Feasibility Study to Examine Potential Hydrological and Biological Benefits from Restoring Flow of a Salt Marsh Creek at the Edisto Beach Causeway

Final Project Completion Report

Prepared by J. David Whitaker

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Charleston, South Carolina

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Executive Summary

The importance of salt marshes in providing primary and secondary productivity for marine systems has been well documented. Estuarine-dependent marine vertebrates and invertebrates, including many of recreational and commercial importance, utilize tidal creeks and salt marsh habitats as critically important nursery habitats.

In the twentieth century, numerous roads were built to the oceanside islands in South Carolina and other salt marsh-surrounded barrier islands. In the process of dredging and filling for roadbeds through marshes, existing tidal creeks were routinely cut off from oceanic tidal flow and filled by constructed causeways. In some cases, upland runoff landward of a causeway resulted in the inland marshes becoming fresh and colonized by freshwater vascular plants. While these areas may be temporarily beneficial to birds, they would often fill in over time, transforming into high ground. On the seaward side of these causeways, creek flow rates would decrease and, over time, sediments would be deposited, slowing reducing the depth of the creek channels and biological function. Because the tides transport foods and nutrients into the marsh, free flowing tidal creeks with ample marsh-water edges are essential for a healthy system that supports marine fauna.

The overall net impact of causeway construction in the salt marshes has been a localized decline of primary and secondary productivity of the ecosystem. The cumulative effect of these marsh alterations has never been computed, but the total impact has, no doubt, been significant, resulting in substantial reductions in *Spartina* and fishery resource production.

This study was initiated as a demonstration project to illustrate the potential for rehabilitating a marsh system that had been degraded because of causeway construction. A successful project could demonstrate to coastal managers and the public at large that, to a degree, some of the consequences of coastal development can be successfully mitigated. A successful project could also give rise to a suite of mitigation options for coastal planners and permitting agencies for in-kind mitigation for projects that are known to negatively impact coastal marshes. It is conceivable that causeway mitigation banks could be developed.

This study was conducted at Edisto Beach which is a small oceanfront community about 33 miles southwest of the mouth of Charleston Harbor. The island is 3.5 miles long and 1.5 miles wide (at its widest). Edisto Beach is just seaward of Edisto Island and the two are joined by a narrow causeway topped by a two-lane highway. The causeway's construction apparently cut off natural tidal flow of Scott Creek which formerly allowed circumnavigation of Edisto Beach. Scott Creek was originally a single estuarine system that was flooded from two directions – through Jeremy Inlet to the east and through Big Bay creek to the west. Construction of the causeway cut off the creek, forming two isolated estuarine systems. Consequently, the marshes and tidal creeks near the causeway have filled in and lost much of their ecological function.

The primary goal of this study is to determine the feasibility of successfully restoring salt marshes and their ecological function through re-opening the Edisto Beach

causeway and allowing the tidal waters of Scott Creek to flow as they did prior to being blocked by causeway construction.

Primary objectives include determining:

- If breached, would water flow through the causeway and at what rate and volume
- Would a channel develop or would dredging be required
- Would species composition and distribution of flora change, and would that result in additional natural salt marsh habitat and enhanced productivity

Secondary objectives include determining:

- Relative productivity of the east and west marshes
- Relative abundance of dominant fauna
- If present elevations were the result of the immediate effects of causeway construction or long term sedimentation.
- If the creek would need to be deepened to sustain normal flow rates
- Where a causeway breach should be made
- How would the biotic composition change with a breach in the causeway

This study was accomplished through three primary areas of research including hydrological, biological, and geological studies.

Hydrological Research

Hydrological research included examination of historical maps and documents, topographic and bathymetric mapping of the east and west Scott Creeks, examination of tidal water heights over time at several monitoring stations, and determination of flow volumes and velocities through the use of Acoustic Doppler current profiling (ADCP) technology. Data collected in this study were used to develop a hydrodynamic model and particle tracking model for Scott Creek Estuary and its application for investigation of restoration and enhancement issues. Depth-integrated continuity and momentum shallow water equations were the basis of the hydrodynamic model that includes particle transport using a random-walk particle tracking method. The numerical solution of the flow model was obtained using a finite volume scheme. The model solves depth-averaged continuity and momentum equations using the finite volume method, and it accounts for flooding and draining of intermittently wetted areas such as mudflats, it has excellent conservation properties, and it is non-oscillatory – even at the wet/dry interface.

A depth-integrated two-dimensional hydrodynamic and particle transport model was developed for Scott Creek estuary. The model was calibrated and verified with measured water surface levels and currents. The verified model was then used to interpret: 1) the effects of the causeway on the environmental quality of Scott Creek and 2) the potential environmental benefits of modifying its design through breaching of the causeway. In the modeling exercise we investigated the effects of various causeway breach configurations on circulation and exchange within Scott Creek. Modeling results indicated:

1. The removal of the causeway will impact flushing rates of Scott Creek. Breaching of the causeway, combined with the natural tidal conditions (amplitude and phase difference between the eastern and western boundaries) increases the self-flushing capacity of the creek. This should improve water quality conditions.

2. The opening of the causeway along the layout indicated in Case 2 (which includes straightening of the creek) gives the best self-flushing capacity to the creek as a whole.
3. All tests indicated that the water from east Scott Creek would cross through the breach at the causeway earlier than that from the west, and the tidal node would occur at roughly a point 950 m west of the causeway. The late-arriving high tide from the west would push the node back to a point 450 m east of the causeway.
4. Comparisons of water surface levels show no noticeable water surface difference before and after the opening of the causeway. It is believed that breaching the causeway will enhance water movement past the highway, mitigating any hazard of flooding.
5. In opening the causeway, there is a slight increase (15-17 percent) in the amount of tidal prism (volume of water) leaving Jeremy Inlet as a small portion of the water from the west joins the water ebbing through Jeremy Inlet. The impact of this increase in discharge along with the change in gradient shows a small increase (1-3.5 percent) in the peak ebb tidal currents near Jeremy Inlet.
6. Computed residual currents indicate an ebb-dominated feature at Jeremy Inlet, where the net direction of the residual current is out of the system.
7. To maintain a zero gradient in net along-channel sediment transport and a stable causeway breach, it is recommended that the causeway breach should have a trapezoidal cross-section with a bottom width of 2.0 m (6.5ft) and a top width of 17 m (56 ft) with a side slope of 0.3.
8. In order to support navigation from Big Bay Creek through Scott Creek to the Atlantic Ocean at Jeremy Inlet, approximately 3.5 ft of sediment for a distance of 0.4 to 0.6 mi would have to be removed. Shorter routes that might mitigate biological impacts to low marsh should be investigated, but these would likely result in reduced flushing rate efficiencies.

Biological Research

Biological research was conducted in three phases: plant community mapping, animal community composition, and a nutrient addition study. The plant community mapping portion of this research was done to establish a baseline map in which to compare changes in salt marsh communities following the potential breach in the causeway. Spatially explicit plant and animal data collected prior to breaching is required to evaluate how the biotic communities might change.

Aerial photography, geo-referenced base maps, and a Trimble Pro XR backpack global positioning system were used to obtain latitude and longitude coordinates of plant community boundaries within the 8.0-hectare area of interest. Six plant communities (tall *Spartina alterniflora*, short *S. alterniflora*, *Salicornia virginica*, *Batis maritima*, *Juncus roemerianus*, and *Borrichia frutescens*) and three areas devoid of vegetation (open water pools, sand, and *Spartina* dieback area) were delineated. The distribution of the plants reflect spatial patterns driven by elevation and associated hydrological dynamics. How these communities will be affected by the reconnection of Scott Creek is unclear, however these baseline data are essential and will allow scientists to quantify any changes following bridge construction.

Distribution and relative abundance of dominant Scott Creek fauna were assessed by surveying fifteen 0.25-m^2 quadrats with *S. alterniflora* for marsh periwinkle abundance, and fishing standard blue crab and minnow traps. *Littoraria* were found in significantly higher densities and relative proportion of larger animals on the west side of the causeway. There appeared to be an inverse relationship between the *Littoraria* density and negative impacts of the plants. *Spartina* total leaf length was approximately three times higher and radula scaring was less than that found in the west marsh.

Crab trap catches were comprised largely of blue crab (*Callinectes sapidus*) along with one spider crab (*Libinia emarginata*), six mud crabs (*Panopeus herbstii*), and nine diamondback terrapin (*Malaclemys terrapin*). Minnow traps collected nine species: spot (*Micropogonias undulatus*), pinfish (*Lagodon rhomboides*), killifish (*Fundulus heteroclitus*), silver perch (*Bairdiella chrysoura*), black drum (*Pogonias cromis*), oyster toadfish (*Opsanus tau*), blue crab, mud crab, and square-backed crab (*Sesarma reticulatum*). Diamondback terrapins, male blue crabs, and immature blue crabs were more abundant in the east marsh than the west marsh.

The animal communities in the east and west sections of Scott Creek, bisected by the earthen Edisto Beach causeway, are different and these differences cross multiple trophic levels. Although data are not adequate to make definitive conclusions, it appears that the higher numbers of blue crab and terrapins on the east side could be related to the much lower or nonexistent recreational and commercial fishing activity in that area. Additionally, the higher periwinkle abundance on the west side could be related to the lower densities of predators (blue crab and diamondback terrapins), but more intensive study is required to substantiate this.

Building of a causeway bridge has the potential to restore Scott Creek's hydrology, thus restoring the connectivity of the currently distinct plant and animal communities associated with the east and west sections of Scott Creek. These data, in addition to the plant community work, can now be used as baseline information for documenting changes in ecosystem functions following breaching of the causeway. We predict that breaching of the causeway would result in a homogenizing of the animal communities.

Previous research has shown that salt marsh plant zonation is driven by stress associated with tidal/elevation interactions and competition. Plant species tend not to be able to move down the elevation gradient because they are unable to survive in these areas of increased water inundation and the associated biogeochemical processes. Furthermore, plant species are believed to be restricted in their movement to higher elevation areas because they are unable to compete with the resident species. Nutrient addition has been shown to alter plant competitive interactions, which effects salt marsh plant zonation. The addition of nutrients could simulate how the system may respond to an improvement in flow conditions resulting from a causeway breach. We conducted a two-season, nutrient-addition experiment in three plant transition zones (*Spartina/Juncus, Salicornia/Juncus,* and *Spartina/Salicornia*) testing the hypothesis that soil nutrient levels affect salt marsh plant zonation.

Nitrogen and phosphorus levels increased by greater than three times ambient nutrient levels, while potassium increase was approximately 1.4 times ambient. Nutrient addition did not appear to significantly affect *Salicornia* or *Juncus* cover, but *Spartina* responded positively with a significant increase in cover over the course of the study.

Juncus appeared to be unaffected by nutrient addition in the *Juncus/Salicornia* zone, but there was a slight increase in *Juncus* cover in the *Juncus/Spartina* zone. This increase in *Juncus* was statistically significant, however the biological significance is debatable given the difference in the number of plots (n=63) relative to the *Juncus/Salicornia* zone (n=31) and the small magnitude of the difference. *Salicornia* showed a significant increase in percentage cover in the *Juncus/Salicornia* zone, but no response in the *Spartina/Salicornia* zone. *Salicornia* increased in the *Juncus/Salicornia* nutrient addition plots and not in the *Spartina/Salicornia* plots because *Spartina* had such a strong positive response to nutrient addition while *Juncus* did not.

It appears that *Juncus* and *Salicornia* zones in the salt marsh are affected more by environmental stress associated with elevation and hydrological dynamics than by competition. This is an important finding because construction of a causeway bridge and any associated changes to the tidal hydrology will affect the spatial distribution of plant zones across the Scott Creek marsh. We predict that plant species distribution will be limited by environmental stresses in the lower elevations and competition in the upper elevation of the Scott Creek marsh.

Geological Research

Periodic ebb and flood tidal currents produce a bi-directional flow; therefore, transport energy from this flow changes daily as a sinusoidal function. In response, deposition of sediment is fractionated in both flood and ebb directions along the channels and into the salt marsh. Sediment sources include the erosion of banks and channels, and the entrainment of beach sediments. Sinuous channels, formed by this tidally induced flow, transport sediment down gradient for eventual deposition.

Forty-five sediment cores were collected by boat along ten (total) transects (five from the western side and five from the eastern side of the causeway). Core length varied from 155cm to approximately 50cm, with most cores averaging within 80 to 100cm. Stratigraphic changes in each archived core were recorded in terms of general grain composition, grain size, and lithologic change.

Mean grain size became larger, on average, with increasing distance from the causeway in most samples from the west and in samples from the bottoms of cores from the east. These results are expected, as flow velocities should decrease toward the distal ends of eastern and western channels. Samples from the top-of-core on the eastern side showed no increase in grain size with distance from the causeway, indicating an induced reduced flow velocity along the length of the channel. Average coarse-to-fine ratios remained constant in all samples with the exception of top-of-core samples from the eastern side. Coarse-to-fine ratios, on average, in samples from the tops of cores on the eastern side became lower, indicating a relative increase in mud content with reduced distance to the causeway. This indicates that flow velocities decreased toward the causeway such that they transported a lower proportion of sandy sediments relative to silt and clay-sized sediments. Results of these data, both mean grain size and coarse-to-fine ratio, suggest a depositional response to reduced volumetric flow from the causeway's damming effect on eastern side channels.

Analysis of grain size data indicates a reduction in flow energy on the east side of the causeway, but shows no significant change on the west side. These data support a reduced tidal flow, indicating that East Scott Creek was impacted by causeway construction, while west Scott Creek was likely not significantly affected.

Based upon these findings, causeway removal would allow waters from the east to flood west past the site of the causeway. Presently occupied channels on the east side would likely increase in cross-sectional area to pre-causeway size. Jeremy Inlet would establish a larger equilibrium cross-sectional area to accommodate an increase in volumetric flow rate.

Summary

Analysis of historical maps clearly indicates that Scott Creek originally flowed freely from Jeremy Inlet to Big Bay Creek behind Edisto Beach. The truncation of the creek by causeway construction occurred ca. 1940, effectively dividing Scott Creek into two separate systems. The completion of the causeway significantly reduced tidal current flow rates and volumes, and consequently resulted in deposition of fine sediments and filling in of Scott Creek and associated secondary creeks and tidal marsh.

As the tidal creeks filled in, particularly those near the causeway, they began to lose biological function. Prior to the causeway's construction, salt marsh in the vicinity was likely comprised largely of healthy stands of smooth cordgrass. As the marsh filled and increased in elevation, there was likely a transition to less productive high-marsh plant communities and a total loss of marsh plants in some areas. This resulted in a net loss of primary productivity. Concurrent with this loss of marsh, shallow water tidal creeks were lost and along with them, optimal nursery habitat for fishes, crustaceans and piscivorous wading birds.

Geological cores taken from creek bottoms throughout the system indicate abrupt changes in grain size of sediments which appear to correlate with the closing of the causeway. Analysis of the cores suggests that post-causeway construction tidal flow velocities decreased as the waters approached the causeway, such that they transported a lower proportion of sandy sediments relative to silt and clay-sized sediments. Core samples from every sampling transect on the eastern side of the causeway showed distinct changes in sediment size, but this was less evident in transects from the western side. This indicates that eastern side flow was more severely reduced by causeway construction than was western side flow.

One concern about breaching the causeway was that the tidal node (where easterly and westerly flowing waters meet) would be near the causeway and therefore that location would become a depositional area for sediments. The hydrological study indicated that the initial tidal node during a tidal cycle would be about 950 m west of the causeway, and as the tide rises the node would gradually shift 1,400 m eastward to a point 450 m east of the causeway. This means that all portions of the creek will experience some tidal flow during every tidal cycle and no single point will be depositional throughout the cycle. This should help maintain creek depth if the causeway is breached.

The hydrodynamic model indicates that water volume exiting Jeremy Inlet on ebb tide after a breach in the causeway would increase 20,000 to 38,000 m^3 or about 9.0 to 17.3%. Ebb tidal flows on the western side would decrease by 21,000 to 62,000 m^3 or about -2.4 to -7.0%. These changes in tidal volumes should result in minor water velocity increases of only 1 to 3.5% at Jeremy Inlet. Consequentially, we do not

anticipate any significant modification of the inlet resulting from breaching of the causeway. Currently, there is a berm (sill) at Jeremy Inlet and this delays flood tide until the ocean tide exceeds the height of the berm. As the tidal level exceeds the berm, flood water velocity is relatively high, and this is thought to be contributory to bank erosion at the first turn of the creek. Breaching the causeway should not substantially change this erosion situation.

There was some concern among property owners on the eastern side of the causeway on Edisto Island that a breach in the Edisto Beach causeway would result in higher high tides that could threaten their low-lying properties. The hydrodynamic model indicates that maximum high tides on both sides of the causeway would be close to 4.4 ft. With a breach, the eastern side tide would not be expected to increase more than a tenth of an inch and should therefore be no threat to residences adjacent to the Scott Creek marsh.

Another concern expressed to DNR is the perception that water quality on the eastern side of the causeway would decline if the causeway is opened because waters from the western side, where there is greater development and urban runoff, would flow eastward. Because the tidal node during flood tide is 950 m west of the causeway, water will be moving largely east-to-west on flood tide. This flow pattern will bring more oceanic water through Jeremy Inlet and the eastern side waters should become cleaner. Additionally, all three investigated causeway breach scenarios showed decreased flushing times which should also improve water overall quality.

Three scenarios for a breach were investigated. The "current meander" scenario required the shortest dredging, but would not substantially improve water flushing and creek depth would likely be inadequate for navigation. Cases 1 and 2 required 3.5 ft of sediment to be excavated for a distance of 0.4 to 0.6 mi, bypassing numerous creek meanders. These two cases provide much improved flushing times and should substantially improve water quality. However, Cases 1 and 2 would likely negatively impact some portions of existing low marsh areas and would probably result in compromising the ecological function of some dendritic creeks that would not be directly connected to the new channel. Investigations should be made into compromise locations for breaches that would not require as much dredging while maintaining a relatively deep channel and maintaining much of the ecological function of existing creeks and marshes.

Much of the plant community currently found near the causeway is comprised of short *Spartina* and high marsh *Salicornia* and *Borrichia* communities, along with two small areas of *Batis maritima*. There are also some areas near the causeway that are high ground (rarely flooded) or salt pannes. These high ground (terrestrial) and high marsh communities are relatively unproductive compared to low marsh areas with tall form *S. alterniflora*. With reconnection of east and west Scott Creek, plant communities will move up or down the elevation gradient relative to any changes in hydrology, while the autogenic successional process of salt marsh accretion will likely be driven by biogeochemical interactions between *S. alterniflora* and the restored hydrology. Better circulation and growth of *S. alterniflora* marsh should provide more "edge effect" for juvenile finfish and crustaceans. The increased area of shallow-water nursery habitat should result in higher densities of marine fauna (secondary productivity) and probably higher species diversity. We believe that opening the causeway should have positive overall effects on associated plant and animal communities.

This report uses the best science available to us to predict what would happen should the Edisto Beach causeway be breached. We have found no serious negative physical impacts and it appears that breaching the causeway would result in positive biological impacts. Reconnecting Scott Creek would reproduce a natural situation that existing before development came to coastal South Carolina. However, the decision to breach the causeway must be considered holistically by the local community (including the town of Edisto Beach), the Edisto Beach State Park, and the Department of Transportation. Factors to be considered include construction and maintenance costs, effects on the viewscape, effects on hurricane evacuation, future highway transportation requirements and public safety, navigation issues, and the hydrological/biological information provided in this report.

This study has found that causeway modification has high potential for wetland rehabilitation, even in an atypically complex system such as Scott Creek. There is currently no estimate of the total number of water flow restriction structures in South Carolina or the acreage of wetlands that could benefit from the removal or manipulation of such structures. A logical first step in addressing statewide potential for wetland rehabilitation would be an assessment using historical maps, remote sensing, interviews with local biologists, and field visits. This would be followed by site-by-site analysis of cost effective alternatives for modifications, and finally by follow-up monitoring of the effects of modifications. To be cost effective for the state, as a whole, sites worthy of modification should be ranked in terms of acreage affected per unit cost to modify them.

Table of Contents

Acknowledgements

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List of Figures

Figure Number **Page**

Tables

Introduction

The importance of salt marshes with regard to providing primary and secondary productivity for marine systems has been well documented. Minello, et al., (1994) examined the relationships between tidal creeks and marsh utilization by macrofauna. Turner (1977) described a positive relationship between commercial yields of penaeid shrimp and acreage of intertidal salt marsh vegetation in the southeastern United States. de la Cruz (1973) related secondary production and the production of fisheries to tidal marshes. Cain and Dean (1976) reported 51 fish species in a South Carolina tidal creek. Weinstein (1979) reported between 39 and 58 species in North Carolina tidal creeks. Annual average size of harvested white shrimp in South Carolina, as reflected in commercial landings, is inversely related to shrimp abundance (Whitaker, et. al., 1989), suggesting that available marsh nursery habitat is a limiting factor resulting in density-dependent growth rates.

European settlers in North America made many alterations to the coastal wetlands, including filling wetlands for home sites and ports, impounding water for rice culture, and building earthen causeways for access to barrier and sea islands. By 1718, rice cultivation was extensive from the Santee River to the Combahee in South Carolina (McKenzie, et al., 1980). In the twentieth century, roads were built to the oceanside islands and other barrier islands bordered by salt marshes. The initial construction method was to simply bring in materials and fill the existing marshes. Because of variable subsidence, this often resulted in undulating roadbeds (Gosselink, et. al., 1972). Towards the middle of the century, the established method for causeway construction was to dredge the salt marsh sediments and typically side-cast those onto adjoining marsh. Sand was then brought in to fill the roadbed (Figs. 1 and 2). The increase in elevation of the marsh from the side-cast dredge disposal resulted in loss of natural salt marsh vegetation with eventual colonization by “high marsh” grasses and shrubs.

In the process of dredging and filling roadbeds through marshes, existing tidal creeks were routinely filled and cut off from oceanic tidal flow. In some cases, upland runoff landward of the causeway resulted in the marsh becoming fresh and colonized by freshwater vascular plants. While these areas may be temporarily beneficial to birds, they would often fill in over time, transforming into high ground. On the seaward side of these causeways, creek flow rates would decrease and, over time, sediments would be deposited, slowly reducing the depth of the channel. Gosselink, et al., (1972) said that marshes act as the “granary” of the system supplying organic foods to the estuarine “food lots” where most commercial fish and shellfish spend at least part of their life cycles. Because the tides transport foods and nutrients into the marsh, free flowing tidal creeks are essential for a healthy system.

Fig. 1. Areal photograph near Harbor River prior to causeway construction.

Fig. 2. Post causeway view of Harbor River Causeway. Note dredge spoil in the marsh and the cut off creeks.

The overall net impact of causeway construction in the salt marshes was a loss of primary and secondary productivity of the marsh ecosystem. The cumulative effect of these marsh alterations has never been computed, but the total has, no doubt, been significant -- resulting in reductions in *Spartina* and fishery resource production.

The present study was initiated as a demonstration project that could illustrate the potential for rehabilitating a marsh system that had been degraded because of causeway construction. A successful project could demonstrate to coastal managers and the public that, to a degree, some of the consequences of coastal development could be successfully mitigated. A successful project could also give rise to a suite of mitigation options for coastal planners and permitting agencies for in-kind mitigation for projects that are known to negatively impact coastal marshes. It is additionally conceivable that causeway mitigation banks could be developed to create programs for rehabilitating marshes that have been impacted by causeways and other water control structures. Researchers in New South Wales, Australia initiated an inventory of all structures restricting tidal flows as a first step in a long-range program of wetland rehabilitation (Williams and Watford, 1997). Among the 1,388 locations that were identified as having potential for wetland rehabilitation, 46 were causeways. A project at Edisto Beach that is successful in demonstrating rehabilitation potential could lead to a statewide inventory of water restriction structures and sites for wetland rehabilitation.

Edisto Beach Causeway and Scott Creek

Edisto Beach is a small oceanfront community about 33 miles southwest of the mouth of Charleston Harbor. Although it has a few hundred year-round residents, most homes are rental units for thousands of summer vacationers who come from a number of southeastern states. The island is 3.5 miles long and 1.5 miles wide (at its widest) and is located on the northern side of the mouth of the South Edisto River (Fig. 3). The island is just seaward of Edisto Island, a relatively large sea island that is still used largely for agriculture, although housing developments are steadily increasing. A narrow causeway topped by a two-lane highway connects Edisto Beach to Edisto Island. The causeway apparently cut off natural tidal flow of Scott Creek which formerly allowed circumnavigation of Edisto Beach.

Edisto Beach is completely surrounded by water (other than the causeway). The southeast-facing side fronts on the ocean (Fig. 3). The southern end of the island is bordered the South Edisto River and Big Bay Creek which connects with a tributary, Scott Creek West, which flows northeasterly approaching the causeway. Scott Creek East flows from Jeremy Inlet to the causeway.

Scott Creek is a tidally flooded, meandering, estuarine creek system (Fig. 3). It is flanked by salt marsh tidal floodplains dominated by *Spartina* vegetation, and drains runoff from the Edisto Beach barrier island and a portion of Edisto Island. This estuary is part of the Edisto River Basin, situated near the mouth of the South Edisto River, in the coastal zone. Scott Creek is located partially within the Ashepoo, Combahee, and Edisto (ACE) Basin National Estuarine Research Reserve (NERR). The creek forms a present-day border between Charleston (to the north) and Colleton (to the south) Counties. Maximum ground surface elevation in the Scott Creek watershed reaches 20 feet above sea level, as estimated from the 1972 topographic maps of the United States Geological Survey (USGS). "Annual rainfall is normally about 49.31 [inches], with August (7.46

[inches]) being the wettest month" and "approximately 40% of the annual rainfall falls in the three-month period from June to August" (SCDHEC, 2006). Sandy soils and lack of topographic relief limit the potential for upland drainage to affect flow and salinity in the waters of Scott Creek, under average rainfall conditions. The mean tidal range of 6 feet regulates exchange between the estuary and the coastal ocean, dominating Scott Creek hydrology.

Mr. David Lybrand, an Edisto Beach resident since 1947, provided some history and maps of the island (provided via B. Hockensmith, 22 Feb 2007). Edisto Beach was owned by the Eddings family until shortly after the Civil War when it was known as Locksley Hall. The island was sold at the Charleston County Courthouse to a McConkey, presumably at auction. The island was then known as the "Big Island" and the beach as "McConkey's Beach." In 1924, the McConkeys sold their land to G.W. and Mitchell Seabrook of Sumter, SC, and between 1926 and 1933 the Seabrooks negotiated with the State of South Carolina to establish a State Park on the beach and nearby on Edisto Island.

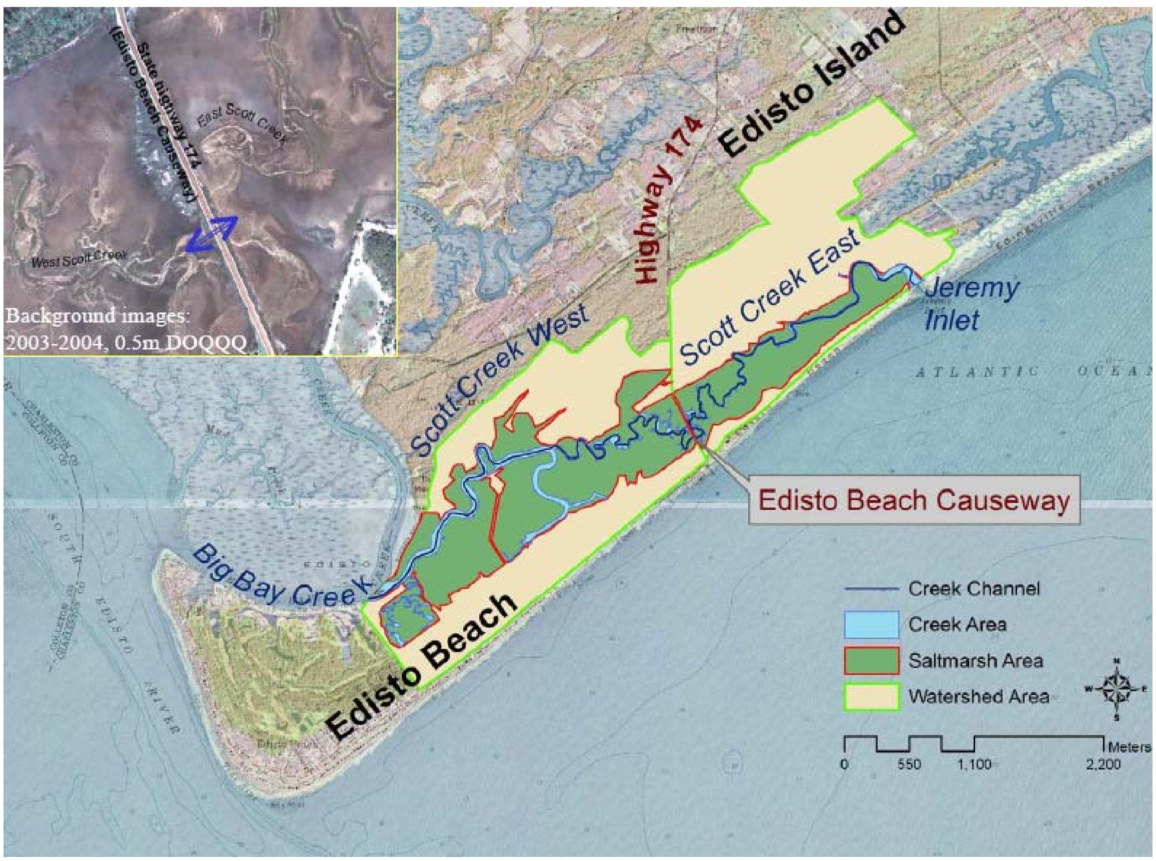

Fig. 3. Map of Edisto Beach showing Scott Creek (east and west) and the Highway 174 causeway that connects Edisto Island to Edisto Beach.

It is presumed that no causeway or bridge existed at Edisto Beach until about 1776 (the approximate start of the Plantation Era). In plantation days, there was a trail to the "Big Island" sufficient for horse-drawn carriage and carts. Reportedly, a causeway of sorts with a timber bridge was in place from the late 1700's until the late 1920's.

However, there is no bridge symbolized on the 1919 USGS topographic map (perhaps because of scale). The belief is that the causeway was probably covered by spring tides and storm events since travel by cart would not have been greatly impeded so long as the causeway base was firm. A raised, paved causeway bridge and a 45-ft timber bridge was in place between 1933 and 1938 according to SC Dept. of Transportation plans, thus allowing flow of Scott Creek and stopping overflow of the highway during spring tides or storm surges. However, the timber bridge was damaged by Hurricane Gracie in 1940 and soon thereafter the causeway was made complete, thus cutting off flow of Scott Creek. The road construction in the late 1930's was believed to have been a stipulation of the property transfer and establishment of Edisto Beach State Park. No residents of Edisto Beach recall a bridge or culverts for Scott Creek since Hurricane Gracie. The current Highway 174 earthen causeway is roughly 40 feet wide and 5 feet tall.

Project Goal and Objectives

The primary goal of this study is to determine the feasibility of successfully restoring salt marshes and their ecological function through re-opening the Edisto Beach causeway and allowing the tidal waters of Scott Creek to flow as they did prior to being blocked by causeway construction.

Primary objectives include determining:

- If water would flow through the causeway and at what rate and volume
- Would a channel develop or would dredging be required
- Would floral species composition change and would that result in more natural salt marsh habitat and enhanced productivity

Secondary objectives include determining:

- Relative productivity of the marshes on eastern and western sides of the causeway
- What faunal species occupy the habitat now
- If present elevations are the result of the immediate effects of causeway construction or sedimentation over time.
- If the creek should be deepened to sustain normal flow rates
- Where a causeway breach should be made

Marine biologists maintain that fishery productivity and ecological function can be significantly enhanced by restoring systems such as Scott Creek. This study is to design to scientifically examine the feasibility of restoring ecological function at Scott Creek through breaching the causeway and restoring the system to its more natural, original state.

Hydrological Studies

Breaching the Edisto Beach Causeway and Evaluating the Effects on Tidal Hydrology of Scott Creek

by

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This feasibility study is the first of its kind for South Carolina and coincides with a developing national trend to expand estuarine and wetland mitigation programs. The study aims “to determine if construction of a bridge, spanning a former creek, which was cut off by construction of the Edisto Beach causeway, would result in a restoration of adequate flow in tidal creeks and adjacent salt marsh areas, ultimately, restoring ecosystem vitality and water quality.” As a contribution to the overall feasibility study, the hydrological study examines the potential to establish and sustain flow by uniting eastern and western portions of Scott Creek and their associated marsh habitats by installation of a new bridge through use of a numerical hydrodynamic model simulation.

SCOPE AND OBJECTIVES

This project was designed to explain what impacts the breaching of the Edisto Beach causeway would have on the hydrology of Scott Creek. A second objective was to recommend scale and dimensions for the breach to enhance water exchange between the East and West Scott Creek estuaries and minimize the residence time of tidal water (i.e., improving water quality). In doing so, answers are provided for a series of questions: 1) if the causeway is breached, would water flow through the breach, assuming the channel is dredged? 2) What would be the volumes and velocities of exchange? 3) Where would the tidal nodes occur and how would water quality be affected? 4) Optimally, where should the bridge be located? 5) To what depth and width should the channel in the vicinity of the bridge be excavated? 6) What quantity of material would need to be removed to enhance flow through the causeway?

A set of secondary questions are also addressed in this study: 1) what will the velocity and volume of water through Jeremy Inlet be before and after a bridge is built? 2) Would decreased velocity cause the inlet to become shallower, and is there potential it could close up altogether? 3) Will the smaller causeway adjacent to Jeremy Inlet be subject to more or less erosion? 4) If Jeremy Inlet gets plugged, what would the water velocity/volume through the breached Edisto Beach causeway be? 5) Would closure of the Inlet improve water quality, by way of allowing the entire area to drain, thus reducing residence time of tidal water?

This report develops a set of products to address the questions posed. They include: 1) A series of maps showing the current watersheds, salt marsh areas, and creeks, and comparisons to historical documents for regional changes in hydraulics, on an annual to decadal scale, 2) An examination of simultaneous water levels and velocities from data sampled throughout the system on both sides of the causeway, to help determine both tidal flow direction and the extent of tidal flood plain inundation, 3) A comprehensive baseline model of tidal hydraulics and its application as a predictive tool for evaluating dynamic effects of various causeway breach alternatives, and 4) A set of recommendations for enhancing exchange between East and West Scott Creeks through the Edisto Beach causeway.

Methodology

The geography of the Scott Creek study area was described with reference to recent maps and tidal data collected from the USGS, South Carolina Department of Natural Resources (SCDNR), and National Oceanic and Atmospheric Administration (NOAA). Maps of the area surrounding Scott Creek were available through a variety of sources including 1972 topographic quadrangles from USGS and aerial photographs from SCDNR (1999, 2003-04). These maps were used to identify and delineate features of Scott Creek including its thalweg (line joining the lowest points along the entire length of a streambed defining its deepest channel), areas of its watershed, floodplain, and creek. The separate East and West Scott Creek portions were identified and the lengths and areas of these features were calculated, in comparison with those of Scott Creek as a whole.

Verified tidal data were available only for Edisto Beach and Big Bay Creek, through NOAA for 1977-79 and 1976-77, respectively (NOAA, 2007a, 2007b). The

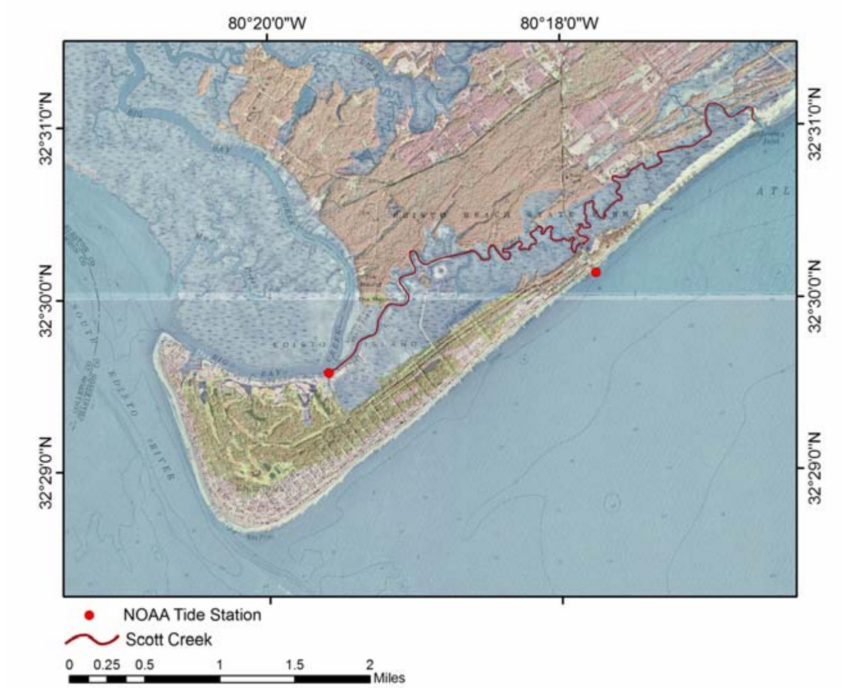

Figure 4. Edisto Beach with Scott Creek East and West historical channel. Red dots indicate Big Bay (inland) and Edisto Beach (Atlantic) NOAA tidal monitoring stations.

locations of these monitoring stations are indicated on the map (Fig. 4). Tidal predictions supporting this study, were provided through NOAA with reference to observations at Charleston Harbor, SC.

Creek Thalweg Delineation.–Creek channels were drawn to approximate the location of the thalweg along the length of the creeks (Fig. 5). Locations were estimated by visual appearance, according to the 2003-04 DOQQQ's and bathymetric data that were sampled. The creek lengths were calculated using ArcGIS 9.1 software.

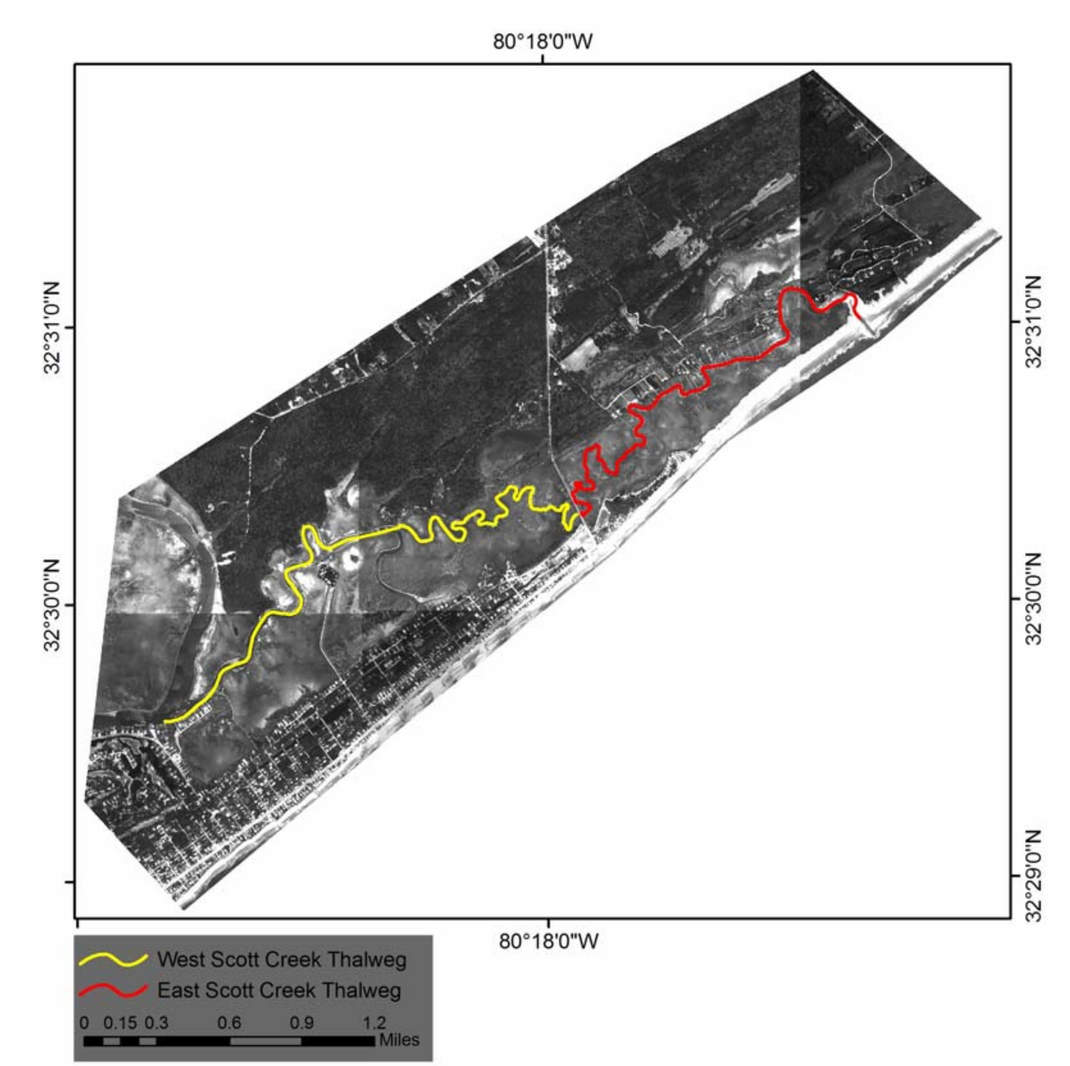

Figure 5. This map mosaic of DOQQQ's was reduced from true color to grayscale to focus more specifically on the area of interest providing the thalweg of East and West Scott Creeks.

Watershed Area Delineation.–Watershed areas draining to East and West Scott Creeks were individually delineated from the 1972 USGS topographic quadrangle and Digital Orthophoto Quarter Quarter Quadrangles (DOQQQ's) for 2003 and 2004 (Fig. 3). Topographic ridges, roadways and midway points between adjacent catchments (streams, floodplains, etc…) were identified as watershed boundaries and digitized to create polygon shape files in ArcGIS 9.1. The areas of these watersheds were calculated using ArcGIS 9.1 software.

Salt marsh Area Delineation.–The area of each estuary's salt marsh floodplain (Fig. 3) was estimated according to the same method used for the watershed area, except how the boundaries were identified. The points where the salt marsh vegetation transitions to upland forests or developed areas, in the DOQQQ's, were visually identified as floodplain boundaries. In some cases Geographic Positioning System (GPS) ground-truthing data were available to help validate using the boundaries identified in the photographs.

Creek Area Delineation.–The creek areas were estimated according to the same methods used for the watershed and floodplain areas except for the interpretation of boundaries. The creek areas were intended to represent those areas below mean sea level. The boundaries were digitized in ArcGIS 9.1, according to visually identifiable marks at the creek banks, according to the 2003-04 DOQQQ's, either by change in vegetation or exposed bed surface slope.

Table 1 provides a list for comparing the calculated lengths and areas of the attributes listed above, for the eastern and western portions as well as the combined Scott Creek Estuary. Table 2 provides ratios comparing each creek to the whole Scott Creek.

Table 1. Comparison of geographic variables for East, West, and combined Scott Creek.

	West Scott Creek	East Scott Creek	Combined
Creek Length (mi)	3.40	2.74	6.14
Linear Distance (mi)	1.91	1.40	3.30
Watershed Area (acres)	1087.67	843.97	1931.64
Salt marsh Area (acres)	527.77	200.90	728.64
Creek Area (acres)	96.30	24.59	120.89
Sinuosity (Length/Distance)	4.78	1.96	1.86
Catchment Ratio (shed/creek area)	11.29	34.32	15.98
Salt marsh/Creek Area	5.48	8.17	6.03

Table 2. Comparison of ratios for geographic variables for East and West Scott Creek.

	Ratio (Creek Portion/Total)	
	West Creek	**East Creek**
Linear Distance	0.58	0.42
Watershed Area	0.56	0.44
Salt marsh Area	0.72	0.28
Creek Area	0.80	0.20

Tidal data (NOAA, 2007a) were collected from "The Pavilion" at Edisto Beach from 1977-79 (Fig. 4). As shown in Table 3, the mean tidal range in these data was 5.96 ft. The highest level recorded during the sampling period for this study was 4.87 feet NAVD88 and the lowest was –6.65 ft NAVD88. The mean tide level at this station was –0.39 feet NAVD88, while mean sea level was –0.32 ft NAVD88. Tidal waters at Edisto and Eddingsville Beaches flow a distance of 2.74 mi. through East Scott Creek, from Jeremy Inlet to the Edisto Beach Causeway. The linear distance however is 1.40 miles. Therefore meanders result in a 96% greater flow distance for East Scott Creek. The watershed area of entire Scott Creek is 782 ha with the portion draining into East Scott Creek accounts for 342 ha (44% of total). Total Scott Creek floodplain area is 295 ha. The portion flooded by East Scott Creek is 81 ha (28% of total).

Table 3. Comparison of NOAA tidal data for Edisto Beach and Big Bay former gauging stations, for the region of Scott Creek and Edisto Beach, SC.

Location	Period of Record	Mean Tidal Range (ft)	Highest Level (ft, NAVD88)	Lowest Level (ft, NAVD88)	Mean Tidal Level (ft, NAVD88)	Mean Sea Level (ft, NAVD88)
Edisto Beach, Pavilion	1977-79	5.96	4.87	-6.65	-0.39	-0.32
Big Bay Cr, Carter's Dock	1976-77	5.97	4.45	-7.15	-0.46	-0.27

GEOGRAPHY OF EAST SCOTT CREEK

To the northeast of the Edisto Beach causeway is the East Scott Creek Estuary, a tidal lagoon. It drains runoff directly to the Atlantic Ocean, through Jeremy Inlet. The shoals at this inlet consist of sands and shell hash and are the shallowest areas of the lower East Scott Creek. Water depths in the inlet are less than one foot deep during mean low tide, inhibiting potential exchange with the Atlantic Ocean. Tidal flow through Jeremy Inlet is asymmetric (the duration of ebb is greater than that of flood) for a given semidiurnal period. The peak current speeds reached during flood were greater than those during ebb. As the tide falls, ebb flow is restricted first by a series of prominent meander bends and second by an internal flood delta comprised of sand and shell hash. The duration of ebb is prolonged by an externally fanning delta or alongshore bar, also comprised of sand and shell hash.

GEOGRAPHY OF WEST SCOTT CREEK

West Scott Creek is the southwest portion of Scott Creek (Fig. 3). This estuary is more like a terminal headwater, drowned river valley type system. It is shallowest and most sinuous near its head at the causeway. The creek bed decreases in elevation and sinuosity towards its mouth, with an abrupt change to substantially lower bed elevations and sinuosity near the confluence with a channel to the “Boat Channel,” as labeled in the 1972 USGS topographic map. The West Scott Creek channel continues to the southwest, from the Boat Channel area, bypassing a prominent meander bend, through a canal that was dredged by the early 1970’s, and opens to Big Bay Creek.

Tidally induced flow transports water and material from the Atlantic Ocean at St. Helena Sound, diverging into South Edisto River and continuing up Big Bay Creek, diverging just above the Edisto Beach marina to enter West Scott Creek. Therefore, water quality of the West Scott Creek is subject to influence of the Atlantic Ocean at St. Helena Sound as well as the discharge from South Edisto River and a portion of Big Bay Creek and watershed drainage associated with this region. One of the concerns prompting this study was related to the potential for enriched waters received by West Scott Creek to flow through and degrade waters of East Scott Creek. Recent reports from the South Carolina Department of Health and Environmental Control indicate all reaches of East and West Scott Creek are closed to shellfish harvesting due to water quality impairment. The water quality problems are discussed in greater detail in a later section of this report.

The southeastern shore of West Scott Creek is along Edisto Beach Island and is dominated by relatively high-density housing. Residential densities in this area are the greatest of the entire Scott Creek watershed. At its head, near the causeway, West Scott Creek’s salt marsh abuts commercial developments – an asphalt parking lot that extends underneath one building which is partially on a pier. Otherwise, it is buffered from several other commercial buildings and parking lots by the two-lane, asphalt paved, Jungle Road. For the next 1,500 ft, a 100-ft thick-forested park area buffers the marsh. The remainder of the southeastern shore is residential property, spanning approximately 1.5 linear miles. Prominent anthropogenic modifications can be identified in this region including 2 peninsulas and a meander bypass canal, which were all created between the mid 1960’s and early 1970’s. One of the peninsulas was created when an earthen causeway was constructed to connect an island in the salt marsh with Edisto Beach. Similar to the Edisto Beach Causeway, this causeway has no provisions for water to flow through it. Plans are currently being considered by the town council to place culverts in this causeway, but maintenance costs and the lack of any studies that directly support a breach are postponing further discussion. Another area labeled “Boat Channel” in the 1972 USGS topographic map and “Yacht Basin” by NOAA’s Coastal Services Center (CSC, 2007) was created in 1954 through dredging of approximately 850,000 cubic yards of sediment for renourishment of the eroding Edisto Beach. Currently, a network of stormwater retention ponds drains through a large PVC pipe into the northeastern end of the Boat Channel.

Tidal data from NOAA (NOAA, 2007b) were collected from “Carter’s Dock” in Big Bay Creek in 1976-77. As shown in Table 3, the mean tidal range in these data was 5.97 ft. The highest level recorded during the sampling period was 4.45 feet NAVD88 and the lowest was –7.15 ft NAVD88. The mean tide level at this station was –0.46 ft NAVD88, while mean sea level was –0.27 ft NAVD88. As shown in Table 1, these tidal waters of Big Bay Creek flow 3.40 mi. through West Scott Creek to reach the Edisto Beach Causeway. The linear distance from the mouth of West Scott Creek to the causeway however is 1.91 mi. Therefore meanders result in a 78% greater flow distance for West Scott Creek. The watershed area of entire Scott Creek is 782 ha. – the portion drained by West Scott Creek accounts for 440 hectares (56% of total). The total Scott Creek floodplain area is 295 ha. The portion of this area flooded by tides of West Scott Creek is 214 ha (72% of total).

WATER QUALITY

Water quality of Scott Creek is impaired with elevated levels of fecal coliform bacteria restricting harvest of shellfish (SCDHEC, 2006). Fecal coliform bacteria were linked to animal sources and a fraction of those collected from East Scott Creek, near the causeway, were of human origin. Stormwater runoff and failing septic systems were suspected as the source for human bacteria. Reducing the residence time of water in Scott Creek is one way to mitigate the impacts of contaminated stormwater received by this estuary. With this understanding, the current study examines how modifications to the causeway could reduce residence time of tidal waters, enhance flushing and dilution, and promote better water quality in Scott Creek. It is, however, recognized that in order to fix the water quality problems in Scott Creek and sustain the increasing human population, changes must be made to improve the quality of stormwater runoff and land use practices in the watershed. The reduction of residence time and more efficient flushing of the system serve to dilute the bacteria concentrations, but may contribute to new problems elsewhere.

HISTORIC MORPHOLOGY OF SCOTT CREEK

Historic documents were collected from the U.S. Library of Congress, the Caroliniana Library of the University of South Carolina, the University of South Carolina Map Library, SCDNR GIS data clearinghouse, and from other various SCDNR studies (SCDNR-Marine Resources Research Institute, Charleston), to compare historic morphology to the present condition of Scott Creek. The earliest documents were a series of coarse resolution maps from the 18th and 19th centuries (Figs. 6-8). Two topographic maps were available for Scott Creek, from 1919 (US Army Corp of Engineers, 1919) and 1972 (SCDNR-GIS). A series of USDA black and white aerial photographs, beginning with 1949, captured 5 to 19-year intervals through 1973 (Fig. 9). Another set of aerial photographs using false-color (infrared) imaging was gathered in 1994 and 1999 (SCDNR-GIS, 2005). A third series of aerial photographs, contracted through the Marine Resources Research Institute of the SCDNR provides 0.5-m (1.64-ft) resolution true-color images. Together in a mosaic, the 2003-2004 Digital Orthophoto Quarter Quarter Quadrangles (DOQQQ’s) cover the study area. The greatest gaps in temporal coverage were from 1973-1994 followed by 1963-1973. By comparing these historic maps and photographs as a series, patterns in the recent evolution of Scott Creek's morphology were exposed. These patterns enabled identification of specific trends in the estuary's current state of development.

Figure 6. Map of Edisto Island region from approximately 1711, copied from holdings of the U.S. Library of Congress, 2007.

Fig. 7. Map of Edisto Island region from approximately 1775, copied from holdings of the U.S. Library of Congress, 2007.

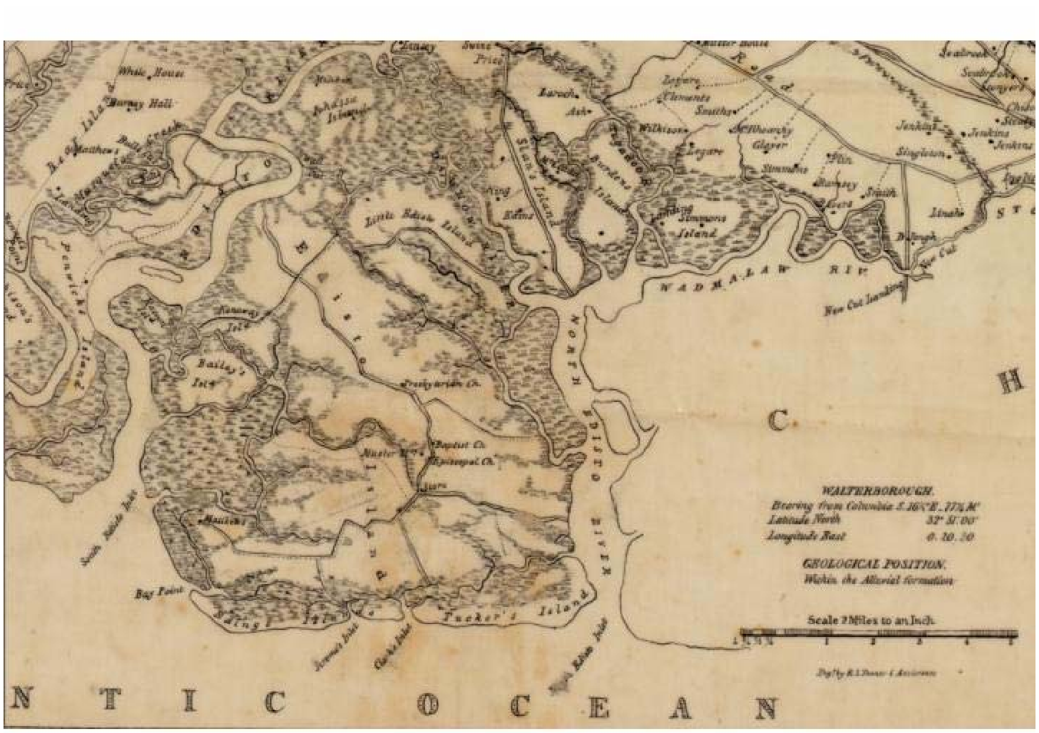

Fig. 8. Map of Edisto Island region produced in 1820, improved for Robert Mill's Atlas of 1825, copied from holdings of the U.S. Library of Congress, 2007.

Fig. 9. The March 11, 1949 aerial photograph shows the new asphalt causeway, after being hit by an unnamed hurricane 9 years prior. Also shows how the system appeared with East and West Scott Creeks united, copied from the University of South Carolina's Map Library, 2006.

Locations in the images were first compared to landmarks in the 1972 topographic map and then to the locations in the 2003-2004 true-color 0.5-m (approximately 0.82-ft) DOQQQ's. The maps from the 18th and 19th centuries were rectified with a targeted accuracy less than 1 mi. The accuracy was anticipated to be poor because of the coarse resolution and lack of identifiable landmarks in these historic maps. The 1919 topographic map was accurately geo-rectified, using the ArcGIS software, to around 20 m. Each aerial photograph dating from 1949 through 2004 was rectified to an accuracy of around 5 m.

The earliest map, from around 1711, was geo-rectified using 6 points corresponding to creek inlets proximal to the study area, accurate to approximately 0.37 mi. The map from 1775 was rectified using similar points, with an accuracy of around 0.5 mi. The map from 1820, shown in Fig. 8, was rectified with an accuracy of around 0.12 mi. The map from 1862 was of higher quality and more accurately rectified with an accuracy of around 20 m (66 ft). The 1919 topographic map was rectified using 15 points of reference, including creek inlets and roadways, with an accuracy of around 20 m (approximately 66 ft). The USDA images were much easier to rectify because they were photographs, rather than human interpretation. Only 4 to 6 points of reference were used for rectifying these images. Accuracies were better than 5 m (approximately 16 ft) for all that were used. The digital images downloaded from the SCDNR GIS data clearinghouse website were already rectified.

Once the images were rectified to the NAD88 UTM geographic coordinate grid system, multiple connected line segments (polylines) were drawn in the same manner as the creek thalweg delineation. In these cases, bathymetric data were not available, so lines were drawn along the middle of the area that appeared as wetted creek, regardless of creek water level, in the 1919 topographic map and in each given photograph. The line for each year sequence was colored sequentially through the color spectrum, with red being earliest and blue corresponding to the most recent creek path. Whenever a full color spectrum from red through the intermediates to purple appeared, a pattern of continued change was revealed.

Comparing historical stream channels with the current system, it appears that the present causeway has had reduced flow through each eastern and western system (Figs. 10 and 11). Channel meander bends in each side of Scott Creek increased in sinuosity, as shown in Table 4, while width of the main channel appeared to decrease. These changes were consistent throughout the series from 1949 through 2004.

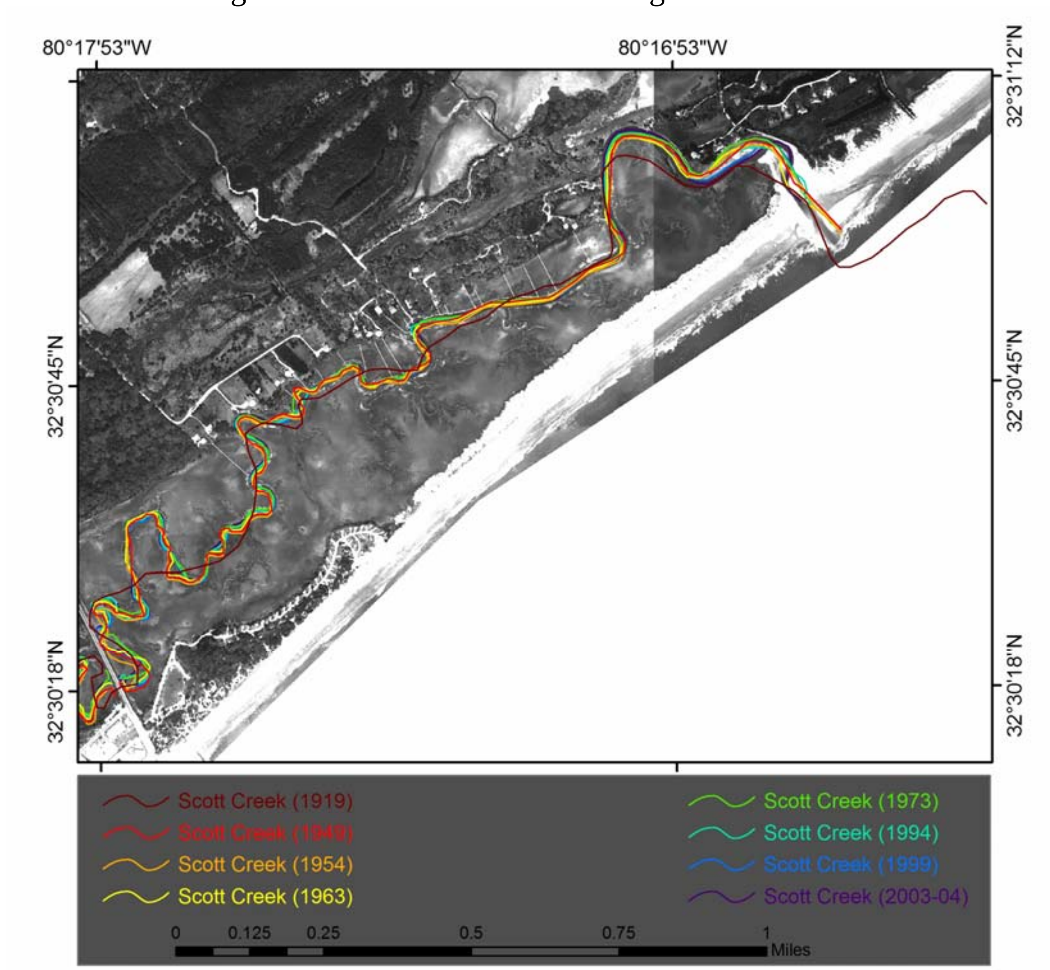

Fig. 10. Map of region surrounding East Scott Creek, S.C. with 1919, 1949, 1954, 1963, 1973, 1994, 1999, and 2003-04 thalweg locations for Scott Creek highlighted (Map from SCDNR-Mar. Resour. Res. Inst).

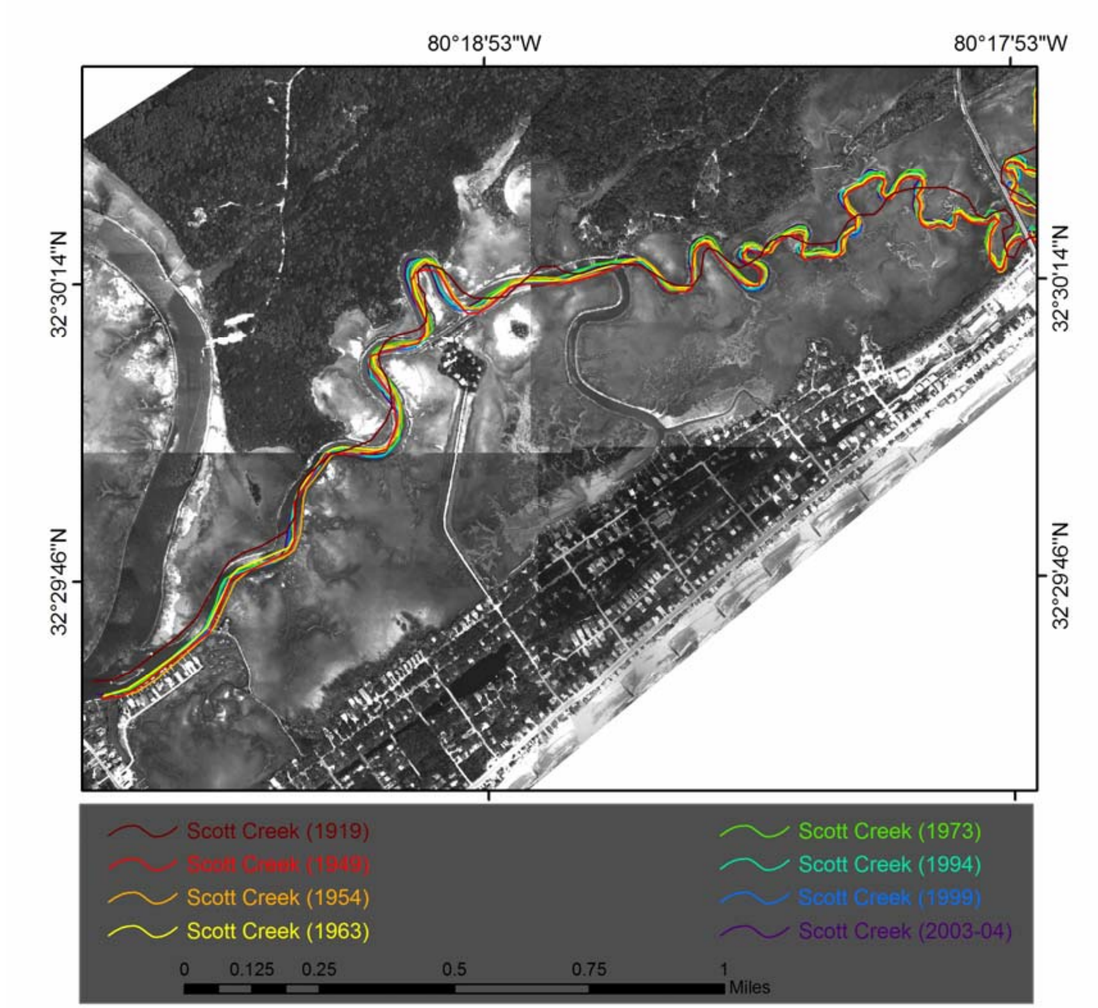

Fig. 11. Map of region surrounding West Scott Creek, S.C. with 1919, 1949, 1954, 1963, 1973, 1994, 1999, and 2003-04 thalweg locations for Scott Creek highlighted (Map from SCDNR-Marine Resources Research Institute).

Table 4. Comparison of Scott Creek Sinuosity values for East, West and combined. The values were calculated in ArcGIS 9.1 from thalweg data. All distances and lengths are in miles.

Year	East Scott Creek			West Scott Creek			Combined East and West Scott Creek		
	Distance	Length	Sinuosity	Distance	Length	Sinuosity	Distance	Length	Sinuosity
1919	1.68	2.40	1.43	1.92	2.57	1.34	3.60	4.96	1.38
1949	1.44	3.15	2.19	1.93	2.75	1.43	3.37	5.90	1.75
1954	1.43	2.65	1.85	1.88	3.15	1.67	3.31	5.80	1.75
1963	1.43	2.69	1.88	1.91	3.19	1.67	3.34	5.88	1.76
1973	1.43	2.64	1.85	1.91	3.33	1.75	3.34	5.98	1.79
1994	1.41	2.69	1.91	1.90	3.31	1.75	3.31	9.00	1.81
1999	1.42	2.68	1.89	1.90	3.29	1.74	3.31	5.97	1.80
2003.5	1.40	2.69	1.92	1.92	3.38	1.76	3.32	6.07	1.83

Various changes have occurred in Scott Creek morphology over the years and changes in the meander characteristics were apparent. West Scott Creek has gone through various anthropogenic modifications of its creek channels, floodplain, and riparian management, which masks trends in historical morphology to such extent that clear patterns in channel migration were not discernable. Therefore, very few trends in the historical morphology of West Scott Creek were identified.

East Scott Creek featured three prominent meander bends – each of which were observed actively scouring upland residential properties and providing sources of fine-grained sediment to the transported-sediment load in the creek. It is likely these materials were deposited along the creek bank levees, floodplain and creek bed near the causeway. The channels and floodplain of East Scott Creek have undergone less modification than West Scott Creek; however, the riparian management appeared to have been related to poor sediment erosion control through the 1960's associated with farming practices adjacent to the creek. This appeared to have delivered more coarse-grained sediment with runoff, identifiable in the prominent mid-channel shoals in vicinity of farmlands. This stream channel behavior is typical in modern urban drainage channels with outdated stormwater management practices. Creeks of this type experience periods or episodes of high flow, high sediment burden, and rapid energy dissipation (highly diminishing velocity gradient, over a short distance). In the case of Scott Creek, this effect may have been related to the terminal condition, as a result of the causeway impediment, in combination with a historic lack of erosion control systems. Farmland was converted to residential estates beginning in the 1970's and has continued. Modern sediment erosion control measures have been mandated and appear to have resulted in less sediment delivered to the creek in recent years.

Landward change in the location of Jeremy Inlet and the adjacent beaches appears to have been increasing through time with a general west-northwesterly migratory trend (Fig. 12). The migratory rate of 15 ft/year through the years 1919 to 2003 has a correlation coefficient (r^2) of 0.77. It appears that landward migration rates may have been increasing in recent years; however this was not assessed in this study. A separate study cited by NOAA's Coastal Services Center (CSC, 2007) reported a migration rate of 9 ft/year during the time period from 1854 to 1956. The causeway may also have been exacerbating this effect by reducing ebb flows through the inlet, especially during rainfall runoff events.

TIDAL PROPAGATION

The tides dominated water level and flow variations in the Scott Creek system. The nearest locations where traditional tidal data have been recorded and analyzed were in the ocean at Edisto Beach and Carter's Dock in Big Bay Creek (NOAA 2007a, 2007b). Information provided from these data indicates that the tide reached Carter's Dock, near West Scott Creek, approximately 25 minutes after reaching Edisto Beach. Prior to this study, no information was available with regard to tides and water levels in Scott Creek. In order to understand how water might flow through a breach in the causeway, it was necessary to gain new information about the tide in Scott Creek. An array of water level sensors was installed and time-varying changes in the water level were recorded at multiple locations (Fig. 13), as reported in Hockensmith (2006). These data were also used to verify the output from the hydrodynamic model that is described later in this report.

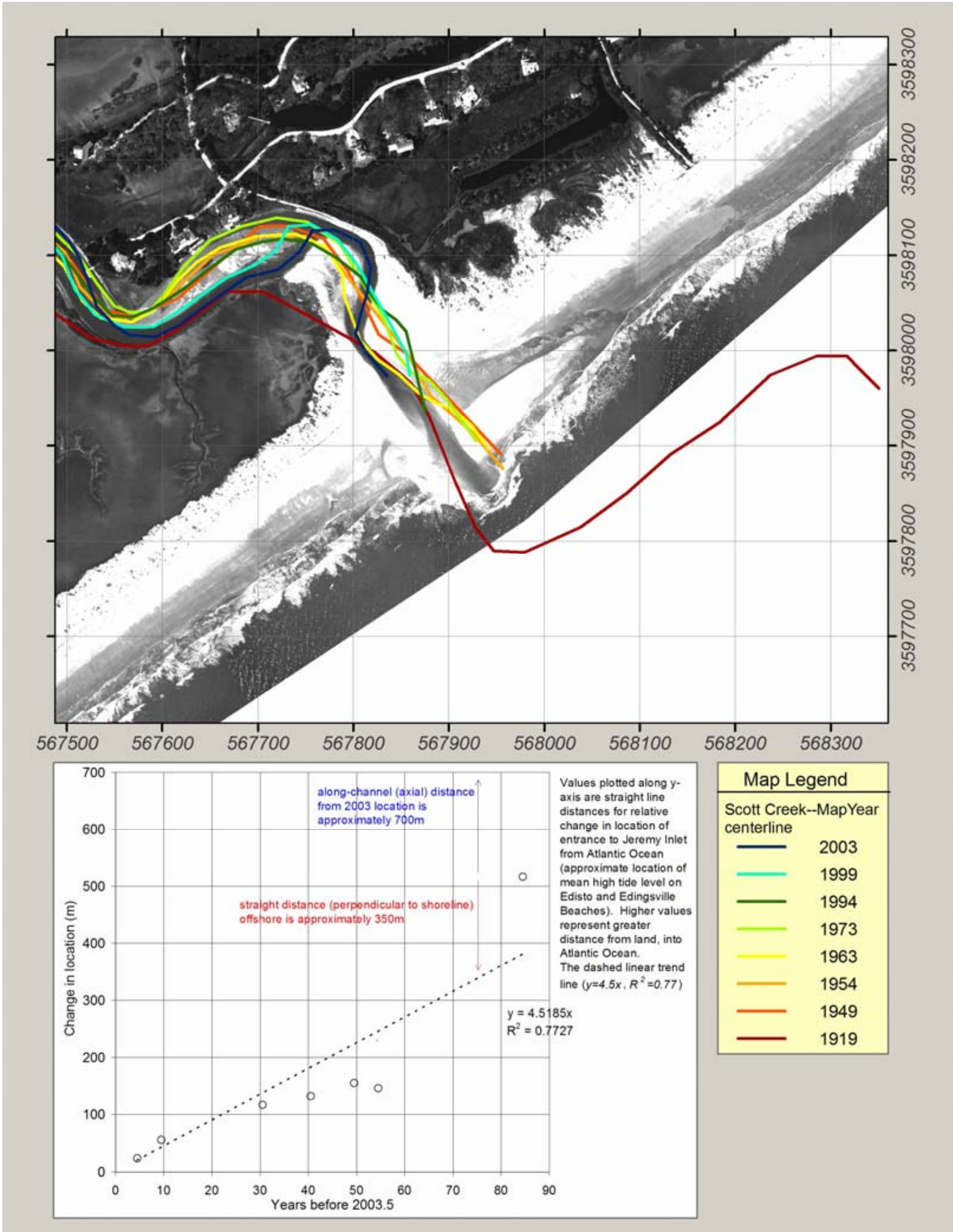

Fig. 12. Map of region surrounding Jeremy Inlet, East Scott Creek with 1919, 1949, 1954, 1963, 1973, 1994, 1999, and 2003-04 thalweg locations. The plot below the map describes change in position of the thalweg endpoint at Jeremy Inlet, plotting distance from the endpoint in 2003, against endpoints from prior years. The dashed line represents the linear rate of change in oceanward distance from the present location of the thalweg endpoint going back in time.

Stage data collected from each side of the causeway were analyzed to interpret the time-varying gradient across the causeway and interpret the potential for water to flow through a breach in the causeway. Results indicated that the tide propagated through East Scott Creek, from station E4 to E1, a creek distance of 1.94 miles, in roughly 40 minutes. For West Scott Creek the tide reaches W1 approximately 25 minutes after passing W4, traveling 2.11 miles along West Scott Creek. During the early part of the incoming tide,

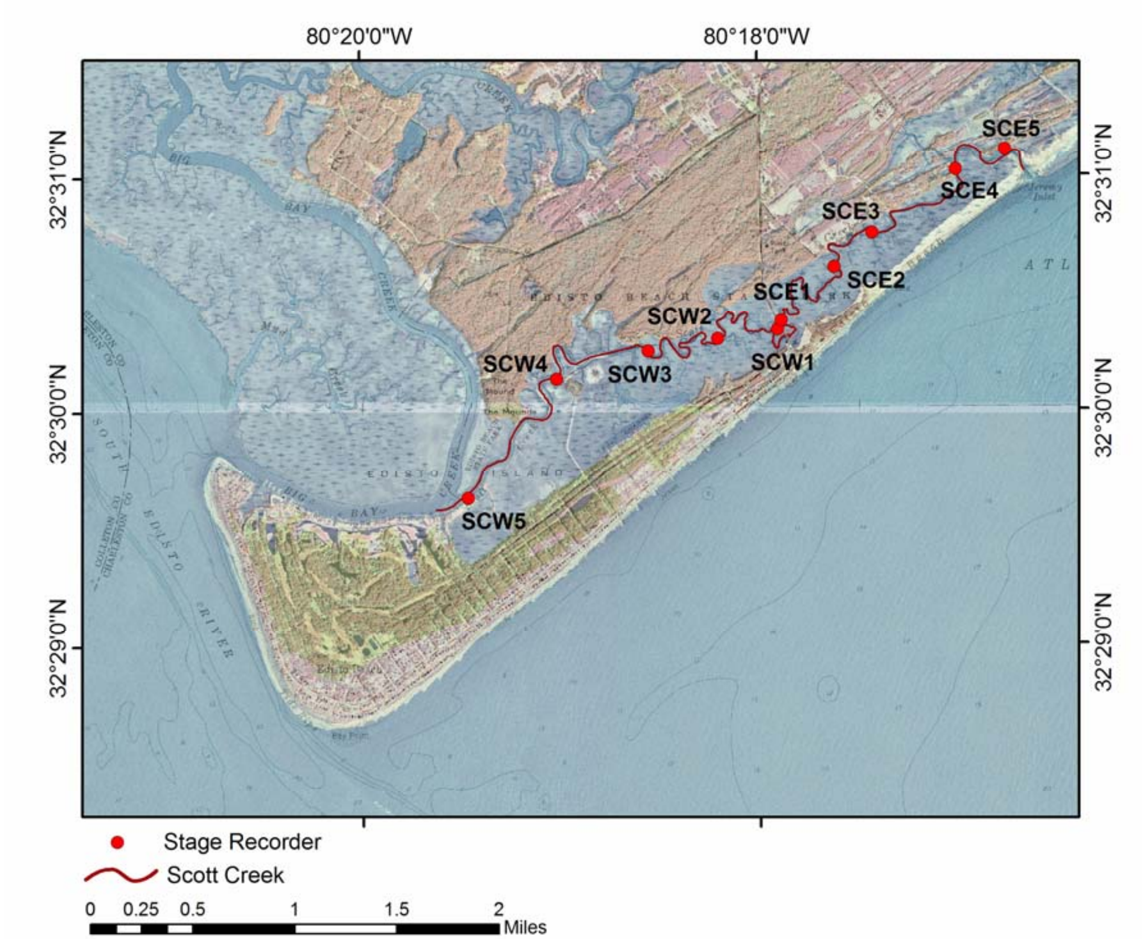

Fig. 13. Locations of DNR water level monitoring stations (stage recorders), labeled according to the identification scheme used in Hockensmith (2006).

the water level was higher east of the causeway than west of it; therefore, stream flow would have been from east to west if a connection existed between both creek reaches. The direction reverses, from west to east, for the outgoing tide at the causeway (Hockensmith, 2006). Further review of these data suggests that a breach in the causeway would result in net flow from West Scott Creek to East Scott Creek. It appears that during higher amplitude tides, especially during spring tidal conditions, the rising tide would reach the causeway from East Scott Creek first and would slowly flow into West Scott Creek (Fig. 14). As the tide neared its crest in East Scott Creek, however, the higher amplitude of West Scott Creek's tide would result in substantial flow towards East Scott Creek. Water would again reverse with gentle flow towards West Scott Creek just before the tide falls below the streambed near the causeway. For a period of 2-4 hours, during low tides, the breachway would be relatively dry. During smaller amplitude tidal

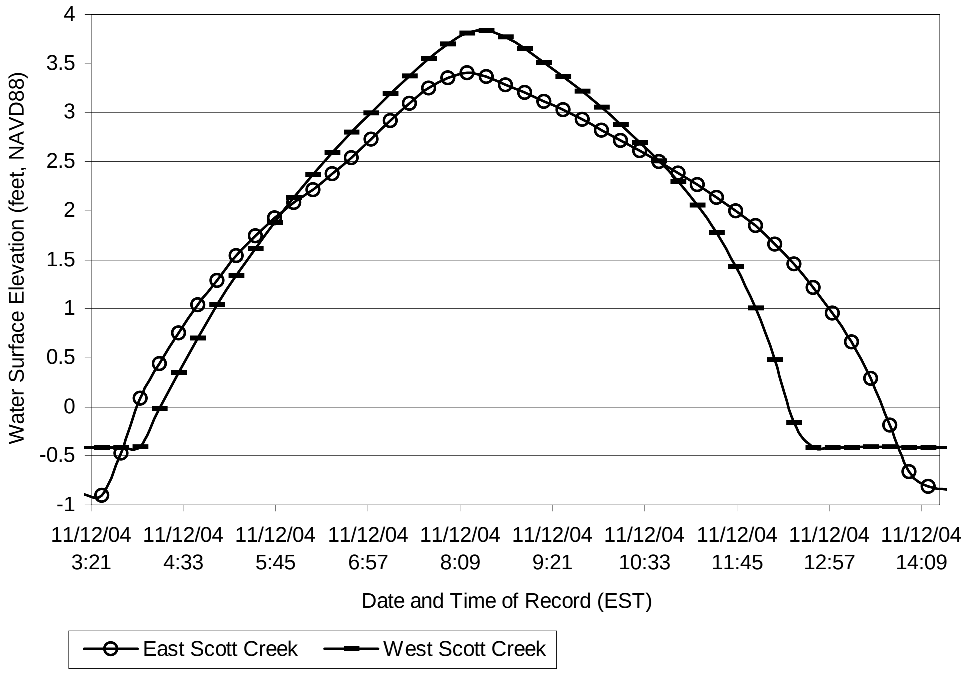

Fig. 14. This plot shows data recorded at the monitoring stations on either side of the causeway (East and West Scott Creeks), during a spring tide. Differences in water level, at a given time, indicate to when water would have flowed through the causeway if it were breached.

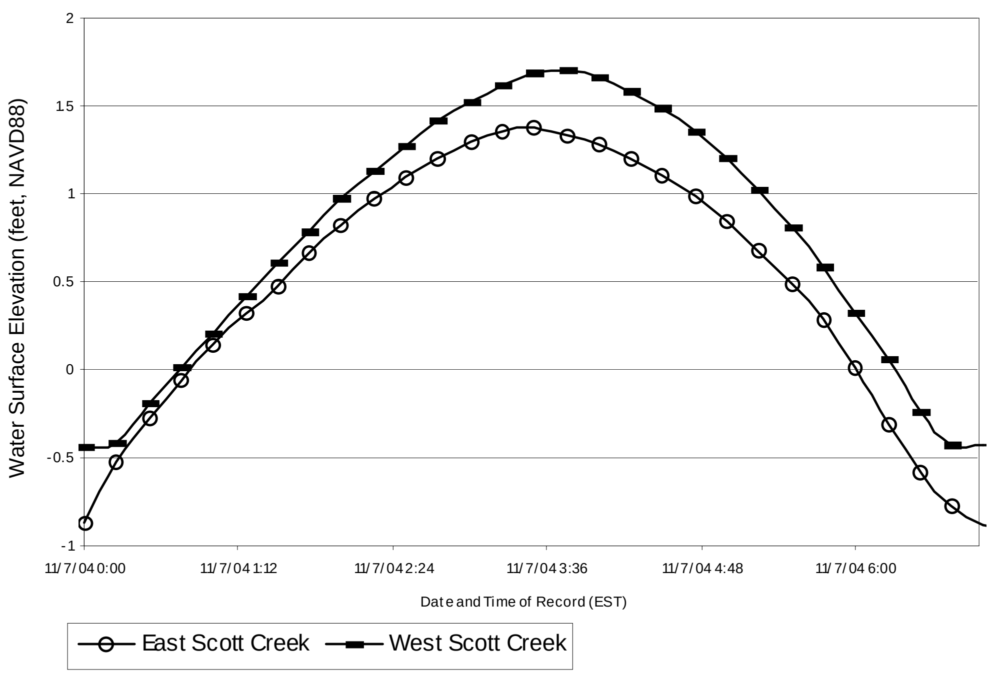

Fig. 15. Data recorded at monitoring stations on either side of the causeway (East and West Scott Creeks), during a neap tide. Differences in water level, at a given time, indicate when water would have flowed through the causeway if it were breached.

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cycles, especially during neap tides, the breachway would be relatively dry for up to 5.5 hours. With a rising neap tide, as shown in Fig. 15, water would slowly begin to flow from East Scott Creek to West Scott Creek as the tide began to rise and would shortly thereafter reverse direction. Approaching high tide water would flow from West Scott Creek to East Scott Creek and continue for the remainder of the tidal cycle, ceasing only when the tide fell below the level of the streambed.

BATHYMETRY AND TOPOGRAPHY

Bathymetric and topographic data were collected to support hydrodynamic modeling and develop baseline information describing land surface elevations prior to causeway modifications. In support of the model, bathymetric data were collected from navigable regions of Scott Creek and the 'boat channel' as well as areas adjacent to the causeway, during spring high tides. Because Jeremy Inlet was too shallow for safe navigation, topographic surveys were required to estimate land surface elevations in this boundary region of the hydrodynamic model. These data were processed to estimate creek bed surface elevations along Scott Creek and compiled into a Digital Elevation Model (DEM) serving as the computational grid for the hydrodynamic modeling. Salt marsh floodplain elevations were sampled throughout East and West Scott Creeks using bathymetric surveying techniques to provide baseline information and support future modeling efforts. A portion of this effort was focused near Big Bay for boundary information, and another targeted areas adjacent to the causeway to develop a reference for any proposed dredging activities.

Four different methods were required to determine land surface elevations along the causeway and in the creeks, floodplains, and inlets of Scott Creek. Topographic surveying methods were used to map elevations in the vicinity of Jeremy Inlet and along the Edisto Beach Causeway. All topographic data were sampled relative to the Universal Transverse Mercator (UTM), according to the North American Datum of 1983 (NAD83), zone 17N and the North American Vertical Datum of 1988 (NAVD88). Elevation data from the vicinity of Jeremy Inlet referenced the first order, class II vertical geodetic marker SCE5, with a 0.01-foot vertical precision, as reported by the South Carolina Geodetic Survey (SCGS) (Hockensmith, 2006). Along the causeway, the SCGS first order, class II vertical geodetic marker SCW1 was used (Hockensmith, 2006).

The other three methods involved sampling water depth, location, and time, from floating vessels, referencing tidal water level to stage recorders. One set of recorders monitored water levels relative to NAVD88, at multiple points along East and West Scott Creeks, as described in Hockensmith (2006). During floodplain surveys, another type of water level recorder was used which included temperature, salinity, and turbidity data at stations near the causeway. Results from the topographic and bathymetric surveys are accurate to 0.02 feet and 0.5 feet, respectively. Bed elevation values are shown in Fig. 20.

Topographic Surveying

To survey topography, an optical surveying level was mounted to a surveying-tripod and used to measure bearing, difference in elevation, and distance from a point of reference to various points of interest (Fig. 16). Calibrated fiberglass surveying rods were vertically oriented at locations of interest. This system allowed for sampling multiple locations within a radius of approximately 300 feet from each surveying reference point.

During the topographic surveying at the causeway, levels of the benchmarks used at monitoring stations SCE1 and SCW1 were checked, as well as level of the creek bed at those stations. Results indicated that the benchmark at SCW1 had shifted from 4.609 ft NAVD88 as reported by the South Carolina Geodetic Survey (SCGS), to 4.42 ft NAVD88 as indicated by Hockensmith (2006). This study indicated that the value of 4.852 feet NAVD88 reported by the SCGS was consistent with new measurements of 4.86 feet NAVD88. The level of the creek bed in West Scott Creek, near SCW1 monitoring station, was found to be –0.54 feet NAVD88, whereas the level of the creek bed in East Scott Creek, near SCE1 monitoring station was found to be –0.84 feet NAVD88. The elevation of the Edisto Beach Causeway, along highway 174 was found to vary from 5.85 ft to 7.01 ft NAVD88 in a generally north-south direction.

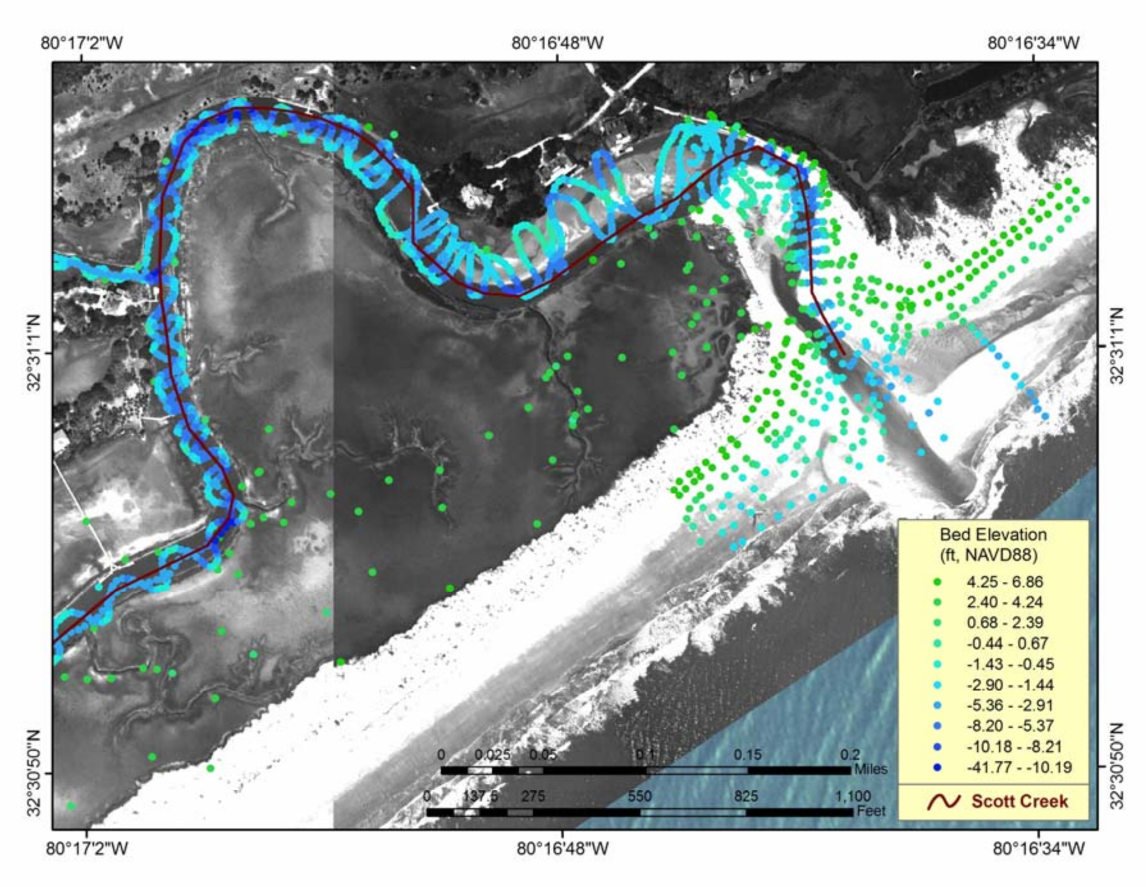

Fig. 16. This map shows Scott Creek thalweg from 2003-04 elevation data that were collected during topography, floodplain, and bathymetry surveying at Jeremy Inlet, with the 2003-04 DOQQQ mosaic and the 1999 aerial photographs in the background.

Bathymetric Surveying

Water depth was measured at locations identified with a RINO130 and reduced to bed elevation by subtracting water level sampled by a nearby stage recorder, relative to

NAVD88. These recorders sampled water surface elevations, calibrated to NAVD88 and time, at 15-minute intervals, with a reported accuracy of 0.016-feet (Hockensmith, 2006). Salt marsh floodplain surveying referenced another water level sensor that, as a non-vented level sensor, has a reported accuracy of 0.4 feet (YSI-Sondes, 2007). For these applications however, the target accuracy was 0.5 ft, and through use of a separate dataset, atmospheric pressure was compensated to enhance the quality of those water level data.

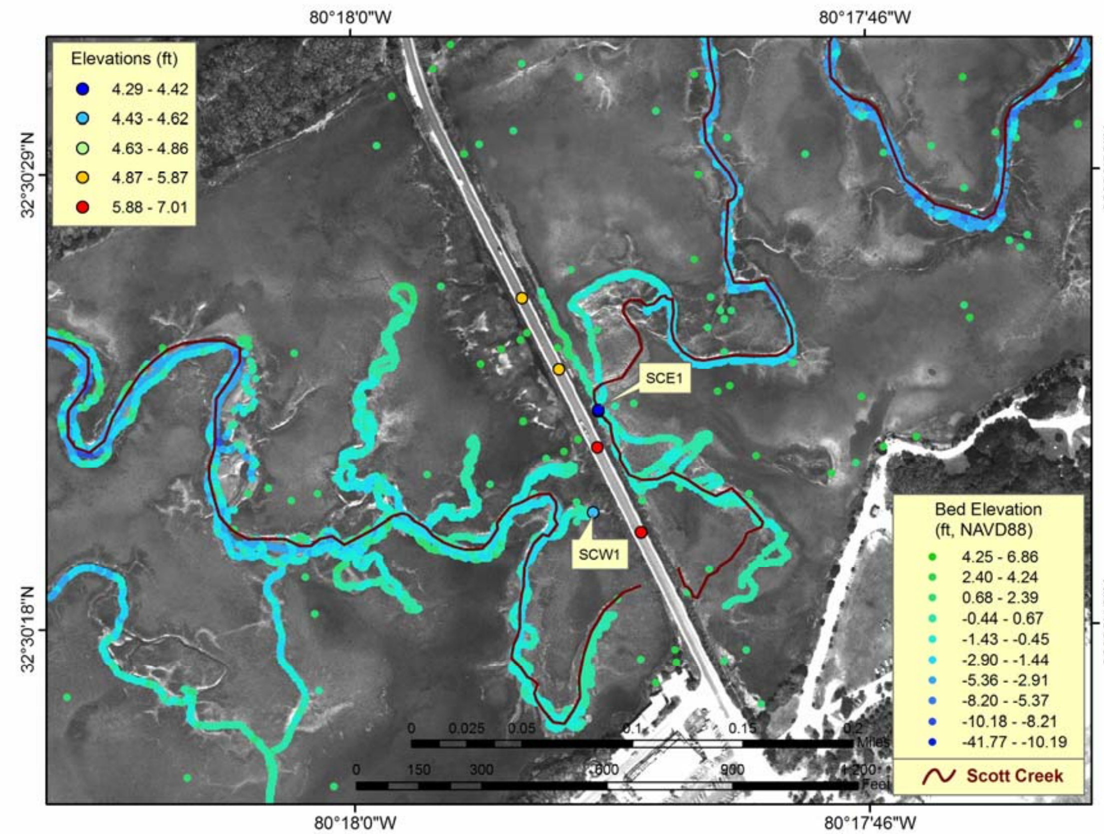

Fig. 17. Scott Creek thalweg from 2003-04 along with elevation data that were collected during topography, floodplain, and bathymetry surveying at and near the causeway.

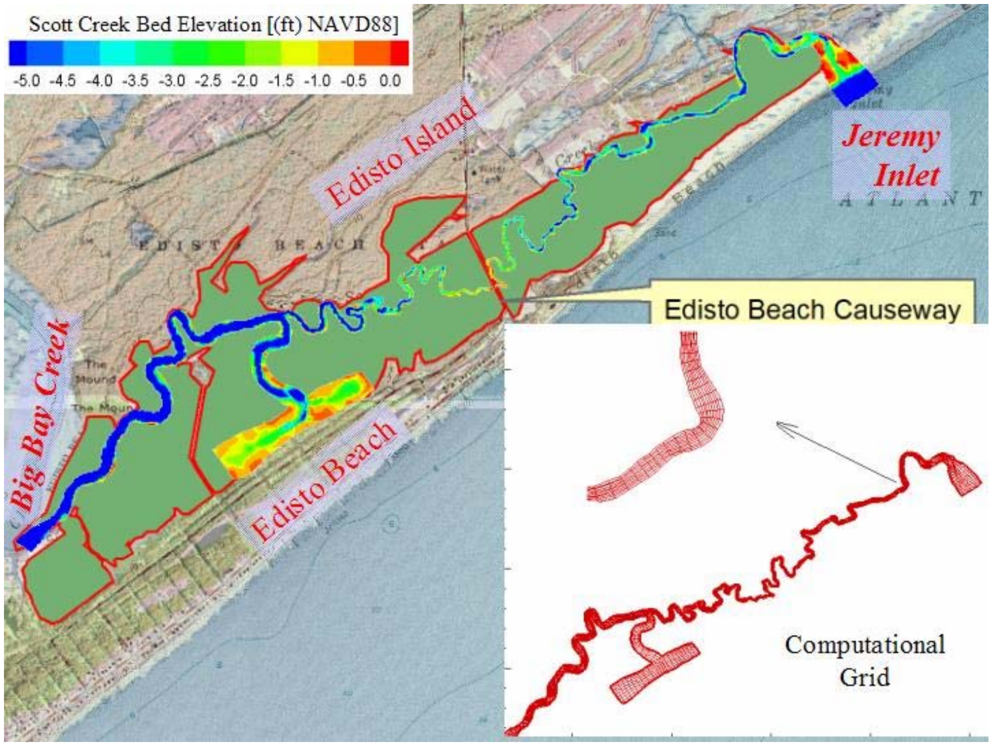

Fig. 18. Digital Elevation Model and grid that were constructed from the bathymetric data to support the hydrodynamic model.

Navigable Reaches – For the navigable domains of Scott Creek, water depths were sampled by towing a 3-ft long Riverboat brand trimaran, produced by the Ocean Science Group, equipped with a Garmin brand Wide Area Augmentation System (WAAS) differential corrected GPS antenna (mounted on the top) and dual frequency (50/200 kHz) 500-watt RMS sonar mounted on the stern. SONAR data were sampled at 0.5-1 Hz using a Garmin GPSMap 178C GPS receiver (referred to as a 'GPSMap' through the remainder of this report). The vessel towing the Riverboat had a Panasonic Toughbook laptop computer connected to the GPS Map receiver console, recording data sampled from the GPS and sonar. The Riverboat was tethered to a 15-ft long, 3-in diameter, schedule 40 PVC pipe, for nearly independent navigation. This system allowed an operator to navigate the Riverboat into shallow areas that the towing boat could not reach or those areas adjacent to obstructions such as shoals, docks and pilings.

For data collection, the Riverboat was pushed approximately 10 ft ahead of a 15-ft aluminum motorboat (Fig. 19). The Riverboat operator was situated on the foredeck, with approximately 5 ft of PVC overlapping the motorboat for control of the Riverboat, holding 2 rope-handles to navigate the riverboat. In this case, ideally the aluminum boat followed the channels of Scott Creek along the left bank, traveling

Fig. 19. Forward-push mount and operation for Riverboat trimaran for use with ADCP, equipped with GPS and sonar.

upstream and the Riverboat was operated so that it sampled from the top of the creek bank towards the thalweg, back and forth, in front of the aluminum boat. The same procedure was followed on the return trip downstream, but sampling along the right bank. This operation allowed for sampling the thalweg both on the upstream and downstream trips, provided double sampling for verification of data collected on the upstream trip, and minimized potential under-estimation of thalweg depths. A similar system was also used from a canoe during spring tides to sample the shallow channels and some floodplain areas adjacent to the causeway. This sampling procedure was nearly identical to that using the aluminum boat, but with the Riverboat in tow behind the canoe. The DEM and grid that were constructed from these data to support the hydrodynamic model are shown in Fig 18, interpolated to grid nodal points for output.

Floodplains and Creek Banks – Salt marsh floodplain and creek bank elevations were determined by measuring water depths at specific locations and subtracting the time-varying elevation of the water surface. However, unlike sampling depths in the creek channels, the floodplain was only accessible using shallow draft vessels and only during spring high tides when the floodplain was fully inundated. This process involved a small aluminum 'jon' boat, kayaks, calibrated survey rods, a water level recorder, a set of RINO130's (handheld GPS instrumentation used for identifying horizontal locations, in geographic space)**,** and waterproof logbooks. The jon boat operator, as well as the kayak paddlers, determined locations using RINO130's and calibrated survey rods. The paddlers would monitor water depths while traversing the floodplain and take measurements when depths changed, noting time, water depth, and location in their logbooks. The jon boat followed the creek channel and sampled the creek bank elevations using a calibrated survey rod and a RINO130, noting location, water depth, and time in a logbook. These sampling efforts focused on areas adjacent to the causeway and the region of floodplain near the Big Bay boundary of West Scott Creek (Fig. 20).

Water Levels and Water Qualities **–** During floodplain surveys, a YSI-6600 Multiparameter Datasonde instrument, referred to henceforth as YSI sonde) was used to monitor water levels. Along with water pressure, this instrument also sampled water temperature, salinity, and turbidity at 5-min intervals. The salinity, turbidity, and water depth were calibrated in the field following standard methods described by the manufacturer (YSI-Sondes, 2007). Water levels were initially referenced to NAVD88 by measuring the distance from a known elevation benchmark to the water surface at multiple times, and noting the elevation of the water surface and time when it was measured. These data were used for post-processing the water level values to change them from water heights above the sensor, to levels of the water surface, relative to NAVD88.

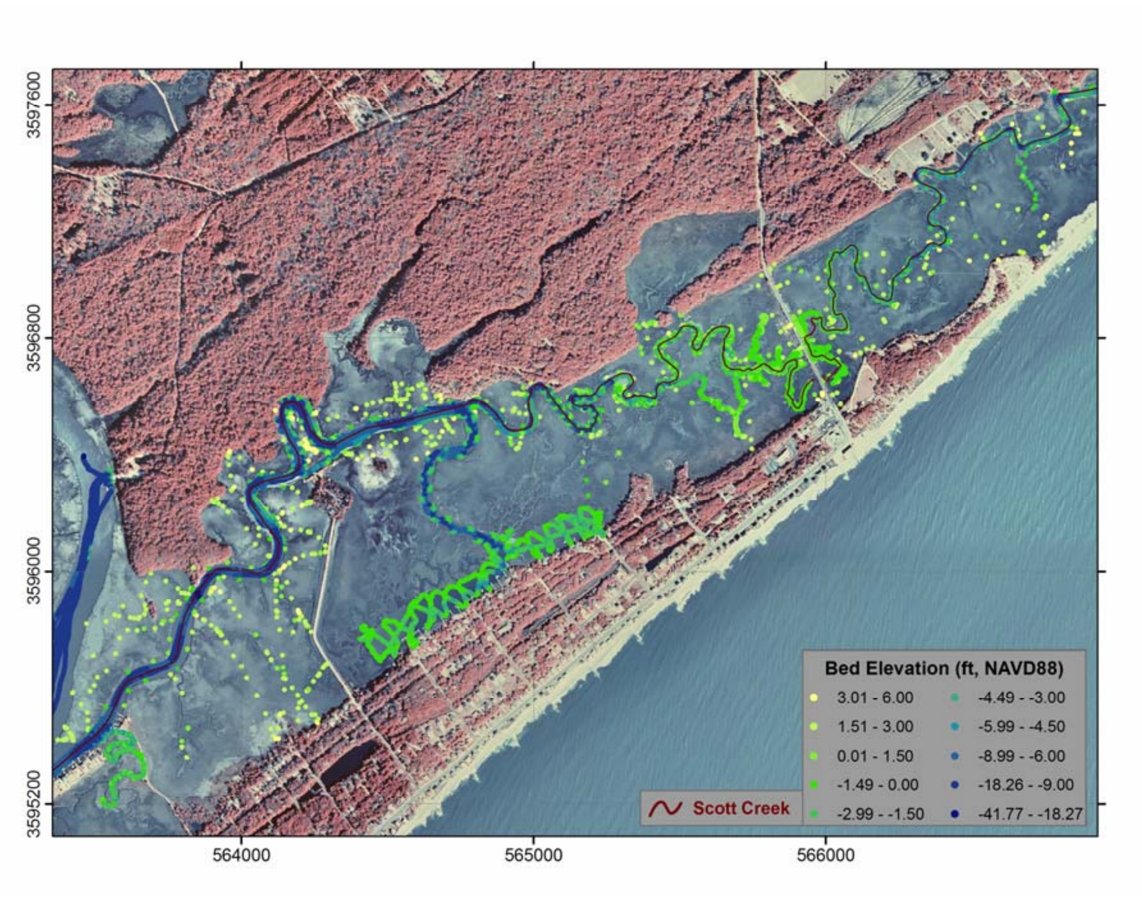

Fig. 20. Bed elevation for the entire Scott Creek system.

The YSI sonde was attached to a piling where a geodetic benchmark was located at each of the monitoring stations SCW1 and SCE1, described by Hockensmith (2006). A non-vented, stainless steel, strain gauge level sensor was used with the YSI sonde, providing measurements of water level, with an accuracy of 0.4-ft, however by compensating for atmospheric pressure, as is the case with the shallow-water vented level sensors, the accuracy improves to 0.01-ft (YSI-Sensors, 2007). All data produced from the floodplain surveying efforts are assumed to have been accurate to 0.5-ft.

A thermistor was incorporated in the YSI sonde, sampling water temperature with an accuracy of 0.15 ºC (0.27ºF). For salinity measurements, the sonde incorporated a 4-electrode cell with autoranging that measured conductivity. Using conductivity and temperature measurements, the sonde calculated salinity values with an accuracy of +/-1.0% of the reading or 0.1 part per thousand, whichever is greater (YSI-Sensors, 2007). The turbidity sensor on the YSI sonde was an optical, 90-degree scatterer type sensor with a mechanical cleaning system. This sensor had a reported accuracy of +/- 2% of the reading or 0.3 Nephelometric Turbidity Units (NTU), whichever is greater (YSI-Sensors, 2007).

Total variations in atmospheric pressure observed at the Edisto buoy were only 7-hPa for the duration of sampling. Using the factor of 29.89- hPa/ft, a 7-hPa variation can only result in a 0.2-ft variation in water level. As previously mentioned, the SCW1 benchmark elevation of 4.42 ft NAVD88 was used for referencing water levels at this site. During low tides, the sensors were out of the water and those data collected during such periods were not considered representative of the water conditions.

A series of spring high tides were monitored for change in water level, temperature, salinity and turbidity, on either side of the causeway. Some patterns appeared in this data series, although measurements were limited to a total of 6 tides sampled in October and November 2006. The high tides that were sampled varied with a low high of approximately 3.6 feet NAVD88, followed by 3.8, then 4.4, 4.4, 4.8, and the highest high tide was around 4.9 feet NAVD88. Tidal range and amplitude could not be determined from these data as bed elevations were higher than the level of low tides, which resulted in a dry creek bed during low tides. However, predictions from NOAA were for tidal ranges of 8.3, 7.6, 8.5, 8.4, 6.6, and 8.1 feet at Edisto Beach (NOAA, 2005a) and 8.2, 7.9, 8.9, 8.8, 6.9, and 8.4 feet at Big Bay Creek (NOAA, 2005b), temporally corresponding to the tides previously described. Temperatures varied at these sites according to time of day, with temperatures rising during daylight hours and cooling at night. The lowest water temperature observed over the course of the hydrographical studies was 55º F, recorded on the east side, and the highest temperature was 74.6ºF, recorded on the west side. Salinities on the eastern side of the causeway were typically 1-2 parts per thousand higher than those on the western side and appeared consistent in the dataset, wherein eastern side salinities varied 33.5-34.4 ppt and western side salinities were 31.8-33.4 ppt. Turbidity values tended to be highest early in the flood tide period and declined thereafter. This appeared to indicate that water had lower clarity near the surface during the rising tide and clarity increased after the sensor was submerged about 1 ft or more below the surface. The data from the YSI sonde indicated that tidal water passing through West Scott Creek was slightly more dilute than that which flowed through East Scott Creek to reach the Edisto Beach Causeway. The differences however were slight, considering the spatial distance between boundary water sources for East and West Scott Creek estuaries.

VELOCITY AND FLOW

Water velocity data were sampled to support numerical hydrodynamic modeling and provide baseline information that describes velocity and volumetric flow variations in Scott Creek. A variety of acoustic Doppler water velocity sensors were used in a variety of manners and at multiple locations throughout Scott Creek to support this study. A contract with Richard Styles, of the University of South Carolina, supported five different bottom-mounted velocity sensors for a one-month period. These sensors were placed in various locations in Scott Creek ranging from Jeremy Inlet to the confluence with Big Bay Creek. Three of the bottom-mounted sensors profiled the water column above them, two of which were situated at the inlets and one was just upstream from the channel to the Boat Basin. Two more sampled velocities near the causeway, generating a baseline dataset that served 3 basic purposes: 1) to verify values produced by the model, when simulating present conditions; 2) to establish a benchmark to evaluate how velocities may change as a result of different causeway breach scenarios simulated in the model; and 3) to produce data for calculating bottom roughness values.

A sixth acoustic Doppler water velocity sensor was mounted to a vessel for downward looking. It was used to provide data for interpreting tidal variability in the exchanges between West Scott Creek and Big Bay Creek, near their confluence. These data were gathered continuously throughout semidiurnal tidal periods – sampling spring, neap, and average phases of the fortnightly tide. The velocity and flow data collected for this study generated information that supported the hydrodynamic model, described present flow conditions, and may be used in future studies to evaluate particle transport, as well as transverse variations in tidal velocities and flux.

Methods

Several different approaches were used to capture a robust and comprehensive baseline set of velocity and flow information. The methods that were used are separated into two principle categories and described in more detail in the following sections. The first category describes methods and results from the 5 bottom-mounted velocity sensors. The second category describes methods and results from the vessel-mounted, downward looking acoustic Doppler current profiler (ADCP) surveys made by boat.

Bottom-mounted Velocity Sensors –The bottom-mounted sensors were installed at 5 different locations in East and West Scott Creeks (Fig. 20), sampling water velocities at 10-minute intervals. These sensors were deployed for a period of 35 days (May 23 – June 27, 2006). Each instrument was mounted to a custom-fabricated aluminum frame. Rectangular lead weights, approximately 25 lbs each, were bolted to the corners of the frames and a 5 to 10-ft length of chain was used to distance an anchor, together securing the frame's position on the creek bed. Another 5 to 10-ft length of chain connected the anchor to a rope and buoy, identifying the instrument's location both for navigational safety and for recovery.

Four different types of bottom-mounted velocity sensors were used in this study. No single type of instrument could provide the information needed because of depth limitations at the deployment sites. Near the mouth of West Scott Creek, water depths averaged around 8.0 ft and were sufficient enough to support vertical profiling of the water column. For this site, a 1.2-MHz RD Instruments Sentinel brand ADCP was used to collect data. In West Scott Creek, near the channel to the Boat Basin, water depths were slightly less, averaging around 7.5 ft. A 2-MHz Nortek Aquadopp Profiler brand ADCP was used at this site. Locations near the causeway required point-sampling acoustic Doppler velocity meters (ADV), as depths were not sufficient enough for vertical profilers. The average water depths, when the tide was high enough to submerge the sensors, were 3.3 ft on the east side and 2.4 ft on the west side of the causeway. For these locations, the point sampling Sontek/YSI brand ADV's were used, rather than profilers. At the site near Jeremy Inlet, A 1.0-MHz Sontek/YSI Acoustic Doppler Profiler brand ADCP was installed to sample water velocities. At this location water depths averaged around 7.0 ft, sufficient enough for vertical profiles of the water velocity to be collected.

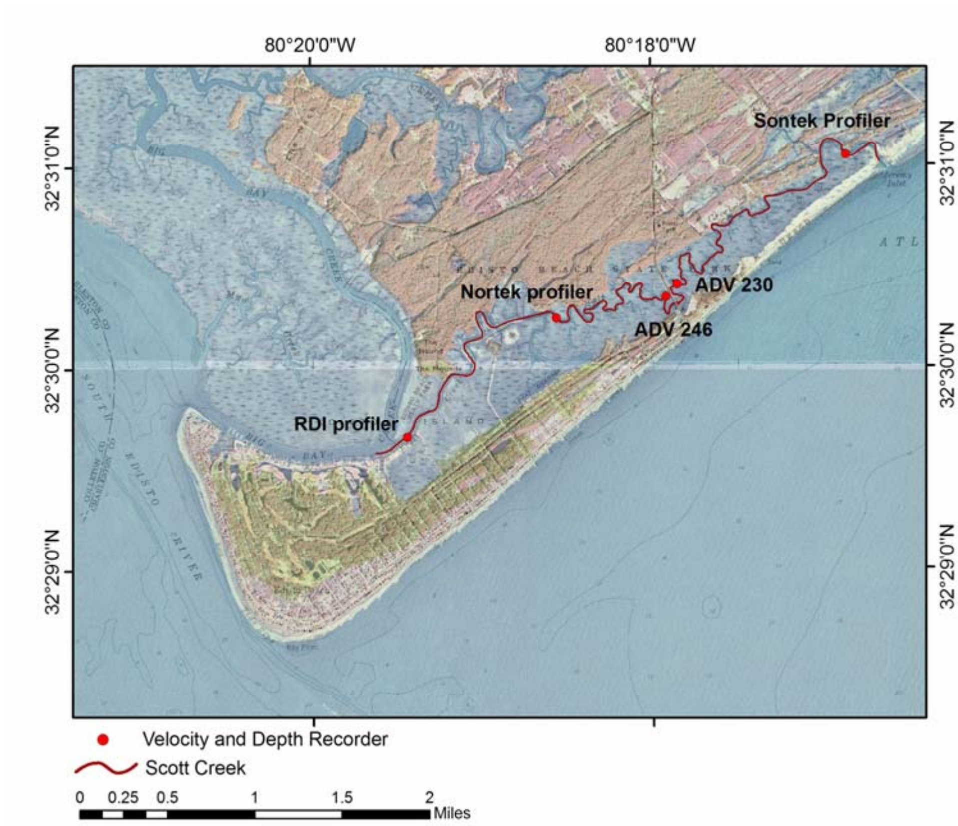

Fig. 21. Locations of University of South Carolina velocity and monitoring equipment.

RDI-ADCP Configuration – The ADCP located near Big Bay Creek was a 1.2-MHz RD Instruments Workhorse Sentinel ADCP, profiling the water column as an upward-looking unit. The transducers were 1.48 ft above the bed and the blanking distance (range from transducers to first good velocity sample) was 2.66 ft, providing the first good velocity sample at 4.13 ft above the bed. The vertical resolution was set to 0.82-

foot increments, sampling the water column at a rate of 1-Hz, averaging 2-min bursts every 10 min. This instrument sampled the height of the water surface above its transducers using 1.2 –MHz acoustic pulses, resolving variations on the order of 0.01 ft.

Profile data were depth-averaged, using all velocity values sampled within the range from the ADCP to those closest water surface. Velocity in the unmeasured range, near the water surface, was estimated using the closest value as a constant for that domain. A no-slip extrapolation was used to estimate velocity values near the bed. The first good velocity sample (just beyond the blanking range, closest to the ADCP) was linearly extrapolated to a zero current speed at the bed. During spring tidal conditions (from 05:10 on May 24, 2004 through 05:10 on May 26, 2004), the maximum tidal range was 7.73 feet and the axial velocities varied between –3 and +3 feet/second. Peak speeds of depth-averaged ebb velocities (period highlighted in figure 75b) reached 3.4 feet/second, consistently exceeding those of flood, which only reached 2.1 feet/second. During neap tidal conditions (from 14:20 on June 4, 2004 through 14:20 on June 6, 2004), the minimum tidal range was 3.20 feet and the axial velocities varied from between –1.4 and +1.4 feet/second. In the entire period of record, depth-averaged ebb velocities consistently (26 occasions out of 67 cycles) peaked at a rate higher than 2.5 feet/second, whereas flood velocities rarely reached 2.5 feet/second (only 3 occasions out of 67 cycles). A pattern appeared consistent between flood and ebb events, on a semidiurnal scale. Following peak flood, the flow quickly transitioned to ebb until peak ebb velocities were reached. From peak ebb, the flow gradually transitioned back to peak flood with frequent turbulent variations in flow continuing through the peak flood velocity phase.

Nortek Aquadopp Profiler Configuration – A 2-MHz Nortek Aquadopp Profiler brand ADCP was used in West Scott Creek, near the channel to the Boat Basin. The transducers on this instrument were 0.36 ft above the creek bed and the blanking distance was 0.33 ft, providing the first good velocity sample at 0.69 ft above the creek bed. The vertical resolution was set to 0.33-ft increments, sampling the water column at a rate of 1-Hz, averaging 2-min bursts every 10 min. Profile data from this instrument were depth-averaged using the same technique described for the RDI-ADCP

Sontek/YSI-ADV Configuration – Two of the water velocity sensors were 5-MHz Sontek/YSI Acoustic Doppler Velocimeter (ADV) Ocean Probe ADV's . These sampled water velocities approximately 0.33 ft above the bed in Scott Creek, near the causeway. These instruments sampled data at a rate of 10-Hz, averaging 2-minute bursts every 10 min.

Sontek/YSI Acoustic Doppler Profiler Configuration – A 1.0-MHz Sontek/YSI Acoustic Doppler Profiler brand ADCP was positioned in East Scott Creek, near Jeremy Inlet, collecting vertical profiles of water velocities. The transducers on this instrument were situated 1.18 ft above the creek bed and the blanking distance was 1.64 ft, providing the first good velocity sample at 2.82 ft above the creek bed. The vertical resolution was set to 0.82-ft increments, sampling the water column at a rate of 1-Hz, averaging 2-min bursts every 10 min.

Vessel-mounted Velocity Surveying – A 1.2-MHz RD Instruments Workhorse Monitor ADCP, equipped with a thermister, a gyro, a fluxgate compass, a pressure sensor, as well as bottom-tracking firmware, was used in a downward looking configuration to map currents and bathymetry around the confluence of Big Bay and West Scott Creeks. The unit provided measurements for distance to the bed with a precision of 0.01ft and an accuracy of 10% of the water depth. Water velocities were sampled at 0.82-ft depth intervals, following a blanking distance of 1.84 ft plus transducer depth of 0.1 to 0.5-ft for a first sample at a minimum water depth of 1.94-2.34 ft. Each depth measurement and profile of water velocities was sampled at a rate of approximately 1-Hz and a horizontal distance that varied depending on the speed of the boat. While surveying, boat speed was targeted to match that of the current to optimize bottom tracking as well as the quality of the resultant water velocity measurements. Actual boat velocities occasionally reached 5 ft/sec, but were typically less than 3 ft/sec.

The ADCP was mounted in the middle of the 3-ft long Riverboat trimaran as previously described in the bathymetric surveying section of this report. In this case, the ADCP was powered by a pair of 12-Volt gel-cell batteries contained in the hull of the Riverboat. Data were transferred through a 900-MHz wireless transceiver also contained in the hull of the Riverboat. Another transceiver was held stored in a plastic container in the jon boat connected via serial port to a laptop computer for data collection. WinRiver software, provided by the manufacturer of the ADCP, was used for communication with the ADCP.

The Riverboat was equipped with a Garmin Wide Area Augmentation System (WAAS) differential corrected GPS antenna, mounted on the top and dual frequency (50/200 kHz) 500-watt RMS sonar mounted on the stern. The display on the GPSMap console allowed personnel on the jon boat to monitor navigation and water depth conditions for the Riverboat. The GPSMap console reported location and depth data received from the Riverboat to a laptop computer, using GPSU 402k brand software.

The Riverboat was maneuvered using a 15-foot PVC pole that was attached to the bow seat pedestal base on a 16-foot aluminum jon boat, during the ADCP surveying. The operator of the ADCP-Riverboat sat on the bow seat and guided the trimaran, enabling ADCP data collection in areas of the creek’s cross-section too shallow for the jon boat to safely navigate. This setup for ADCP surveying is shown being used, in Fig. 19.

The first acoustic water velocity surveying was done during an average tide (range of approximately 5 ft), and was repeated to sample a spring tide (range of approximately 7.25 ft) on February 17 and March 1, 2006, respectively. These sampling efforts involved hourly cross-channel surveying of velocity profiles in Big Bay Creek, upstream and downstream from West Scott Creek and within West Scott Creek, near the confluence, as shown on the map in Fig. 22.

Navigation and data collection during each circuit proceeded as follows. Using WinRiver software, the ADCP was instructed to begin pinging. The boat was driven toward the first point, on the right bank of Big Bay Creek, just upstream from West Scott Creek. On approach to the marker, boat speed was reduced and the helmsman began turning the boat to head from the right bank marker towards the left bank marker. Once the right bank marker was reached, the jon boat operator would turn the boat to head down Big Bay Creek towards the next survey cross-section. On approach to this marker, survey operations were repeated. In doing so, 2 cross-sections were surveyed at the downstream end of Big Bay Creek and the jon boat was driven upstream into West Scott Creek to the second cross-section sampling site near the creek's mouth.

The Riverboat-mounted ADCP system was used again after the 5 bottom-mounted sensors were installed (as described in a previous section of this report). At that time, cross-channel surveying was done only in West Scott Creek on May 24 and June 6, 2006. This involved continuous surveying, following an hourglass pattern of cross-channel transects, as recommended by Li, et al (2006). This pattern serves the purpose of surveying regional bathymetry, changes in water levels, and velocities, while gathering data for interpreting tidal flux.

These data were collected to generate information on the volumetric exchanges between Big Bay Creek and West Scott Creek during a variety of tidal phases (spring, neap, and average). The objective of these sampling efforts was to sample a wide range of flow conditions for comparison with the 35-day period data from bottom-mounted ADCPs, so that volumetric flows from the survey data could be extrapolated through time to estimate volumetric exchanges throughout the entirety of the period and to compare with results from the numeric hydrodynamic modeling.

Information from the acoustic backscatter dataset, available from the ADCP, provides relative values of particulate fluxes into and out of the system during ebb and flood tide conditions. During one semidiurnal period, the ADCP flow study at the mouth of West Scott Creek focused on optical turbidity, temperature, and salinity profiles at hourly intervals to reveal the vertical distribution of these parameters as a function of tidal ebbing and flooding, and for comparison with the acoustic backscatter dataset.

HYDRODYNAMIC MODEL

The importance of understanding existing water motions/transport and prediction of effects of possible changes to the system is critical for any restoration or enhancement projects. A poor understanding and prediction of the physical water circulation can cause a restoration or enhancement project design to fail. Engineers use both physical and numerical models to evaluate different wetland restoration plans. A hydrodynamic model is an important tool to study different restoration schemes, which otherwise would be costly or difficult to test. A well-calibrated model can be used to predict rates of accretion, potential for scour as a result of either watershed runoff or storm surge, and other relevant physical processes.

This section presents a hydrodynamic and particle tracking model for Scott Creek and its application for investigation of restoration and enhancement issues. Depth-integrated continuity and momentum shallow water equations are the basis of the hydrodynamic model that includes particle transport using a random-walk particle tracking method. The numerical solution of the flow model was obtained using a finite volume scheme that closely follows methods presented by Bradford and Katopodes (1999) and used by Arega and Sanders (2004). The model solves depth-averaged continuity and momentum equations using the finite volume method, and it accounts for flooding and draining of intermittently wetted areas such as mudflats. It has excellent conservation properties, and it is non-oscillatory – even at the wet/dry interface.

Before the model could be used to investigate different restoration schemes at the Edisto Beach causeway, it had to be calibrated and verified for hydrodynamic processes.

Calibration is the process of comparing model predictions against measured field data of water surface elevations and currents and adjusting certain model parameters until the model prediction adequately matches observed field data. In this application, the bed roughness term (Manning Coefficient) is the calibration parameter. The process of verification is subsequent to calibration where the calibrated model performance is evaluated by simulation of an independent set of field data. Once the model is calibrated and verified, it can be applied to investigate different restoration schemes compared to present hydrologic conditions.

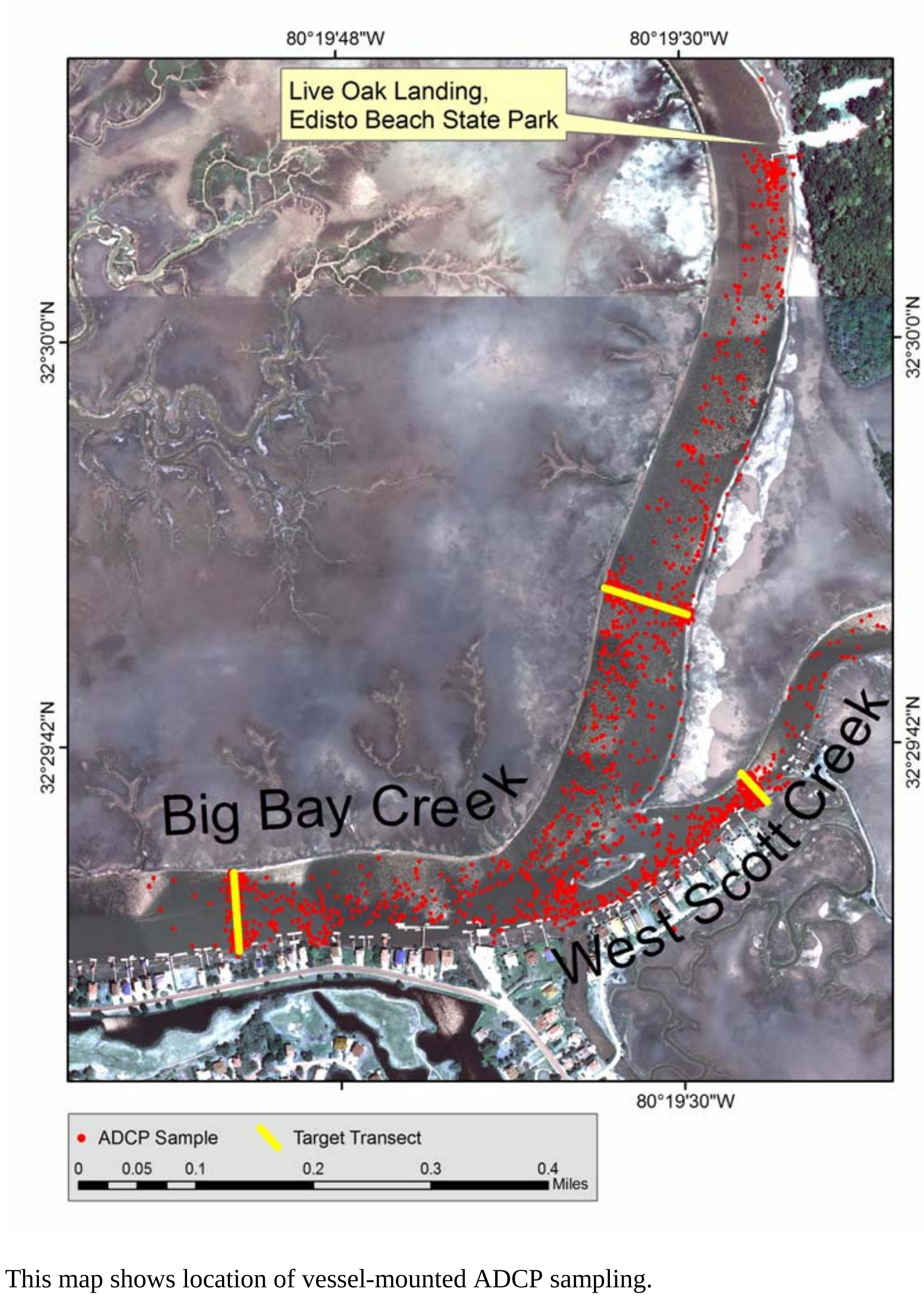

Fig. 22. This map shows location of vessel-mounted ADCP sampling.

Model Input

A numeric model for realistic simulation of flow and circulation needs correct bathymetric information and proper boundary conditions. Bathymetric data appearing in Fig. 18 were obtained from several sources and then compiled into a Digital Elevation Map (DEM) that served as the computational grid. There were two pressure tide gauges near the project site operated by National Oceanographic and Atmospheric Administration (NOAA) – Edisto Beach (NOAA Station ID 8667630) and Carter's Dock, Big Bay Creek (NOAA Station ID 8667679). The gauge at Edisto Beach was located at the Pavilion, on the pier, to the south of Jeremy Inlet. The Carter's Dock gauge was near the confluence of Edisto Creek and Big Bay, in Big Bay Creek. The stations at Edisto Beach and Carter's Dock were close to the eastern and western side open boundaries. However, there were no verified data at these stations that could be used as a boundary condition for the hydrodynamic model. The closest NOAA Station providing verified data was in Charleston Harbor (NOAA Station ID: 8665530). To determine the phase lag and relative amplifications, least square harmonic analysis of tidal constituents was carried out on predicted water surface levels at Edisto Beach, Carter's Dock and the Charleston Harbor station. Five tidal constituents were chosen whose amplitudes were greater than 0.1-foot. These were M2 (principal lunar semidiurnal tidal harmonic component with a 12.42-hr period, S2 (principal solar semidiurnal tidal harmonic component, with a 12.00 hr period, N2(larger lunar elliptic semidiurnal tidal harmonic component, with a period of 12.66 hr, K1 (lunisolar diurnal tidal harmonic component with a period of 23.93 hr, and O1 (principal lunar diurnal tidal harmonic component).

Table 6 provides the results of the harmonic analysis at the three stations. The last two columns refer to verified data from Charleston Harbor. Also shown are computed amplitudes, phases, ratios of the tidal amplitudes, and phase difference for each station. A computed form number (defined by the sum of the amplitudes of the two principal semi-diurnal tidal constituents, divided by the sum of the amplitudes of the two principal diurnal constituents) of 0.21 indicated the semi-diurnal nature of tides at Scott Creek. High tide arrived at Edisto Beach earlier than at Charleston Harbor, whereas high tide at Carter's Dock was later than that of Charleston Harbor. The tidal amplitude at Carter's Dock, on average, was 1.03 times that of Edisto Beach with a phase difference of 0.42 hrs (25 minutes). Based on the phase lag differences and amplifications shown in Table 6, a new set of water surface elevations was generated for Edisto Beach and Carter's Dock. These predicted values were used as open boundary conditions. It was assumed that the wind impact in this small creek was incorporated in the incoming tidal forcing from the open boundaries and was therefore neglected.

Table. 6. Results of harmonic analysis for Edisto Beach, Carters Dock and Charleston tidal stations.

											Charleston			
Tidal Const	Edisto					Big Bay					Predicted		Verified	
	Amp Ft.	Phase Degree	Amp. Ratio	Phase Difference				Amp Ratio	Phase Difference		Amp Ft.	Phase Deg	Amp Ft.	Phase Deg
				Deg	Hrs	Ft.	Degree		Deg	Hrs				
M2	2.85	164.28	1.13	8.81	0.3	2.94	176.57	1.17	-3.5	-.12	2.51	173.09	2.53	170.77
S2	0.38	234.85	1.19	6.47	0.22	0.4	247.41	1.24	-6.1	-.2	0.32	241.33	0.3	241.92
N2	0.74	73.93	1.17	10.85	0.38	0.77	85.88	1.21	-1.1	-0.14	0.63	84.77	0.68	77.92
K1	0.37	113.12	0.94	7.7	0.51	0.39	119.61	0.98	1.21	0.08	0.4	120.82	0.43	112.87
O1	0.21	85.39	0.85	3.81	0.27	0.22	91.49	0.87	-2.3	-0.16	0.25	89.19	0.26	88

Model Calibration and Validation

Scott Creek was discretized into 6,960 discrete grid cells. Fig. 18 shows the model domain and the inset on the top shows the typical grid scheme. The lateral grid size with the creek varies between 2-4 m (6.6-13.1 ft). The hydrodynamic model was applied to characterize circulation and mixing in Scott Creek. A Manning Coefficient of 0.02 was used for all grid cells in this system and the model was numerically integrated with a time step of 0.1-sec. The model was calibrated using water surface elevation data collected during December 2004 and January 2005. Fig. 13 shows the location of monitoring stations for water surface elevations. Using tide levels at Edisto Beach and Carter's Dock, the model was forced for the period of December 12, 2004-January 10, 2005 and comparisons between the measured and predicted water levels were made.

There were strong agreements between the observed and predicted water surface elevations at monitoring stations SCE1 and SCE4 (Fig. 23). The ebb profile for station SCE4 shows a slower rate of ebbing than during the flood period. This was caused primarily by the constriction at the outlet, where the bed elevation is slightly [(0.1 to 0.2-m) (0.33 to 0.66-ft)] above the mean lower water level of the ocean. Similarly there were good agreements between the model predictions and observations at stations SCW1 and SCW4 (Fig. 24). Quantitative model performance in surface water propagation was evaluated using different statistical tests on observed and computed time series data. Root Mean Square (RMS) values of 0.24, 0.28, 0.44, and 0.18-ft were computed for SCE1, SCE4, SCW1, and SCW4, respectively. Computed Mean Errors (ME) were -0.01, 0.00, -0.18, and -0.14-foot for stations SCE1, SCE4, SCW1, and SCW4, respectively. The negative root meant that the model "over-predicted values", when compared with field data. Generally, the agreements were satisfactory and the errors were less than, or comparable to, previously reported values for similar estuarine model studies.

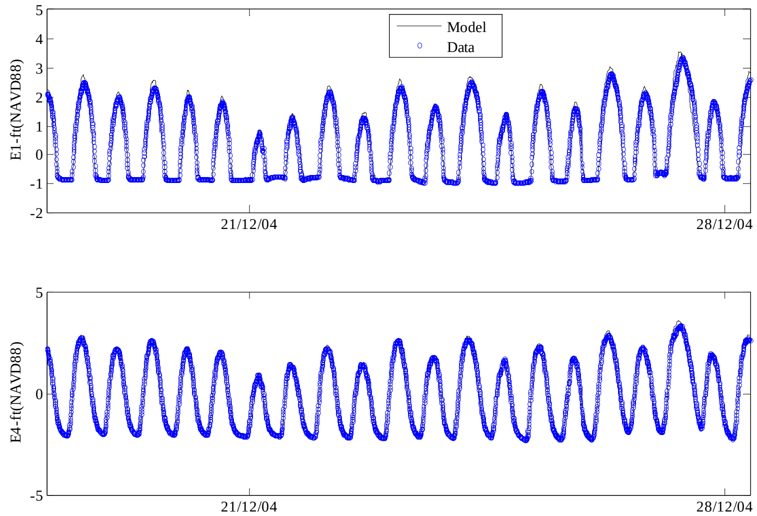

Fig. 23. Comparison of simulated (Model) and measured (Data) water surface levels at the SCE1 (E1) (upper panel) and SCE4 (E4) (lower panel) stations.

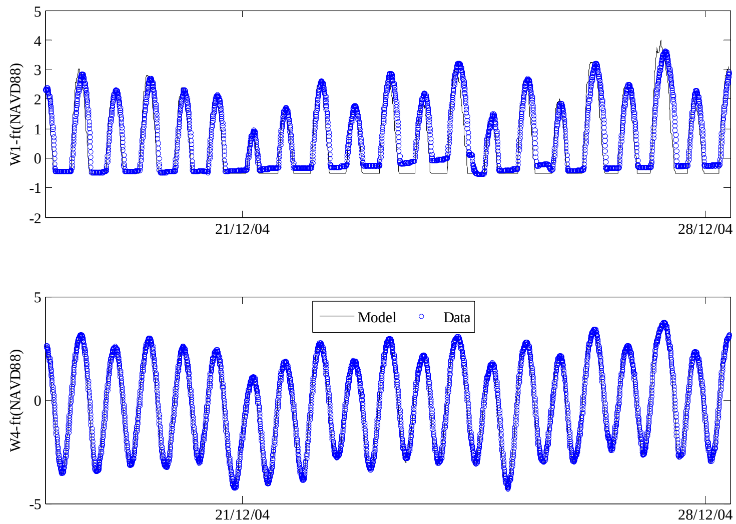

Fig.24. Comparison of simulated (Model) and measured (Data) water surface levels at the SCW1 (W1) and SCW4 (W4) stations.

Model performance was verified using water surface elevation and current data collected during May-June 2006. The monitoring stations for this period are shown in Fig. 21. Figs. 25, 26, 27, 28, and 29, show comparisons of model-predicted water surface elevations and currents with field data for all 5 stations monitoring velocity and water depths. There were strong agreements between the observed and predicted water surfaces, although the comparisons for currents were not as good. Highly accurate agreement between point observations of tidal velocities and numerical model predictions is difficult to achieve for a number of reasons. In tidal channels, considerable variation in velocity amplitude and phase can occur in the lateral or cross-channel direction due to variations in bathymetry and channel geometry. Velocities predicted by a model represent spatial averages over model grid cells. In the limit of a model grid fine enough to represent bathymetric variations, differences between predicted and observed velocities can arise due to differences in actual bathymetry and bathymetric data interpolated to the fine grid. A coarse grid resolution introduces another source of bathymetric error due to the smoothing inherent in interpolating bathymetry to model grid cells. Overall, the model was able to capture the tidal propagation reasonably well.

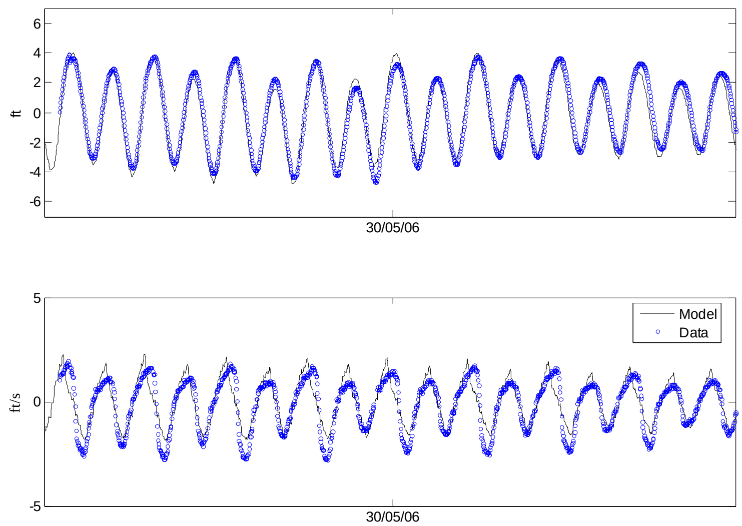

Fig. 25. Comparison of simulated (Model) and measured (Observed Data) for water depths and depth-averaged currents at the RDI profiler station indicated in Fig 21.

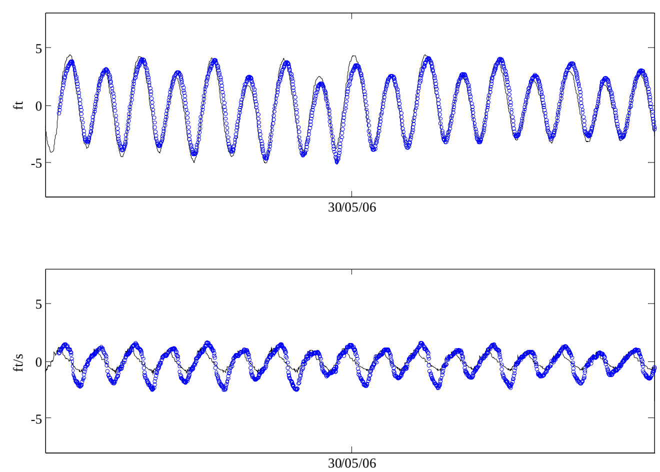

Fig. 26. Comparison of simulated (Model) and measured (Observed Data) for water depths and depth-averaged currents at the Sontek profiler station indicated in Fig. 21.

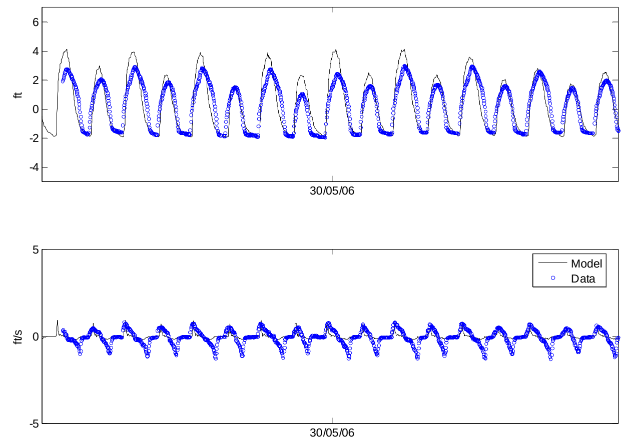

Figure 27. Comparison of simulated (Model) and measured (Observed Data) water depths and currents at the ADV 246 station indicated in Fig 21.

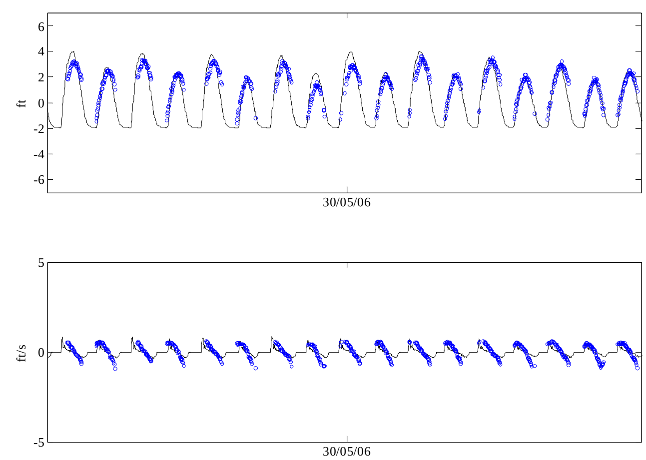

Figure 28. Comparison of simulated (Model) and measured (Observed Data) for water depths and currents at the ADV 230 station indicated in Fig. 21.

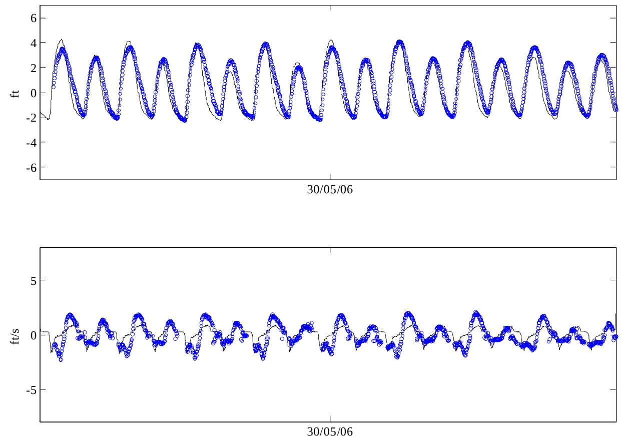

Figure 29. Comparison of simulated (Model) and measured (Observed Data) water depths and depth-averaged currents at the Nortek profiler station indicated in Fig 21.

Flushing Times and Water Quality

The calibrated and verified hydrodynamic model was applied to investigate possible restoration and enhancement issues in Scott Creek. One of the key concerns at the inception of the project was the deterioration of water quality near the causeway. Water quality has a strong relation to the circulation and flushing characteristics of a water body. Flushing rates tell how quickly water inside the creek is replaced or leaves the water body. The particle-tracking component of the model was applied to simulate particle transport and residence time distribution for the existing creek and how it would change after potential breach of the causeway. In breaching the causeway, the bed elevation of the opening was determined from the natural gradient between the nearby stations SCE1 and SCW1. Similarly, the opening width was also maintained as the average of the approaching channels. The model was forced with a harmonic tide of 1.3 m (4.3 ft) amplitude and a period of 12 hours that roughly represents the maximum tidal amplitude and dominant period for Scott Creek. In applying the boundary conditions, the appropriate phase difference and amplitude amplification between Edisto Beach and Big Bay were applied. The residence time within the Creek was computed by simulating particles transported for a 6-day period (144 hours). Fig. 30 shows the computed along-channel residence time distribution for the existing creek condition (top panel) as well as the existing and after-breach scenarios (bottom panel). River mile zero was set near the confluence at Big Bay Creek. As seen in the top panel, for the existing condition, between river mile 2.5 and 3.5, a substantial fraction of pollutants entering or originating in this area took a longer (more than 4 days) time to leave the system. Pollutants near the causeway had a residence time greater than 6 days. It is presumed that this value is linked to the poor water quality observed at this location. The model computed a global maximum residence time of 5.5 days after breaching the causeway. This was an improvement compared to more than 6 days for the status quo condition. However, as shown in Fig. 30 (bottom panel), the residence time close to west side-approaching channels increased. This was due to reduced velocity where the two tides converge. Although there was improvement in the global flushing rate, the overall improvement was not substantial.

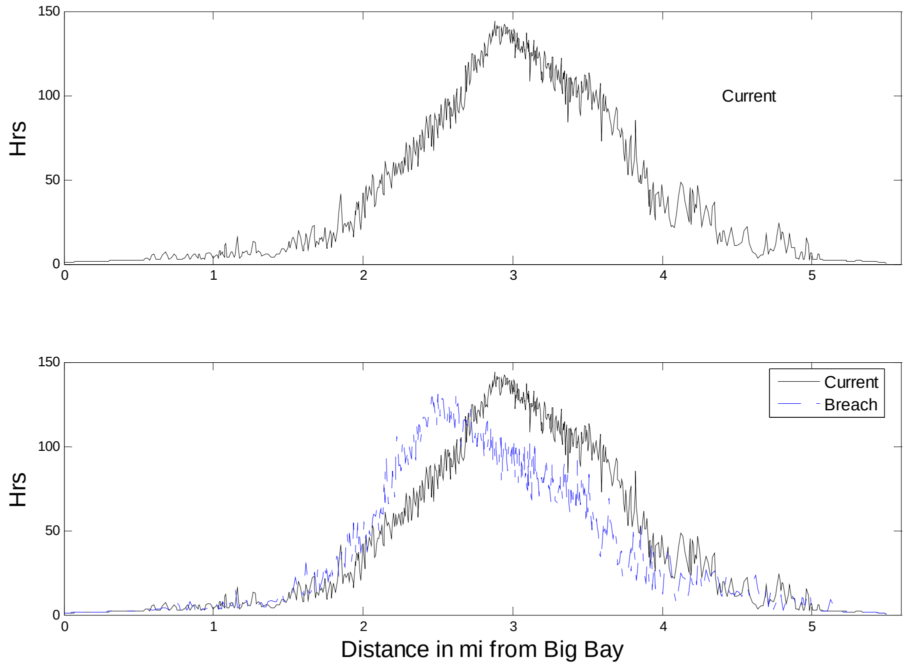

Fig. 30. Longitudinal profiles of computed residence times of water for the present situation with the causeway intact (Current) and breached causeway (Breach) conditions.

In order to improve the circulation and other water quality issues, different causeway-opening alternative layouts were considered. In doing so, two important factors were considered. First, the creeks near the causeway showed a strong meandering nature. These features were prone to siltation/deposition by increasing drag on the axial flow and reducing net current speeds. Secondly, these meandering stretches would reduce the flushing rate of the system and hence exacerbate water quality problems. In light of these factors, a bypass to the meanders near the causeway was evaluated. Two additional breach schemes were tested that avoid the more pronounced meanders (Fig. 31). The layout in Case 2 had less meanders. The widths of the opening were set to be roughly 22-25 m (75-82 ft) based on the average width of the approaching channels. The bed elevations of the openings' channels were linearly interpolated from the bed elevations of the approaching channel ends. Generally, the bed elevation in the new openings (Case 1 and Case 2) varied between -4.9 and -6.0 ft (NAVD88). A number of test runs were conducted to simulate the residence time distribution for the different breachway alternatives.

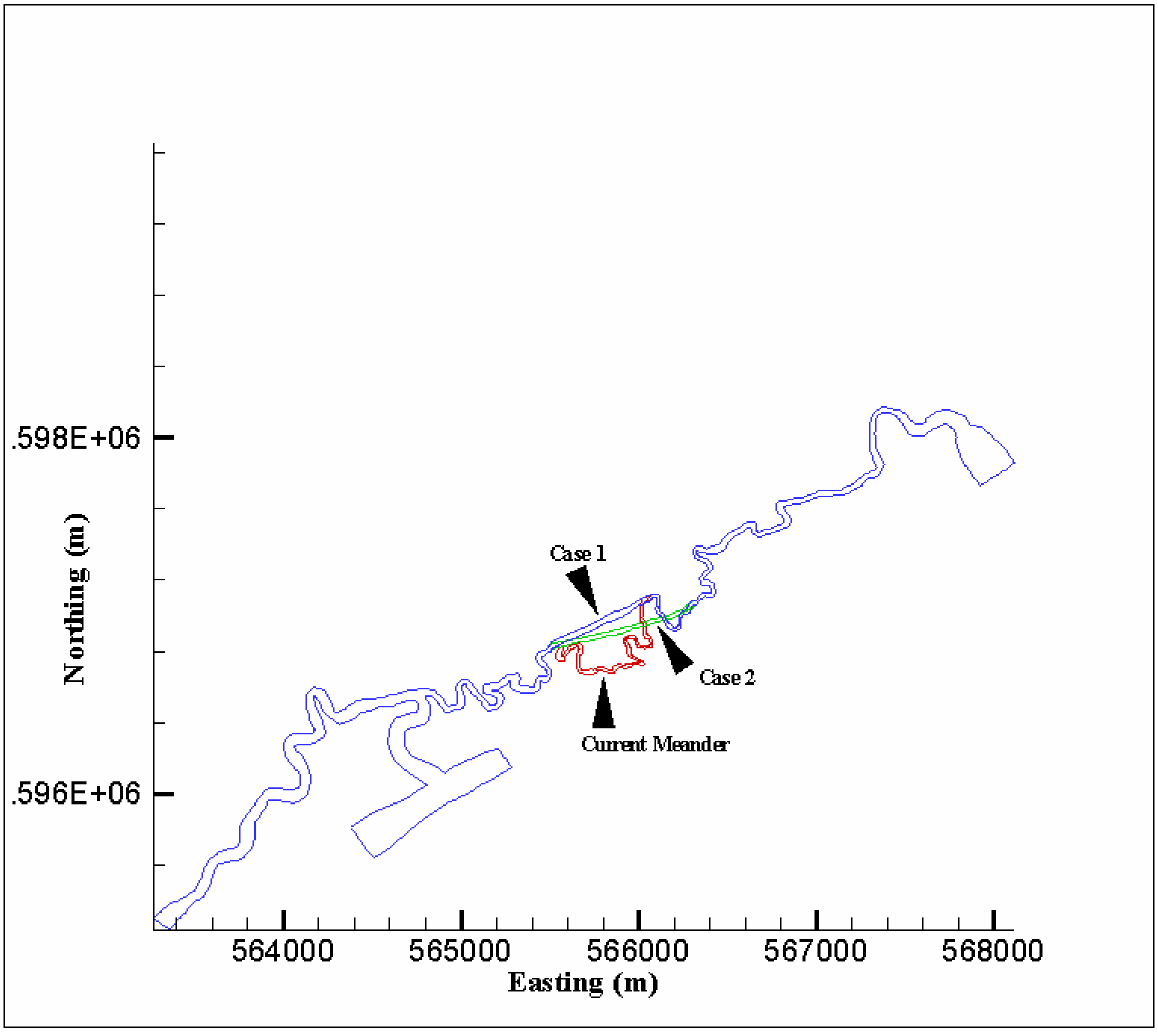

Fig. 31. Alternative schemes for breaching the Edisto Beach Causeway.

Fig. 32 shows computed residence time profiles along the centerline of the creek for different opening layouts along with the status quo condition. Residence time distribution for different opening (breach) layouts were compared with the present status quo condition (Fig. 33). There was a substantial improvement in flushing rates in Case 1 and Case 2 layouts. The maximum global residence times computed were around 134, 111, and 116 hours for the breach, Case 1 and Case 2 layouts, respectively. The average residence times for the breach condition, case 1 and case 2 layouts were 49, 36, and 29 hours, respectively. The average and global maximum residence times computed for the status quo were more than 60 and 144 hours, respectively. Although the maximum global residence time for Case 2 was 5 hours higher than Case 1, the average residence time for Case 2 was smaller than Case 1, which indicated that, on the average scale, the whole creek could be flushed faster according to the Case 2 layout with large portions of the creeks flushing within one day. Generally, the comparisons of the simulations

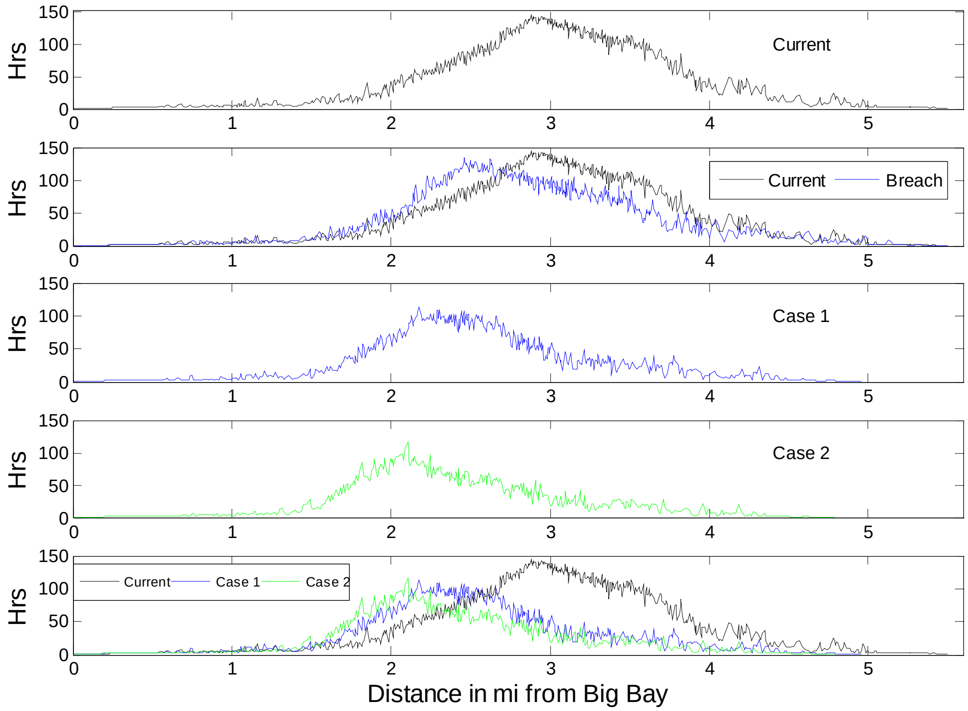

Fig. 32. Longitudinal profiles of computed residence times for alternative breach schemes shown in Fig. 31, including the: current meander (Current), Case 1 (Breach), and Case 2 (Breach) scenarios.

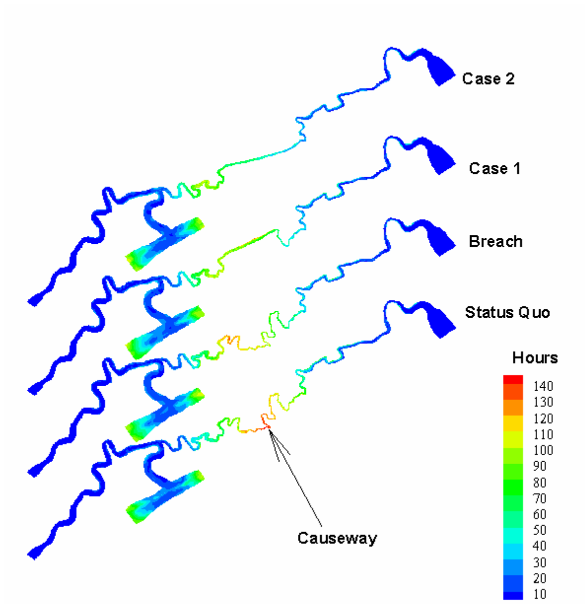

Fig. 33. Longitudinal profiles of computed residence times for alternative breach schemes shown in Fig. 32, including the: current meander (Current), Case 1 (Breach), and Case 2 scenarios.

indicated that the opening of the causeway would substantially improve circulation and exchange in Scott Creek. The opening layout in Case 2 gave the best mixing and self-flushing capacity for the whole creek.

Nearly half of the area inundated during an average spring high tide has velocities that are not substantial enough to transfer coarse sediment greater than fine sand, and may be classified as headwaters, precipitation drainage areas or critical habitat areas. Without consideration for sea level rise, this system should infill over time; however, results from Sharma, et al. (1987), for salt marsh environment of North Inlet, South Carolina, show vertical accretion rates were keeping pace with local sea level change (~2.5 mm/yr). In the case of Scott Creek, it is anticipated that a channel through the causeway would result in greater mobilization of in-channel sediment and reduced floodplain inundation, increasing exchange rates and ultimately decreasing residence time of waters in this East Scott Creek basin. Therefore, neglecting the influence of West Scott Creek, for the moment, a breach in the causeway may improve water quality and reduce sensitivity of the floodplain habitat areas by reducing the stagnation of waters over these areas.

Tidal Nodes

Another interest in this project was to determine tidal flow direction after the opening of the causeway: where would the tidal nodes develop for eastern and western side tidal confluence and what would the magnitude of tidal currents be under the openings. Fig. 34 shows comparisons of tidal water surface elevations between stations SCE1 and SCW1. The top panel shows the comparison between observed data at SCE1 and SCW1 while the bottom shows the comparison between model predictions at SCE1 and SCW1. The tide level at SCW1 had higher tidal amplitude, but the tide level at SCE1 arrived at the causeway earlier than SCW1. This meant that if the causeway was to be breached, the water would initially flow from east-to-west, past the causeway location. Later, when the high tide arrived at the causeway, the direction of flow would reverse from west-to- east, due to the difference in tidal amplitude. In order to substantiate this argument, different model runs with each alternative layout were made. In all cases, the model was forced with a harmonic tide of 1.3 m (4.3 ft) amplitude and a period of 12 hrs. All tests indicated that the water from the east would cross the opening earlier than that from the west, and the tidal node would occur at roughly the point designated as ‘ET’, in Fig. 35, which is 950 m (3,117 ft) to the west of the causeway. The late arriving high tide from the west would push the node back to the point labeled ‘WT’ which is 450 m (1,476 ft) east of the causeway. The distance between ET and WT was roughly 1,400 m (4,600 ft).

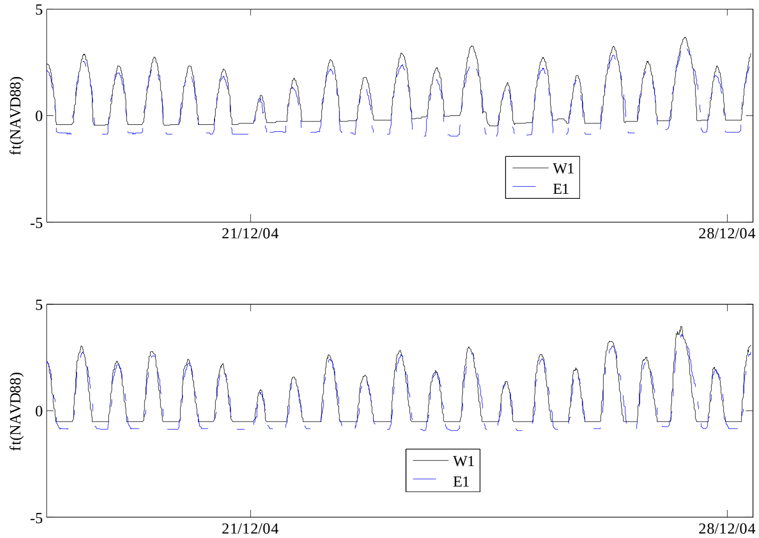

Figure 34. Comparison of measured (top panel) and simulated (bottom panel) water surface levels at the SCW1 (W1) and SCE1 (E1) stations.

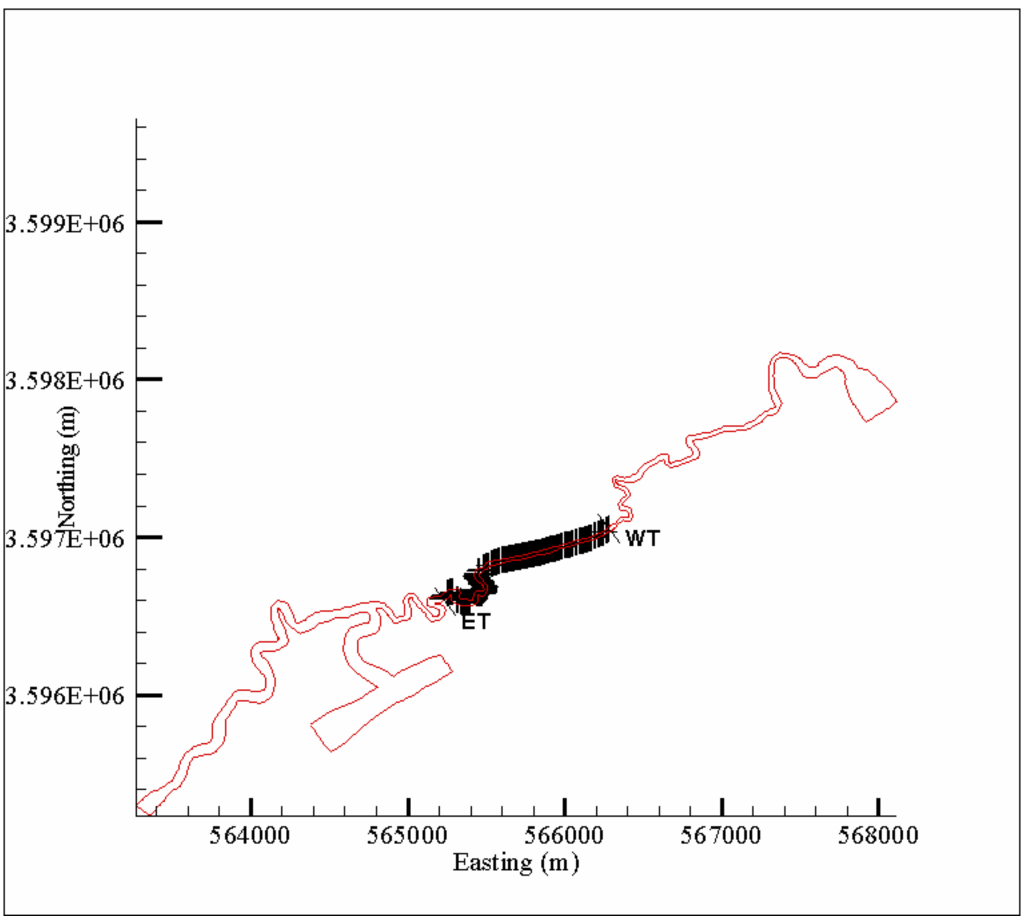

Fig. 35. Range of East and West Scott Creek tidal convergence occurrence indicates zone of tidal node development that would occur under breach condition Case 2.

Water Level Changes

Fig. 36 shows plots of water surface variations along the centerline of Scott Creek for three high tide conditions. The profile indicated by 'EHIGH' refers to a condition of high tide at Jeremy Inlet. Similarly, 'BHIGH' and 'CHIGH' refer to high tide at Big Bay and near the causeway, respectively. River mile zero was positioned at Jeremy Inlet. The top panel shows the comparison for the existing (current) situation. The middle and bottom panels show the Case 1 and Case 2 layouts, respectively. As seen from these plots, the model predicted no significant variations (rise or fall of water surface levels). In all cases, the maximum water surface elevation on the western side of the causeway was nearly 4.4 ft (NAVD88). Similarly, the maximum surface elevation on the eastern side of the causeway was 4.35 ft (NAVD88). There would not be a noticeable difference in water height as a result of the breaching or opening of the causeway. Furthermore, these analyses did not include flood plain inundation. The flood plain naturally provides a relief environment whereby the incoming tidal amplitude is dampened. Hence, the result without inclusion of the flood plain should be considered a more liberal approach regarding potential rise of the water surface. On the other hand, the causeway can be considered a headwall or weir that prevents the natural flow of water and raises water levels. Hence, the breach of the causeway would create an environment where the water easily finds a natural flow for either side of the causeway, without raising water surface levels.

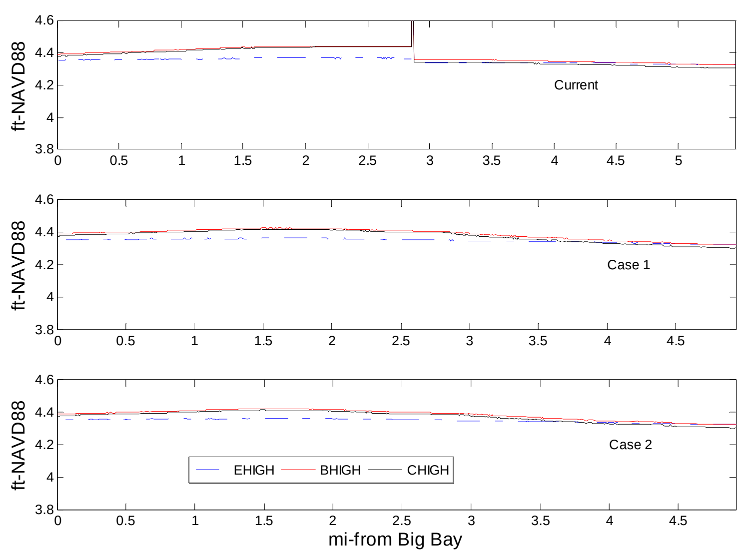

Fig. 36. Longitudinal profiles of creek centerline water surface levels during high tides near Jeremy Inlet (E HIGH), Big Bay Creek (B HIGH), and the causeway (C HIGH) under present conditions with the causeway intact (Current), as well as Case 1 and Case 2 breach scenarios.

Fig. 37 shows water levels and current variations for two points designated as 'east' and 'west'. The east point refers to a location close to the starting point of Case 2 layout on the eastern side of the causeway and the west point refers to the starting point of the of Case 2 layout on the western side of the causeway. As seen in the plots, there was no noticeable difference in surface elevations for the three cases. However, there was a slight increase in the magnitude of currents at the east station.

Tidal Prisms

Tidal prisms were computed to assess possible changes in the volumes of tidal water moving in and out of Scott Creek according to the different scenarios. The tidal prism is defined as the total volume of water that is exchanged between the creek and the open sea during one tidal period. Table 7 shows computed tidal prisms for the status quo, breach condition, and Case 2 layouts. The model results indicated that the tidal prisms for the status quo condition were nearly balanced when comparing ebb and flood. The tidal prism exchange between Big Bay Creek and West Scott Creek (western boundary) was approximately 3 times that of East Scott Creek and the Atlantic Ocean through Jeremy Inlet (eastern boundary). The opening of the causeway (in the breach condition and Case 2 layout) would cause a slight increase in the ebb and flood tidal prism passing through Jeremy Inlet and would slightly reduce that of the western boundary (Fig. 38). There would be a slight increase in the peak ebb volumetric exchange at Jeremy Inlet for the breach and Case 2 openings. This increase in discharge along with change in the creek bed gradient would slightly increase the peak currents (1-3.5 percent) during tidal ebb near Jeremy Inlet.

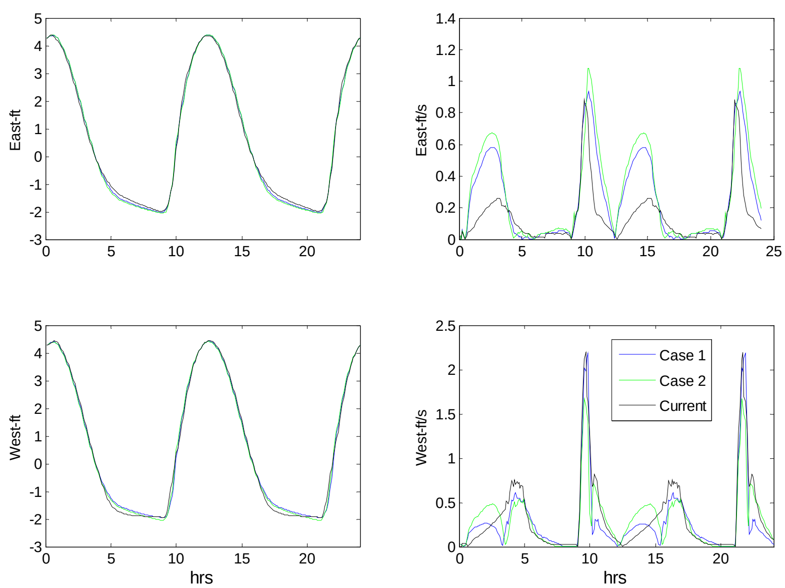

Fig. 37. Tidal variations in water surface elevations (left panels) and currents (right panels) at two locations near the causeway, in East Scott Creek (top panels) and West Scott Creek (bottom panels) simulated for 2 semidiurnal tidal periods for the present condition with the causeway intact (Current), as well as Case 1 and Case 2 breach scenarios.

Table 7. Computed tidal prisms for various scenarios at Scott Creek.

Scenario/Grid Layout	Inlet	Tidal Prism			
		Flood		Ebb	
		Million m^3	Million ft^3	Million m^3	Million ft^3
Status Quo	East	0.225	7.938	0.221	7.796
	West	0.896	31.610	0.891	31.399
Breach	East	0.237	8.361	0.241	8.502
	West	0.885	31.222	0.870	30.693
Case 2	East	0.251	8.855	0.259	9.137
	West	0.847	29.992	0.829	29.247

Residual Currents

In tidal environments, residual currents are generally regarded as indicators of the net movement of suspended particles during a tidal cycle. Fig. 38 shows computed residual currents for different scenarios discussed earlier for a harmonic tide of 1.3 m (4.3 ft) amplitude. Computed residual currents generally indicated an ebb-dominated feature where the net direction of the residual currents was out of the system. The magnitudes of

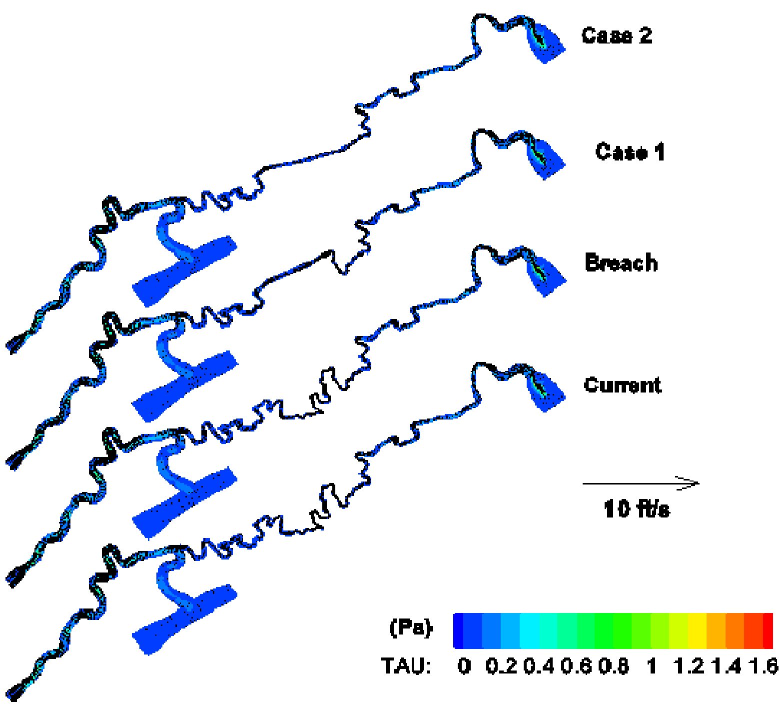

Fig. 38. Interpolated colorimetric plots of residual currents and shear stress distributions for the present condition with the causeway intact (Current) as well as alternative breach schemes shown in Fig. 31, including: the present meander (Breach), Case 1, and Case 2.

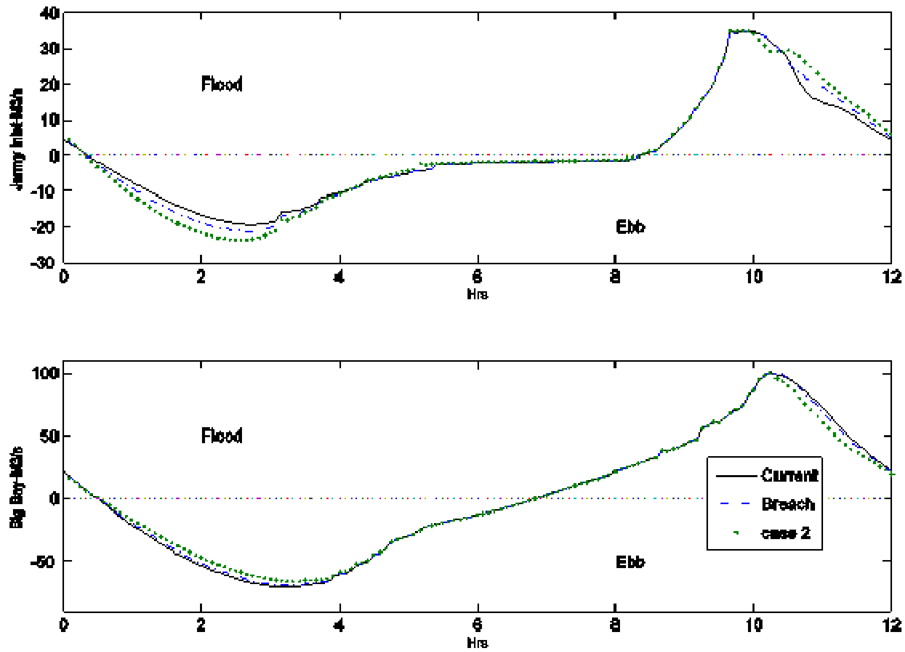

Fig. 39. Semidiurnal tidal variations in volumetric flux through Jeremy Inlet (top panel) and to Big Bay Creek (bottom panel) under the present condition with the causeway intact (Current) as well as alternative breach schemes shown in Fig. 31, including: the present meander (Breach) and Case 2.

the residual currents varied from 0.0 to 0.2 ft/sec. Maximum residual currents (up to 0.3 ft/sec) were computed near the Jeremy inlet, where there was a constriction of the inlet. There was no noticeable difference in residual currents between the status quo and the different opening layouts. Fig. 38 shows computed residual shear stress. The shear stress is a critical parameter for the stability of the creek bed. Maximum shear currents were computed near Jeremy Inlet.

Breach Opening Widths and Stability

The peak water current velocity in a breach in the causeway is an important variable that affects the stability of the channel opening. The stability of the bed material is important as it is related to the stream's ability to maintain a near-stable bed profile over the course of time. Peak velocities in tidal channels depend on the opening width of the causeway and on the relative size of the tide amplitude. The stability of the opening depends on several factors including the shear stress, particle size of the bed material, particle size of particles in suspension, etc.

Friedrichs (1995) related channel embayment morphology to the flow properties through stability shear stress theory. The stability shear stress (τs) is defined as a minimal shear stress that is necessary to maintain a zero gradient in net along-channel sediment transport. It is assumed that if the peak shear stress during spring tide is locally greater than the τs, net erosion will occur, whereas if it is less than τs, there will be net deposition. The lower boundary on (τs) was derived from the condition where the maximum grain size shear stress is equal to the critical grain size shear stress necessary for ignition of sediment motion. He gave equation 1, for the upper boundary on equilibrium cross-sectional geometry (lower boundary on critical shear stress), as a function of discharge (Q), and other externally fixed variables, describing sediment (grain diameter, specific gravity), and roughness characteristics (n).

$$AH_R^{1/6} = Qn\left(\frac{\rho g}{\tau_c}\right)^{0.5}, \qquad (1)$$

where the critical shear stress, τ_c, is defined as $\tau_c = \psi_c \rho g G d \left(\frac{\tau'}{\tau}\right)^{-1}$, where A is the cross sectional area, H_R is the hydraulic radius of flow, G is the specific gravity of the sediment in fluid, d is the grain diameter, and the dimensionless constant ψ_c is the critical Shields parameter (usually 0.05).The $\left(\frac{\tau'}{\tau}\right)$ is the ratio of grain shear stress to total shear stress .

To estimate the peak discharge flowing through the opening (causeway breach), the model was forced with a harmonic tide of 1.3 m (4.3 ft) amplitude and a period of 12 hrs. Two model runs were made. The first model run was done using the status quo grid scheme and the second run was done with the status quo grid scheme, but with a breached condition in the causeway (where only the causeway was removed). Discharges were computed at four sections. These were two locations at or near the open boundaries and two interior locations. The two interior locations coincided with the beginning sections (east and west side of the causeway) of the alternative opening layout.

Fig. 40 shows the computed time series of discharges at four locations. The top rows show computed discharges at the open boundaries in Jeremy Inlet (top left) and near Big Bay Creek (top right). Two locations were also chosen at the eastern and western sides of the causeway. These points coincided with the beginning sections of the alternative opening layout shown in Case 2 at the eastern and western sides of the causeway. The left figure in the bottom row shows the computed time series of discharge on the eastern side of the causeway and the right figure shows the computed time series on the western side of the causeway. Ebb discharge to Big Bay (the western boundary) was almost four times that through Jeremy Inlet (the eastern boundary). This difference was attributed to the small inlet width at Jeremy Inlet versus the wider opening at the confluence with Big Bay. The model computed nearly 2.4 and 9.7 X 10^6 m^3 tidal prisms at the eastern and western boundaries, respectively. The peak ebb discharge at Jeremy Inlet showed a slight increase after the breach of the causeway. This was due the additional floodwater that came from the western side.

The peak discharge that would flow through the new opening was the maximum of the peak discharges approaching from the eastern and western sides of the causeway. The maximum computed peak discharge was 8.1 m^3/sec (285 ft^3/sec) approaching from the eastern side. To use Equation 1, the following assumptions were made. First, the grain diameter was 0.25-mm (0.01-in) (for medium sand) based on observed sediment core profiles for the western side of the causeway (Dumars, 2007). The specific gravity of medium sand, G, was taken as 1.65 and for (τ'/τ) the value of 0.4 was used (Friedrichs, 1995). The combination of these values gave $\tau_c = 0.5$ Nm^{-2} (Newton/m^2).
Using the peak discharge, previously calculated, and a Manning Coefficient of 0.02, Equation 1 was solved for a trapezoidal cross-section with a side slope of 0.5. The side slope and trapezoidal cross-section were chosen for maximum stability. The solution

gave a bottom width of 2.0 m (6.5 ft) and top width of 17 m (56 ft) for a maximum flow depth of 2.5 m (8.2 ft). This was the upper boundary of the area. The above solution applies mainly for non-cohesive sediment.

In applying the critical shear stress theory to cohesive sediments, Friedrichs (1995) used the magnitude of critical erosion shear stress (τ_e) typically observed above mud bottoms in place of τ_c. τ_e represents the shear stress necessary to initiate substantial erosion. Friedrichs (1995), based on literature review, gave a value of 0.7 Nm^{-2} for τ_e. Using this value and solving Equation 1 gave a bottom width of 2.0 m (6.5 ft) and top width of 17 m (56 ft). Reported values of τ_e vary from 0.05 to 1.30 Nm^{-2}. Given this great variability, more accuracy would be gained choosing the size of the area based on the non-cohesive sediment model.

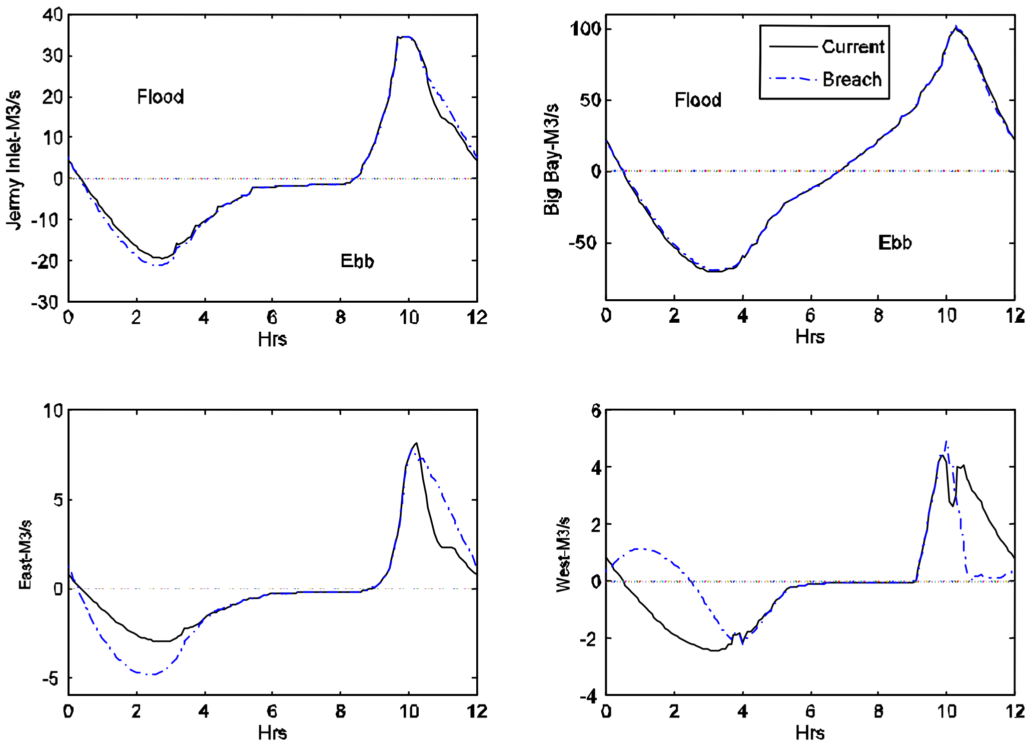

Fig. 40. Semidiurnal tidal variations in volumetric flux through Jeremy Inlet and near Big Bay Creek (top left and right panels, respectively) and at locations near the causeway, to the east and west (bottom left and right panels, respectively) under the present condition with the causeway intact (Current) as well as the Case 2 breach scheme as shown in Fig. 31.

Navigation Potential For Scott Creek

Water depth at the mouth of West Scott Creek reaches -11.5 ft and the thalweg of West Scott Creek maintains a nearly constant elevation (-11.5 ft to -9.8 ft) until it passes the channel going to the 'boat basin', 1.6 miles from its confluence with Big Bay Creek. From this point northeast to the causeway, the West Scott Creek channel is highly sinuous and navigability is reduced during low tide, with thalweg elevations rising from -6.5 ft (within 300 ft of the fork) to -0.5 ft near the causeway. This domain of West Scott Creek appears to have been filling with fine grain sediment during recent history, whereas below the 'boat basin' split, the channel appears to be scoured. The channel going to the ‘boat basin’ supports navigation with bed elevations reaching –10.5 ft until it splits at the basin. The ‘boat basin’ itself is flanked by high stands of pluff mud, which seem to indicate fine sediment deposition. From the research of historical morphology, it appears that the ‘boat basin’ split from West Scott Creek has been increasing in width since its creation in the 1950’s. Following the 1950’s, West Scott Creek from the split to the causeway has been getting narrower. Presumably, episodes of local runoff combined with continuous discharge from a storm water detention system for Edisto Beach has helped to maintain flow and thereby navigability from this basin toward Big Bay Creek.

The mouth of East Scott Creek at Jeremy Inlet has a shoal comprised of coarse marine sediment at –2.6 ft elevation. Within 0.2 miles from Jeremy Inlet, thalweg elevations of –2 ft to –3 ft restrict navigation. East Scott Creek deepens beyond this point, to elevations of –6 ft to –5 ft, supporting navigation during most tide levels for 1.5 miles of its length toward the causeway. At this point the Creek maintains a bed elevation near -4 ft through another 0.75 miles of creek length where it rises to reach –0.85 ft over the final 0.25 miles to the causeway. The last one-mile portion of the creek also has higher sinuosity, similar to the region of West Scott Creek from the ‘boat basin’ fork to the causeway.

In order to support navigation from Big Bay Creek through Scott Creek to the Atlantic Ocean at Jeremy Inlet, the first step would involve breaching the causeway, and the second would involve removal of approximately 3.5 ft of sediment for a distance of 0.4 to 0.6 mi, bypassing the numerous meanders and passing through the causeway. This alteration would directly impact approximately 0.6 to 0.9 mi of East Scott Creek through meander bypassing and around 0.7 mi of West Scott Creek, in the same manner, much of this distance being high areas that are rarely inundated with tidal water.

Although much of the area proposed for excavation of sediments for Case 1 and Case 2 breachways for the Edisto Beach Causeway would occur in high-ground areas that are seldom flooded with tidal water, some portions of the proposed channels would involve low marsh areas which are of biological importance. In addition, the reaches of creek near the causeway that would be bypassed by the new canals would lose flow and likely fill in with time. This could result in loss of marsh-water edge habitat, fringing marsh and other associated low *Spartina* marsh. Hackney et al. (1976) noted that small, first order tidal creeks had higher species richness because they were less tidally influenced and had more stable salinity. A study in Tijuana Estuary in California found that first order creeks had lower dissolved oxygen and occasionally higher temperatures at low tide (Desmond et al, 2000). Similar conditions have been noted in South Carolina and this physical condition may serve to extirpate predatory fishes at low tide when juvenile fishes and crustaceans are relegated to the shallow waters in the creek bottoms (A. F. Holland, pers. comm.) . Desmond, et al., (2000) recommended that “incorporating small tidal creeks at restoration sites could increase the extent to which resident fishes use the marsh and could also provide increased nursery habitat for some species. They did note, however, that excavations below the marsh plain elevation could result in natural development of small dendritic tidal creeks although dense marsh plant roots could inhibit this.

There are probably additional alternatives for causeway breaches that would result in less dredging and less alteration of existing marsh (Fig. 41). However, these other alternatives would likely result in less efficiency in flushing of the system,

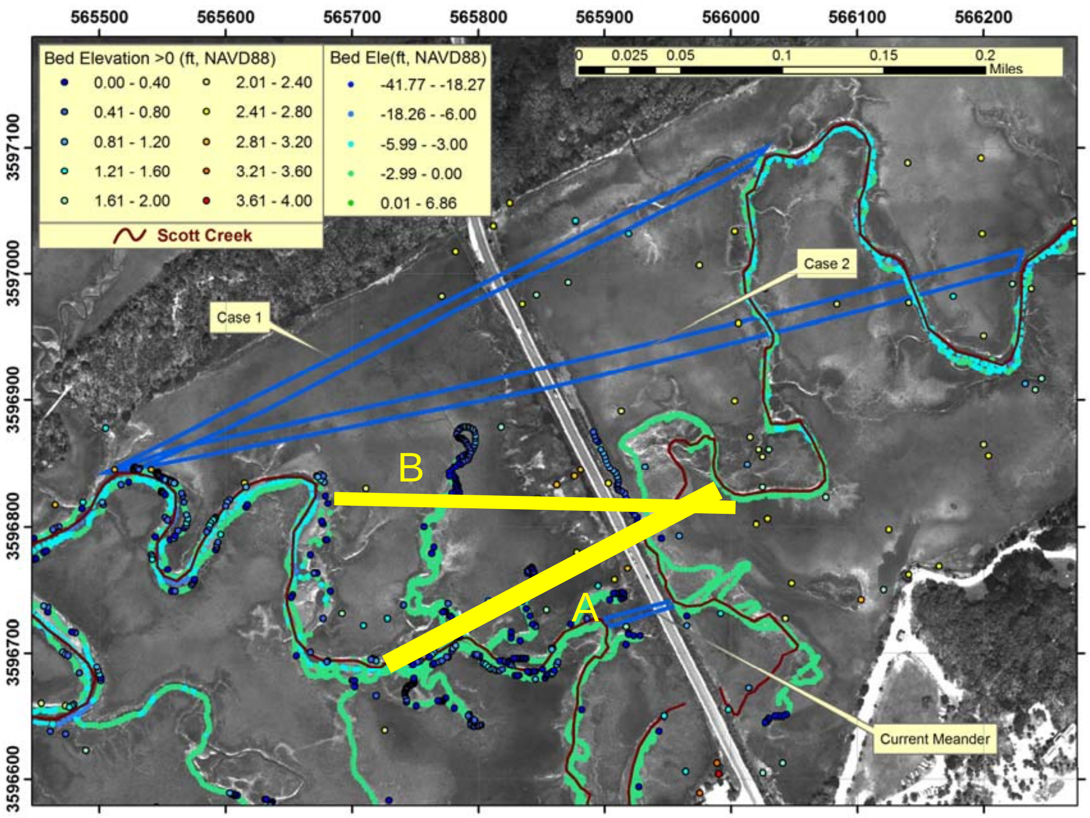

Fig. 41. Illustration of various breachway alternatives investigated in this report (Case 1, Case 2 and Current Meander) along with two other potential alternatives (A and B).

with flushing rates being intermediate between the Cases 1 and 2 and the current meander scenario (as discussed in the Flushing Rates section). Alternatives for dredged areas shorter than those of Cases 1 and 2 would likely be less costly in terms of dredging and channel stabilization dollars. Additionally, the Department of Transportation may have logistical or engineering preferences for picking a breach location. Determination of the ideal breach scenario should probably be accomplished through a thorough Environmental Impact Statement that would include all factors (hydrological, water quality, engineering, biological, social, and economic).
would be shorter and perhaps more acceptable from biological and funding perspectives, although less efficient in terms of flushing.

Summary of Hydrological Studies

A depth-integrated two-dimensional hydrodynamic and particle transport model was developed for Scott Creek estuary. The model was calibrated and verified with measured water surface levels and currents. The verified model was then used to interpret 1) the effects of the causeway on the environmental quality of Scott Creek and 2) the potential environmental benefits of modifying its design through breaching the causeway. In the modeling exercise we investigated the effects of various causeway breach configurations on circulation and exchange within Scott Creek. Modeling results indicated:

1. Removal of the causeway will impact flushing rates of Scott Creek. Breaching of the causeway, combined with the natural tidal conditions (amplitude and phase difference between the eastern and western boundaries) increases the self-flushing capacity of the creek. This should improve water quality conditions.
2. The opening of the causeway along the layout indicated in Case 2 (which includes straightening of the creek) gives the best self-flushing capacity to the creek as a whole.
3. All tests indicated that the water from east Scott Creek would cross through the breach at the causeway earlier than that from the west, and the tidal node would occur at roughly the point 950 m to the west of the causeway. The late arriving high tide from the west would push the node back to a point 450 m east of the causeway, a distance of about 1,400 m (4,600 ft).
4. Comparisons of water surface levels show no noticeable water surface difference before and after the opening of the causeway. It is believed that the removal of the causeway will enhance water movement across the highway, mitigating any hazard of flooding.
5. Opening the causeway will result in a slight increase (15-17 percent) in the amount of tidal prism (volume of water) leaving Jeremy Inlet as a small portion of the water from the west joins the water ebbing through Jeremy Inlet. The impact of this increase in discharge along with the change in gradient shows a small increase (1-3.5 percent) in the peak ebb tidal currents near Jeremy Inlet.
6. Computed residual currents indicate an ebb-dominated feature at Jeremy Inlet, where the net direction of the residual current is out of the system.
7. To maintain a zero gradient in net along-channel sediment transport and a stable causeway breach, it is recommended that the causeway breach should have a trapezoidal cross-section with a bottom width of 2.0 m (6.5ft) and a top width of 17 m (56 ft) with a side slope of 0.3.
8. In order to support navigation, after causeway breaching, from Big Bay Creek through Scott Creek to the Atlantic Ocean at Jeremy Inlet, approximately 3.5 ft of sediment for a distance of 0.4 to 0.6 mi would have to be removed. However, shorter routes that might mitigate biological impacts to low marsh should be investigated, but these would likely result in reduced flushing rate efficiencies.

Biological Studies

Vascular Plant Community Mapping Study of Scott Creek
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The purpose of the plant community mapping portion of this research is to establish a baseline map in which to compare changes in salt marsh communities following the construction of a proposed causeway bridge. From an ecological perspective, construction of a bridge on the Edisto Beach Causeway will restore the historical tidal creek connection of Scott Creek, which was disrupted with the construction of the earthen causeway in late 1930's. Approximately 64 years of reduced or no water flow between the eastern and western sections of Scott Creek has altered the hydrology, sedimentation, and water/substrate chemistry, which has affected the plant and animal community structure. Without spatially explicit plant and animal community structure data prior to causeway construction, we are unable to assess how these communities have changed or predict changes resulting from the reintroduction of creek flow. This portion of the report documents the initial mapping of plant communities within the Edisto Beach back barrier salt marsh that is likely to be affected by construction of a causeway bridge.

Methods

Aerial photography was used to assess the general spatial relationships among the different plant communities within the marsh system (Fig. 41). A geo-referenced base map was established using ArcView GIS version 3.1 (Environmental Systems Research Institute, Inc.) and the Edisto Island southeastern (http://www.dnr.state.sc.us/water/nrima/gisdata) 1994 digital orthophoto quarter quadrangles. There were no noticeable differences in creek topology between the 1994 and 2004 photographs. Trimble Pro XR (Trimble Navigational Limited Surveying and Mapping Division, Sunnyvale, CA) backpack global positioning system was used to obtain the latitude and longitude coordinates of plant community boundaries within the 8.0 hectare area of interest. Six plant communities (tall *Spartina alterniflora*, short *Spartina alterniflora*, *Salicornia virginica*, *Batis maritima*, *Juncus roemerianus*, and *Borrichia frutescens*) and three areas devoid of vegetation (open water pools, sand, and *Spartina* dieback area) were delineated. In order to objectively locate borders between community types, we defined the boundary of a plant community type as having greater than 90% relative cover of the target species in a 0.25 m^2 quadrat. Longitude and latitude coordinates were used to map the current spatial distribution of community types onto the 1994 base map. As a result of our sampling protocol, every datum point used to map community types was based on quantitative field data.

A.

B

Fig. 42. Oblique aerial photographs taken at an elevation of 1500 ft in (A) March and (B) June of 2004.

Quantitative Measures

A minimum of three randomly located 0.25 m^2 quadrats were used to assess plant species composition and abundance, and densities of crab burrows (> 7.0 mm diameter), ribbed mussels (*Modiolus demissus*) and gulf periwinkles (*Littoraria irrorata*) within each community type. In addition to *L. irrorata* densities, we recorded the number of individuals belonging to five shell height size classes (class 1= 0-5 mm, class 2= >5-10 mm, class 3= >10-15 mm, class 4= >15-20 mm, class 5= >20-25 mm). These quantitative measures were used to characterize the each polygon.

Analyses

Plant community relationships were assessed using unweighted pair group means analysis (UPGMA) using relative Euclidean distance matrix. Because we randomly sampled plant abundance within a priori plant communities, we also used Multi-Response Permutation Procedures (MRPP) to test the hypothesis, which found no difference in plant species abundance between the a priori plant communities. A nonsignificant MRPP result indicates no statistical difference between the a priori groups, suggesting the a priori groupings were not correct. Cluster and MRPP multivariate analyses were preformed with PC-Ord version 4.2 (McCune and Mefford 1999). ANOVA was used to determine if there were differences in plant species abundance, burrow and *M. demissus* densities, and *L. irrorata* size class distributions among plant communities. Data were log transformed when appropriate and REGWQ means separation procedure used to test for difference among means. All ANOVA and summary statistics were performed using SAS version 8.2 (SAS International, Cary NC).

Results

There were nine community types identified from the field, with six plant communities and three were defined by no plant species presence (sand, open water, dead) (Fig. 42). There was a higher concentration of high marsh plant communities (*Borrichia* & *Salicornia*) along the western side of the causeway relative to the low marsh tall *Spartina* community to the east. There were two *Batis* communities unique to the eastern marsh, despite suitable habitat in the western marsh.

Cluster analysis revealed predictable patterns of quadrat to plant community type associations (Fig. 3). Despite the six quadrats not associating with their plant communities, the MRPP analysis (T=-48.98, A=0.79, P<0.0001) supported our plant communities as appropriate groups. These groupings were based on field data which clearly illustrate the characteristic species for each community (Figs. 44 and 45).

The distribution of *M. demissus* ($F_{5,107}$=1.34, P=0.253) and crab burrows ($F_{5,107}$=1.82, P=0.115) did not vary among plant communities, but there were differences in *L. irrorata* densities ($F_{5,107}$=28.42, P<0.0001). *Littoraria irrorata* populations were most abundant in short *Spartina* followed by tall *Spartina* and *Juncus* communities and there were significant differences in size distributions among plant communities (Fig. 46). Individuals in class size five (>20-25 mm) were most common in *Juncus* and *Spartina* communities ($F_{5,107}$=5.35, P<0.001), while the fourth (>15-20 mm; $F_{5,107}$=11.95, P<0.0001) and third (>10-15 mm; $F_{5,107}$=20.44, P<0.0001) class sizes more most prevalent in short *Spartina* followed by *Juncus* and tall *Spartina* communities (Fig. 46).

Recruitment class densities two (<5-10mm; $F_{5,107}$=13.02, P<0.0001) and one (0-5mm; $F_{5,107}$=13.62, P<0.0001) were highest in the short *Spartina* community (Fig. 46).

Discussion

There were six plant communities and three non-plant community types mapped along the Edisto Beach causeway in June 2004. These plant communities were similar to other southern salt marshes and represent the typical salt marsh communities along an elevation gradient. The tall *Spartina* community was concentrated along the tidal creeks, while short *Spartina* occupied the transition to the high marsh *Salicornia* and *Borrichia* communities (Fig. 42). *Batis maritima* community consisted on only two small areas (total area 85 m^2) in the eastern high marsh, despite sufficient habitat on the western side of the causeway. This may indicate that the earthen causeway is a significant barrier to plant dispersal and reconnection of Scott Creek will help restore the potential for dispersal.

The ribbed mussel (*Modiolus demissus*) and crab burrow (as a measure of sediment burrowing crab community) densities did not differ between plant communities; however this does not mean that they will not be affected by alterations to Scott Creek hydrology. The lack of a clear association between *M. demissus* and our plant communities may reflect the natural heterogeneous spatial distribution of these animals in southern marshes, which could result in a sampling bias. No difference in the number of crab burrows suggests that the ecosystem functions conducted by these crabs may stay relatively constant among plant communities. Spatial shifting of crab species in association with shifting hydrology and plant communities may be an important change following bridge construction, although documenting the spatial / temporal dynamics of these may be complicated by intraspecific, interspecific, and predator-prey dynamics.

The gulf periwinkle (*L. irrorata*) is one of the most abundant animals in this marsh system, with difference in size distributions among plant communities. These differences reflect elevation and tidal inundation as well as the height of the dominant plant species. There were twice as many animals in the short *Spartina* compared to the taller *Juncus* and tall *Spartina* communities, with fewer in the high marsh *Batis, Salicornia,* and virtually no animals in the *Borrichia* communities. If this distribution is based strictly on elevation, one would have predicted similar densities between the *Juncus* and other high marsh plant communities. It is also clear that the distribution is not solely driven by host plant identity as evident by the striking difference between tall and short *Spartina*. The distributions of size classes among plant communities reflect significant implication for population dynamics within each plant community. There was a consistent pattern of relatively similar numbers of smallest and largest size classes with significantly more intermediate sized animals in short *Spartina, Salicornia, Batis,* and *Juncus* communities (Fig. 46). The size class distribution within the tall *Spartina* community is skewed to the right, with an increasing number of animals in larger size classes. One possible, but not exclusive, explanation for these differences could be differences in predation rates between plant communities. Contact with keystone predators such as blue crabs and terrapins are more likely in the tall *Spartina* community, due to proximity to the creek and water depth, which may result in increased predation rates. Prey size biases could also contribute to this difference in size distribution. Large *L. irrorata*, for example, may be too large to handle efficiently or the shells too thick to crush, resulting in increased predation on small size classes. Regardless of the causes for the differences in size class among plant communities, alterations to the hydrology and potential shifting of the plant communities will likely have a significant affect on the spatial distribution of *L. irrorata* in the Edisto Beach back barrier island salt marsh.

Conclusions and Recommendations

This progress report documents six plant communities that are located within the salt marsh area most likely to be affected by construction of a causeway bridge. The distribution of the plant and animal communities reflect spatial patterns driven by elevation and associated hydrological dynamics. How these communities will be affected by the reconnection of Scott Creek is unclear, however these baseline data are essential and will allow scientists to quantify any changes following bridge construction.

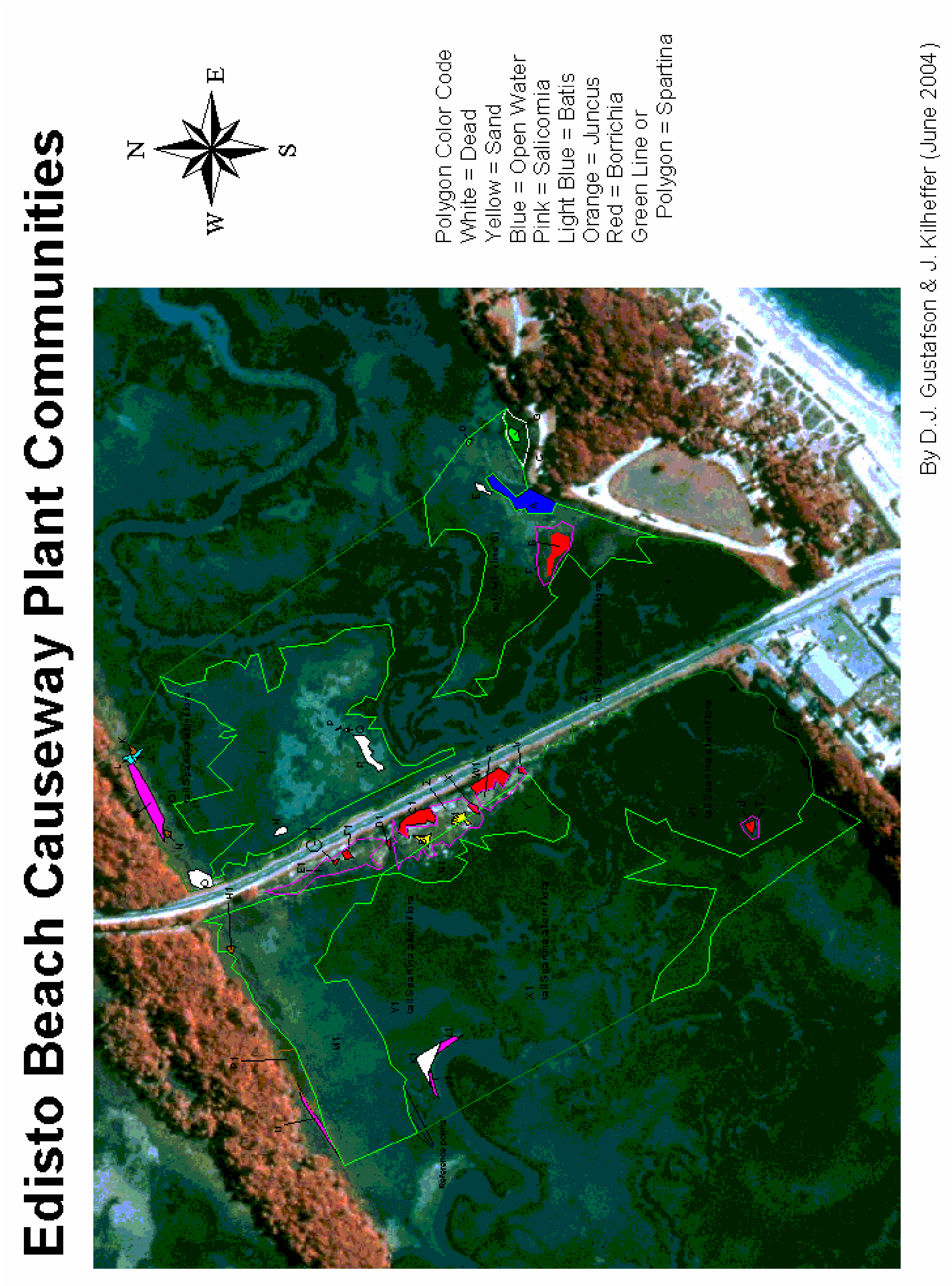


Fig. 43. Community type map overlaid upon the 1994 geo-referenced Edisto Island southeastern quadrangle orthopicture.

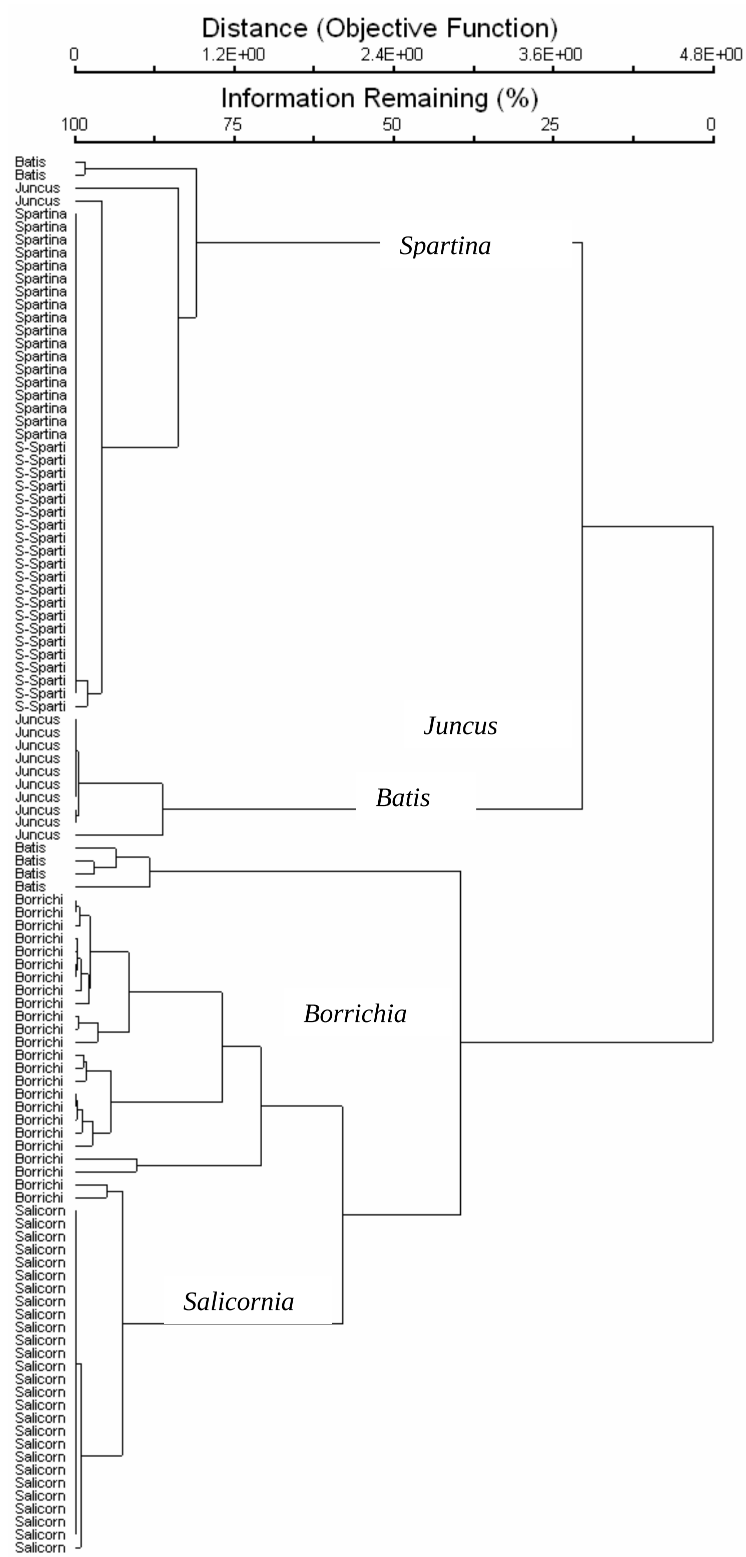


Fig. 44. UPGMA cluster analysis of plant abundance data randomly sampled within tall *Spartina* (Spartina), short *Spartina* (S-Sparti), *Juncus* (Juncus), *Batis* (Batis), *Salicornia* (Salicorn), and *Borrichia* (Borrichi) communities. Each entry represents single quadrats sampled in June 2004.

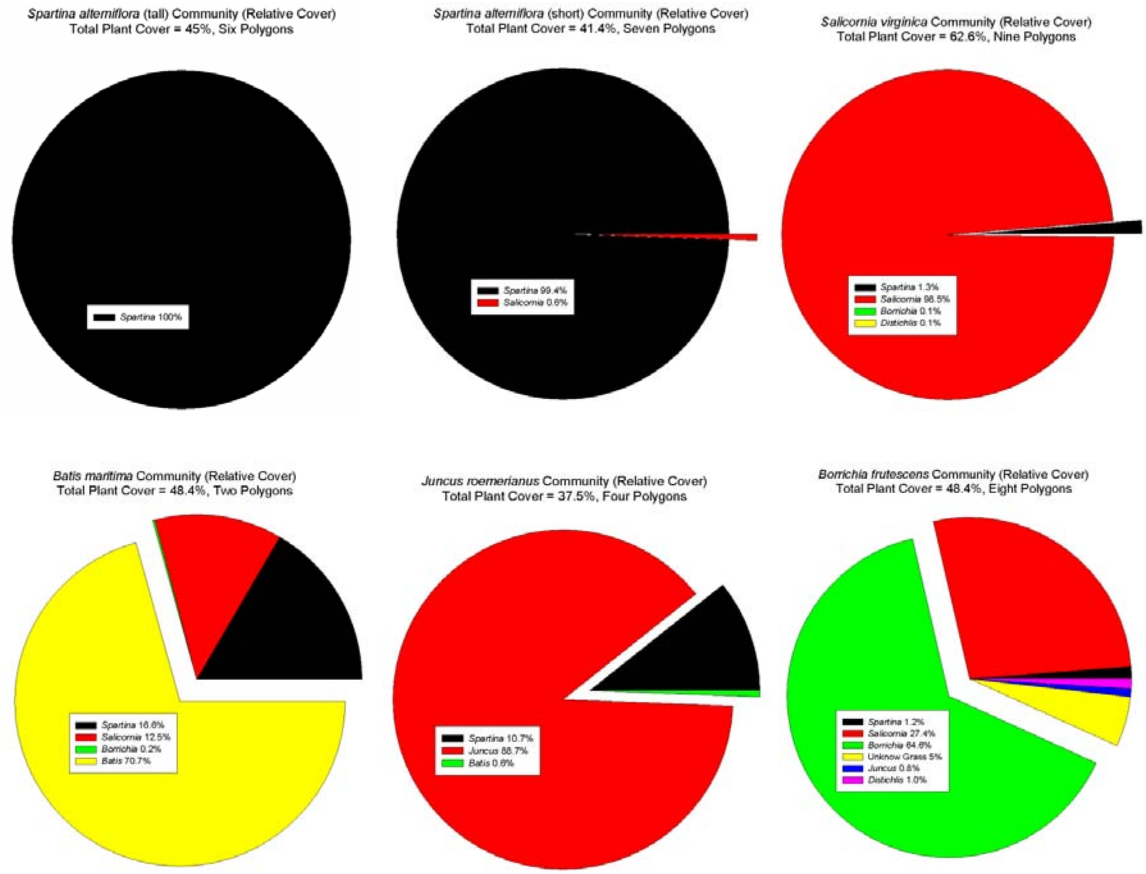


Fig. 45. Relative percent cover of plant species in each plant community type. Total plant cover was similar among the plant community types, while the relative cover by species clearly defined the community types.

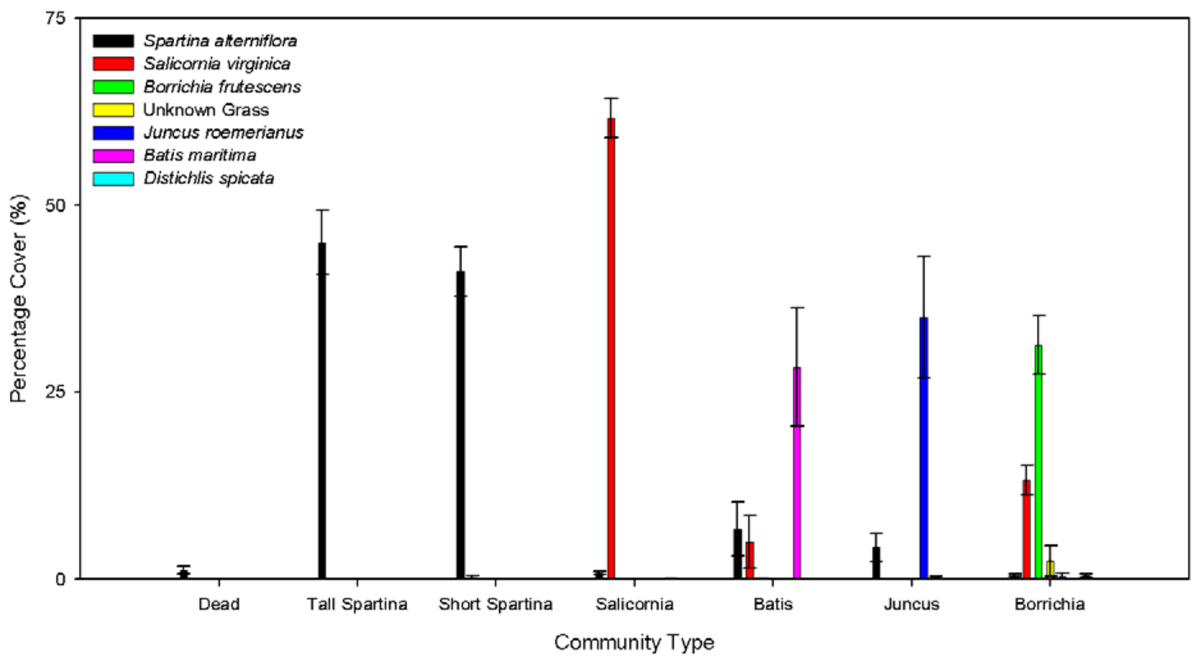
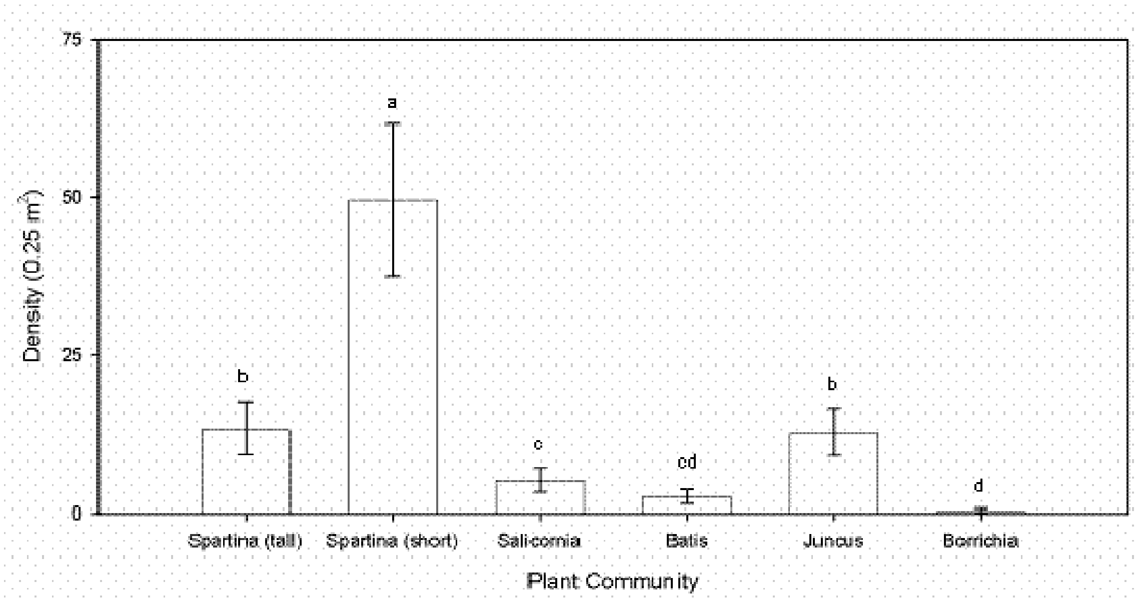
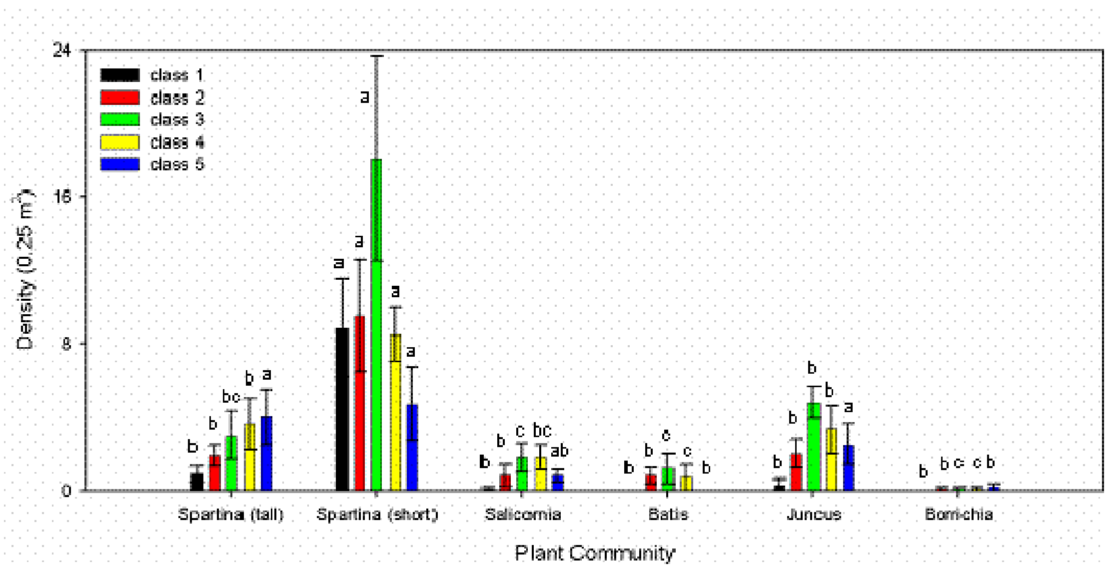


Fig. 46. Percent cover (mean ± 1 S.E.) by species per community type. The Dead community type represents as area that was formally covered with *Spartina alterniflora*, but has recently become devoid of most of the plant cover. The unknown grass is thought to represent *Muhlenbergia sericea* (Michx.) P.M. Peterson, however we are unable to confirm the identity without reproductive structures. Data collected in June 2004.

A.





B.

Fig. 47. Distribution of (A) total density and (B)size classes of *Littoraria irrorata* across six plant communities. Values represent means $\pm$ 1 S.E. and different letters within the same size class are significantly different.

Edisto Beach Causeway Project: Characterizing Scott Creek Animal Community Composition on Both Sides of the Earthen Causeway

By
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In order to effectively manage natural resources, one must first establish baseline information about the ecosystem. This research provides information on multiple trophic level consumers on the east and west sides of the Edisto Beach Causeway. Without spatially explicit plant and animal community data prior to causeway construction, we are unable to determine how or if these communities have changed. This report characterizes the animal communities on both sides of the causeway in areas that are likely to be affected by construction of a causeway bridge, as well as the animals' impact on the smooth cord grass, *Spartina alterniflora*.

Methods

Littoraria irrorata population structure was determined by randomly locating 15 0.25-m^2 quadrats within the *Spartina alterniflora* mid-marsh community within the eastern and western sides, collecting all individuals, and assigning each to one of five shell height classes. In order to assess *Littoraria* impact on *Spartina,* we randomly selected four *Spartina* ramets in each quadrat, removed aboveground biomass, and measured the total leaf length and length of radula scaring. Standard four-hole crab traps and minnow traps were used to assess animal communities in the east and west sections of Scott Creek. Five sampling points were established, GPS coordinates were recorded, and a single crab trap was located in the middle of the creek. A minnow trap was attached to a 10-ft half-in. PVC pipe driven into the edge of the creek bank next to the *Spartina* and juxtaposition to the crab traps. The traps were placed in the field during low tide where they were always covered with water with at least 20m between each pot. Fresh mullet (*Mugil curema*) for bait was collected locally and frozen for at least 12 hours. Approximately 0.6 kg of frozen mullet was used to bait the each crab trap and 0.2 kg in each minnow trap. All traps were placed in the field and checked after two tidal cycles, animal information was recorded, traps re-baited, and placed in the field for a second 24 hr period. Crab and minnow trap data were generated from two consecutive 24-hr soaks with data from the east and west sides of Scott Creek collected within a single seven-day period (May 24-28, 2005).

Littoraria population structure was analyzed using a two-way ANOVA on transformed (log10[x+1]) densities within each of five subclasses. Total leaf and radula scaring length per four ramets were randomly selected per quadrat were analyzed using a Wilcoxon non-parametric procedure testing for difference between the east and west creeks. Crab and minnow trap data were analyzed using Wilcoxon testing for differences between each creek as well as with principle components analysis. Univariate and non-parametric tests were conducted with SAS version 9 (SAS 9.1, SAS Institute Inc., Cary, NC). Principle Components Analysis (PCA) was used to characterize the animal communities caught by crab and minnow traps. Relationships among samples were investigated using principal components analysis (PCA – PCOrd, MjM Software, Gleneden Beach, Oregon) and parallel analysis to establish which PCA axes were appropriate for interpretation. Parallel analysis was used to derive the 95th percentile values for each successive PCA axis. Only axes with eigenvalues greater than the PA eigenvalues were retained for interpretation.

Results

Crab trap catches were comprised largely of blue crab (*Callinectes sapidus*) along with one spider crab (*Libinia emarginata*), six mud crabs (*Panopeus herbstii*), and nine diamondback terrapin (*Malaclemys terrapin*). Minnow traps collected nine species: spot (*Micropogonias undulatus*), pinfish (*Lagodon rhomboides*), killifish (*Fundulus heteroclitus*), silver perch (*Bairdiella chrysoura*), black drum (*Pogonias cromis*), oyster toadfish (*Opsanus tau*), blue crab, mud crab, and square-backed crab (*Sesarma reticulatum*).

There were significant site by *Littoraria* interactions ($F_{4,149}$=15.65, P <0.0001), as well as site ($F_{1,149}$=256.77, P <0.0001) and size ($F_{4,149}$=37.34, P <0.0001), indicating higher densities and relative proportion of larger animals on the west side of Scott Creek (Fig. 47). There appeared to be an inverse relationship between the *Littoraria* density and negative impacts of the plants (Fig. 48). *Spartina* total leaf length was approximately three times higher (W=2672, P<0.0001) and radula scaring 1/10th (W=8.67, P <0.0001) that found in the west marsh.

Diamondback terrapins (W=130, P<0.05), male blue crabs (W=131, P<0.05) and immature (W=129, P<0.05) blue crabs were more abundant in the east marsh (Fig. 49). Parallel analysis indicated that the first three axes of Crab and Minnow trap PCA's were statistically appropriate for interpretation. Axis 1 (eigenvalue=2.057), axis 2 (eigenvalue=1.103), and axis 3 (eigenvalue=0.78) accounted for 79% of the cumulative variance in the Crab Trap PCA correlation matrix, with the east and west creek communities best separated by the first and third axes (Fig. 50A). Axis 1 (eigenvalue=2.651), axis 2 (eigenvalue=2.077), and axis 3 (eigenvalue=1.794) accounted for 71% of the cumulative variance in the Minnow Trap PCA correlation matrix, with the relationships among samples between the two sides of Scott Creek more complex than the Crab Trap samples (Fig. 4B). There were more large predators (crab traps) and fewer small fish (minnow traps) species present in the east creek compared to the west creek (Table 8).

D***iscussion***

The animal communities in the east and west sections of Scott Creek, bisected by the earthen Edisto Beach causeway, are different and these differences cross multiple trophic levels. The population of large secondary consumers (blue crabs and terrapins) is higher in East Scott Creek and the *Littoraria* primary consumer population is small, relative to the West Scott Creek. Not only is the *Littoraria* density much greater in the west marsh system, the negative impact on primary productivity is striking (Fig. 48). The primary and small secondary consumers collected in the minnow traps did vary in abundance and number of different species between the two creeks. There were more individuals collected in the east creek, but a greater number of species in the west creek.

It is possible that these differences could simply be sampling error due to small sample size (2 reps, 5 traps), although we can not rule out reduced consumer pressure increasing prey diversity.

Building of a causeway bridge has the potential to restore Scott Creek's hydrology, thus restoring the connectivity of the currently distinct plant and animal communities associated with the east and west sections of Scott Creek. These data, in addition to the plant community work, can now be used as baseline information for documenting changes in ecosystem functions following the construction of a causeway ridge. We predict a homogenizing of the animal communities once connectivity of Scott Creek is restored.

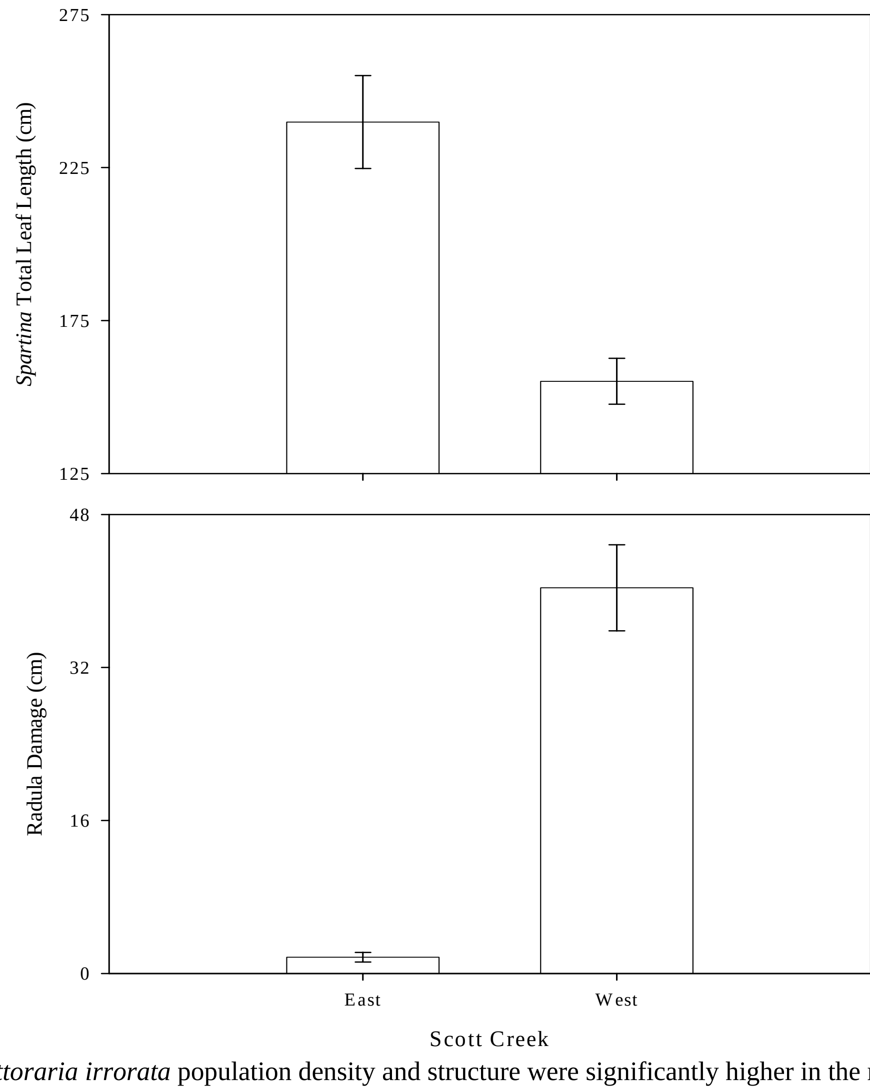


Fig. 48. *Littoraria irrorata* population density and structure were significantly higher in the marsh system west of the causeway.

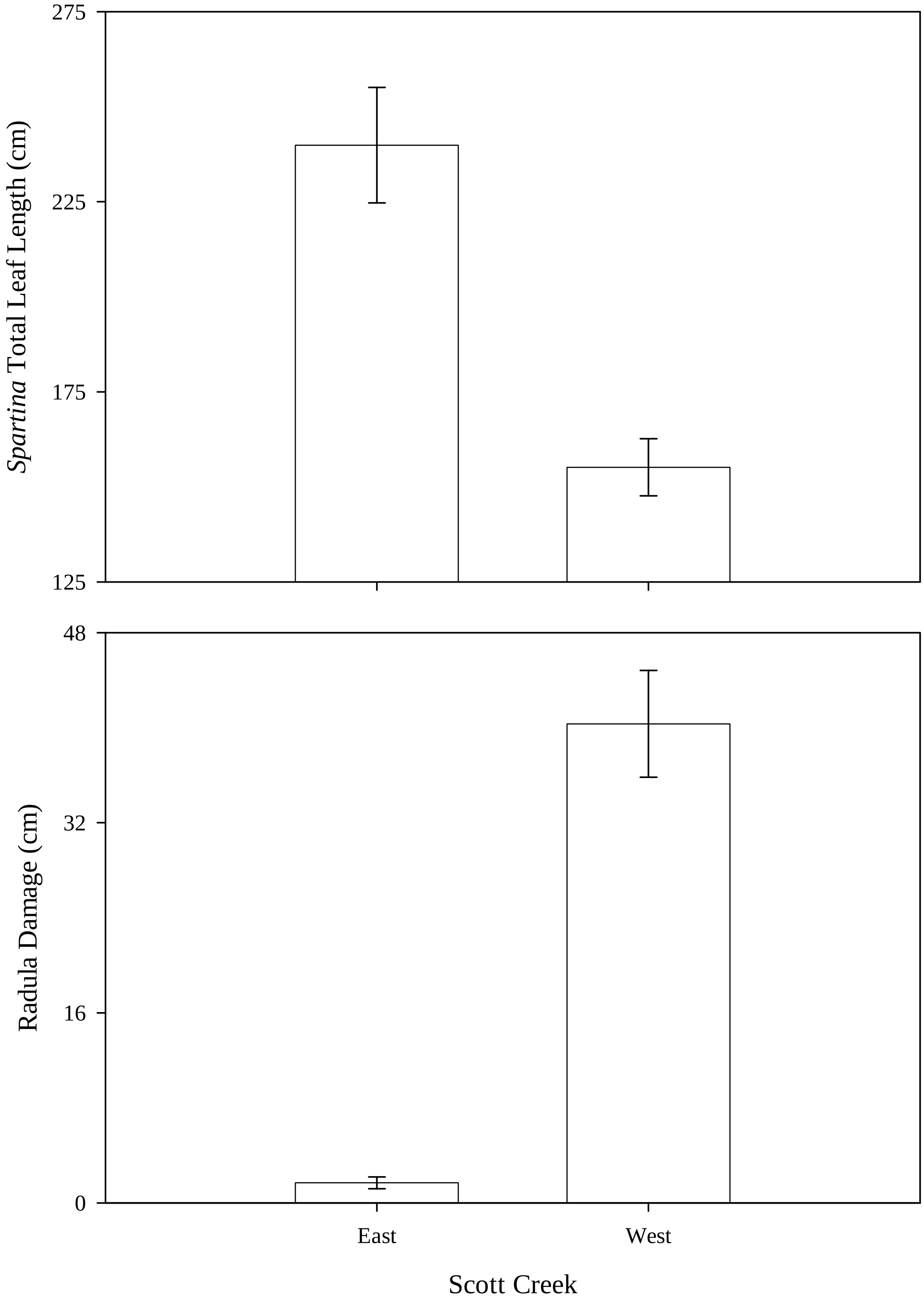


Fig. 49. There was an inverse relationship between total leaf length and length of radula damage, with the east creek having greater total leaf length per plant with less radula scaring than plants from the west section of Scott Creek.

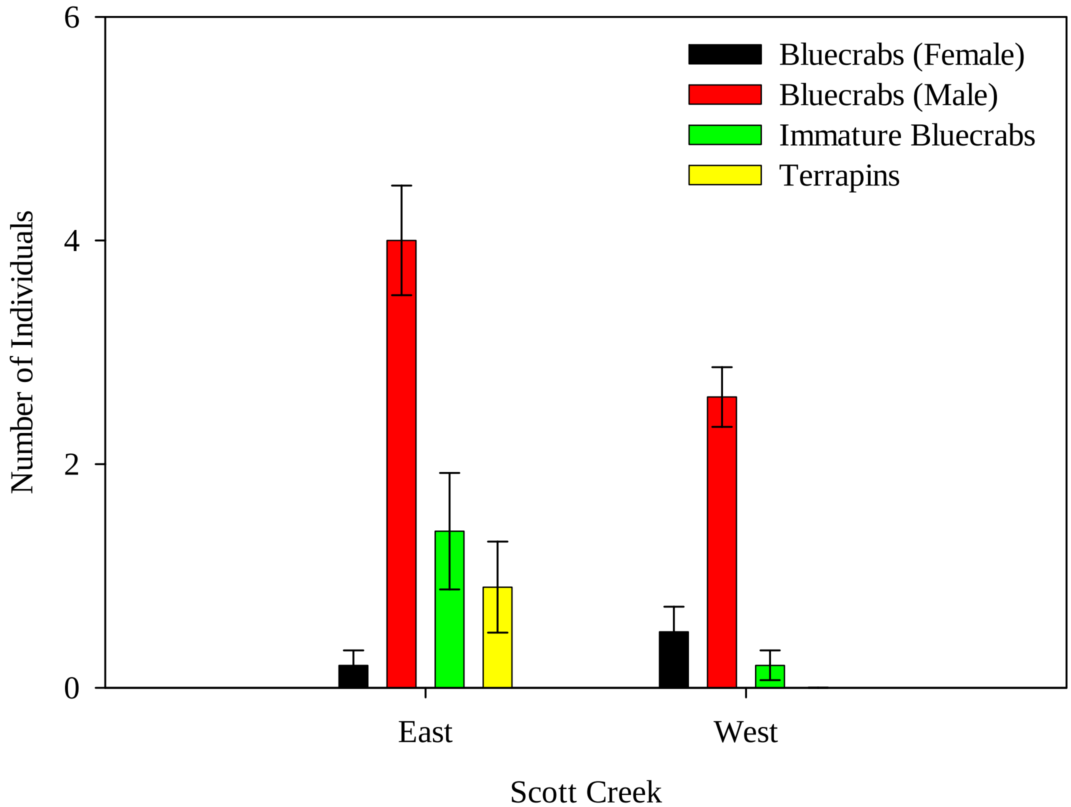
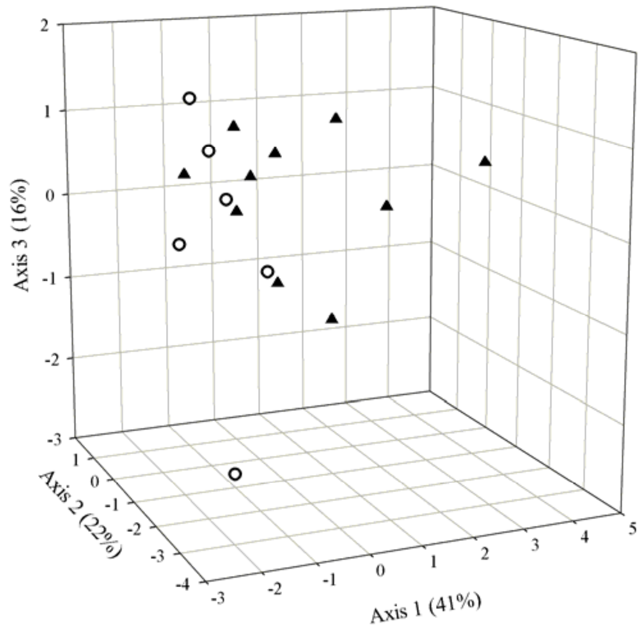
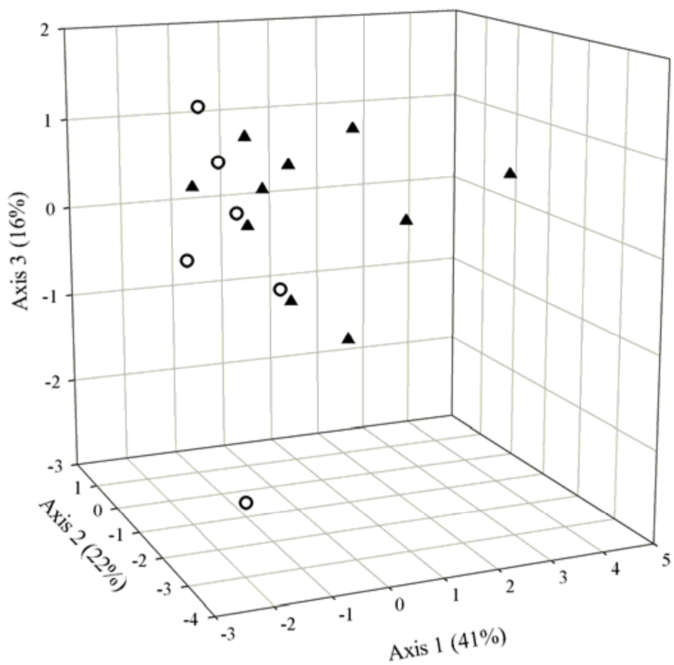


Fig. 50. There were significantly more male blue crabs, immature blue crabs, and terrapins in Scott Creek east of the causeway, but no difference in female blue crabs or total blue crabs.



A.



B.

Fig 51. Animal community analysis for crab (A) and minnow (B) traps in the east (triangle) and west (circle) sections of Scott Creek, Edisto Beach, South Carolina. Percentage of variance in the correlation matrix for each axis is in parentheses.

Table 8. Summary data for five crab and minnow traps with two 24 hour soak periods in the east and west sections of Scott Creek. Dates May 24 – 28, 2005

	East			West		
	Total	**Mean**	**SE**	**Total**	**Mean**	**SE**
Crab Traps						
Callinectes sapidus (male)	40	4	0.49	26	2.6	0.27
Callinectes sapidus (female)	2	1	<0.01	5	1.25	0.25
Libinia emarginata				1	1	<0.01
Panopeus herbstii	5	1.25	0.25	1	1	<0.01
Malaclemys terrapin	9	1.8	0.58			
Minnow Traps						
Micropogonias undulatus	41	20.5	7.5	33	8.25	3.98
Lagodon rhomboides	63	31.5	11.5	38	12.66	5.60
Fundulus heteroclitus				1	1	<0.01
Bairdiella chrysoura				4	1	<0.01
Pogonias cromis				1	1	<0.01
Opsanus tau				1	1	<0.01
C. sapidus (immature)	14	2.33	0.615	2	1	<0.01
P. herbstii (immature)				8	4	1.00
Sesarma reticulatum	5	1.25	0.25	1	1	<0.01

Scott Creek Nutrient Addition Experiment

By

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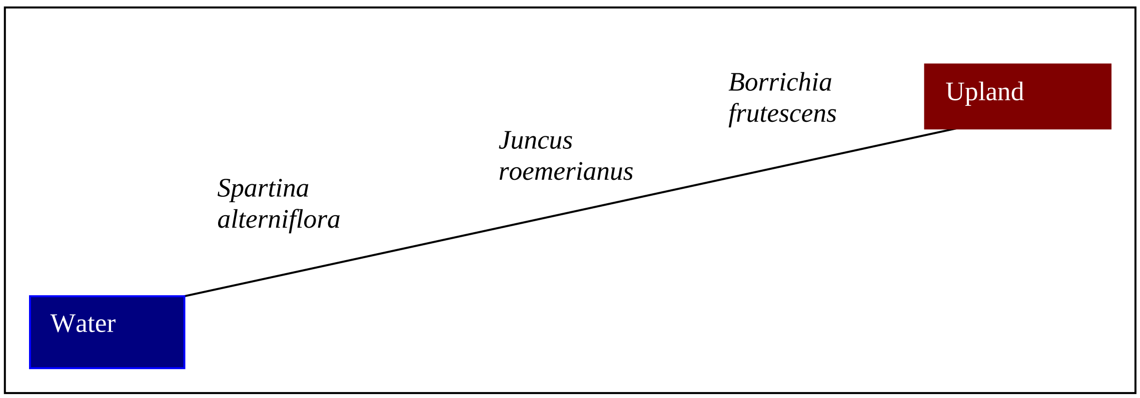
Department of Biology

The Citadel

Previous research has shown that salt marsh plant zonation is driven by stress associated with tidal / elevation interactions and competition (Howes et al. 1986, Bertness and Pennings 2000, Pennings et al. 2005). Plant species tend not to be able to move down the elevation gradient because they are unable to survive in these areas of increased water inundation and the associated biogeochemical processes. Furthermore, plant species are believed to be restricted in their movement to higher elevation areas because they are unable to compete with the resident species. For example, *Juncus roemerianus* is unable to move down the elevation gradient into the *Spartina alterniflora* zone because it is unable to tolerate the increased water inundation. In addition, the *Borrichia frutescens* prevents *J. roemerianus* from moving up elevation gradient due to competitive exclusion. Nutrient addition has been shown to alter plant competitive interactions, which effects salt marsh plant zonation.

In this study, we selected three plant transition zones (*Spartina/Juncus,*



Salicornia/Juncus, and *Spartina/ Salicornia*) of the Scott Creek marsh to conduct a two-season nutrient-addition experiment testing the hypothesis that soil nutrient levels affect salt marsh plant zonation. This research is unique in that this marsh system has an altered hydrological dynamic due to the construction of the Edisto Beach earthen causeway in 1939. There is a possibility that the Scott Creek hydrology could be restored with the removal of the existing earthen causeway and the construction of a causeway bridge. The causeway bridge would restore connectivity to Scott Creek and its associated marsh communities. When and if a causeway bridge is constructed, we will conduct another two-season nutrient addition experiment in the same plant zones. This Before-After-Control-Impact experimental design will allow us to test the effects of nutrient addition and alterations to the hydrological dynamics on salt marsh plant zonation in the field.

Methods

Three plant zones (*Spartina/Juncus, Salicornia/Juncus,* and *Spartina/ Salicornia*) were selected for this study and half-meter, squared plots were established in May 2005. These plant zones were selected from marshes on both sides of the causeway and located in areas that are most likely to be impacted by changes in hydrologic dynamics. Each plot was divided into two 0.5x0.5 m^2 subplots for nutrient application and control. Sixty grams of Scott's peletized slow release fertilizer (Osmocote™) (N:P:K; 10:10:10) was added to the nutrient addition plots in May and September of the 2005 and 2006 growing seasons, while control plots received no nutrient addition. Percent plant cover was estimated in all plots in May and September. In order to determine if the nutrient addition treatments effectively changed the soil nutrient levels, three replicated soil samples (10x10x10 cm) were collected in the control and nutrient addition plots in each plant zone in September 2006. These soils were air dried and sent to Clemson University for soil analysis. Plant cover data were analyzed using paired t-tests. Spearman correlation analysis was used to determine if there was an association between plant cover and nutrients, while Wilcoxon nonparametric analysis was used to test for difference in soil nutrients between control and nutrient addition plots. Data analyses were conducted using SAS (SAS Enterprise Guide 4.1, SAS Institute Inc., Cary, NC).

Results and Discussion

Fertilization increased soil nutrient levels for nitrogen, phosphorus, potassium, calcium and sodium (Table 1). Nitrogen and phosphorus levels increased by greater than three times ambient nutrient levels, while potassium increase was approximately 1.4 times ambient. Nutrient addition did not appear to significantly affect *Salicornia* or *Juncus* cover, but *Spartina* responded positively with a significant increase in cover over the course of the study. *Juncus* cover showed no correlation with increased nutrient levels, while *Salicornia* cover was negatively correlated with the increased phosphorus and nitrogen levels (r=-1.0, P<0.0001 for both). *Spartina* cover was negatively correlated with *Juncus* and *Salicornia* cover (r=-1.0, P<0.0001 for both) under ambient nutrient levels, but this negative association was lost with nutrient addition.

The three plant species responded differently with nutrient addition (Table 1). *Juncus* appeared to be unaffected by nutrient addition in the *Juncus/Salicornia* (Fig. 51), but there was a slight increase in *Juncus* cover in the *Juncus/Spartina* (Fig. 52) zone. This increase in *Juncus* was statistically significant, however the biological significance is debatable given the difference in the number of plots (n=63) relative to the *Juncus/Salicornia* zone (n=31) and the small magnitude of the difference. Previous studies have shown *Juncus'* lower limit to be mediated by flooding and salinity rather than competition or nutrients (Levine et al. 1998, Weinstein and Kreeger 2000, Penning et al. 2005).

Salicornia showed a significant increase in percentage cover in the *Juncus/Salicornia* zone (Fig. 51, but no response in the *Spartina/Salicornia* zone (Fig. 53). *Salicornia* occupies a section of the southeastern salt marsh elevation equal to or higher than *Juncus*, although this species is most often found in salt panne areas. Salt panne (a.k.a. salt pan, salt flat) areas are formed where water drainage is incomplete and evaporation results in hyper-accumulation of salts in the soil. *Salicornia virginica* and *Batis maritima* are two obligate halophytes that tolerate these high salt areas, while species like *Spartina* and *Juncus* may be present in transitional or developing salt panne areas. *Salicornia* increased in the *Juncus/Salicornia* nutrient addition plots and not in the *Spartina/Salicornia* plots because *Spartina* had such a strong positive response to nutrient addition while *Juncus* did not.

Spartina was the only species in our experiment that showed consistent positive response to nutrient addition, regardless of the plant zone (Fig. 52 & 53). Several studies have shown an association between water inundation, soil oxygen levels, sulfide concentration and nitrogen availability to *Spartina* plants under greenhouse and field conditions (Howes et al. 1986, Smart and Barko 1980, Bradley and Morris 1990, Levine et al. 1998, Weinstein and Kreeger 2000, Penning et al. 2005). In this study, *Spartina* appears to be limited in its upper elevation distribution by nutrient competition (Levine et al. 1998, Penning et al. 2005), however expansion into a developing salt panne community will likely be restricted due to the increasing soil salinities. As the salt panne community develops, *Spartina* will be displaced by the obligate halophyte *Salicornia* which illustrates the dynamic interaction between environmental stress and competitive interactions in structuring salt marshes.

In conclusion, the results of this study are consistent with our understanding of salt marsh plant zonation. We found that *Juncus* did not respond to nutrient addition, while *Salicornia* only increased its abundance when it was growing with the non-responsive *Juncus*. *Spartina*, however, is the dominant vascular species at the lower salt marsh elevation and it can move up the elevation gradient with nutrient addition (Levine et al. 1998, Weinstein and Kreeger 2000, Penning et al. 2005). It appears that *Juncus* and *Salicornia* zones in the salt marsh are affected more by environmental stress associated with elevation and hydrological dynamics than by competition. This is an important finding because construction of a causeway bridge and any associated changes to the tidal hydrology will affect the spatial distribution of plant zones across the Scott Creek marsh. Following the construction of the Edisto Beach causeway bridge, should it occur, and reconnecting of Scott Creek, we will conduct another two-season nutrient addition experiment to finish the BACI experiment -- testing nutrient addition and tidal hydrology effects on plant zonation in southeastern salt marshes. We predict that plant species distribution will be limited by environmental stresses in the lower elevations and competition in the upper elevation of the Scott Creek marsh.

Table 9. Summary statistics and Spearman correlation coefficients testing an association between plant cover and soil nutrient addition levels.

	Control Mean(SE)	Nutrients Mean(SE)		*Juncus roemerianus*	*Salicornia virginica*	*Spartina alterniflora*
Soil pH	6.6 (0.09)	6.3 (0.08)	*	-0.5	-0.5	1.0 †
Buffer pH	7.9 (0.01)	7.9 (0.01)		-1.0 †	0.5	0.5
P (lbs/A)	63 (3.6)	209 (7.4)	*	0.5	-1.0 †	0.5
K	481 (13)	657 (43)	*	-0.5	-0.5	1.0 †
Ca	663 (15.7)	861 (58)	*	-0.5	-0.5	1.0 †
Mg	1173 (14)	1218 (58)		-0.5	-0.5	1.0 †
Zn	1.6 (0.1)	1.7 (0.2)		0.5	-1.0 †	0.5
Mn	4.8 (0.2)	6.6 (1.1)		-0.5	-0.5	1.0 †
Cu	0.36 (0.02)	0.41 (0.03)		-0.5	-0.5	1.0 †
B	9.4 (0.4)	9.5 (0.9)		-0.5	-0.5	1.0 †
Na	7506 (192)	8529 (386)	*	-0.5	-0.5	1.0 †
S	655 (38)	775 (72)		-0.5	-0.5	1.0 †
NO_3-N (ppm)	17.5 (0.8)	67 (6.2)	*	0.5	-1.0 †	0.5

- Significant difference ($P \leq 0.05$) between control and nutrient addition treatments.

† Significant correlation ($P \leq 0.05$).

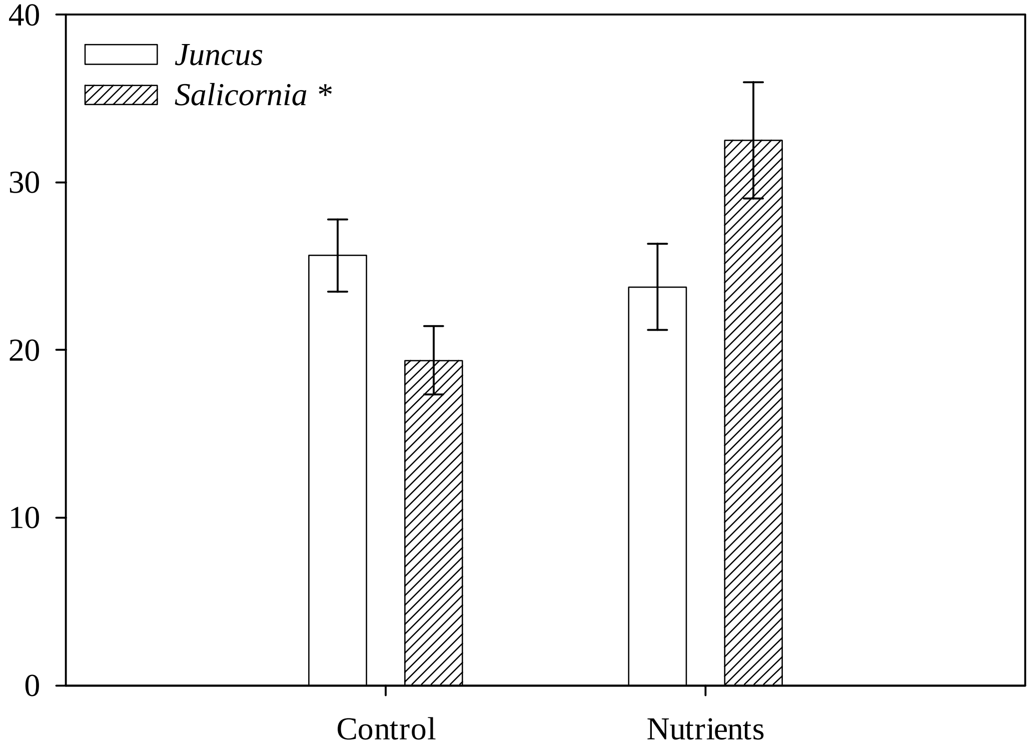


Fig. 52. Response of *Juncus roemerianus* and *Salicornia virginica* to a two year nutrient addition experiment in the Scott Creek marsh system, Edisto Beach, South Carolina. *Juncus* did not show any enhanced growth relative to the paired control plots (t=-0.74, d.f.=31, P=0.46) while *Salicornia* responded positively (t=4.70, d.f.=31, P<0.0001) to nutrient addition.

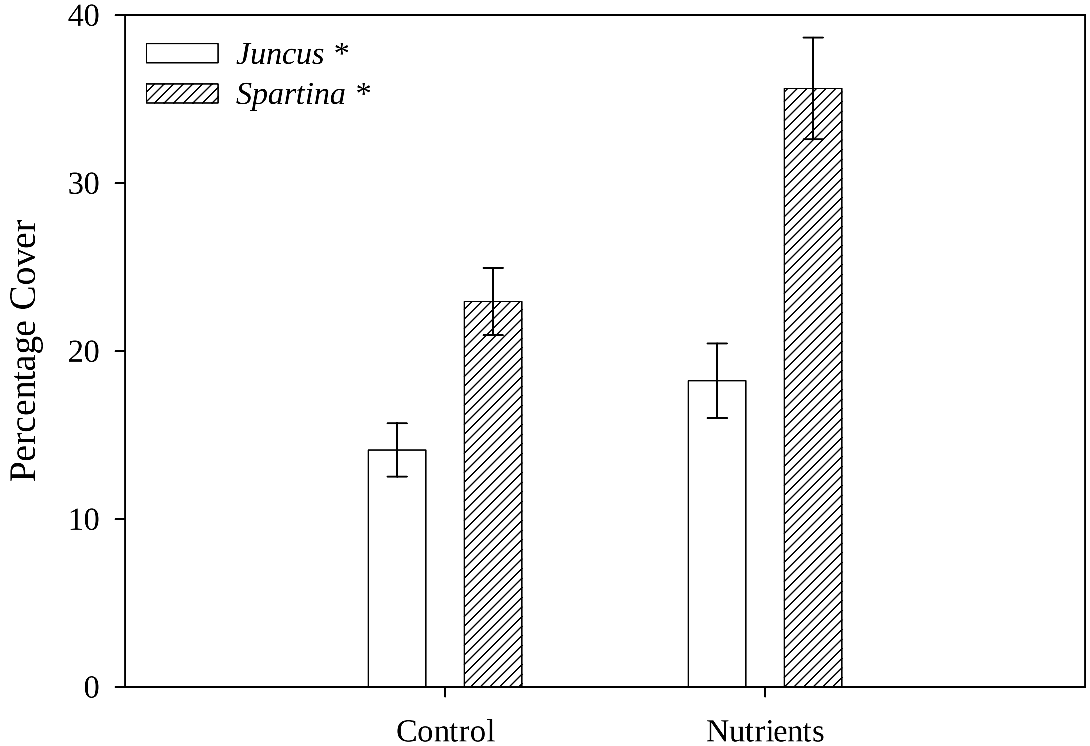


Fig. 53. Response of *Juncus roemerianus* and *Spartina alterniflora* to a two year nutrient addition experiment in the Scott Creek marsh system, Edisto Beach, South Carolina. Both *Juncus* (t=3.67, d.f.=63, P=0.0005) and *Spartina*(t=5.30, d.f.=63, P<0.0001) responded positively to nutrient addition, however *Spartina* showed a much larger response.

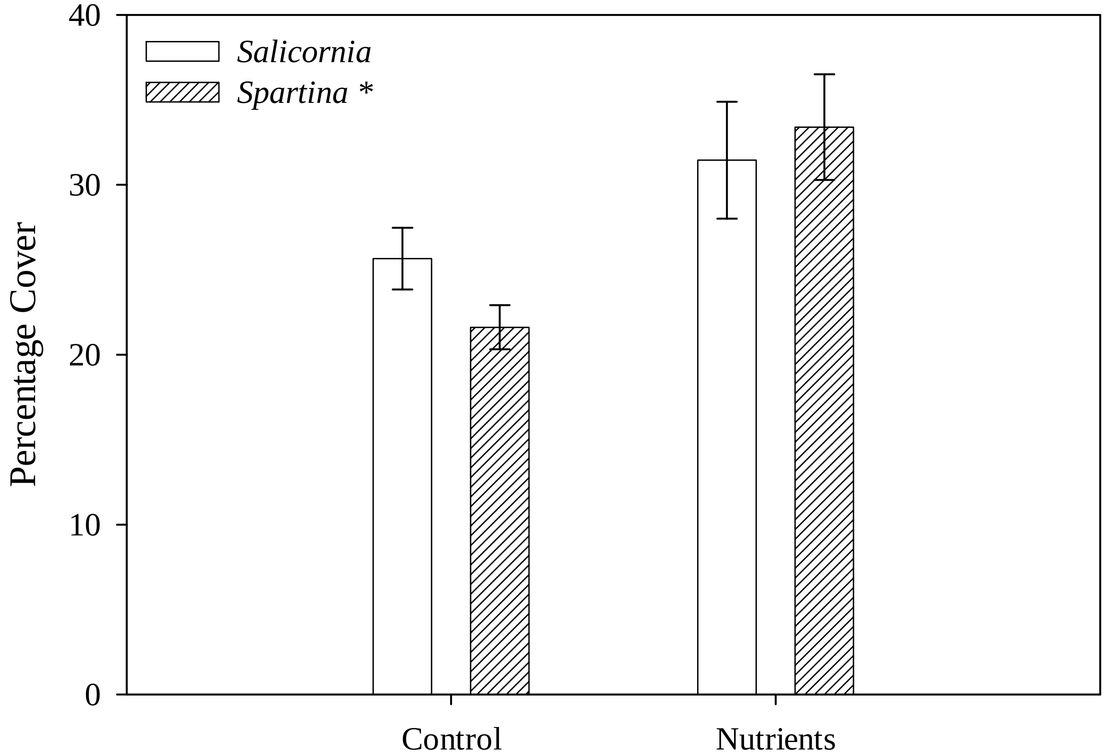


Fig. 54. Response of *Salicornia virginica* and *Spartina alterniflora* to a two year nutrient addition experiment in the Scott Creek marsh system, Edisto Beach, South Carolina. *Salicornia* did not show any enhanced growth relative to the paired control plots (*t*=1.67, d.f.=30, *P*=0.10) while *Spartina* responded positively (*t*=4.02, d.f.=30, *P*=0.0004) to nutrient addition.

Geological Studies

Investigation of Causeway-induced Sedimentation, Edisto Island,
South Carolina
by
Anton Dumars
Department of Geology and Environmental Geosciences
College of Charleston

An expanse of salt marsh divides a Holocene barrier complex, known as Edisto Beach, from Edisto Island, a Pleistocene age beach/barrier complex (Figs. 55 and 56). During modern times, a mesotidal influx of ocean water has flooded this salt marsh twice daily. Periodic tidal ebb and flood produces a bi-directional flow; therefore, transport energy from this tidally-influenced flow changes over time as a sinusoidal function, In response, deposition of sediment is fractionated in both flood and ebb directions along the channels and into the salt marsh. Sediment sources include the erosion of banks and channels, and the entrainment of beach sediments. Sinuous channels, formed by this tidally induced flow, transport sediment down gradient for eventual deposition. This particular salt marsh is fed from two directions. Scott Creek, branching from the larger ocean-fed Big Bay Creek, provides flow from the southwest. Jeremy Inlet, found on the northern end of a wash-over beach, provides influx from the northeast. A causeway has effectively isolated this once-connected marsh into two separate systems.

Fig. 55. Geological study area.

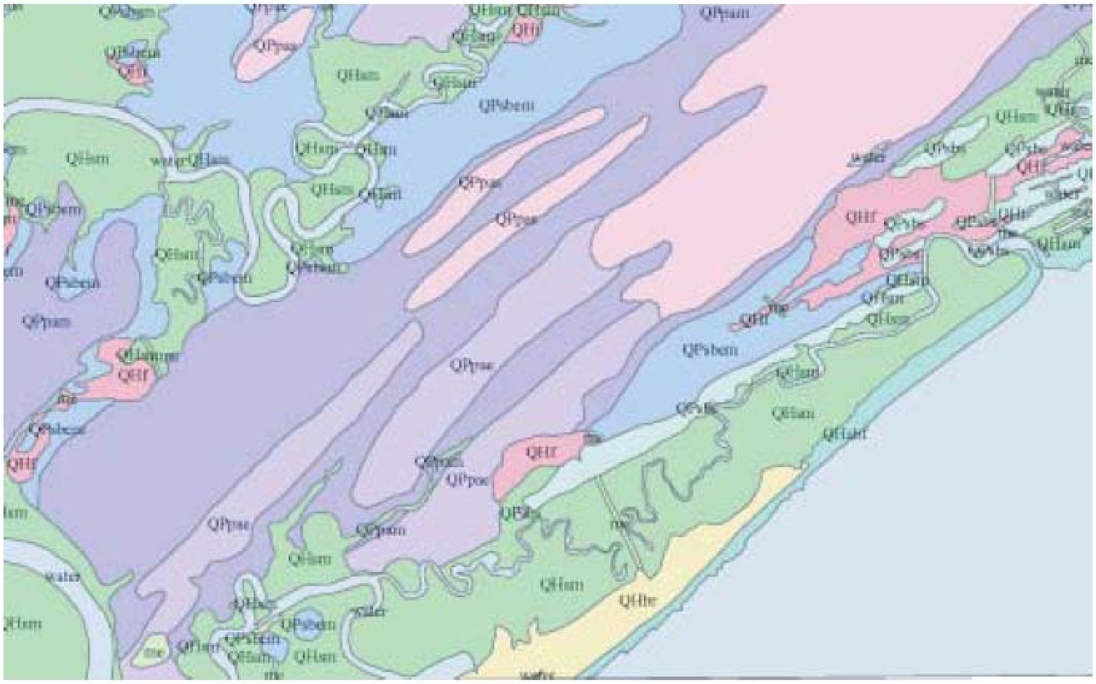


Fig. 56. Geologic map of study area. QP=Quaternary Pleistocene; QH=Quaternary Holocene.

Methodology

Data collection fieldwork was conducted in the first week of May 2005. Forty-five sediment cores were collected by boat along 10 (total) transects (five from the western side and five from the eastern side of the causeway) (Figs. 57 and 58). Coring elevations were determined using a rotary laser level, reference to a known benchmark elevation, NADV88. Each core location was recorded using a WAAS capable GPS receiver. Transect locations started approximately 300m (total channel distance) from the causeway, with each subsequent transect stepping seaward. Core length varied from 155cm to approximately 50cm, with most cores averaging within 80 to 100cm. Cores were spit into two equal haves for analysis. One half was archived and the other sub-sampled for grain size analysis. Stratigraphic changes in each archived core were recorded in terms of general grain composition, grain size, and lithologic change. In addition, each archived core was digitally photographed. Core logs were transcribed into a digital format and arranged into cross-sections along their perspective cross-channel transect. Two of four grain size samples were collected from each core. Sediment samples averaged 50 grams (dry weight) and were weighed to an accuracy of 1/1000 gram. Sample picks were selected below and above a potential horizon, or at regular intervals, in addition to the top and bottom of each core. Each sample was dried at 100ºC for 24 hours and weighed. Fine sediment (clay and silt-size grains) was then washed from the weighted sample through a 4-phi (63 micrometer) sieve. The sample was then dried and weighed again. The weight difference between the tow represented the weight of the fine fraction. The coarse fraction (grains of sand-size and larger) was then sieved at 0.5 phi increments to determine statistical grain size distribution. Graphic mean grain

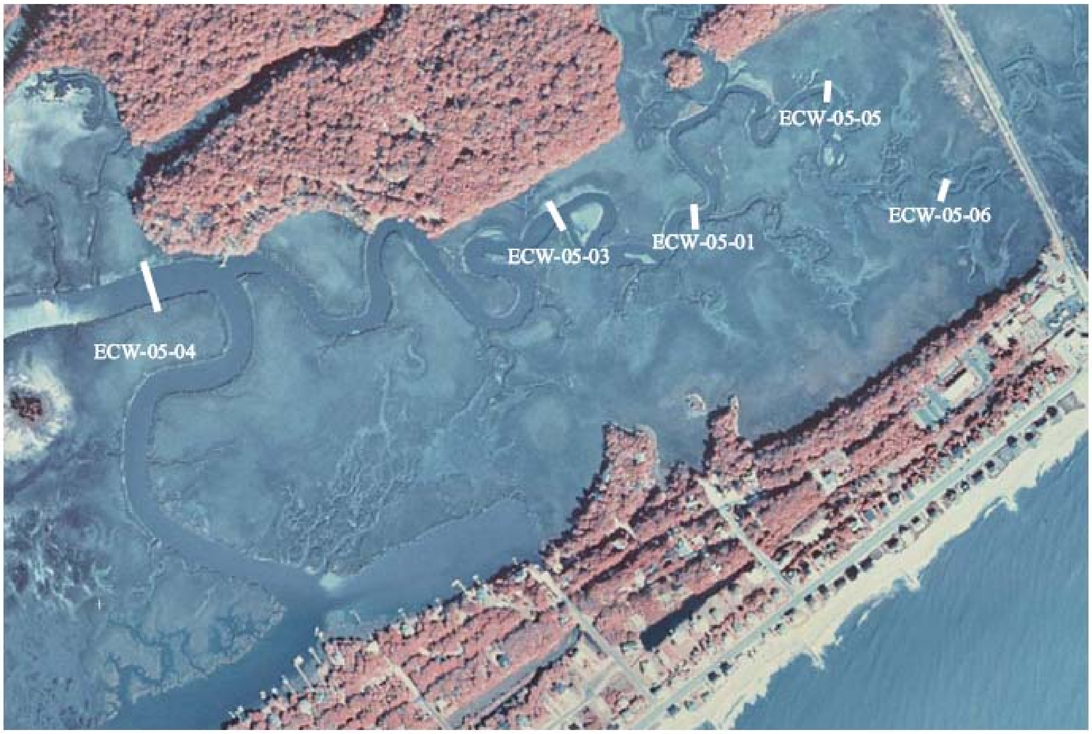


Fig. 57. Scott Creek cross-channel transect locations.

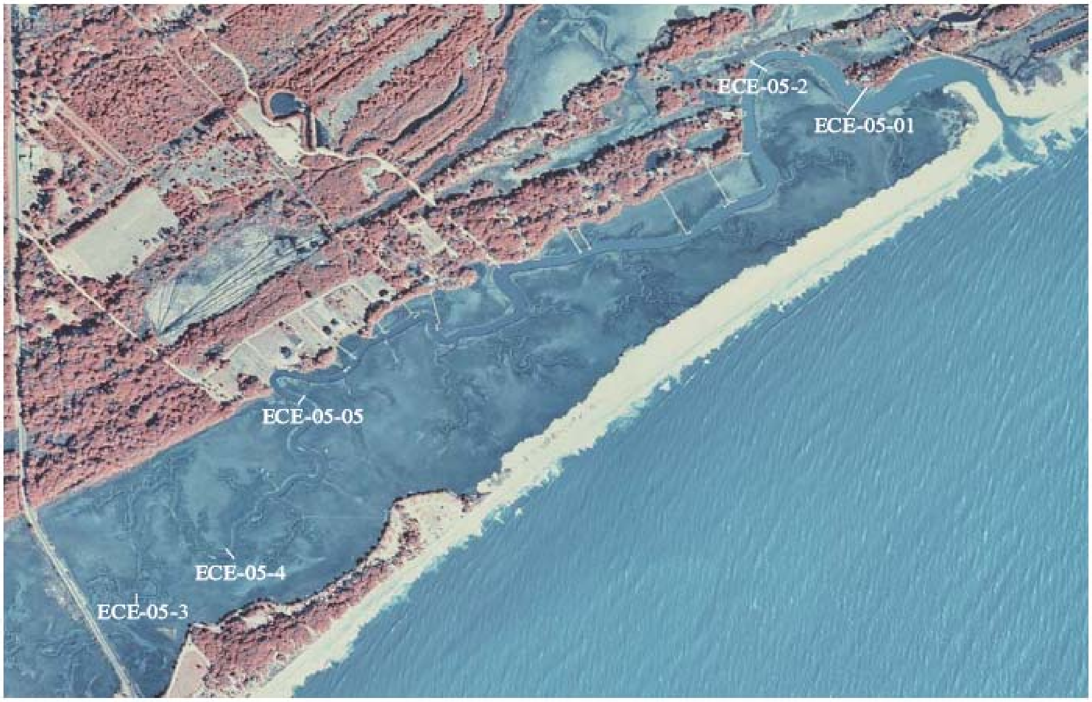


Fig. 58. Jeremy Creek (=east Scott Creek) cross-channel transect locations.

size, inclusive standard graphic deviation, and kurtosis of each sample were computed at 0.5 phi increments to determine statistical grain size distribution. Graphic mean grain size, inclusive standard graphic deviation, and kurtosis of each sample were computed (Folk, 1980; Prothero, 1996).

Results

General

Sediment sample grain analyses from each core were compared both within tidal basin and cross-causeway. Samples, both top and bottom, indicated, on average, medium to fine sand, except for top-of-core samples from the east side, in which fine sand was predominant. Mean grain size of top-of-core samples from the west was larger than that of top-of-core samples from the east (Fig. 59). Sixty-five percent of the east-side cores showed a larger average grain size in bottom-of-core samples compared to top-of-core samples. Forty percent of the west side cores showed a larger average grain size in bottom-of-core samples compared to top-of-core samples. Thirty-two percent of the west side cores showed a smaller average grain size in bottom-of-core samples compared to top-of-core samples.

Coarse to fine ratio (sand size grains compared to silt and clay size grains) was observed down-core. Sixty percent of samples from the eastern side showed a fining –up of sediment, while forty percent from the west side showed a fining up. Ten percent of the samples from the eastern side showed a coarsening up, while sixteen percent of the samples from the west side showed a coarsening up.

Top-of-core samples on the west side showed a slightly increased mud ratio with increased distance from the causeway. Top-of-core samples from the east side showed an increased sand ratio with increased distance from the causeway (Fig. 60).

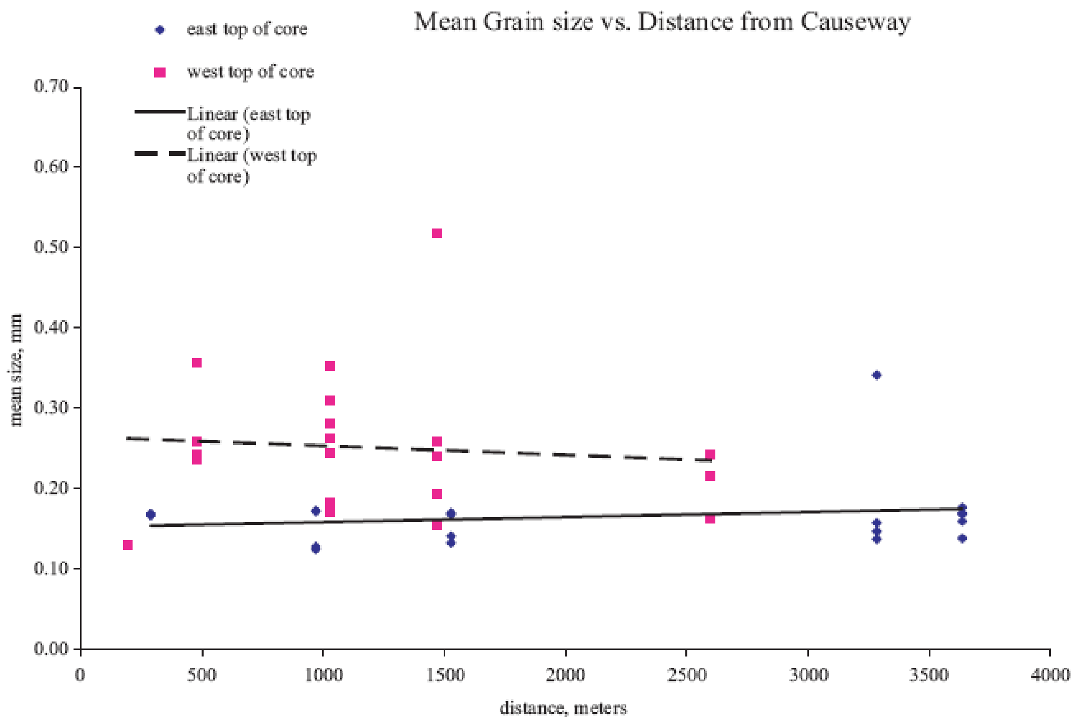


Fig. 59. Mean grain size of top-of –core sediments from east and west of the causeway compared to distance from causeway.

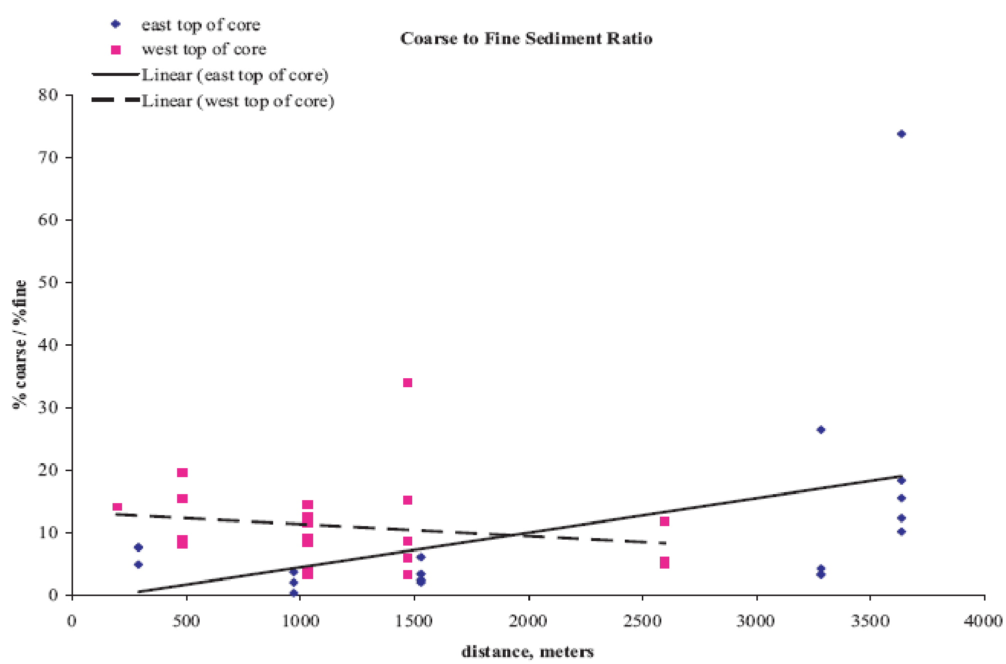


Fig. 60. Coarse-to-fine sediment ratio of top-of-core sediments from east and west of the causeway compared to distance from the causeway.

East Side

Changes in sedimentation patterns were detected in every transect on the eastern side. Abrupt changes in sediment color and apparent grain size were considered significant. These abrupt changes in sediment color and apparent grain size were considered significant. These abrupt changes included scour and fill contacts, sharp color changes from light to dark, and abrupt cessation of tidal laminations overlain by muddy sand, for example. Seventy-five percent of cores observed from the eastern side showed a coarse to fine horizon up-core. Transect ECE-05-01, located in a meander near Jeremy Inlet, showed indications of abrupt channel fill in cores 3 and 4. Fine sand abruptly overlies tidal laminations in core 3 at an elevation of -1m and a down-core depth of 0.2m. In core 4, tidal laminations abruptly overlie incised shelly mud at an elevation of -3.5m and a down-core depth of 0.5m. A cross-sectional view of cores from ECE-05-01, indicates an overall reduction in cross-channel area (Fig. 61). ECE-05-05, located midway to the causeway from Jeremy Inlet, shows a similar abrupt channel fill and reduced cross-channel area (Fig. 62). Grain size data supports the fining-up observations.

West Side

Sedimentation of cores observed from the west side of the causeway showed, in general, no change in some cores and abrupt changes in others. Fifty-two percent of the cores from the western side showed an up-core coarse-to-fine horizon, while thirty-two percent showed a fine-to-coarse horizon. Transect ECW-05-06 showed a significant change from coarse to fine at -1m elevation at a down-core depth of approximately 0.5m. Transect ECW-05-03 showed a rapid change from shelly-mud to tidal laminations in core 3 and fine sand deposition in core 2.

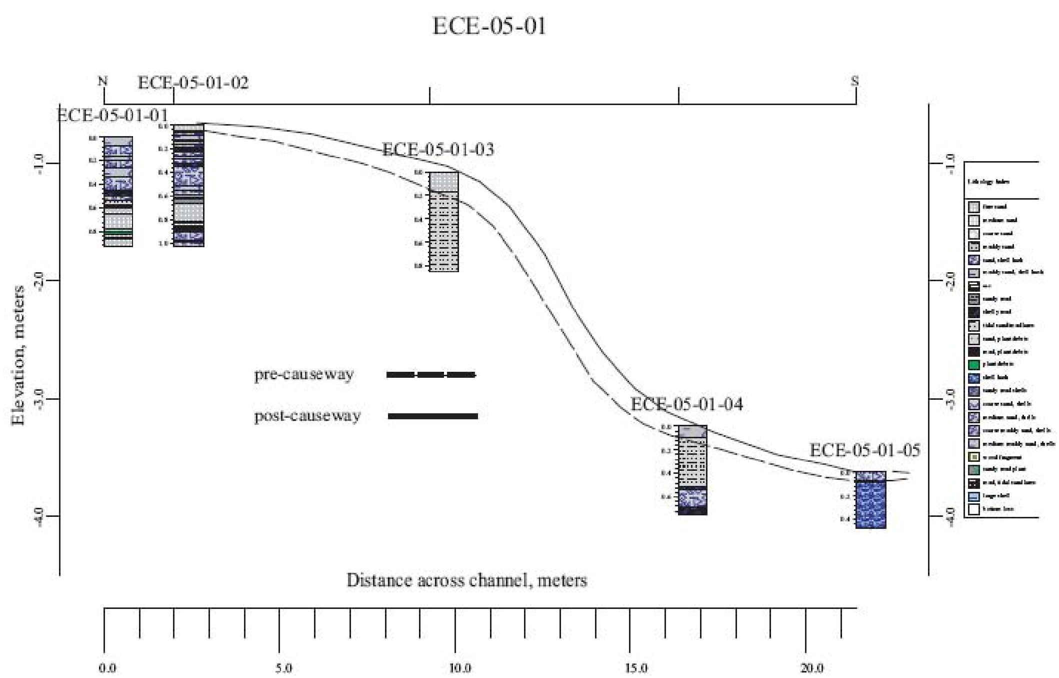


Fig. 61. Interpreted pre- and post- causeway channel cross-section, transect ECE-05-01.

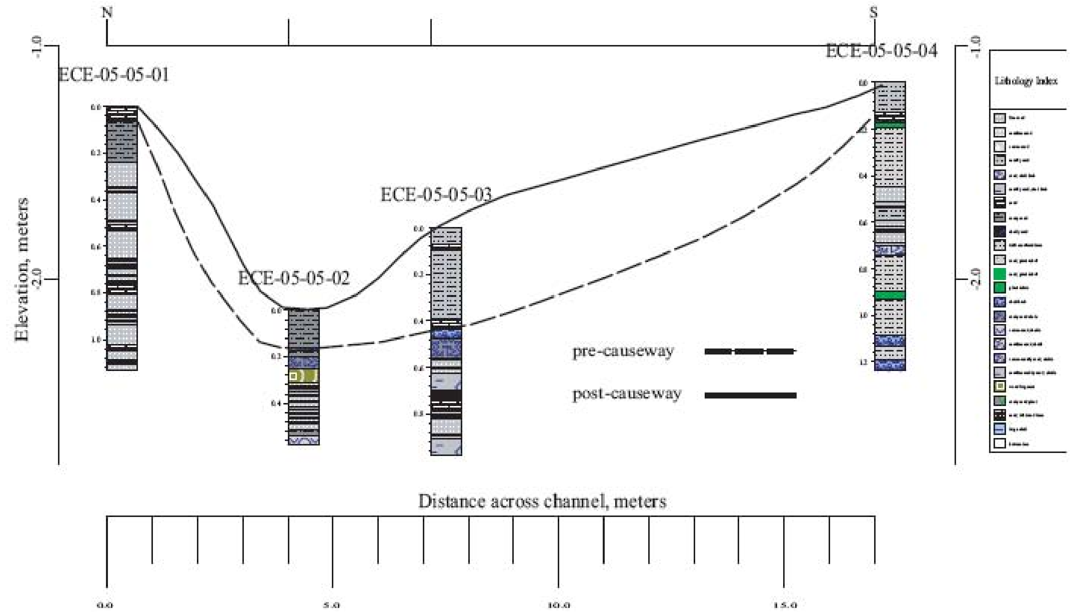


Fig. 62. Interpreted pre- and post- causeway channel cross-section, transect ECE-05-05.

Discussion

The causeway emplacement instantaneously created a barrier between two natural tidal basins. After causeway construction, both sides had to re-establish some type of hydrologic and depositional equilibrium. It is not known whether the two sides had interconnected channel systems, but during spring tide inundation, the two basins likely intermingled at distal ends. Aerial photos from 1939 clearly show that Jeremy Inlet was actively providing tidal flow into the marsh behind Edisto Beach. Flow distance from Jeremy Inlet to the causeway is approximately 4,070 m. On the west side of the causeway, the mouth of Big Bay Creek lies 7,370 m from the causeway. Scott Creek branches off from Big Bay Creek 5,370m from the causeway. This difference in distance from the causeway to open-ocean water, east and west of the causeway, would produce a differential in timing of peak flood tide elevation on either side. Flood peak elevation should reach the east side first, followed by a peak elevation on the west side. Pre-causeway open flow conditions would likely have allowed Jeremy Creek to flood farther west into the salt marsh than the causeway now allows. Given this, Jeremy Creek likely lost some flow volume and flow velocity along its main channel and tributaries. Grain size statistical data were interpreted in two ways. First, mean grain size distribution within the system indicated the relative flow energy available to transport native sediments (Hjülstrom, 1939). Second, the coarse-to-fine ratio of sediment samples indicates the relative numbers of each sediment population available for transport for a given maximum flow velocity. Native sediment distribution available to a coastal tidal system stays relatively constant for a given sea level. If the transport energy in a given system is high enough to transport all available sediments within the system, then the coarse-to-fine ratio should remain somewhat constant throughout the system, except at the very distal ends. If transport energy is reduced such that the larger grains are no longer transported, the coarse-to-fine ratio will adjust towards fine.

Mean grain size became larger, on average, with increased distance from the causeway in most samples from the west and in samples from the bottoms of cores from the east. These results are expected, as flow velocities should decrease toward the distal ends of channels. Samples from the top-of-core on the east side showed no increase in grain size with distance from the causeway, indicating an induced reduced flow velocity along the length of the channel. Average coarse-to-fine ratios remain constant in all samples with the exception of top-of-core samples from the east side. Coarse-to-fine ratios, on average, in samples from the tops of cores on the east side became lower, indicating a relative increase in mud content with reduced distance to the causeway. This indicates that flow velocities decreased toward the causeway such that they transported a lower proportion of sandy sediments relative to silt and clay-sized sediments. Results of these data, both mean grain size and coarse-to-fine ratio, suggest a depositional response to reduced volumetric flow from the causeway damming effect on east side channels.

Sedimentary layering in cores was logged and examined. The main objective was to identify significant changes in depositional patterns. For example, a change upwardly from coarser to finer sediments would indicate reduction in transport energy, allowing an increased rate of fine-grained deposition. Conversely, a change in sedimentation from finer to coarser material would suggest an increase in transport energy. Both such instances were recognized in many cores. These abrupt changes, referred to in geologic terms as horizons, were interpreted as a response to causeway emplacement. Core samples from every transect on the east side showed such horizons. These horizons were less evident in transects from the west side. Grain size analysis data indicate a reduction in flow energy on the east side of the causeway, but show no significant change on the west side. These data support a reduced tidal flow, indicating that Jeremy Creek was shortened by causeway construction, while Scott Creek was likely not significantly affected.

Evidence supporting suppression of flow on the east side of the causeway, though not particularly strong, is consistent. Further investigations of the sedimentation processes may include constructing a more precise timeline of sedimentation rates. Radiometric dating techniques, using Cesium 137 and /or Lead 210 isotopes could give high resolution results in short time-scale applications, such as the Edisto Causeway study. It is likely that some of the cored sediments represent ancient depositional environments, such as beachface and washover. Sediment facies analysis coupled with radiometric dating would likely produce a higher confidence level in the conclusions.

Conclusions

Data and observations from the east and west side of the Edisto Beach Causeway support the following conclusions:

1. Tidal flow path length on the east side of the causeway is 3,265m shorter than the tidal flow path length on the west side, a difference of 44%. The peak high tide wave likely reaches the east side of the causeway before it reaches the west. Based upon this supposition, tidal waters entering from the east were suppressed with construction of the causeway; therefore, volumetric flow through Jeremy

Inlet was reduced. In addition, flow velocities toward the mid-section and distal ends of the main stream and tributaries on the east side were likely reduced.

2. Core samples from every transect logged from the east side of the causeway showed abrupt changes in sedimentation patterns, but were less evident in cores from the west side of the causeway. These horizons are interpreted as a sedimentary response to causeway emplacement. A reduced channel cross-sectional area is evident in transect ECE-05-01, located near Jeremy Inlet and ECE-0-05, located midway to the causeway from Jeremy Inlet.
3. Sediment grain size statistical data from the east side, including mean grain size and fine/coarse size ratios, indicate an overall fining-up trend, which indicates a reduction in flow velocity. Sediment grain size statistical data collected from the west side of the causeway showed no significant change down core.
4. Data and observations indicate that Jeremy Inlet, the main channel, and tributaries on the east side of the causeway would increase in cross-sectional area and volumetric flow rate if the causeway is removed. Channels on the west side would experience no significant change.

Based upon these findings, causeway removal would allow waters from the east to flood west past the site of the causeway. Presently occupied channels on the east side would likely increase in cross-sectional area to pre-causeway size. Jeremy Inlet would establish a larger equilibrium cross-sectional area to accommodate an increase in volumetric flow rate (Hughes, 2002).

Summary

Analysis of historical maps clearly indicates that Scott Creek originally flowed freely from Jeremy Inlet to Big Bay Creek behind Edisto Beach. The truncation of the creek by causeway construction occurred ca. 1940, effectively dividing Scott Creek into two separate systems. The completion of the causeway significantly reduced tidal current flow rates and volumes, and consequently resulted in deposition of fine sediments and filling in of Scott Creek and associated secondary creeks and tidal marsh.

As the tidal creeks filled in, particularly those near the causeway, they began to lose biological function. Pre-causeway salt marsh in the vicinity was likely comprised largely of healthy stands of Spartina. As the marsh filled and increased in elevation, there was likely a transition to less productive high-marsh plant communities and a total loss of marsh plants in some areas. This resulted in a net loss of primary productivity. Concurrent with this loss of marsh, shallow water tidal creeks were lost and along with them, optimal nursery habitat for fishes, crustaceans and piscivorous wading birds.

Geological cores taken from creek bottoms throughout the system indicate abrupt changes in grain size of sediments which appear to correlate with the time of the closing of the causeway. Core analysis suggests that post-causeway tidal flow velocities decreased as the waters approached the causeway, such that they transported a lower proportion of sandy sediments relative to silt and clay-sized sediments. Core samples from every sampling transect on the east side of the causeway showed distinct changes in sediment size, but this was less evident in transects from the west side. This indicates that east side flow was more severely reduced by causeway construction than was west side flow.

One concern about breaching the causeway was that the tidal node where easterly and westerly flowing waters meet would be near the causeway and therefore that location would become a depositional area for sediments. The hydrological study indicated that the initial tidal node during a tidal cycle would be about 950 m west of the causeway, and as the tide rises the node would gradually shift 1,400 m eastward to a point 450 m east of the causeway. This means that all portions of the creek will experience some tidal flow during every tidal cycle and no single point will be depositional throughout the entire cycle. This should help maintain creek depth if the causeway is breached.

The hydrodynamic model indicates that water volume exiting Jeremy Inlet on ebb tide, after a breach in the causeway, would increase 20,000 to 38,000 m^3 or about 9.0 to 17.3%. Ebb tidal flows on the western side would decrease by 21,000 to 62,000 m^3 or about -2.4 to -7.0%. These changes in tidal volumes should result in minor water velocity increases of only 1 to 3.5% at Jeremy Inlet. Consequentially, we do not anticipate any significant modification of the inlet resulting from breaching of the causeway. Currently, there is a berm (sill) at Jeremy Inlet and this delays flood tide until the ocean tide exceeds the height of the berm. Once exceeded, water velocity is relatively high as the tide begins flooding, and this is thought to be contributory to bank erosion at the first turn of the creek. Breaching the causeway should not substantially change this eroding bank situation.

There was some concern among Edisto Island property owners on the east side of the causeway that a causeway breach would result in higher high tides that could threaten their low-lying properties. The hydrodynamic model indicates that maximum high tides on both sides of the causeway would be close to 4.4 ft. With a breach, the east side tide would not be expected to increase more than 1/10 of an inch and should therefore be no threat to residences adjacent to the Scott Creek marsh.

Another concern expressed to DNR is the perception that water quality on the eastern side of the causeway would decline if the causeway is opened because waters from the western side, where there is greater development and urban runoff, would flow eastward. Because the tidal node during flood tide is 950 m west of the causeway, water will be moving largely east to west on flood tide. This flow pattern will bring more oceanic water through Jeremy Inlet and the eastern side waters should become cleaner. Additionally, all three investigated causeway breach scenarios showed decreased flushing times which should also improve water overall quality.

Three scenarios for a causeway breach were investigated. The "current meander" scenario required the shortest dredging, but would not substantially improve water flushing and creek depth would likely be inadequate for navigation. Cases 1 and 2 required 3.5 ft of sediment to be excavated for a distance of 0.4 to 0.6 mi, bypassing numerous creek meanders. These cases provide much improved flushing times and should substantially improve water quality. However, Cases 1 and 2 would likely negatively impact some portions of low marsh areas and would probably result in compromising the ecological function of some dendritic creeks that would not be directly connected to the new channel. A compromise location or locations for a breach should be investigated which would not require as much dredging while maintaining a relatively deep channel and maintaining much of the ecological function of existing creeks and marshes.

Much of the plant community currently found near the causeway is comprised of short *Spartina* and high marsh *Salicornia* and *Borrichia* communities, along with two small areas of *Batis maritima*. There are also some areas near the causeway that are high ground (rarely flooded) or salt pannes. These high ground (terrestrial) and high marsh communities are relatively unproductive compared to low marsh areas with tall form *Spartina alterniflora*. With reconnection of east and west Scott Creek, plant communities will move up or down the elevation gradient relative to any changes in hydrology, while the autogenic successional process of salt marsh accretion will likely be driven by biogeochemical interactions between *Spartina alterniflora* and the restored hydrology. With better circulation and growth of *S. alterniflora* marsh, this should provide more "edge effect" for juvenile finfish and crustaceans. The increased area of shallow-water nursery habitat should result in higher densities of marine fauna (secondary productivity) and probably higher species diversity. We believe that opening the causeway should have positive overall effects on associated plant and animal communities.

This report uses the best science available to us to project what would happen should the Edisto Beach causeway be breached. We have found no serious negative physical impacts and it appears that breaching the causeway would result in positive biological impacts. Reconnecting Scott Creek would reproduce a natural situation that existed before development came to coastal South Carolina. However, the decision to breach the causeway must be considered holistically by the local community (including the town of Edisto Beach), the Edisto State Park, and the Department of Transportation. Factors to be considered include construction and maintenance costs, effects on the viewscape, effects on hurricane evacuation, future highway transportation requirements and public safety, navigation issues, and the hydrological/biological information provided in this report.

This study has found that causeway modification has high potential for wetland rehabilitation, even in an atypically complex system such as Scott Creek. There is currently no estimate of the total number of water flow restriction structures in South Carolina or the acreage of wetlands that could benefit from the removal or manipulation of such structures. A logical first step in addressing statewide potential for wetland rehabilitation would be an assessment using historical maps, remote sensing, interviews with local biologists, and field visits (Williams and Watford, 1997). This would be followed by site-by-site analysis of cost effective alternatives for modifications, and finally by follow-up monitoring of the effects of modifications. To be cost effective for the state, as a whole, sites worthy of modification should be ranked in terms of acreage affected per unit cost to modify them. Working in New South Wales, Australia, Williams and Watford (1997) recommended that a survey of microtidal topography be conducted at each site and that local landowners by consulted and advised with regard to potential changes in tidal regimes and impacts upon existing habitats.

Literature Cited

Arega F and Sanders BF. (2004). "Dispersion Model for Tidal Wetlands," Journal of Hydraulic Engineering, ASCE, 130(8), pp. 739-754.

Bradford SF and Katopodes ND. (1999). "Hydrodynamics of Turbid Underflows Part I: Formulation and Numerical Analysis," Journal of Hydraulic Engineering, ASCE, 125(10), pp. 1006-1015.

Bradley, P.M. and Morris, J.T. 1990. Influence of oxygen and sulfide concentration of nitrogen uptake kinetics in *Spartina alterniflora.* Ecology 71: 282-287.

Cain, R.I., and J.M. Dean. 1976. Annual occurrence, abundance, and diversity of fish in a South Carolina tidal creek. Mar. Biol. 36:369-379.

CSC. 2007. NOAA Coastal Coastal Services Center website, Charleston, SC. http://www.csc.noaa.gov/products/sccoasts/html/edisto.htm

de la Cruz, A.A. 1973. The role tidal marshes in the productivity of coastal waters. Assoc. S.E. Biol. Bull. 20:147-156.

Desmond, J.S., J.B. Zedler, and G.D. Williams. 2000. Fish use of tidal creek habitats in two southern California salt marshes. Ecol. Eng. 14 :233-252.

Dumars, A. 2006. Investigation of causeway-induced sedimentation, Edisto Beach, South Carolina. Final Rep. to South Carolina DNR. Dept. of Geology and Environmental Geoscience, College of Charleston, Charleston SC. 89 pp.

Folk, R.L. 1980. The Petrology of Sedimentary Rocks. Hemphill, Austin TX. 184 pp.

Friedrichs CF. (1995). ”Stability Shear Stress and Equilibrium Cross-sectional Geometry of Sheltered Tidal Channels,” Journal of Coastal Research, 11 (4), pp. 1062-1074.

Hockensmith, B. Stage Data for Scott Creek, Edisto Beach, South Carolina. South Carolina Department of Natural Resources, Land, Water and Conservation Division. Open File Report 12. 2006.

Howes, B.L., Dacey, J.W.H., and Goehringer, D.D. 1986. Factors controlling the growth form of *Spartina alterniflora*: feedbacks between above-ground production, sediment oxidation, nitrogen, and salinity. Journal of Ecology 74, 881-898.

Hjulstrom, F. 1939. Transport of detritus by moving water. *In* a

Hughes, S.A. 2002. Equilibrium cross sectional area of tidal inlets. Journal of Coastal Research 18:160-174.

Levine, J.M., Brewer, J.S., and Bertness, M.D. 1998. Nutrients, competition and plant zonation in a New England salt marsh. Ecology 86: 285-292.

Li C, Armstrong S, and Williams D. (2006). "Residual Eddies in a Tidal Channel," Estuaries and Coasts, 29(1), pp. 147-158.

Minello, T.J., R.J. Zimmerman, and R. Medina. 1994. The importance of edge for natant macrofauna in a created saltmarsh. Wetlands 14:184-198.

NOAA , 2005 Tidal predictions for Big Bay Creek, updated 3/10/2005. http://tidesandcurrents.noaa.gov/get_predictions.shtml?year=2006&stn=2815+Savannah+River+Ent.&secstn=South+Edisto+River,+Edisto+Marina,+Big+Bay+Creek+entrance&thh=-0&thm=11&tlh=-0&tlm=14&hh=*0.88&hl=*1.00

NOAA, 2005b. Tidal predictions for Edisto Beach, updated 3/10/2005. http://tidesandcurrents.noaa.gov/get_predictions.shtml?year=2006&stn=2815+Savannah+River+Ent.&secstn=Edisto+Beach,+Edisto+Island&thh=-0&thm=21&tlh=-0&tlm=29&hh=*0.84&hl=*0.95

NOAA, 2007a. NOAA website, tides and benchmarks http://tidesandcurrents.noaa.gov/benchmarks/8667630.html (Edisto Beach, from data sampled at the Pavilion from 1977-1979)

NOAA 2007b. NOAA website, tides and benchmarks http://tidesandcurrents.noaa.gov/benchmarks/8667679.html (Big Bay Creek, from data sampled at Carter’s Dock from 1976-1977)

Pennings, S.C., Grant, M-B, and Bertness, M.D. 2005. Plant zonation in low-latitude salt marshes: disentangling the roles of flooding, salinity, and competition. Journal of Ecology 93:159-167.

Prothero, D.R. and F. Schwab. 1996. Sedimentary Geology – An Introduction to Sedimentary Rocks and Stratigraphy. W.H. Freeman and Co. New York. P 27-41.

SCDHEC, 2006. South Carolina Dept of Health and Environmental Control (SCDHEC) Shellfish Sanitation Program, Water Monitoring, Assessment and Protection Division of the Environmental Quality Control – Bureau of Water. Shellfish Management Area 13, 2006 Annual Update. July, 2006.

SCDNR. 1999. Flood Mitigation A Plan for South Carolina. http://www.dnr.sc.gov/water/envaff/flood/img/floodhazardplan.pdf

Sharma P, Gardner LR, Moore WS, Bollinger MS. (1987). "Sedimentation and Bioturbation in a Salt Marsh as Revealed by 210Pb, 137Cs, and 7Be Studies" Limnology and Oceanography, 32(2), pp. 313-326.

Smart, R.M. and Barko, J.W. 1980. Nitrogen nutrition and salinity tolerance of *Distichlis spicata* and *Spartina alterniflora*. *Ecology* **61**, 630-638.

Turner, R.E. Intertidal vegetation and commercial yields of penaeid shrimp. Trans. Amer. Fish. Soc. 106(5):411-416.

US Army Corps of Engineers, 1919. “South Carolina Edisto Island quadrangle / Geological Survey.” 1919 Topographic Survey Map from the War Department, Corps of Engineers, U.S. Army. [Washington, D.C.: The Survey], 1919 (1932 printing Available at University of South Carolina Caroliniana Library. Call Number: Map 1919 No. 26 Size 2. Permission for image reproduction made available to SCDNR, 2006.

Weinstein, M.P. 1979. Shallow marsh habitats as primary nurseries for fishes and shellfishes, Cape Fear River, North Carolina. U.S. Fish. Bull. 77: 339-357.

Weinstein, M.P. and Kreeger, D.A. 2000. Concepts and controversies in tidal marsh ecology. Kluwer Academic Publishers, Boston, MA. pp.875.

Whitaker, J. D. , L.B. DeLancey, and J.E. Jenkins. 1989. A study of the experimental closure of South Carolina’s sounds and bays to commercial trawling. SC Dept. of Nat. Resources, Division of Marine Fisheries. Tech Rep. No. 72. 54 pp.

Williams, R.J. and F.A. Watford. 1997. Identification of structures restricting tidal flow in New South Wales, Australia. Wetlands Ecology and Management 5:87-97.

YSI Sondes, 6-Series Sondes section of the Environmental Monitoring Systems Operations Manual. 2007 https://www.ysi.com/DocumentServer/DocumentServer?docID=EMS_S_D

YSI-Sensors, 2007 https://www.ysi.com/DocumentServer/DocumentServer?docID=EMS_S_Z