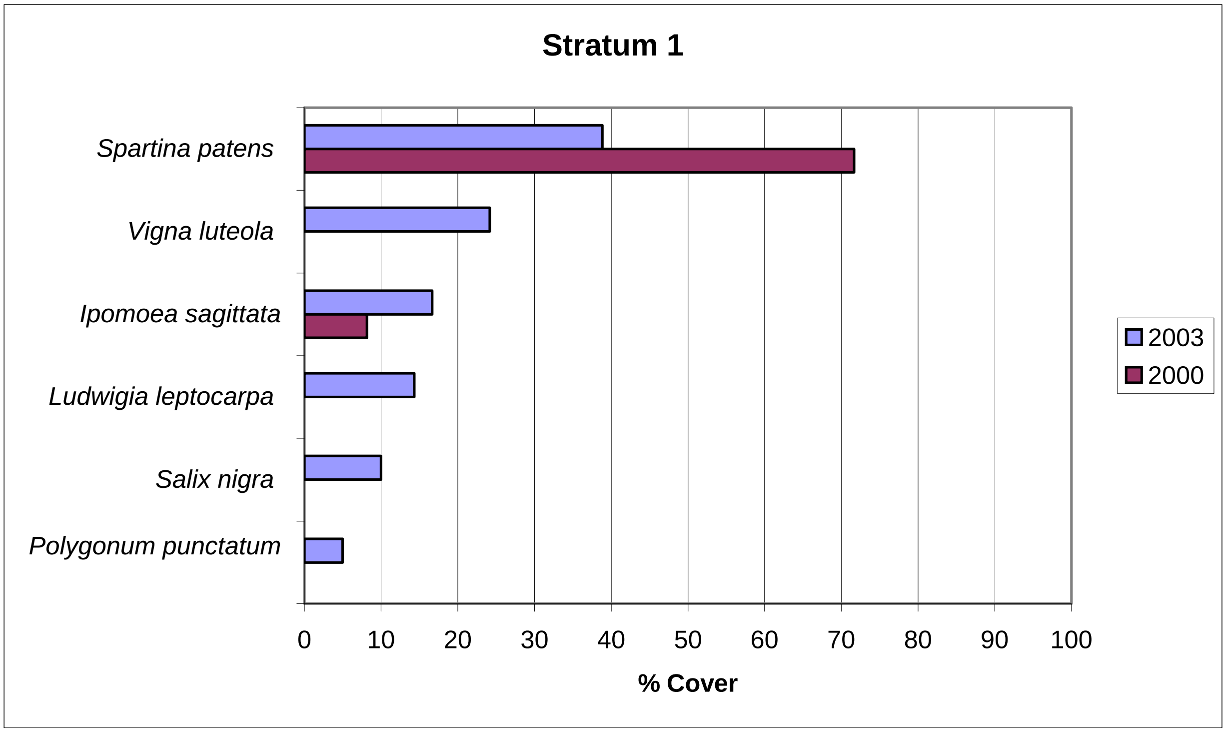

Figure 25. Mean % cover of dominant vegetative species across all 4m^2 plots during 2000 (pre-construction) and 2003 (post-construction) vegetation surveys for stratum 1 of the Caernarvon Outfall Management (BS-03a) project.

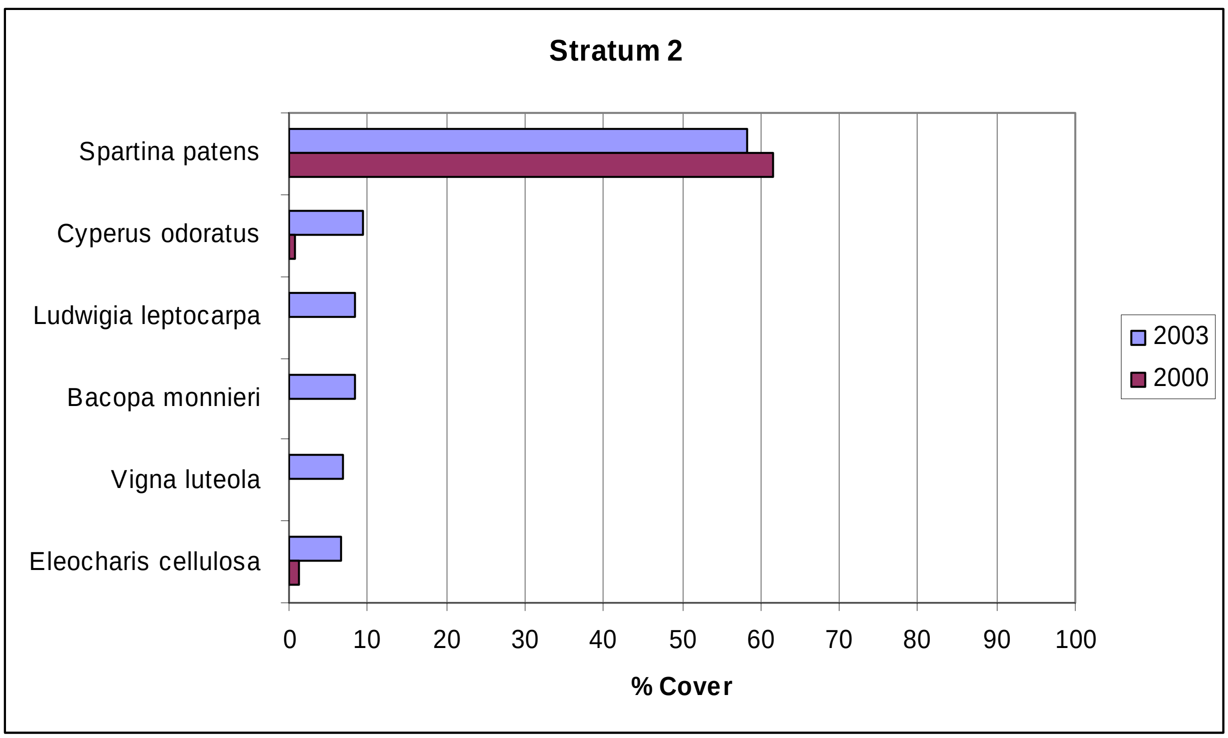

Figure 26. Mean % cover of dominant vegetative species across all 4m^2 plots during 2000 (pre-construction) and 2003 (post-construction) vegetation surveys for stratum 2 of the Caernarvon Outfall Management (BS-03a) project.

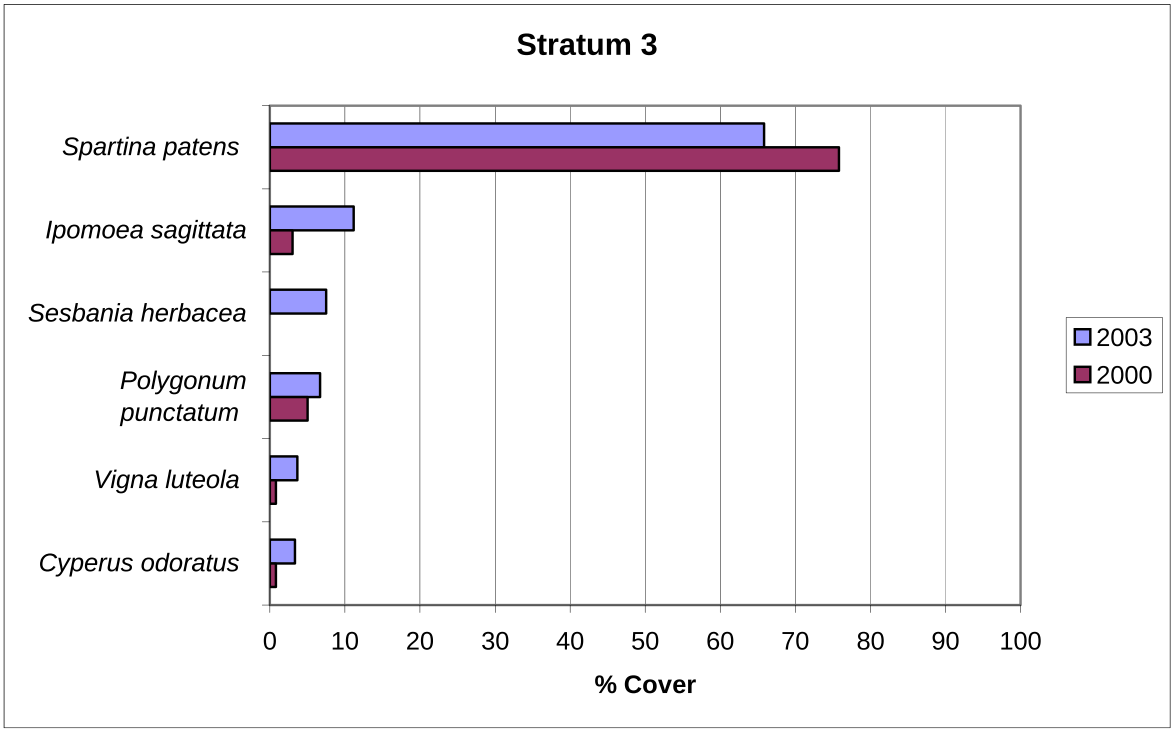

Figure 27. Mean % cover of dominant vegetative species across all 4m^2 plots during 2000 (pre-construction) and 2003 (post-construction) vegetation surveys for stratum 3 of the Caernarvon Outfall Management (BS-03a) project.

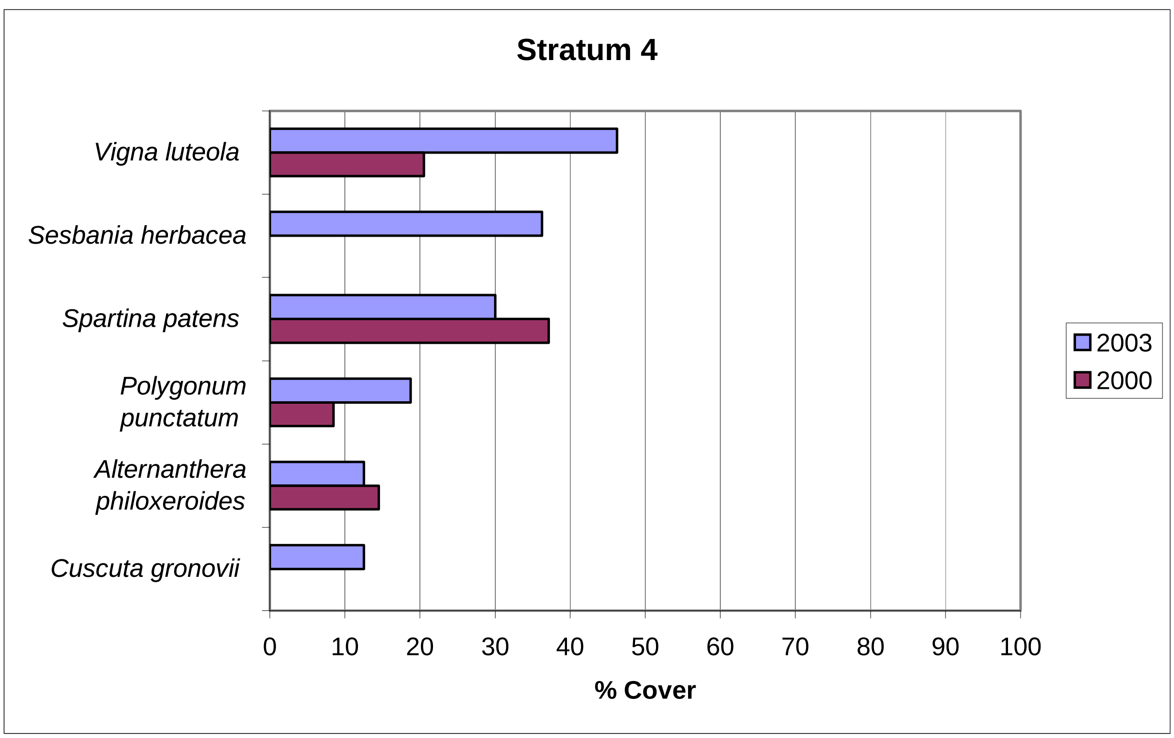

Figure 28. Mean % cover of dominant vegetative species across all 4m^2 plots during 2000 (pre-construction) and 2003 (post-construction) vegetation surveys for stratum 4 of the Caernarvon Outfall Management (BS-03a) project.

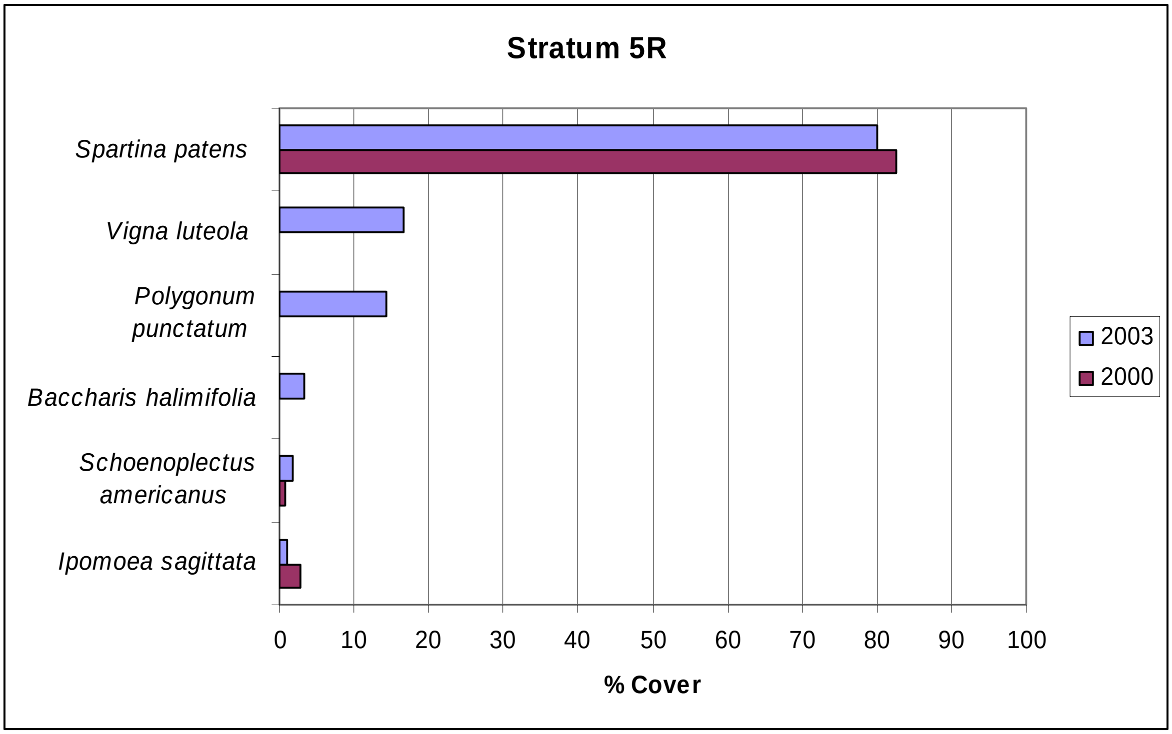

Figure 29. Mean % cover of dominant vegetative species across all 4m^2 plots during 2000 (pre-construction) and 2003 (post-construction) vegetation surveys for stratum 5R of the Caernarvon Outfall Management (BS-03a) project

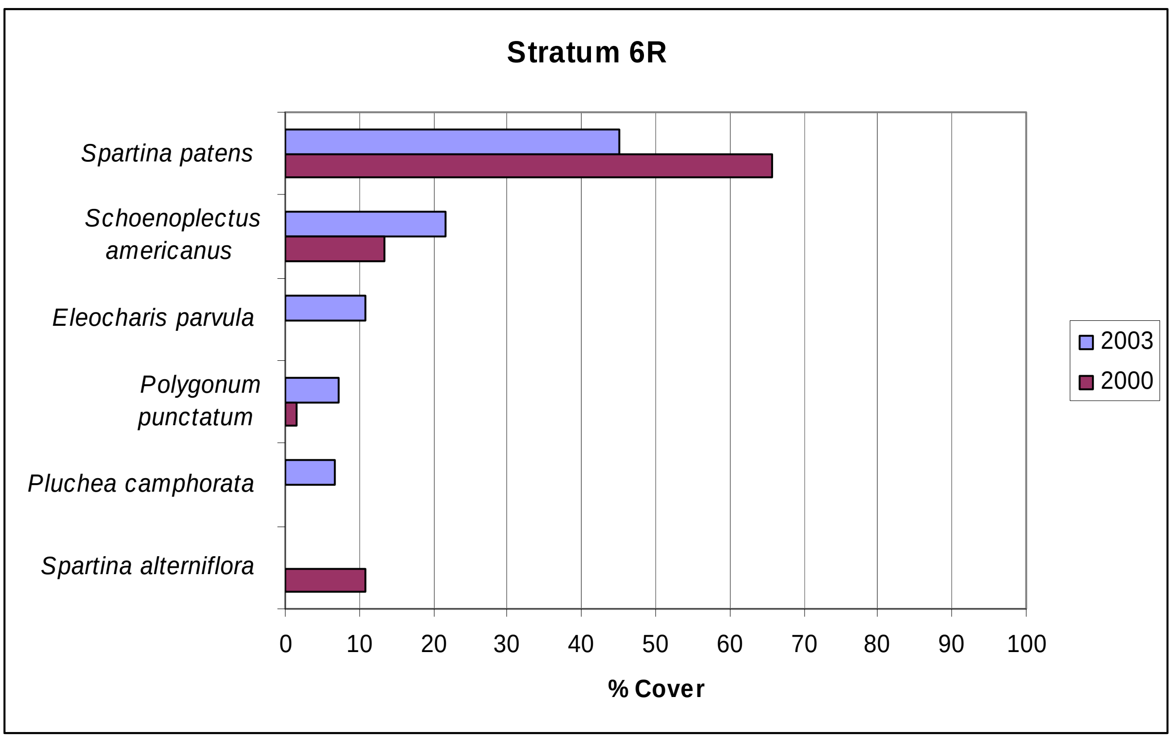

Figure 30. Mean % cover of dominant vegetative species across all 4m^2 plots during 2000 (pre-construction) and 2003 (post-construction) vegetation surveys for stratum 6R of the Caernarvon Outfall Management (BS-03a) project

Table 2. Frequency of occurrence and total cover by stratum for the Caernarvon Outfall Management project areas during 2000 (pre-construction) and 2003 (post-construction) vegetation surveys.

	Stratum 1				Stratum 2				Stratum 3				Stratum 4			
	Frequency (%)		Total Cover (%)		Frequency (%)		Total Cover (%)		Frequency (%)		Total Cover (%)		Frequency (%)		Total Cover (%)	
	2000	2003	2000	2003	2000	2003	2000	2003	2000	2003	2000	2003	2000	2003	2000	2003
Alternanthera philoxeroides		50.00		0.83	16.67	16.67	0.33	4.17		33.33		1.17	33.33	25.00	14.50	12.50
Amaranthus australis					16.67		1.00						16.67		0.67	
Ammannia coccinea					16.67		0.17			16.67		0.50				
Ammannia latifolia																
Baccharis halimifolia					16.67	16.67	0.83	0.17	50.00	16.67	0.68	2.50	16.67		0.83	
Bacopa monnieri		33.33		1.33		16.67		8.33		33.33		0.67	33.33		0.33	
Cuscuta gronovii		16.67		0.83										25.00		12.50
Cyperus odoratus		16.67		0.50	33.33	33.33	0.67	9.33	16.67	16.67	0.83	3.33	16.67	25.00	2.50	0.25
Distichlis spicata					16.67		3.33									
Echinochloa walteri													16.67	50.00	0.33	9.25
Eleocharis baldwinii					16.67		1.17									
Eleocharis cellulosa					16.67	16.67	1.17	6.67		16.67		1.67				
Eleocharis parvula																
Galium obtusum																
Hydrocotyle umbellata		16.67		0.50	16.67		4.17			50.00		0.50				
Hydrocotyle verticillata													16.67		6.67	
Ipomoea sagittata	83.33	100.00	8.17	16.67					33.33	83.33	3.00	11.17	100.00	25.00	13.50	10.00
Kosteletzkya virginica					16.67	16.67	0.17	0.50		16.67		1.17				
Ludwigia leptocarpa		66.67		14.33		50.00		8.50		50.00		2.67		25.00		0.50
Ludwigia peploides																
Lythrum lineare	16.67	16.67	0.02	0.83	33.33	16.67	0.52	0.33	16.67		0.02					
Mikania scandens		16.67		1.67									16.67		0.83	
Phyla nodiflora													33.33		0.18	
Pluchea camphorata						16.67		0.50		33.33		0.50				
Pluchea foetida					16.67		0.02									
Polygonum punctatum		50.00		5.00	16.67	16.67	0.33	1.33	33.33	66.67	5.02	6.67	66.67	25.00	8.50	18.75
Salix nigra		33.33		10.00		16.67		0.83								
Schoenoplectus americanus					33.33	50.00	0.50	5.17		16.67		0.17	16.67	25.00	2.50	0.50
Schoenoplectus robustus																
Sesbania drummondii													33.33		1.33	
Sesbania herbacea		16.67		0.17						16.67		7.50		50.00		36.25
Solidago sempervirens																
Spartina alterniflora																
Spartina patens	100.00	100.00	71.67	38.83	100.00	100.00	61.67	58.33	100.00	100.00	75.83	65.83	100.00	50.00	37.17	30.00

	Stratum 1				Stratum 2				Stratum 3				Stratum 4			
	Frequency (%)		Total Cover (%)		Frequency (%)		Total Cover (%)		Frequency (%)		Total Cover (%)		Frequency (%)		Total Cover (%)	
	2000	2003	2000	2003	2000	2003	2000	2003	2000	2003	2000	2003	2000	2003	2000	2003
Symphyotrichum subulatum		16.67		0.33						33.33		0.33				
Thelypteris palustris		33.33		1.33												
Typha latifolia														25.00		2.50
Vigna luteola	16.67	83.33	0.02	24.17		50.00		6.83	16.67	33.33	0.83	3.67	100.00	100.00	20.50	46.25
Zizaniopsis miliacea													16.67		1.67	

Table 3. Frequency of occurrence and total cover by stratum for the Caernarvon Outfall Management reference areas during 2000 (pre-construction) and 2003 (post-construction) vegetation surveys.

	Stratum 5R				Stratum 6R			
	Frequency (%)		Total Cover (%)		Frequency (%)		Total Cover (%)	
	2000	2003	2000	2003	2000	2003	2000	2003
Alternanthera philoxeroides	16.67		0.33		50.00	16.67	0.92	0.50
Amaranthus australis								
Ammannia coccinea					16.67		0.33	
Ammannia latifolia		16.67		0.83		16.67		1.67
Baccharis halimifolia		33.33		3.35				
Bacopa monnieri		16.67		0.17	16.67	66.67	2.50	2.17
Cuscuta gronovii								
Cyperus odoratus					16.67	50.00	0.83	5.17
Distichlis spicata	16.67		0.17					
Echinochloa walteri								
Eleocharis baldwinii								
Eleocharis cellulosa								
Eleocharis parvula						16.67		10.83
Galium obtusum		16.67		0.17		16.67		0.83
Hydrocotyle umbellata						16.67		0.17
Hydrocotyle verticillata								
Ipomoea sagittata	50.00	33.33	2.75	1.00	33.33	33.33	4.17	5.67
Kosteletzkya virginica								
Ludwigia leptocarpa						16.67		2.50
Ludwigia peploides					16.67		0.08	
Lythrum lineare					16.67	16.67	1.67	0.83
Mikania scandens								
Phyla nodiflora								
Pluchea camphorata						16.67		6.67
Pluchea foetida					33.33		5.17	
Polygonum punctatum	33.33	83.33	0.35	14.25	33.33	83.33	1.50	7.17
Salix nigra								
Schoenoplectus americanus	50.00	16.67	0.75	1.67	50.00	66.67	13.50	21.67
Schoenoplectus robustus					16.67		8.33	
Sesbania drummondii								
Sesbania herbacea						16.67		0.02
Solidago sempervirens	16.67		0.02					
Spartina alterniflora					16.67		10.83	
Spartina patens	100.00	100.00	82.50	80.00	100.00	100.00	65.83	45.00
Symphyotrichum subulatum								
Thelypteris palustris								
Typha latifolia								
Unknown #1					16.67	33.33	0.08	0.04
Vigna luteola		50.00		16.75	16.67	16.67	0.83	0.33
Zizaniopsis miliacea								

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 July 2000 & July 2003 (N=6 for all strata each year, except N=4 for stratum 4 in 2003).

Stratum	2000	2003
1	2.17	6.67
2	3.83	4.33
3	2.67	6.33
4	6.33	4.50
5R	2.83	3.67
6R	4.5	6.0

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 30). 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, and 2003. It is suspected that the stations used for accretion monitoring are located on flotant marsh, and therefore cannot be used to quantify elevation changes. Preliminary analysis seems to support this claim. Once 2004 data are collected and analyzed the results will be presented.

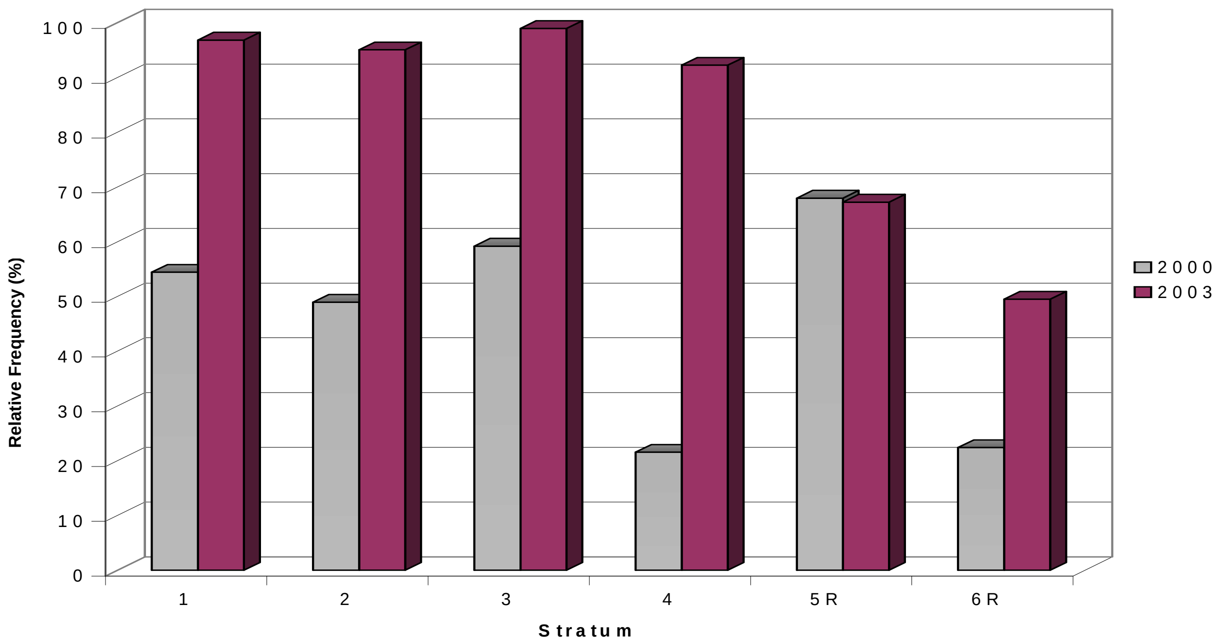

Figure 24. Relative frequency (%) of all submerged aquatic vegetation species combined across two transects within two ponds per stratum of the Caernarvon Diversion Outfall Management (BS-03a) project and reference areas in April 2000 and 2003.

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

Salinities in the project area are fresh, and have been since the beginning of data collection. Seasonal events seem to have the biggest affect 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 had no ecological affect on the area. Although there was a drought during the pre-construction period, diversion operations seem to have “diluted-out” 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, seems to have benefited greatly from this project showing significant reductions in salinity and variance during the post-construction period.

Water levels within the project area have increased significantly for all project strata, except stratum 2, during the post construction period. At low flow operations strata 1, 3 and 4 saw significant increases in water level, indicating a greater retention of water within the project area. 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 restrict 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, with a reduction of brackish species percent cover has been realized. 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. Moreover, it is relatively early to discuss project effectiveness on the marsh vegetation community, because only one post-construction vegetation survey has been conducted, and it was just over a year after project construction.

b. Recommended Improvements

Stratum 4 “behaves” differently than all other project strata. Once dominated by forested wetlands, the area is now characterized by natural ridges surrounded by open water or highly fragmented flotant marsh. These natural ridges, which trapped the salty storm surge during hurricane Betsy in 1965 (USDA/NRCS 1996), restrict freshwater from dispersing throughout the stratum. The storms of 2002 further complicated water flow through the area by blocking the channel leading from structure 54, which extended through two ridges, with floating marsh mats.

Due to these natural barriers, some areas receive little, if any, benefit from diverted waters. To improve conveyance of diversion waters through the stratum, a proposal is being drafted to dredge the outfall canals behind structures 26, 40 and 54, to allow a greater volume of water to reach the interior marshes.

In order to evaluate structural settlement, stability of the rock structure, toe scour, and any vertical accretion on the rock structure, a structural assessment survey performed by a licensed engineering/ land surveying firm is recommended within the first 5 years of construction. The date of assessment survey is to be agreed upon by the state and federal sponsor at the annual maintenance inspection.

Several options have been suggested and should be evaluated to improve upon the flow of fresh water from the diversion to stratum 4.

1. Refurbish the small diversion at White Ditch to possibly increase the size of the siphon to provide a larger volume of freshwater to the area.

2. Construct a rock weir or rock dike to restrict the flow through Bayou Mandeville and push more flow through Delacroix Canal. Note: Even though St. Bernard Parish adamantly opposes this option, it is still thought to be a viable solution.

3. Dredge a canal through the west side of Big Mar to Delacroix Canal to increase the flow to the west side of the project.

4. Construct a deflecting dike at the southeast corner of Big Mar.

The first suggestion appears to be the best solution, but a structural measure to restrict flow down Bayou Mandeville and promote flow through Delacroix Canal would be a viable solution as well. Currently the only way we are able to get the water into stratum 4 is through flow pulsing, when the river permits. This fills up all the other regions first and creates a head differential causing the water to flow westward toward stratum 4.

Water Hyacinths (*Eichhornia crassipes*) have flourished since the beginning of diversion operations, and have become a real problem for landowners throughout the project area. Water hyacinths can constrict flow and make navigating among monitoring stations difficult. It is suspected that station BS03a-01 in stratum 1 may have been destroyed by a moving mass of water hyacinths, resulting in three months of data being lost. Since water hyacinths growth can occur adjacent to all diversion and siphon structures, the administration should evaluate and develop a statewide policy for addressing this issue.

Structure 32 was vandalized and has since been partially repaired. The structure should be completely repaired as soon as possible to ensure it performs as was designed.

The water control structures are currently being operated without a contract. Although current procedures are adequate, a more permanent method of operations is desired. LDNR is currently looking into working with the landowners to operate the structures for a more satisfactory result.

c. Lessons Learned

The most important lesson we should learn 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 they can 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.

Due to the freshness of the project area, salinity is not a good indicator to the amount of water entering and remaining within each stratum. Reference areas for the projects seem to show similar trends as project areas, and make comparisons between the two difficult. From data presently recorded, frequency and duration of flooding seems the most useful in determining the projects affects on conveying and retaining water in interior marshes. The structures feeding stratum 4 have recently been fitted with flow meters to quantify the amount of water entering the area, and investigation into the possible use of turbidity measurements in determining project success has been initiated Nutrient analyses could also prove useful in determining benefits the marsh is receiving from diversion operations.

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