Inlet Management Restudy for St. Augustine Inlet, St. Johns County, Florida

T. L. Walton Jr., R. G. Dean, J. Gay, M. Manausa, S.Y. Wang

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Executive Summary -   St. Augustine Inlet Management Recommendations

The following short history of St. Augustine Inlet and recommendations for the State of Florida management and permitting activities of St. Augustine Inlet are based on both technical investigations and computations utilizing existing historical and recent survey data collected by the National Ocean Survey (NOS), the Florida Department of Environmental Protection (FDEP), and the United States Army Corps of Engineers (COE) and on information derived from an extensive literature search of reports by the Corps of Engineers, FDEP, Universities, and consulting engineering companies. The recommendations summarize, in a concise manner, the findings documented in detail within the St. Augustine Inlet Report by the Florida State University Beaches and Shores Resource Center.

St. Augustine Inlet is about 35 mi south of the mouth of the St. Johns River and approximately 23 miles north of Matanzas Inlet (a much smaller inlet complex that provides a "back entrance" to the City of St. Augustine). The inlet connects the Atlantic to a continuous estuary of rivers and tidal creeks that runs north-south between barrier islands and the mainland. Three of the estuary's dominant water bodies converge near or in the inlet; the Tolomato and Matanzas Rivers located to the north and south of the inlet respectively (and which converge west of the inlet entrance to form Matanzas Bay) and Salt Run, a 2 mi long embayment (which extends south from the inlet and separates Conch Island from Anastasia Island). The southernmost extent of Porpoise Point and the northernmost extent of Conch Island define the present inlet channel boundaries. Numerous single family residences have been built on a tenuous emergent spit of land formed after the U.S. Army Corps of Engineers (COE) cutting of the new channel in the 1940's which is now part of Porpoise Point (a remnant of area on the channel side of the north jetty once referred to as Vilano Point and North Point, at the southern extreme of Vilano Beach). Conch Island, directly south of the inlet channel connects at its southern extreme to Anastasia Island (separated only by Salt Run).

Core borings taken near the inlet by the COE (USACE (1979)) suggest that sand reaches depths exceeding 50 ft (MLW) in those areas. This information along with the belief that the original dredging of the new inlet was in sand would suggest that the jetties and hydrodynamic characteristics of the inlet complex control the location and migration of the inlet.

Considerable shell hash is found on St. John's County beaches and coquina (calcified shells and shell hash) outcroppings are found throughout the St. Augustine area where there are at least two historic quarries of coquina rock previously utilized for building purposes during Spanish colonization of the area. Other unidentified coquina outcroppings could be reasons for localized patterns of accretion and erosion found throughout the St. Johns County area and particularly on the beaches to the north of St. Augustine Inlet although there is insufficient evidence of subsurface geology in the area to substantiate this hypothesis.

Wind and wave information from various sources show a dominance of wind and waves from the northeast resulting in a **net** southward transport of sand along most regions of St. John's County beaches. This direction of **net** sand transport is confirmed as well by the historical downdrift erosion patterns south of the south jetty at the St. Johns River to the north of St. Augustine, as well as by wave hindcast study of littoral transport in the St. Johns County area.

The shoreline of St. Johns County has been subject to numerous storms (both northeaster's and hurricanes) which in the St. Augustine Inlet area have caused erosion on beaches to the north and south of St. Augustine. Accretion and erosion has occurred historically both north and south of the inlet although since the 1940 construction of the COE inlet, the predominant erosion problem has been on the south side of the inlet in the northern reach of the City of St. Augustine Beach.

A survey of historical maps and charts show that the natural orientation of the inlet channel was typically from the northwest toward the southeast although COE historical reports have noted that the historical main inlet channel has moved both southward and then back northward suggesting a cyclic pattern of migration of the inlet channel which would be consistent with similar processes (whereby the channel migrates in the direction of net drift and then breaks through, restarting the process) although insufficient survey records or other historical information exist to document or confirm the process.

Between 1937 and 1957, the U.S. Army Corps of Engineers (COE) along with the newly created St. Augustine Port, Waterway, and Beach District providing local sponsorship, undertook a series of measures to stabilize the inlet and improve navigation. A study was done by the Beach Erosion Board (BEB) for Headquarters COE and the Jacksonville District COE that recommended a new channel be cut to more efficiently provide access to the ocean with the thought that the new channel would have less friction and thereby be easier to maintain. It is believed that war time considerations were also part of the rationale for the new channel although the BEB report could not be obtained from COE so this statement remains speculative. As shoreline property values were of lesser concern than navigation at the time of these studies, lesser thought probably went into possible shoreline re-adjustments that could be caused by the new inlet channel location.

In 1940, the Corps of Engineers based on findings in the noted BEB/COE studies cut a new channel oriented east to west approximately 2 to 2½ miles north of the natural inlet channel and, in the following year, constructed a short north jetty (referred to in old COE reports as a groin). The jetty/groin was meant to trap sand on its north side as it did to some extent, although considerable sand has overtopped and bypassed the structure since its construction. The area created by this overtopping and bypassing of sand at the north jetty is referred to as Porpoise Point.

The original design for the 1940 navigation project specified a 6,000 ft access channel cut 200 ft wide, 27 ft deep (MLW), and oriented slightly northeast - southwest. In 1941, however, the authorized channel depth was reduced to 20 ft (MLW) due to the difficulty maintaining the channel to its design depth. Another reduction occurred in 1950 to 16 ft (MLW), which remains the currently authorized channel depth. The new channel cut and the construction of the north jetty reduced the inlet's natural migratory nature as desired although other consequent unforeseen changes occurred. As a consequence of the new inlet configuration, North Point separated from Vilano Beach during inlet construction and merged with Crazy Bank, the most significant shoal south of the new inlet channel. The new land mass resulting from this merger became known as Conch Island which later became a part of Anastasia Island. The development of this shoal merging into Anastasia Island can best be following in the many figures provided in St. John's County erosion control project reports listed in the Reference section of the main report. Additional findings and rationale have been provided in the present study that the ebb tidal shoal increased in magnitude from a survey performed in 1924 (pre- COE inlet construction) to a survey performed in 1972 (post-COE inlet construction). The Corps of Engineers further stabilized the new channel with the construction of a 3,695 ft long south jetty in 1957. The south jetty was built to prevent the inlet from trapping sand from Anastasia Island and thus prevent undesirable shoaling within the new navigation channel. With the construction of the south jetty, the inlet's location was fixed in position and a new ebb tidal shoal began to form adding sediment to the historical ebb tidal shoal platform. Between 1952 and 1970 Conch Island merged with Anastasia Island which in turn merged with and enveloped Bird Island creating a massive spit by 1970. Conch Island enclosed the 2 mile embayment called Salt Run which was part of the original inlet channel. Width of the inlet is approximately 1000 feet at the throat of the inlet at present and sand encroaching into the channel from the north side is pressing the main channel toward the south bank and against the south jetty.

Over the years, the Corps of Engineers experimented with different outer access channel alignments to minimize channel maintenance. Whereas the original dredging work opened a channel oriented east to west, subsequent dredging operations (as the new ebb shoal began to develop) typically followed many different alignments trying to capture the natural channel offshore of the jetties. Although dredged material from the inlet (prior to year 2000) has been historically small in quantity, this dredged material was previously disposed offshore rather than onto the adjacent St. Augustine beaches. As of 1991, the Corps of Engineers (USACE 1991) report noted that *"it is evident that the relocation of the federal navigation project has had a negative impact on the beaches to the south [of the inlet]"*. The USACE (1991) report also notes that shorelines directly north of the inlet were typically stable or accreting prior to the creation of the COE inlet channel except for the Vilano Beach shoreline which retreated as rapidly as 16 ft/yr in the decade or so prior to construction of the north jetty. After construction of the COE inlet and the building of the north jetty, the area to the north of the inlet has remained somewhat stable although minor fluctuations in shoreline occurred with some areas experiencing recession, especially in recent years. All areas of St. Johns County suffered considerable damage and erosion/recession during the northeaster of 1962, Hurricane Dora of 1964, and more recently the "Thanksgiving Day" Northeaster storm of 1984, as well as other lesser storms. Recent period shoreline data (1970 – 2007) show > 1 ft/yr long term average annual recession rates have historically been constrained to within approximately 7 miles north of the inlet and 3 miles to the south of the inlet although the shoreline south of the inlet has experienced much higher rates than 1 ft/yr in a limited area at the north end of the City of St. Augustine Beach where structural hardening has been applied to the worst erosion area. It should be recognized that the recent period data include the effects of ebb shoal dredging and beach nourishment placement and thus cannot be directly compared to the historical trends.

The new COE inlet's navigation channel and area of influence on adjacent shorelines has never been clearly delineated nor quantified with any degree of certainty due to lack of good extensive synoptic surveys of both adjacent beaches and inlet ebb and flood shoals In the inlet management report conducted for the FDEP- State of Florida in the 1990's, Taylor

Engineering (1994) estimated the area of influence for the St. Augustine inlet system extending from approximately 4 mi to the north of the inlet to 4 miles to the south of the inlet. The inlet area of influence would be expected to increase with time if the inlet system is allowed to continue to trap sand in its flood and ebb shoals and if the original bypassing nature of the inlet is changed without a man-induced bypassing or backpassing component(s) to restore the natural balance.

Since the construction of the new inlet channel and associated jetties, numerous changes have occurred. One such change involves the area inside of the north jetty known as Porpoise Point. The low profile of the north jetty although stabilizing the shoreline north of the new St. Augustine Inlet somewhat, has precluded significant accretion of the northern beaches and sand has washed over and around the north jetty and has deposited between the inlet channel and the jetty. This sand should have been bypassed to the south shoreline either naturally on the ebb shoal complex or artificially via some type of sand bypassing operation. At present, the north jetty is completely filled and considerable sand is continuing to be bypassed around the outer end of the north jetty, and during high storm wave activity, overtopping the jetty. This material bypassed and over-washed has increased the Porpoise Point area as well as shoals in the vicinity where considerable development of residential homes has taken place. This sand has been permanently lost to the inlet system as neither the State of Florida nor the Federal Government appears to have claimed the created land and private development has taken place on a portion of the area. No dredging of this sand has taken place in the Porpoise Point area to best knowledge at time of this report. It is important to the stability of the north beaches that material moving to this area be retained on the north beaches which can best be accomplished via making the north jetty sand tight and raising the north jetty somewhat above the natural template of the natural beach and dune system in that area. Further possible lengthening of the north jetty should be considered after such changes have been made and after subsequent monitoring of the area has been performed. Details of needed monitoring are discussed in the main report.

As noted previously, the south jetty was completed in 1957. The south jetty is 3695 ft long and constructed of stone with a varied crown elevation from +6 ft MLW at its seaward end to +10 MLW at its landward end. The landward end of the jetty transitions into a 620 ft long revetment which stabilizes the eastern shoreline of Salt Run near its northern terminus at the inlet. At present the south jetty is filled to capacity and the shoreline south of the south jetty extends considerably seaward of the Eastern tip of the south jetty. It would appear that present material reaching the south jetty area from further south during periods of northward drift along the Anastasia State Park shoreline is subject to being washed into the navigation channel and recycled to the ebb tidal shoal. Although a lengthening of the south jetty would be beneficial, a series of low profile rubble mound groins in the area from the south jetty and proceeding through the Anastasia State Park area to the south end of the hardened structures (near the north end of the City of St. Augustine Beach) might be a cost effective solution to slow the loss of material from the eroding area. This option should be considered by the COE and will be discussed further in paragraphs below.

The predominant construction of a seawall and revetment complex now existing near the north end of the City of St. Augustine Beach occurred following the severe storms of the early

1960's. A county fishing pier has also been built in this area. The seawall is an 800 ft long concrete seawall with cap elevation at +13.5 MLW while the revetment is a 4200 ft long coquina rock and granite stone revetment. The fishing pier is 600 ft. long and oriented perpendicular to the shoreline. It is important to note that this area was stabilized in places up to approximately 500 feet seaward of the natural shoreline trend (i.e. the probable shoreline location without the ebb shoal reattachment point of the historical pre-COE inlet). This "promontory" area has been subject to considerable erosion pressure subsequent to the COE construction of the new inlet due to the changed inlet ebb shoal attachment location which had provided a seaward offset in the shoreline from approximately FDEP monument locations R-134 to R-152. When the inlet was relocated northward, this area (which includes the old Salt Run natural channel location) was changed from a zone of limited but shifting shoreline stability to a zone of longshore sand divergence, shoreline recession, and erosion. Figure ES-1 is derived from a 1928 National Ocean Survey Hydrographic Chart and shows both the historical ebb shoal attachment location at that time and the area of more recent hardened structures which is undergoing serious erosion stress.

The first nourishment of the St. Johns County Shore Protection Project was initiated in September 2001 and completed in January 2003. The project length was approximately 2.9 miles from Anastasia State Park to the City of St. Augustine Beach. The State of Florida, in conjunction with the federal nourishment project extended the beach nourishment project approximately 0.9 mi further north into Anastasia State Park. The entire project extended from approximately 0.9 mi north of northern boundary of Federal project in Anastasia State Park (FDEP monument T-132) to approximately 600 ft south of FDEP monument R-151 in the City of St. Augustine Beach in St. Johns County, Florida, i.e. the area of the historical pre-COE inlet attachment point.

The 2004 hurricane season resulted in a need to re-nourish the project before anticipated re-nourishment, and after the 2004 and 2005 hurricane seasons, a second beach nourishment (i.e. first re-nourishment project) was placed. This project was constructed between June and December 2005 and extended over approximately the same area as the original 2003 Federal project (i.e. from FDEP monument R-137A to R-151).

With the nourishment project placements, the shoreline advanced over its eroded previous condition but will continue to erode and recede without continuous sand nourishment and possibly groin construction to slow the divergence of sand due to the offset/promotory nature of the shoreline in this area, a result of the new COE inlet shift to the north from the historical inlet channel openings. The post-nourishment advancement of the shoreline south of the hardened City of St. Augustine Beach Park structure complex is evidenced by old rubble revetment/mound structures in areas south of the pier which are now inland (behind the more recent frontal dune system).

The St. Augustine Inlet ebb tidal shoal was the source of borrow material for both projects. It is noted that the 2003 borrow area encompassed the larger footprint of the two project borrow zones, and included the 2005 borrow area as well as extending into the northern lobe of the St. Augustine Inlet ebb shoal. A summary of these large nourishment projects is provided below.

Federal/State Combined Nourishment History of St. Augustine Beach

Project Completion Date	Volume Placed	Time of Construction
First Nourishment	4,200,000 c.y.	Sept 2001 – Jan 2003
Re-nourishment	2,800,000 c.y.	June 2005 – Nov 2005

A present concern is whether the past nourishment projects have caused erosion of the beaches to the north and specifically as far northward as South Ponte Vedra beach. Specific findings by others as well as findings by BSRC in the present report suggest that the inlet dredging was not the cause of the recent (early 2000's) northernmost noted erosion at South Ponte Vedra beach although it is herein recommended that further dredging of the north lobe of the tidal ebb shoal could cause future reduction of the inlet's natural bypassing ability on the ebb shoal and should be discontinued. It is also recommended that any dredging of the tidal ebb shoal be limited to the south side of the inlet channel with an intent to re-train the inlet channel to open toward the southeast and consequently mimic the historical channel natural by-passing that occurred at St. Augustine Inlet. A suggested area for dredging on the tidal ebb shoal has been recommended for preliminary consideration but quality of sand and volume of material available would need to be established by the COE via survey and testing beyond the scope of the present limited State study.

Although historical shoreline information shows much of the south beach nourished area presently advanced over its most historical landward location, the continuing loss of beach nourishment material from the armored area in the City of St. Augustine Beach and in the southern reach of Anastasia State Park poses serious problems. Although the nourishment area is somewhat limited in length by the existing State and Federal beach nourishment project lengths, recession (where hardened structures do not exist) and erosion will continue to plague this area due to the inlet relocation to the north. This area is presently a zone of sand divergence in the longshore direction with sand further to the north of the Salt Run area flowing northward and sand further south of the structure complex flowing southward. If the area is not maintained in some manner, a consequence of eventual shoreline loss would tend to straighten the shoreline, eventually moving the shoreline in this former salient area back to the approximate vicinity of Highway A1A in some locations (approximately a 500 foot loss of shoreline in the most exposed structure hardened area (see Figure ES-2)). For purposes here, we consider the hardened shoreline to remain in place. Relocating the County Park infrastructure and elimination of the hardened shoreline in this area would allow the shoreline to retreat naturally but is considered unacceptable due to the numerous private residences and public property that would eventually be lost. An additional consequence of not maintaining the shoreline in a somewhat "status quo" (nourished) situation is that Anastasia Island State Park would be subject to beach/dune breaching in the area of Salt Run with potential serious environmental problems (as well as cutting off access to a part of the State Park). To maintain the existing "offset hardened promontory" the shoreline will require considerably more sand placement than would be needed if the hardened structure complex had not been built in this area and the COE constructed inlet was never built.

As a consequence of the construction of the COE St. Augustine inlet channel further to the north, there are only three options to retaining the seawall/revetment structure complex:

(1) hardening of the shoreline alone via massive seawall and revetment (with consequent continuing loss of beachfront and land adjacent to the hardening);

(2) continuous "large magnitude" beach fill placement as has been preformed in the 2001 through 2005 period; or

(3) a groin field with additional beach fill placement to fill and maintain the groin compartments;.

Each of these options is explored here.

Option #1

Structure hardening would allow the shoreline at the structure complex to maintain its present (seaward) position although it is expected that serious problems would need to be addressed as the offshore beach profile would continue to lower in the area (due to the continued divergence of sand transport). The pier would eventually be undermined by scour and would have to be replaced with much longer and more substantial pilings. Additional problems would occur in that the State Park beach/dune system would continue to erode at its south end with the eventual breaching of the beach/dune in the Salt Run area as the sand source which is presently feeding this area has been the beach nourishment at the structure complex. Additional erosion would occur south of the structure complex due to the loss of sand placement (and net southward transport). This option is not considered a viable option due to the loss of recreational beach and the potential adverse impacts within the State Park (including either future hardening of the State Park area or a future breakthrough of the beach dune system within the State Park area).

Option #2

Continuous "large magnitude" beach fill is a viable option provided sufficient beach material is placed to maintain the shoreline in the desired position. A sediment transport figure that should be needed to offset the natural system bypassing and material recycling to the south side of the inlet has been provided via the present investigations as a multiple (approximately 1.41) of the **net** sediment transport as seen on the beaches to the north of the inlet (i.e. Q_{net} = ~402,000 c.y./yr). This multiple of the **net** transport (=$1.41 \cdot Q_{net}$) is due to both the northward sediment flow from this region as well as **net** southward flow (i.e. a zone of divergence). Due to the "headland/promontory" nature of the shoreline in this area, an additional volume of material will need to be placed as the constant readjustment of the beach nourishment fill should remain seaward of the target shoreline (which juts out approximately 500 feet seaward of the naturally trending shoreline). Preliminary calculations for such effects (see example Figure ES-3 for a trapezoidal fill which provides for beach in front of hardened structures) as well as the arguments of Appendix P of the main report suggest that the multiple of Q_{net} (= 402,000 c.y./yr as estimated on the north beach) will need to be higher than 1.41 (depending on beach fill configuration) based on fill placements at 1 to 3 year intervals. Based on performance of the 2001-2003 and 2005 beach fills, it is suggested that approximately 700,000-800,000 c.y. per year will be needed (based on 1 to 3 year placement interval) to maintain "status quo" if no additional structures are considered.

Option #3

Beach fill with a properly designed groin field is a potential option for the erosion stressed portions of the area from the south shore of the COE inlet through the seawall/revetment structured area as it would provide for a slowing of the natural process of northward sediment transport feeding sand back to the inlet at or near to the south shore of St. Augustine inlet while at the same time allowing the southward **net** flow of sand to progress to the beaches south of the inlet thus mimicking the natural continuity of flow if there was no interruption of sand at St. Augustine inlet. Should this option be chosen, a groin field could be within the area starting south of St. Augustine inlet and ending at the south end of the seawall/revetment structured area. It would be best to fill the groin field with sand over the area of groin construction while allowing the shoreline to adjust within the groin field over the area to the north of the north end of the beach fill placement (i.e. approximately FDEP range R-134). Sand should additionally be placed to the south of the seawall/revetment structured area in proportion to the annualized amount of material placed in this area of the beach in the past two nourishment projects with a minimum of sand to be placed based on the **net** sediment transport cited earlier. This sand would allow for reestablishment of the net sediment transport generally flowing along St. Johns county beaches and interrupted by the St. Augustine Federally maintained inlet. Additional benefits would be the reduction in longshore transport within the groin field area reducing the rate of erosion from the problem area. A reduction of the cycling of material from the nourishment area to the north end of the State Park and then out onto the ebb tidal shoal (or inner shoals) would reduce the frequency of dredging. Design and cost of this option and associated potential savings are beyond the scope of the present study.

A final recommendation is that the State of Florida approach Congress for funding of a Section 111 study of St. Augustine Inlet. At present USACE (1979) concludes that the Federal Navigation project is responsible for 50% of the erosion in St. John's County although it is suggested that this figure is much higher (but due to the sparse nature of the available data and fact that much of the data is not synoptic, a fair percentage of Federal costs short of 100% is not possible at present). Part of a Section 111 Study (or study precursor) should be the collection of synoptic detailed surveys of the ebb shoal complex at St. Augustine Inlet (prior to and after all dredging and nourishment episodes), and the digitization of all historical COE surveys of the inlet channel and inlet complex. Such data collection and digitization is well beyond the scope of this existing State study. It is recommended that a panel of at least two to three Florida coastal engineering experts be appointed by the State of Florida who would serve on behalf of the State's interests in the performance of this study. These experts should be intimately involved in an overview of all data collected by the Corps of Engineers (or their contractors) as well as being involved in all study components and study findings of the Section 111 study to be performed by the Corps of Engineers.

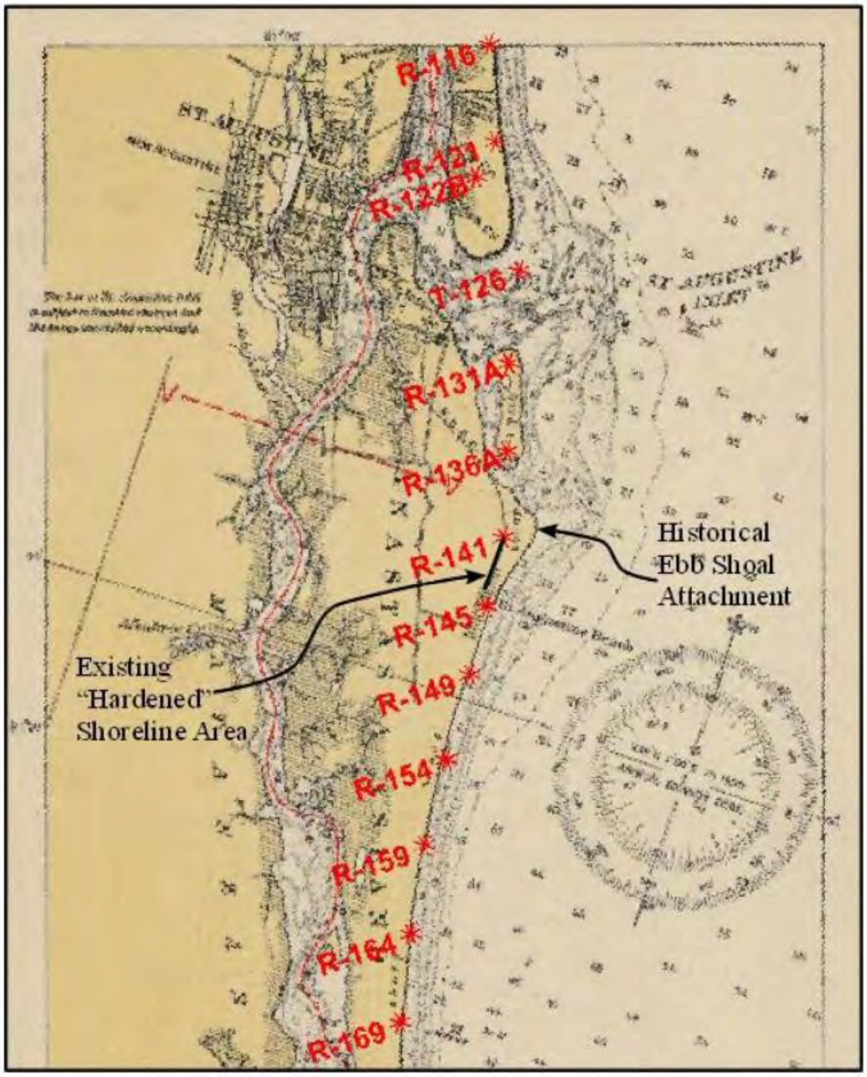

Figure ES-1. Historical Ebb Shoal Attachment (NOS 1928) and Existing Hardened Structure Area Subject to Severe Erosion.

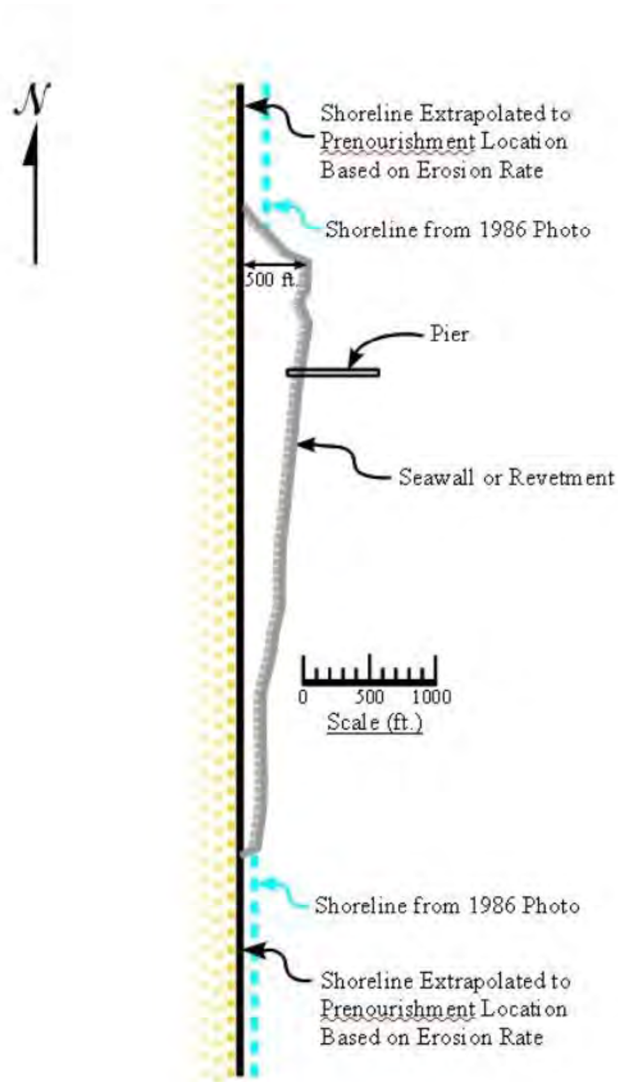

Figure ES-2. Existing Hardened Structure Projection from Adjacent Projected Shorelines.

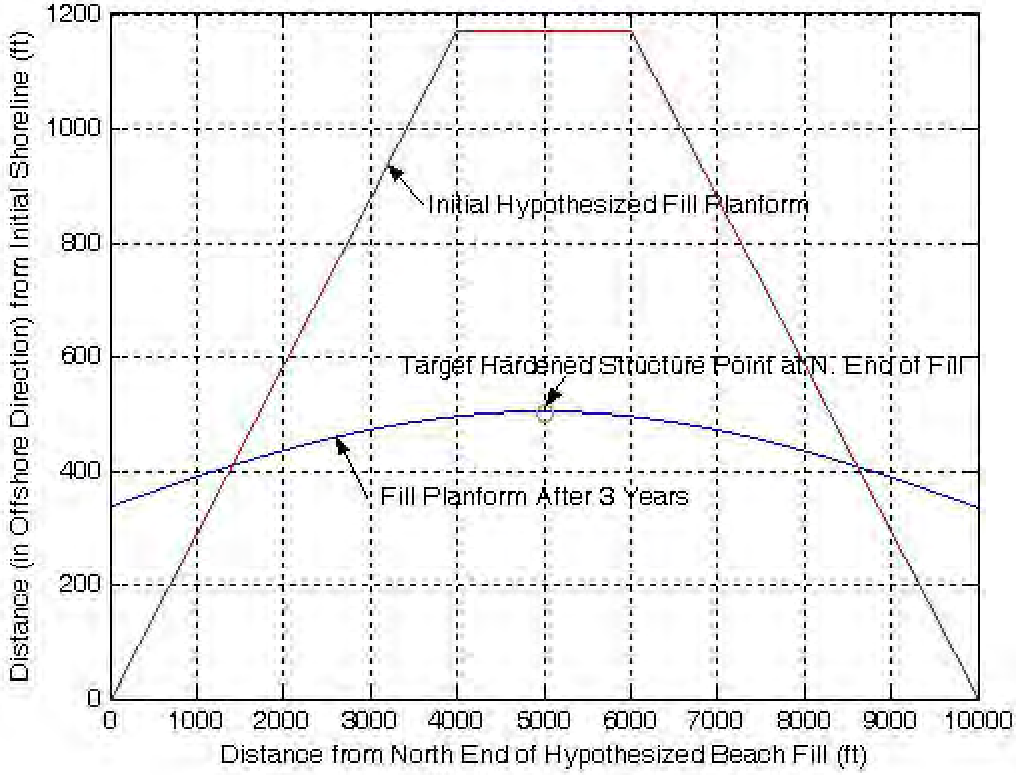

Figure ES-3. Example Hypothesized Fill Performance for 3 Year Interval Placement.

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Authors Comments

Contributions to the report have been made by various persons in the BSRC staff as well as one sub-consultant (R .G. Dean) and one OPS person. In addition to the above, all tidal data collection and current collection field work discussed herein was performed by Surfbreak Engineering as a sub-consultant feature of FSU-BSRC contract. All historical information, records, inlet history, photo collection, map collection, etc. were gathered and reported on by T. Walton (including various items and data from reports provided by G. Weeks (FDEP), B. Brantly (FDEP), R. Clark (FDEP), individuals at Taylor Engineering including Ken Craig and Rajesh Srinivas, and U.S.A.C.E.-Jacksonville, FL). Numerical modeling referenced in the report was accomplished by M. Manausa and R. Wang while sediment volume and shoreline calculations were made by M. Manausa and J. Gay. Sediment transport calculations were made by T. Walton and in part checked by R. G. Dean. Various appendices except for numerical modeling items were developed by T. Walton and R.G. Dean. The writing of the report was done by T. Walton with limited section contributions by R. G. Dean. The editorial help of Virginia Williams for doing tables, lists of Figures, etc. is also acknowledged. Acknowledgement and thanks are due to all the above individuals who provided data and information for this report.

1. Purpose of Study and Objectives

In accord with amended Section 161.142, Florida Statutes, the Florida Legislature finds that it is in the public interest to maximize inlet sand bypassing to ensure that beach-quality sand is placed on adjacent eroding beaches. Within the legislation, the FDEP-BBCS has been directed to maintain a current estimate of sand budgets within inlet complexes for purposes of prioritizing, planning, and permitting activities of the state. Wise management of limited natural resource beach sediment at its inlet systems for addressing mitigation of beach erosion and consequent flood damage to coastal areas adjacent to inlet systems will benefit the State of Florida.

The objective of the present study is to update/develop a "best estimate" sediment budget and recommendations for sediment resource allocation to adjacent beaches for St. Augustine Inlet. Additional objectives of the study were to provide recommendations as to: need for additional or modified sediment control structures (i.e. possible lengthening of jetties, sand tightening of jetties, spur jetties, etc.); quantity of material needed to control/mitigate the south side inlet erosion, and suggestions regarding potential ebb shoal dredging; possible site of sediment impoundment basin for additional bypassing should it be recommended; possible realignment of navigation channel; identification of potential sediment bypass pathways at inlet; and possible revision of maintenance dredging quantities and schedules to improve bypassing.

Results of the present study are summarized in this report and include data findings of sediment budget based on additional data obtained by the FDEP and its subcontractors, significant inlet impact and quantities of bypassing necessary to develop sediment balance updrift and downdrift of inlet and mitigation of the south side erosion problem. Additional recommendations addressed within the report include needed modifications to an existing coastal structure (i.e. north jetty), needed additional work necessary to identify optimal coastal structures on the south side of inlet (i.e. groins), and recommendations regarding future dredging practices such as ebb shoal dredging, channel maintenance alignment, potential sediment basin (if needed), and optimal dredged quantities.

2. Inlet Historical Perspectives

2.1 Geographical setting

St. Augustine Inlet is one of the few tidal inlets (not counting river or sound entrances) that connects the Atlantic Ocean to the inland waters of northeast Florida. St. Augustine Inlet is about 35 mi south of the mouth of the St. Johns River and approximately 23 miles to the north of Matanzas Inlet (a much smaller inlet complex that provides a "back entrance" to the City of St. Augustine). Geographic location of St. Augustine Inlet is at approximate coordinates 29°54'20" North .and 81°17'29" West in St. Johns County. The inlet connects the Atlantic to a continuous estuary of rivers and tidal creeks that runs north-south between barrier islands and the mainland. The inlet channel cuts through approximately 3,500 ft of the adjacent barriers and is approximately 1000 (at the throat of the inlet) to 2000 ft. in width. At present, sand encroaching into the channel from the north side is pressing the main channel toward the south bank and against the south jetty. Three of the estuary's dominant water bodies converge near or in the inlet; the Tolomato and Matanzas Rivers located to the north and south of the inlet respectively (and which converge west of the inlet entrance to form Matanzas Bay) and Salt Run, a 2 mi long embayment (which extends south from the inlet and separates Conch Island from Anastasia Island). The southernmost extent of Porpoise Point and the northernmost extent of Conch Island define the present inlet channel boundaries. Numerous single family residences have been built on the tenuous emergent spit of land just south of the north jetty (i.e. Porpoise Point) formed after the COE cutting of the new channel in the 1940's. Porpoise Point is now the southernmost terminus of the beaches to the north of St. Augustine Inlet whereas, prior to the new inlet construction, the area at the southern most terminus of the old inlet was referred to as Vilano Point (or North Point). Conch Island, directly south of the inlet channel connects at its southern extreme to Anastasia Island (separated only by Salt Run). Conch Island shorelines have been principal attractions to visitors to Anastasia State Park, a well-maintained nature reserve.

2.2 Geology and Physiography

A large portion of Florida is part of a geographic unit called the Floridian Plateau, a partially submerged plateau that separates the Atlantic Ocean and the Gulf of Mexico. This plateau at times during peaks of ice ages showed a much larger emergent area than exists today although the plateau has existed partially dry and partially submerged for millions of years. Although in past times this plateau might have been characterized as a "shoreline of emergence" (USACE (1979)) it is clearly now undergoing sea level rise and is no longer emerging. St. Johns County is near the south end of the sea island chain that extends from South Carolina through Georgia and into the northeastern portion of Florida. It is near the beginning of a transition between the sea islands (to the north) and barrier islands that dominate the Florida East Coast further to the South. The St. Augustine Inlet area is characterized by sandy barrier islands, lagoons, and swamps that separate inland from ocean. The sandy beaches near St. Augustine Inlet are composed primarily of silica sand that derives from the Savannah, Altamaha, and other Georgia and Carolina rivers, and which was carried southward by littoral drift and possibly by ancient rivers in earlier times. There is also a large biogenic component of beach material in the form of shells and shell hash deriving from coquina outcroppings in the area. St. Augustine lies on a portion of the Anastasia formation that exists along much of the East Coast of Florida and is characterized by a sandy upper layer on top of an under layer of coquina rock. Core borings near the inlet taken by the Corps of Engineers (USACE (1979)) suggest that sand reaches depths exceeding 50 ft (MLW) in areas bored. This information along with the assumption that the original dredging of the new inlet was in sand suggests that the jetties and hydrodynamic characteristics of the inlet complex most likely control the location and migration of the inlet. Onshore (near the surface in this area) and possibly in the nearshore, outcroppings of consolidated sand and (biogenic origin) shell fragment mixes (coquina) exist and can be seen at very shallow depths below land/air interface in quarries in St. Johns County (i.e. Old Spanish Quarry at entrance to Anastasia Island State Park). In the settlement of St. Augustine, coquina rock played a major role in the building of the Spanish forts as well as many of the buildings. This coquina rock (part of the Anastasia Formation that exists along the East Coast of Florida) is in various stages of consolidation, and reworking of the coquina is often found on the beaches (typically along the foreshore of the beach) as shell hash. In tidal lagoons north and south of the inlet, subsurface conditions can vary widely with up to 100% shell content. Soft silts and organic materials are typically found in marsh areas and range in thickness from very thin up to several feet in thickness. Below the soft silts and organic top soils lie a variety of elements ranging from sands to fine silt and clay (USACE (1979)). Characteristics of sand located at St. Augustine Inlet and on adjacent beaches are noted in references covered in both Taylor Engineering (1994) as well as Charles et al (1994). The sands found on the beaches north and south of the inlet differ significantly in grain size, although it is not clear that significant hydraulic fall velocity is different for these beaches. north of the inlet, mechanically measured sand grain sizes range from .07 to 2.28 mm at Vilano Beach compared to .18 to .51 mm on Conch Island, south of the inlet. The normally larger grain size sand found on the beaches at Vilano Beach is consistent with higher amounts of shell than found on beaches south of the inlet. Data by Charles et al.(1994) suggests that the large shell component does not extend to the offshore regions of the beach profiles. The percentage of heavy minerals varies on beaches both north and south of the inlet. For further information on grain size distribution and spatial variability relevant to St. Augustine Inlet, see Taylor Engineering (1994) (adapted from Higgins' 1965 study of shoreline sands from the Georgia border to Anastasia Island) and Charles et al (1994).

The physiography of the St. Augustine Inlet area as associated with wave climate, hydrodynamics, hydraulic characteristics, and bathymetry is covered in Taylor Engineering (1994) although a limited discussion is included herein. Numerous sources (see Taylor Engineering (1994)) have reported wind data based on wind diagrams from the U.S. Weather Bureau at Jacksonville, and other sources. These reports indicate that winds are well distributed in all directions although winds from the northeast dominate (which agrees with predominant wind wave direction later noted). Most frequent wind speeds range between 7 and 16 knots, and calms occur less than two percent of the time. One source of both wind and wave data utilized in the present work is the Hindcast Wave Information Study (WIS) program of the Corps of Engineers (to be discussed further later). The Wave Information Studies (WlS) present a characterization of winds and waves for stations offshore the U.S. coastline. In particular, WlS provides a 20-year data set for station 2024 (Latitude 29.75°N, Longitude 8l.0°W) located near St.Augustine Inlet. Wind and wave information from this WIS data show a dominance of wind and waves from the northeast. Winds associated with severe storm damage typically originate in the northeast. Northeast storms causing damage to the area have been noted by the COE to have occurred during the years of 1925, 1932, 1947, and 1962, while more recent storms causing damage have been the northeasters of 1963, 1972, and 1984. Sustained northeasters having high tides over a number of tidal cycles, such as the 1962 "Ash Wednesday" Northeaster storm and the "Thanksgiving Day" Northeaster storm of 1984 have caused significant damage to the beaches of St. Johns County (see for example USACE (1979). The 1962 "Ash Wednesday" Northeaster storm lasted through five high tides that directly contributed to erosion along the entire East Coast of the U.S. as well as northeast Florida. In addition to severe erosion on the beaches, damages to seawalls, ramps, U.S. Highway AlA and numerous private residences were also noted. Following the 1962 northeaster season, the Corps of Engineers (COE) authorized 50,000 c.y. sand fill and 450 l.f. of granite revetment for St. Augustine Beach (along with 1800 l.f. of granite revetment and considerable A1A road replacement directly south of Matanzas Inlet). Most northeasters cause considerably less damage than the 1962 storm but still have detrimental impacts on the beaches. Tropical storms and hurricanes can often be more destructive to a localized area due to the intensity of their wind patterns over a significantly smaller area. Numerous sources document the history of tropical storms in St. Johns County (see USACE reports in References) although the most destructive hurricane to date since Corps of Engineers construction of the new inlet in the 1940's was Hurricane Dora which made landfall near St. Augustine shortly after midnight on September 10, 1964. Hurricane Dora had measured low pressure of 28.52 hPa and winds at St. Augustine in excess of 125 mph. This hurricane produced reported high storm tide levels as much as 12 feet above normal along Anastasia Island and waves 20-30 feet high (estimated 7 ft storm surge at the sheltered Mayport Ferry tidal gage station to the north in the St. Johns River entrance). It caused severe damage to many coastal structures and beaches in the area (see USACE (1979)) as well as breaching the beach/dune system and opening up the old natural inlet channel (Salt Run).

Although ocean currents have a significant impact on the physiography of some regions, large-scale ocean currents (i.e. the Gulf Stream (USACE (1979)) are not expected to affect the physical processes in the vicinity of St. Augustine Inlet as the eastern edge of the Florida Current (Gulf Stream) is typically located approximately 70 miles east of the St. Johns County coast.

2.3 Inlet Channel History

Although maps and documents exist from the late 1500's that pertain to the early history of the inlet complex, this study is aimed primarily at looking at the existing inlet configuration and present sediment budget. In view of understanding present sediment budget and sand transport considerations for management of the inlet, it is still important to understand a limited portion of this history as well as more recent changes to the inlet complex, the most significant of which is the new Corps of Engineers (COE) constructed channel in the 1940's. As noted previously in the section on historical maps and charts, the natural configuration of the inlet channel was typically from the northwest toward the southeast over the history of the inlet from the late 1500's till the new COE inlet was constructed although deviations are noted from this typical pattern. The COE conducted the National Shoreline Study Regional Report for this area (see USACE 1971) and noted that the inlet moved southward between 1860 and 1923 and back northward between 1923 through 1941 suggesting a cyclic pattern although insufficient survey records or other historical information exist to confirm such a hypothesis.

Between 1937 and 1957, the U.S. Army Corps of Engineers along with the newly created St. Augustine Port, Waterway, and Beach District providing local sponsorship, undertook a series of measures to stabilize the inlet and improve navigation. A study was done by the Beach Erosion Board of the COE and the Jacksonville District COE that recommended a new channel be cut to more efficiently provide access to the ocean with the thought that the new channel would have less friction and thereby be easier to maintain. As shoreline property values were of lesser concern than navigation at the time of the studies, lesser thought went into possible shoreline re-adjustments that might be caused by the new inlet location.

In 1940, the Corps of Engineers based on findings in the noted COE studies cut a new channel oriented east to west approximately 2 ½ miles north of the natural inlet channel and, in the following year, constructed a 1580 ft long north jetty (referred to in old COE reports as a sand trapping groin). The jetty/groin extended 450 feet seaward of MLW as built and was meant to trap sand on its north side (as has happened), although considerable sand has overtopped and bypassed the structure since its inception.

The original design for the 1940 navigation project specified a 6,000 ft access channel cut 200 ft wide, 27 ft deep (MLW), and oriented slightly northeast - southwest. In 1941, however, the authorized channel depth was reduced to 20 ft (MLW) due to the difficulty maintaining the channel to its designed depth. Another reduction occurred in 1950, this time to 16 ft (MLW), which remains the currently authorized channel depth. The new channel cut and the construction of the north jetty reduced the inlet's natural migratory nature as was desired although other consequent (apparently unforeseen) changes occurred. As a consequence of the new inlet, the North Point area separated from Vilano Beach during inlet construction and merged with Crazy Bank, the most significant shoal south of the new inlet channel. The new land mass resulting from this merger became known as Conch Island and later became a part of Anastasia Island and what is now Anastasia State Park. This area is now of considerable environmental and recreational value to the State of Florida.

The Corps of Engineers further stabilized the new channel with the construction of a 3,695 ft long south jetty in 1957. The south jetty was built to prevent the inlet from trapping sand from Anastasia Island and thus prevent undesirable shoaling within the new navigation channel. With the construction of the south jetty, the inlet's location was permanently fixed in position and a new ebb shoal began to form. Between 1952 and 1970 Conch Island merged with Anastasia Island which in turn merged with and enveloped Bird Island creating a massive spit by 1970. Conch Island enclosed the 2 mile embayment called Salt Run which was part of the original inlet channel.

During the 1970's, Florida Coastal Engineers (1976) in a study for the St. Augustine Inlet District, noted that the new inlet was responsible for the steepening of beach profiles north and south of the inlet and for critical erosion of the City of St. Augustine Beach.

Over the years, the Corps of Engineers experimented with different outer access channel alignments to minimize channel maintenance. Whereas the original dredging work opened a channel oriented east to west, subsequent dredging operations (as the new ebb shoal began to develop) typically followed many different alignments trying to capture the natural channel offshore of the jetties. For maintenance quantities dredged during this period refer to the dredging history section. As of 1991, the Corps of Engineers (1991) report noted that *"it is evident that the relocation of the federal navigation project has had a negative impact on the beaches to the south [of the inlet]"* which appears to be continuing as of the time of this report.

The navigation channel and inlet system's area of influence on adjacent shorelines has never been clearly delineated although Florida Coastal Engineers (1976) reported that shorelines at Ponte Vedra, South Ponte Vedra, and Crescent Beach were located outside the influence of St. Augustine Inlet. In the inlet management reports conducted for the FDEP- State of Florida, Taylor Engineering (1994) estimated the area of influence for the St. Augustine inlet system extending from approximately 4 mi to the north of the inlet to 4 miles to the south of the inlet. Inlet area of influence would be expected to increase with time if the inlet system continues to trap sand in its flood and ebb shoals and if the original bypassing nature of the inlet has been permanently changed without man-induced bypassing to restore a natural balance.

2.4 Navigation/Channel dredging and disposal

Surveys of the inlet and inlet complex by the Jacksonville District COE were requested in digital form for the present study but were furnished in print (non–digitized) form (see Table 2.4.1). As the typical coverage in the furnished survey files provided was non-digitized and was very limited or constrained to the dredged channel width area, limited information for the present study could be obtained from COE furnished materials.

Table 2.4 1

Maintenance Dredging Surveys of Record.
(information provided via Jacksonville District COE)

DO File No.	Date	Description	
10-13602	Nov 1943	Maintenance Dredging (limited coverage)	
10-13740	Nov 1944	Maintenance Dredging (full coverage)	**
10-13832	June 1945	Maintenance Dredging (full coverage)	**
10-13922	June 1946	Maintenance Dredging (full coverage)	**
10-14556	June 1947	Maintenance Dredging (full coverage)	**
10-15382	July 1948	Maintenance Dredging (full coverage)	**
10-31808	Mar 1974	Maintenance Dredging (limited coverage)	
10-31835	May 1974	Maintenance Dredging (limited coverage)	
10-31917	Dec 1974	Maintenance Dredging	

COE dredging activity information (i.e. quantities dredged, locations of dredging, locations of dredge spoil, etc.) was provided by the Jacksonville District COE to the extent of their known records, although much of the early history of the inlet spoiling practices as well as locations where the dredging occurred appears to be unknown. The provided information is summarized in Table 2.4.2 below.

Table 2.4 2

Spoil Volumes Dredged and Placed Offshore or on Beach from COE Dredging Operations (information provided via Jacksonville District COE)

Year	Volume (Cu Yds)	Spoil Location	Beach Material%	Dredging Location
1940	247,562	?	?	St. Augustine Inlet (27' x 200' new channel)
1956	101,870	?	?	St. Augustine Inlet
1971	104,811	?	?	St. Augustine Inlet
1974	189,120	?	?	St. Augustine Inlet
1975	393,824	?	?	St. Augustine Inlet
1977	158,931	?	?	St. Augustine Inlet
1978	35,135	?	?	St. Augustine Inlet
1986	142,000	?	?	St. Augustine Inlet
1996	253,327	Anastasia State Park R138 -R142	100.0%	St. Augustine Inlet (-)9+40 to 31+00
1999	241,887	Anastasia State Park R135A -R138A	100.0%	St. Augustine Inlet 90+42.72 to 108+48.86
2000	177,000	Anastasia State Park R133 -R136	100.0%	St. Augustine Inlet (-)9+40 to 31+00
2005	124,904	Anastasia State Park R133A - R137	100.0%	St. Augustine Inlet St 90+50 to 104+30

2.5 Structures - jetty, revetment history

The primary existing structures of importance to the present study are the St. Augustine Inlet jetties (north and south). As noted previously the north jetty was completed in 1941. Conceptual plan for a north jetty (at the time referred to as a groin) was included in the original federal plan for inlet improvement. The north jetty (a.k.a. groin) was constructed of timber piles and rock 1580 ft in length and having a +6 MLW crown elevation. Jetty modification in 1943 extended the jetty approximately 300 ft. landward (USACE (1979)). Olsen Associates (1988) noted that the low profile of the north jetty precluded significant accretion of the northern beaches and that sand washes over the jetty and becomes trapped on its south side depriving beaches south of the inlet of the nourishing sand they would otherwise have received. At present time, the north jetty is completely filled. Considerable sand is both naturally bypassing around the outer end of the jetty and overtopping the jetty, increasing the area referred to as Porpoise Point where considerable development of residential homes has taken place. Sand may also be being transferred through the jetty as the outer portion of the jetty appears to be permeable. <u>The sand moving over, through, and around the north jetty to this area is lost to the adjacent beaches as neither the State of Florida nor the Federal Government appears to have claimed the created land and private development has taken place on a portion of the area. No dredging of this sand has taken place to best knowledge at time of report.</u>

As noted previously, the south jetty was completed in 1957. The south jetty is 3695 ft long and constructed of stone with a varied crown elevation from +6 ft MLW at its seaward end to +10 MLW at its landward end. The landward end of the jetty transitions into a 620 ft long revetment which stabilizes the eastern shoreline of Salt Run near its northern terminus at the inlet (Taylor Engineering (1993)). At present the south jetty is filled to capacity and the shoreline south of the south jetty extends considerably seaward of the eastern tip of the south jetty.

As far back as 1889, the COE constructed three groins on Anastasia Island and Vilano Beach in efforts to improve the original St. Augustine Inlet channels for navigation. It is reported that four groins were also built at Vilano Beach by private interests although there does not appear to be a record of them nor of the original COE constructed groins. Additional concrete pipe permeable type groins were reportedly constructed at St. Augustine Beach in the 1960's but no record of them or of their performance is known. Although it is reported that seawall construction in the Anastasia Island area began as early as 1892, predominant construction for the seawall and revetment complex now existing near the north end of the City of St. Augustine Beach occurred following the severe storms of the early 1960's (primarily the Northeaster of 1962 and Hurricane Dora in 1964) as discussed in an earlier section. The seawall, revetment, and pier complex now visible at the shoreline in the Anastasia Island area is located south of the new COE constructed inlet in the City of St. Augustine Beach (in the vicinity of Pope Road) and the St. Johns County ocean pier). Information on these structures is as follows: an 800 ft long concrete seawall (cap elevation +13.5 MLW); a 4200 ft long coquina rock and granite stone revetment; and, a 600 ft long concrete fishing pier perpendicular to the shoreline. More history of these structures is discussed in USACE (1979) and USACE (1991). Additionally numerous undocumented rock revetments and seawalls/bulkheads exist at various locations in St. Johns County but are not believed to influence shoreline processes to a large extent at present time.

2.6 Erosion problems (include shoreline history)

In looking at informational resources on shoreline change as documented in United States Army Corps of Engineers (USACE) reports as well as consultant reports, periods of historic shoreline change have been divided as follows:

(1) pre-inlet stabilization period (1858-1937);
(2) inlet stabilization period (1937-1957);
(3) post-inlet stabilization and pre-nourishment period(1957-2003); and
(4) post-inlet stabilization period and post-nourishment period (2003-2010).

The following information on the changes in these periods is derived from USACE reports, old charts and maps, aerial photography from numerous sources, NOAA shoreline survey information, and, consulting engineer reports.

Pre-Inlet Stabilization Period (1858-1937)
Accretion and erosion occurred both north and south of the inlet. Erosion/accretion cycles have been hypothesized although insufficient evidence exists to provide evidence of a true cyclic occurrence of any sort. South of the inlet, protuberance of the shoreline exists in historical charts ranging from the north portion of the City of St. Augustine to further north within the area that is now the southern portion of St. Augustine State Park where it appears that sand from the offshore ebb tidal shoal was being furnished to the shoreline. A USACE (1991) report notes that shorelines directly north of the inlet were typically stable or accreting except for the Vilano Beach shoreline which retreated as rapidly as approximately 16 ft/yr in the decade or so prior to construction of the north jetty (as might be expected of natural shoreline fluctuations in close proximity to an unstructured inlet).

Inlet Stabilization Period (1937-1957);
This period covers the construction of the COE new inlet and construction of the north jetty. During this period, the new inlet was beginning to form and the old channels close. The Atlantic shoreline receded in the northern portions of the City of St. Augustine Beach as well as the southern portions of the (now) Anastasia State Park area. During this same period the Vilano Beach area receded about 3 ft/yr (USACE (1991)).

Post-Inlet Stabilization and Pre-nourishment Period (1957-2003)
This period begins with construction of the south jetty after which Conch Island, Crazy Bank, and Bird Island merged to form a continuous barrier beach south of the inlet and the shoreline immediately south of the inlet began to advance. Eventually, the shoreline advanced as much as 1200 ft in the area directly south of the south jetty (USACE (1991)). Further south erosion intensified with the southern portion of Anastasia State Park and the northern portion of the City of St. Augustine Beach receding the most until the seawall and rock revetment at St. Augustine Beach slowed the erosion rate. From the City of St. Augustine Beach south toward

Butler Beach, erosion rates decreased steadily and transitioned into accretion rates at Butler Beach where the shoreline advanced an average of approximately 10 ft/yr over the period 1867–1988 (USACE (1991)). North of the inlet the beaches remained reasonably stable although minor fluctuations in shoreline occurred with some areas experiencing minimal recession. All areas of study suffered considerable damage and often (potentially temporary) erosion/recession during the Northeaster of 1962, Hurricane Dora of 1964, and more recently the "Thanksgiving Day" Northeaster storm of 1984, as well as other less significant storms. As the City of St. Augustine Beach continued to be under more erosional stress, the pier and seawall area was further subject to large wave action with no protective beach.

Post-Inlet Stabilization Period and Post-nourishment Period (2003-2010).
With the initiation of material placement on the southern portion of Anastasia State Park and the northern end of the City of St. Augustine Beach during the 2001 through 2005 beach nourishment period (see nourishment section), the shoreline has advanced over its eroded state as evidenced by old rubble revetment/mound structures in some areas south of the pier which are now considerably inland (behind the frontal dune system). Additionally, historical shoreline information shows much of the area advanced over its most landward location, although loss of beach nourishment material from the structured area in the City of St. Augustine Beach and in the southern reach of Anastasia State Park continue to pose a structure undermining and degradation problem to the City complex and a barrier beach integrity/barrier breakthrough problem to the State Park. It is expected that recession/erosion will continue to plague this area unless re-nourishment occurs on a continuing basis. In this same time period, minor shoreline recession has occurred north of the inlet at Vilano Beach and in some areas further northward. Views of the City of St. Augustine pier and seawall complex area are presented below in Figures 2.6.1 and 2.6.2, providing an overview of the situation prior to and after the recent year nourishment projects.

Figure 2.6. 1 City of St. Augustine Pier and Seawall Complex, Pre and Post Nourishment

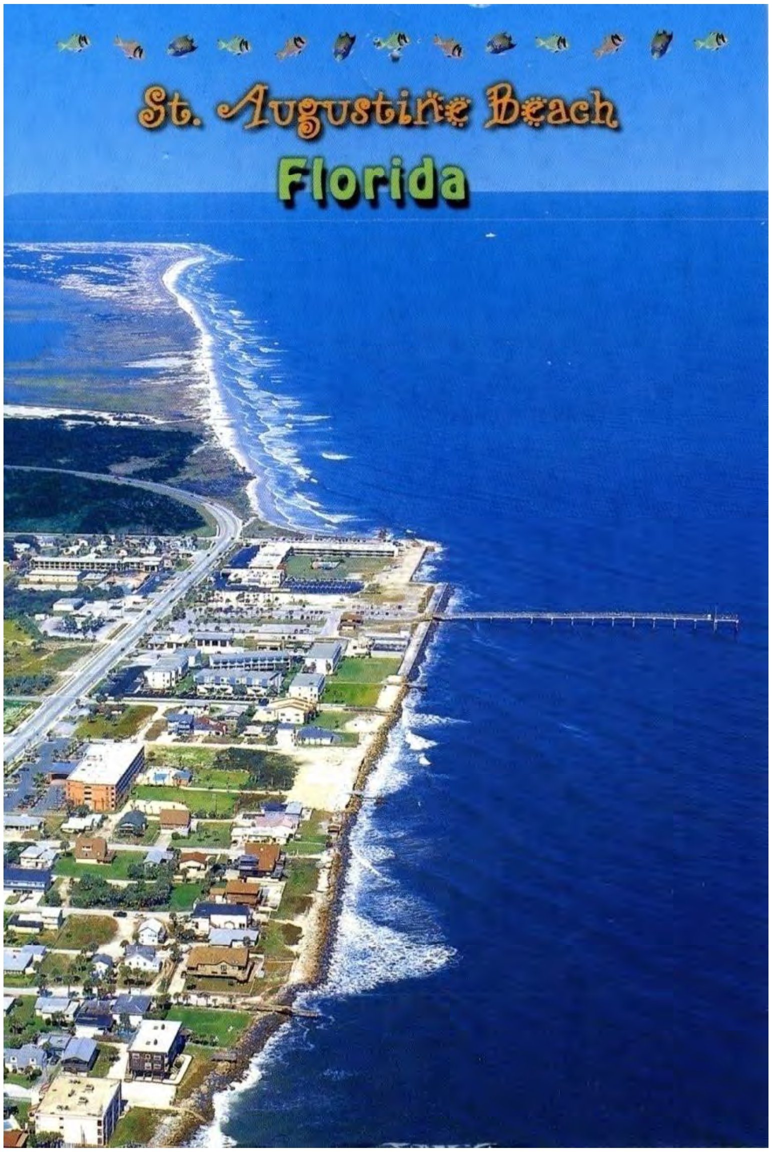


Figure 2.6. 2 Nourishment postcard aerial view (circa 2000) of the City of St. Augustine Beach Pier and Seawall/Revetment Area.

In more recent work for this study which utilized the FDEP shoreline database for assessing present condition of the shoreline in a historical context, shoreline recession rates have been investigated for three periods of time as follows:

- Early (1858-1970) covering from first USCGS chart until the 1970's;
- Recent (1970 -2007) covering the most recent period chosen for sediment budget analysis; and
- Total (1858-2007)

Results of this work are provided in Appendix A and show that for the Early period, the shoreline of St. Johns County has been fairly stable while the more Recent period shows

> 1 ft/yr long term average annual recession rates have historically been constrained to within approximately 7 miles north of the inlet and 3 miles to the south of the inlet although the shoreline south of the inlet has experienced much higher rates than 1 ft/yr (see Appendix A Tables). It should be recognized that the Recent data (and Total data) utilized in this assessment has the effects of ebb shoal dredging and beach nourishment placement in them and thus cannot be directly compared to the historical trends previously discussed.

2.7 Beach Nourishments

The first nourishment of the St. Johns County Shore Protection Project was initiated in September 2001 and completed in January 2003. The project length was approximately 2.9 miles from Anastasia State Park to the City of St. Augustine Beach. The state of Florida, in conjunction with the federal nourishment project extended the beach nourishment project approximately 0.9 mi further north into Anastasia State Park. The entire project extended from approximately 0.9 mi north of northern boundary of Federal project in Anastasia State Park (FDEP monument T-132) to approximately 600 ft south of FDEP monument R-151 in the City of St. Augustine Beach in St. Johns County, Florida.

The 2004 hurricane season resulted in a need to re-nourish the project before anticipated re-nourishment and after the 2004 and 2005 hurricane seasons, a second nourishment (i.e. first re-nourishment project), was placed. This project began in June and was completed in December 2005. The project extended over the same area as the original 2003 Federal project (i.e. from FDEP monument R-137A to R-151).

The St. Augustine Inlet ebb tidal shoal was the source of borrow material for both projects. A series of monitoring reports by Taylor Engineering (2004, 2005, 2006, 2007) documents the performance of the projects (i.e. the effects of the combined nourishment projects on the fill placement area, the north control area, the south control area, Vilano Beach, and the borrow area) and also shows the borrow areas for the project. It is noted that the 2003 borrow area encompassed the larger footprint of the two project borrow zones, and included the 2005 borrow area as well as extending into the northern lobe of the St. Augustine Inlet ebb shoal (Taylor Engineering, 2006). A summary of these large nourishment projects is provided in Table 2.7 below. Results of nourishment and re-nourishment monitoring of the St. Augustine Beach area are provided in Taylor Engineering (2004, 2005, 2006, 2007) reports.

Table 2.7 Federal/State Combined Nourishment History of St. Augustine Beach

Project Completion Date	Volume Placed	Time of Construction
First Nourishment	4,200,000 c.y.	Sept 2001 – Jan 2003
Re-nourishment	2,800,000 c.y.	June 2005 – Nov 2005

2.8 Historical ebb shoal/flood shoal (tidal prism and ebb shoal storage)

The ebb shoal complex at St. Augustine inlet covers an extremely large area and is a unique physiographic feature, the likes of which does not exist elsewhere in Florida. This ebb shoal complex consists of both the old inlet ebb shoal that covered an extensive area due to the numerous migrating channels of the natural St. Augustine inlet and the more recent COE created inlet ebb shoal. This section will focus on the ebb shoal complex (i.e. both the natural pre-COE created inlet ebb shoal and the new COE created inlet ebb shoal) unless noted otherwise.

In an earlier report, Florida Coastal Engineers (1976) estimated that between 1940 and 1976, the ebb shoal had trapped 18,000,000 c.y. of sand. This is presumed to be an increase in the ebb shoal from the old inlet to the new inlet as considerably more sand accordingly existed within the ebb shoal complex itself at that time than did prior to the new COE inlet. An increase in ebb shoal quantity can also be inferred from the ebb shoal computations of Walton and Adams (1976) and Marino (1986) which showed post-COE channel/jetty construction ebb shoal volumes in approximate agreement of 106,000,000 c.y. [=81,000,000 m^3] and 110,400,000 c.y. [= 83,000,000 m^3] respectively when compared with the estimate (provided by of Marino and Mehta (1986)) for an early 1924 survey showing 78,700,000 c.y. [60,200,000 m^3].

Using the Marino (1986) ebb shoal estimate (which appears to be confirmed by Walton and Adams (1976) earlier estimate for post inlet survey) suggests that the inlet has increased shoal volume on the ebb shoal platform by 110,400,000-78,700,000 = 31,700,000 c.y. [= 24,300,000 m^3] due to the new configuration of the inlet and the lack of readjustment of the former ebb shoal.

<u>Based on these earlier reported findings noted above, it can be argued that the construction of the new inlet channel in the location to the north of the old inlet channel/shoal complex has required a minimum of 18,000,000 to 31,000,000 c.y. of sand derived from material that would have benefitted the adjacent beaches. If one assumes (for the purpose of rough calculations) a net littoral transport in the area of ~400,000 cy/year, this amounts to about 45 to 78 years of beach material additionally tied up (at least temporarily) in the ebb shoal complex due to the construction of the new COE inlet.</u>

Table 2.8 Previously estimated Ebb Shoal Volumes

Marino and Mehta (1986)	$60.2 \cdot 10^6\, m^3$ = $78.7 \cdot 10^6$ c.y.	(date of survey 1924)
Walton and Adams (1976).	$81.1 \cdot 10^6\, m^3$ = $106.0 \cdot 10^6$ c.y.	(date of survey 1954-57)
Marino Thesis (1986)	$83.3 \cdot 10^6\, m^3$ = $110.4 \cdot 10^6$ c.y.	(date of survey 1979)

An additional ebb shoal volume was computed by Taylor Engineering (1996) as part of the inlet management studies (see Taylor Engineering (1996), Srinivas et al, St. Augustine Inlet Management Plan- Part 2) which listed the inlet ebb shoal volume to be $23.0 \cdot 10^6$ c.y., considerably less than that of other estimates. It is noted that the tidal prism volume (TP) measured in the same study was $13.6 \cdot 10^8\ ft^3$ which is similar to the tidal prism volume (TP) cited in Walton and Adams (1976) derived from a publication by Bruun and Gerritsen (1960). It is believed that this low volume figure for the Taylor Engineering estimated ebb shoal is due to the limited nature of the surveys made by COE/Taylor at that time and consideration of only recently surveyed portions of the newer COE created inlet ebb shoal. More will be said in a later section regarding both the tidal prism and the ebb shoal volumes although it is evident that wide discrepancies in previous tidal prism volume and ebb shoal volume estimates exist for St. Augustine Inlet. It is also evident that even with a larger tidal prism as previous measured (see Flood and Ebb Tidal Prism section of report), the ebb shoal volumes of St. Augustine Inlet reported by Walton and Adams (1979), Marino and Mehta (1986), and Marino (1986), are considerably higher than other inlets with similar tidal prisms as can be seen in the figure of tidal prism versus ebb shoal volume provided by Walton and Adams (1979).

As identified in this literature search, only the study performed by Florida Coastal Engineers (1976) developed tidal prism estimates from measured data for St. Augustine Inlet. Of the two estimates reported, the first value, $2.88 \cdot 10^9\ ft^3$ {$= 81.7 \cdot 10^6\ m^3$ }, resulted from computations based on measured current and tide data. A second estimate by Florida Coastal Engineers (1976), $2.87 \cdot 10^9\ ft^3$ {$= 81.7 \cdot 10^6\ m^3$ }, was computed using the Keulegan asymptotic method. Both methods, as noted, produced similar results. Subsequent publications cite these results. A tidal prism was estimated in the Taylor Engineering (1996) study (see Taylor Engineering (1996), Srinivas et al., St. Augustine Inlet Management Plan- Part 2) of $13.6 \cdot 10^8\ ft^3$ similar to the tidal prism volume (TP) cited in Walton and Adams (1976) study. As noted above, in the graph of ebb shoal volume versus tidal prism (see Walton and Adams (1979)), the St. Augustine Inlet ebb shoal volume is much larger than would be expected via the ebb shoal volume – tidal prism relationships provided therein suggesting either tidal prism or ebb shoal volume is in error or that further reasons exist for the "outlier" behavior of the St. Augustine Inlet ebb shoal delta in relation to other tidal inlets. The Florida Coastal Engineers (1976) tidal prism measurements combined with the Walton and Adams (1976) results and Marino (1979) results provide a tidal prism-ebb shoal volume more consistent with other inlets although the ebb shoal is still larger than the Walton and Adams (1976) relationships predict. More will be said about tidal prisms in a later section.

Literature reviewed does not include any computations of flood shoal sediment volumes although aerial photography suggests bathymetric changes within the interior (landward portion) of the inlet bay/estuary /marsh drainage system. In particular development of flood shoals at the mouth of Salt Run, at the entrance of the Tolomato River, and on the western side of Matanzas Bay near the entrance to Hospital Creek are noted although no data on shoal volumes could be found.

2.9 Current Patterns and Inlet Stability

St. Augustine lies on a portion of the Anastasia formation characterized by a sandy upper layer supported by a basement of coquina rock. The depth of the upper layer is unknown as jet probing to hard bottom in St. Johns County was not found in a literature search. Limited core borings near the inlet (COE (1979)) report sand to depths exceeding 50 ft (MLW) might suggest that the jetties and hydrodynamic characteristics of the inlet rather than geological conditions control the location of the inlet although numerous outcroppings of coquina near the surface (i.e. Old St. Augustine quarry near the entrance to the State Park) make this speculation uncertain.

Scour studies conducted at the Vilano Bridge (Taylor et al., 1992) and the Bridge of Lions (Hull et al., 1993) contain the only extensive documentation of measured flood and ebb current patterns at St. Augustine Inlet. These studies used a hydrodynamic model called TRANQUAL to assess the flood and ebb patterns in more detail than the measurements noted. Applications of the TRANQUAL model were utilized to evaluate bridge scour for which a crude representation of inlet geometry was used in combination with limited 1991 bathymetry and an idealized storm surge hydrograph. The model study made no attempt to represent offshore bathymetry in the vicinity of the inlet.

Florida Coastal Engineers (FCE 1976) characterized the inlet's 1976 hydraulic conditions based on field measurements. Parameters relative to this characterization include:
Cross-sectional area at throat of inlet =55,300 ft^2; Hydraulic radius =18.3 ft;
Inlet length =5,400 ft; Head loss coefficient at entrance = l.0; Head loss coefficient at exit = l.0; Dimensionless Darcy-Weisbach friction coefficient = 0.08; Bay plan area = $4.32 \cdot 10^8\ ft^2$. Using this data, Florida Coastal Engineers' (1976) made an analysis of inlet stability based on Dean and O'Brien's (1972) procedure to determine the inlets equilibrium cross-sectional area. FCE (1976) indicated that the St. Augustine Inlet was stable. This procedure combined a Keulegan (1951) type analysis along with O'Brien's (1969) empirically-derived equilibrium cross section formula to produce two intersecting curves. The intersection of the curves on the stable side of the Keulegan hydraulic curve gives the equilibrium cross-sectional area ($5.2 \cdot 10^4\ ft^2$) for the inlet. The result is in accord with FCE measurements noted above. The margin of stability was greater than 2 in the FCE study suggesting that the inlet has the ability to reestablish an adequate (equilibrium) cross-sectional area should significant shoaling of the inlet occur.

Fields, Marino, and Weishar (1988) characterized the inlet's bypassing behavior using net longshore transport of sand, maximum inlet flow rate, and the ratio of both although limited details of the study do not appear to provide adequate justification for any conclusions reached therein.

3. Literature and Data Reviewed (for present study)

3.1 Historical Maps Reviewed - discussion of channel bar depths and channels

In the course of studying the inlet for State of Florida recommendations, collection and review of historical inlet channel locations and bar depths (prior to the existing Corps of Engineers navigation channel cut in the 1940's) was made to assess the preexisting inlet conditions prior to USACE man-made inlet changes (i.e. new channel cut and jetties). The following provides a listing of inlet maps collected or viewed from various sources (St. Augustine Historical Society, National Oceanic and Atmospheric Agency (NOAA), internet web sites, FSU and UF libraries). Many of these maps have been reproduced herein in Appendix B.

Listing of Early Maps/Charts of St. Augustine Inlet

1589 Sir Francis Drake Map
This early map is the only one known to suggest a channel to the north and shows a ship entering the north channel. Numerous ships are shown inside the entrance sheltered by a bar trailing from south side.

1740 Thomas Silver -- View of St.Augustine (published in Gentleman's Magazine July 1740)
This early map/chart shows the main channel relatively close to southern shore and oriented toward the south with 9 feet depth (datum unknown) over the outer bar. There are other channels shown which appear to be flood channels.

1764 Jacques Bellin -- Plan du Port de St. Augustin
This map/chart shows one channel (close to southern shore) oriented toward the south (and then opening to the East with unknown depth over the outer bar. No other channels are shown.

1765 Wm Gerard DeBrahm - Plan of St. Augustin Inlet and Town with its Environes.
This map/chart shows one channel (close to southern shore) oriented toward the south (and then opening to the southeast) with "8 feet depth at Low Water in the channels of the Bar". No other channels are shown.

1783 John Bew - Plan of St. Augustin
This map/chart shows a main channel (close to southern shore) oriented toward the south (and then opening to the east) with 9 feet depth (at Low Water) over the outer bar. Another shallow channel further to the south shows 9 feet depth (at Low Water) over the outer bar. There are other channels shown which appear to be flood channels.

1819 John Birch - Plan of St.Augustine
This map/chart shows a main channel (close to southern shore) oriented toward the south (and then opening to the east) with 5 feet depth (at Low Water) over the outer bar. There are other channels shown which appear to be flood channels.

1862, St. Augustine Harbor, U. S. Coast Survey
This chart shows a main channel close to the southern shore and opening to the east at the south end of the inlet entrance. There are other channels shown which appear to be

secondary to the main channel or else flood channels.

1887 Corps of Engineers, Capt. Black -part of a 1888 report
This chart shows similar conditions to the 1862 U.S. Coast Survey chart.

1911 Coast Chart No. 150 St. Augustine Inlet to Halifax River, Florida,
U. S. Coast Survey
This chart shows similar conditions to the 1887 Corps of Engineers chart except for the main channel exiting in a more northeasterly direction.

1924 Hydrographic Chart 3257 – Sapelo Sound to St. Augustine (published 1924),
U.S. Coast and Geodetic Survey.
This chart shows two main channels bifurcating at Bird Island with southern channel running close to the southern shore and opening to the East at the south end of the inlet entrance while the north channel running close to north end of Bird Island and opening to the east.

1928 Hydrographic Chart 3258 – St. Augustine to Titusville (published 1928),
U.S. Coast and Geodetic Survey.
This chart shows two main channels bifurcating at Bird Island with southern channel running close to the southern shore and opening to the east at the south end of the inlet entrance while the north channel running close to north end of Bird Island and opening to the northeast.

1933 Hydrographic Chart 1243 – Amelia Island to St. Augustine (published 1933),
U.S. Coast and Geodetic Survey.
This chart shows two main channels bifurcating at Bird Island with southern channel running close to the southern shore and opening to the east at the south end of the inlet entrance while the north channel running close to north end of Bird Island and opening to the northeast.

The main information suggested by the review of these historical maps/charts is that the natural main channel for St. Augustine Inlet typically ran somewhat close to the southern shoreline of the inlet complex and opened over the ebb shoal between south and east directions. Secondary channels (when present) ran across the bar in an easterly to northeasterly direction and were probably due to the start of a new emergent channel created when the friction in the older main channel would be large and/or when waves would break through the bar to create a shorter more hydraulically efficient channel. The natural bypassing of the inlet was probably enhanced by the natural process of sand flowing southward which led to a smaller ebb shoal complex with a smaller volume of sand stored in it than exists after the new COE inlet. Further evidence of this will be discussed in regard to tidal prism and ebb volume storage discussed later.

3.2 Historical Inlet Photography

Overhead Aerial Photography of the inlet and shoal complex was collected from numerous sources, NOAA, Corps of Engineers, internet web sites, St. Augustine Historical Society, etc. and is presented in chronological order in Appendix C As can be seen from the aerial photography, major changes in the inlet complex (i.e. welding of Bird Island, Conch Island, Vilano Point, etc. into what is now Anastasia State Park and closing off of the original main inlet channel at Salt Run) occurred prior to the 1970's. The present inlet complex configuration has undergone lesser change (but not necessarily insignificant change) since that time. A specific item that should be noted in the photography and is important to the overall inlet system complex (as well as this inlet system study) is the change in the location of the ebb shoal where it joins the south beach on Anastasia Island. Although fluctuating in location, this offset area was typically in the vicinity of the City of St. Augustine Beach Park (seawall and revetment location) and/or the Salt Run (old inlet channel) area of Anastasia Island State Park. Figure 3.2.1 shows the approximate FDEP monument locations on a 1928 NOS hydrographic chart of the area and notes the presently existing "hardened" shoreline area (i.e. City of St. Augustine Beach seawall and revetment complex area) and the historical attachment location of the tidal ebb shoal at that time. Since construction of the new COE inlet channel, considerable changes to the old inlet ebb shoal have occurred and a new ebb shoal complex is forming that extends somewhat further offshore and further to the north of the historical ebb shoal complex. More will be said about these changes later. The area where the historical shoal welded to the shoreline has shifted northward accordingly due to the COE inlet channel relocation. As a result, the area of major erosion concern now (with regard to historical erosion patterns) is in an area that historically (i.e. pre- COE inlet construction) gained sand from the pre-COE inlet ebb shoal complex. As the area no longer is directly fed by the old ebb shoal complex (i.e. the ebb shoal has relocated further to the north), the former stable (or accreting) area is now undergoing erosion. The City of St. Augustine Beach pier, seawall, and revetment complex, as well as the south end of the Anastasia Island State Park are in this part of this shoreline now under erosional stress. Figure 3.2.2 adapted from an earlier Corps of Engineers (1979) publication shows the 1937 pre-COE inlet construction shoreline and the shoreline in 1975. Since the construction of the new inlet this shoreline has been under erosion stress. Shorelines of the St. Augustine Inlet - St Johns County area over the historical period in the FDEP database were constructed in a series of graphs not included in report due to size and resolution considerations.

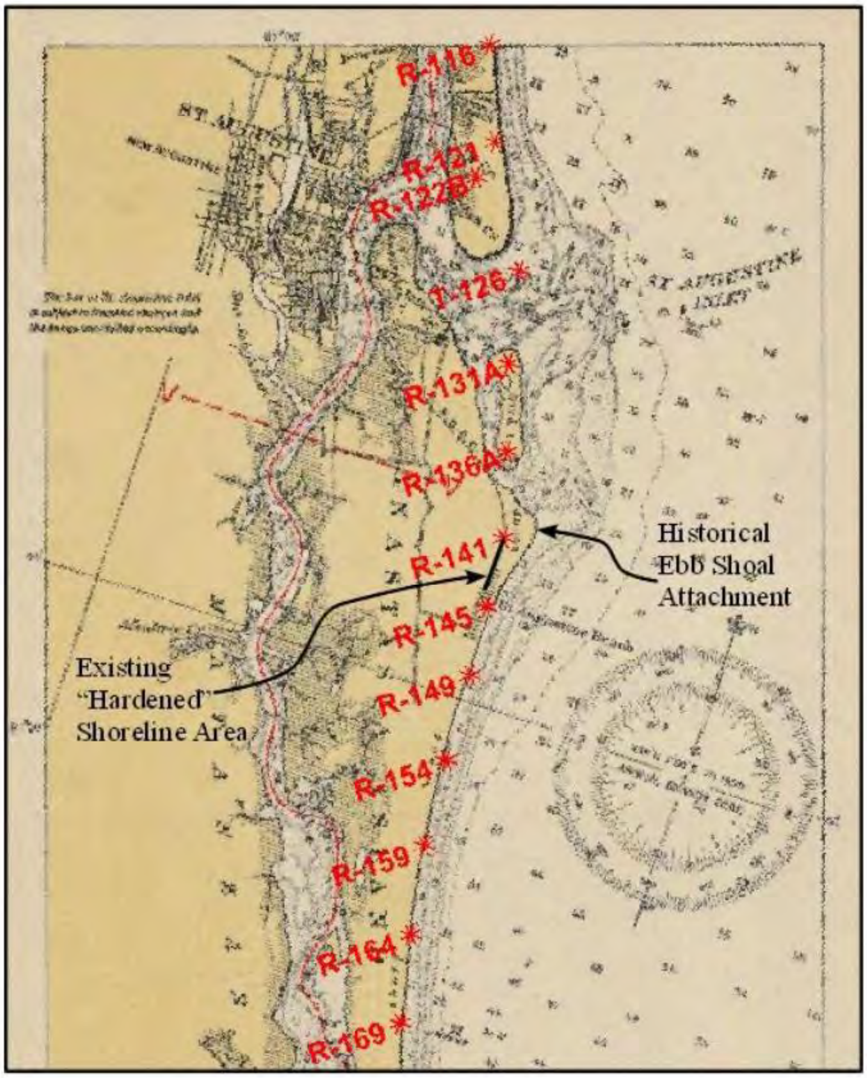


Figure 3.2 1 Historical Tidal Ebb Shoal Attachment (1928 NOS Hydrographic Chart)

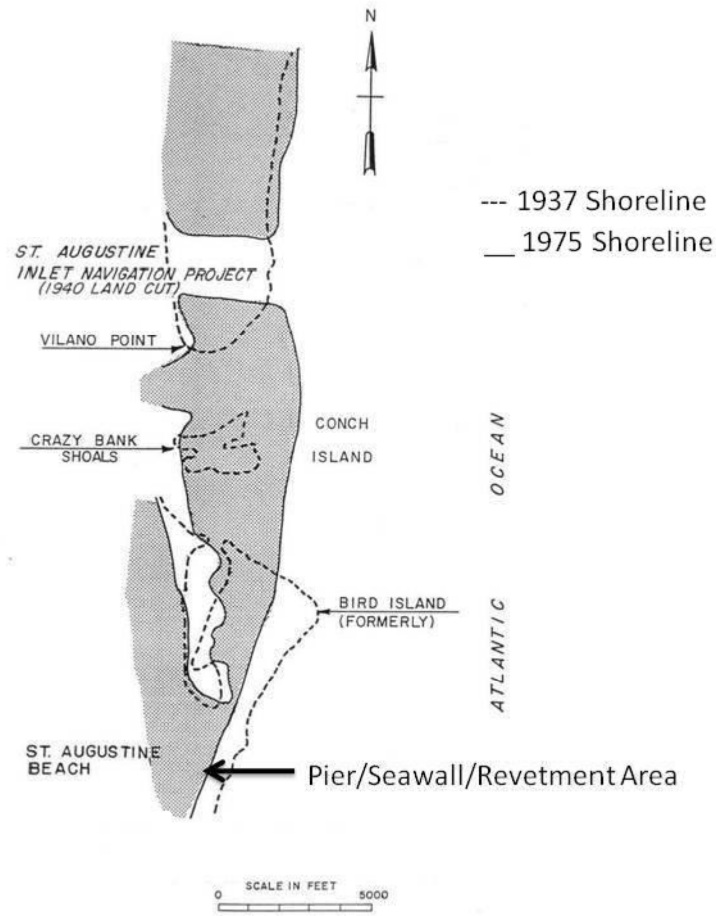


Figure 3.2 2   Historical Shoreline Reconfiguration (adapted from COE 1979 Report)

4. Analysis of Climatologic, Hydraulic, Shoreline, and Survey Data

4.1 Historical Tide and Current Information

Astronomical ocean tide ranges in the St. Augustine area have been reported (USACE (1979)) as:

4.5 ft (mean tidal range)
5.3 ft (spring mean tidal range)

Supporting evidence for the tidal ranges noted above is provided by the FDEP in an earlier study. The FDEP has measured tides for different periods in two bay locations near the St. Augustine Inlet. The first station (DNR 8720576), located in the Matanzas River immediately south of the Bridge of Lions; recorded from February, 1974 to April 1979 reported a mean tidal range of 4.5 ft. comparable to the ocean tide range noted by USACE (1979). A second FDEP station (DNR 8720554) located in the Tolomato River north of Vilano Bridge, recorded from July to December 1978 and provided a mean tidal range of 4.48 ft. similar to the ocean tide range noted by USACE (1979).

In the 1990's the National Oceanic and Atmospheric Administration installed a tide gage on St. Augustine Beach Pier although the gage is no longer operational. As the record length is short and numerous time periods were missing, no specific data are reported on this gage herein.

As part of a two-day field study (from August 6 and 7, 1975) Florida Coastal Engineers (1976) measured bay and ocean tides simultaneously. Florida Coastal Engineers (1976) found the bay tidal range 5 cm smaller than the ocean tidal range suggesting that St. Augustine Inlet is very efficient from a hydraulic standpoint.

The only known historical field measurements of tidal currents in the throat section of the main channel of St. Augustine Inlet reported maximum flood current velocities of 3.9 ft/sec and maximum ebb current velocities of 5 ft/sec for the period August 6 and 7, 1975 (Florida Coastal Engineers (1976)).

4.2. Winds and Wave Climate

4.2.1 Wave and Wind Information

Wave information for the study area can be found in the sources as follows:

U.S. Naval Weather Service Command, SSMO (see Walton (1979));
Corps of Engineers 1948 wave gage observations (USACE (1979));
U.F. wave gage observations at Marineland, FL. (UF, Wang et al., 1991);
Wave Information Study (USACE – internet and COE request);
Surfbreak Engineering Hindcast (FDEP);
NOAA-Wave Watch (NOAA-internet and NOAA request); and

NDBC- NOAA- buoys

USN-WSC-SSMO

The U.S. Naval Weather Service Command provides wind and wave diagrams based on shipboard observations. The accuracy of the data has been discussed previously by Walton (1973) where it has been used to predict littoral drift. SSMO Wave height diagrams for the St. Augustine area with this SSMO data indicating that the largest waves originate out of the northeast with predominant waves coming from the northeast and east. Both wave roses and littoral drift roses are presented in Walton (1973) and are investigated in this study (along with other noted data sets) for the estimation of longshore sand transport (i.e. littoral drift).

USACE-1948

The Corps of Engineers feasibility report (1979) briefly mentions wave gage observations obtained in January and February, 1948. From these data, a maximum wave height of 10 ft was reported off St. Augustine lnlet. Corresponding maximum wave heights reported for St. Augustine lnlet and Matanzas Bay were 7 ft and 0.7 ft, respectively. The report contains no wave directional information.

UF-COEL

The University of Florida Coastal and Oceanographic Department gathered wave information (1984-1990) at Marineland (south of Matanzas lnlet) to provide: seasonal distribution of significant wave height and period; seasonal probability distributions of wave height; seasonal distribution of wave period; and, mean, max, standard deviation of significant wave height and period. A maximum siginificant wave height of 12.3 feet was measured during the study. No directional wave information is provided.

USACE-WIS

Wave Information Study (WIS) is a wave hindcast modeling program aimed at providing a long term data base of wave height, period, and direction information. Existing data posted on the WIS web site of the Corps of Engineers consists of wave data from 1980 through 1999 and is noted to include tropical storm and hurricane hindcasts within the data set. Previous WIS data for an earlier period was also provided (via request) for similar locations for the time period of hindcast dating from 1956 through 1975. Both data sets were investigated within the present study for the estimation of longshore sand transport (i.e. littoral drift). The maximum significant wave height predicted by WlS study during both the 1956-1975 and the 1980-1999 periods offshore of St. Augustine show significantly higher max significant wave height than the maximum significant wave height reported at the inlet by the Corps of Engineers (~10 ft) and the maximum significant wave height reported by UF at Marineland (12.3 ft) which might be as expected since frictional reduction of wave height between the deeper water hindcast sites and the gage sites would be expected to reduce the wave height.

SURFBREAK ENGINEERING

A long term wave hindcast study (see Surfbreak Engineering Sciences (2009)) was performed under contract to the FDEP which provides approximately 50 years (July 1954 through June 2004) of wave hindcast data where wave height was calibrated with two weeks of field data at the approximate 10 meter depth of water. A large set of meteorological wave data formulated in deeper water (see Swail and Cox (2000)) was used as input to the STWAVE+ model (a modified version of STWAVE which incorporates bottom friction) utilized in the study. Wave height model output at the ~10 meter depth was compared to the field data to calibrate the friction coefficient for the model and then the calibrated results were utilized to generate a 50 year nearshore (~10 m depth) synthetic wave climate. This data set was investigated in the present study for the estimation of longshore sand transport (i.e. littoral drift).

The maximum significant wave height predicted by the Surfbreak Engineering Sciences study during the 1956-1975 period offshore of St. Augustine shows maximum significant wave height higher than the maximum significant wave height reported at the inlet by the Corps of Engineers (~10 ft) although closer to the maximum significant wave height reported by UF at Marineland (12.3 ft). This is as expected since frictional reduction of wave height was taken into consideration from the deep water hindcast site (at least to the 10 meter depth).

WAVEWATCH-NOAA

The National Oceanic and Atmospheric Administration (NOAA) also has a wave hindcast modeling program. The model utilized in the NOAA approach is WaveWatch and data are available on the NOAA-WaveWatch web site. This data was investigated for the present study but it was found that only seven years of data existed which was considerably shorter than the WIS data time series information of 20 years and also the Surfbreak Engineering hindcast information of ~ 50 years. As a result of the short data series, this set of data was not pursued further.

NDBC-NOAA buoys

The National Oceanic and Atmospheric Administration (NOAA) operates a number of buoys in the Atlantic Ocean which collect both meteorological data as well as wave data. Although large heave-pitch-roll buoys as well as a smaller Datawell Waverider buoy have existed in northeast Florida, the data collected from the buoys is sporadic and is available for only limited data periods (four years for the longest non-continuous record). As the data is collected in deeper water (typically > 15 meters) and often utilized in calibration of the wave hindcast programs that produce longer wave records, this data was not pursued further. It should be noted that none of the directional wave information coming from these gages in North Florida has been verified or checked by shoreline measurements or nearshore gages.

4.2.2 Historical Storms of Importance

Storms of importance to the area in recent years include Hurricane Floyd (1999), Hurricane Irene (1999), Tropical Storm Gabrielle (2001), Hurricane Frances (2004), Hurricane Jeanne (2004), Hurricane Ophelia (2005), Tropical Storm Tammy (2005), Subtropical Storm Andrea (2007), Tropical Storm Noel (2007), and numerous (often unnamed) northeaster storms that have typically occurred in the Fall months. Previous storms of major erosive impact to the area include the Ash Wednesday Northeaster (1962), Hurricane Dora (1964), February Northeaster (1973), and the "Thanksgiving Day" Northeaster (1984). The erosive impact of many of these storms is discussed in the Corps of Engineers reports listed in the reference section of this report as well as numerous FDEP –Bureau of Beaches and Coastal Systems reports provided online at the FDEP website.

4.2.3 Wave Refraction

Florida Coastal Engineers (1976) performed an earlier wave refraction analysis on the inlet using an older model referred to as the CERC ray-tracing refraction program. The study considered waves ranging from 4 to 8 seconds over the bathymetry that existed in 1974. On the basis of results provided by the study it was concluded that, given the shoreline configuration, the assumptions of the refraction model utilized were inappropriate to quantitatively predict nearshore wave transformations.

Taylor Engineering (1999, 2005) performed limited wave refraction analysis using the REF/DIF wave model around the inlet ebb shoal complex to assess the effects of COE dredging of the ebb shoal on changes that might occur to the inlet ebb shoal complex and adjacent inlet shorelines as a result of the ebb shoal mining for beach nourishment. Findings were that *the mining of the shoal complex would only have significant effects in the vicinity of the dredging and that shoreline effects/changes as a result of the mining would be minimal.*

A more recent model referred to herein as STWAVE+ (see Surfbreak Engineering Sciences 2009) which has been enhanced to account for bottom friction effects was utilized in the present study along with the same grid system utilized in the creation of the Surfbreak Engineering Sciences hindcast wave data to assess the refraction effects of the outer bar. Combinations of wave heights, wave periods, and wave angles were run to qualitatively interpret the effects of the ebb shoal on the refraction patterns away from the inlet with the intent to assess the qualitative shoreline influenced by refraction over the ebb shoal. As the hindcast wave grid system utilized by Surfbreak Engineering Sciences did not completely encompass the shoreline over the area of interest but only extended to the 5 meter depth contour in areas, the wave angles were assessed at various constant depth contours (where the closest inshore depth contour that could be assessed was the -5 meter contour due to grid limitations discussed previously). Results of using this upgraded model for St. Augustine Inlet are discussed in a later section of this report.

4.3 Longshore Sediment Transport

Previous studies related to longshore transport characteristics at St. Augustine Inlet and nearby shorelines are discussed below. For the purposes below, net rates are provided where a net positive drift rate implies a net southward directed littoral drift unless otherwise noted.

Walton (1973)

Walton (1973) using SSMO data constructed littoral drift roses (LDR) for the coast of Florida, two of which provide information on the St. Augustine Inlet area. One LDR covered the area from St. Johns River to St. Augustine Inlet while another LDR covered the area from St. Augustine Inlet to Ponce De Leon Inlet. No specific littoral drift estimate is shown herein for the study region since the study region encompasses a wide variety of shoreline orientations and hence estimates must be made from the LDR's dependent on the orientation of the shoreline at that location.

USACE (1979)
From a location south of the inlet, USACE (1979) provides a southerly littoral drift estimate of 569,000 c.y./yr and a northerly littoral drift estimate of 329,000 c.y./yr, yielding a net southerly drift of 240,000 c.y./yr to the south. This study also notes an increase in the net southerly drift to approximately 350,000 c.y./yr near Butler Beach.

Fields et al. (1988)
Fields, Marino, and Weishar studied the inlet's bypassing, transport rate, maximum flow rate, and r value (the ratio between the net longshore transport and the inlet flow rate) in an attempt to understand the effects of tidal inlets on adjacent shorelines. In this study the authors determined a transport rate near the inlet is given as 455,000 c.y./yr [=348,000 m^3/yr].

USACE (1991)
Using a 20 year WIS wave information study data set, USACE (1991) performed an estimate of longshore transport at the inlet. This analysis predicted a net southerly transport rate of 232,000 c.y./yr for the south beach about three miles south of St. Augustine Inlet, a similar rate to the earlier cited rate in USACE (1979).

Taylor Engineering (1996)
Using a 20 year WIS wave information study data set from 1956-1975, Taylor (1996) performed an estimate of longshore transport at the north end of the sediment budget study area delineated in the report to provide an estimate of 212,000 c.y./yr net southerly transport. A similar estimate at the south end of their study area provided an estimate of ~307,000 c.y./yr net southerly transport.

UFL-Brown (2002)
A sediment budget for St. Johns County was estimated by Brown (2002) as part of a Master's Thesis at the University of Florida using a 20 year set of WIS hindcast data for the period 1976-1995. In the area corresponding to the northern boundary of the Taylor IMP (1994, 1996, 1997), a southerly directed net longshore transport potential is noted with a value somewhat smaller than that of Taylor or earlier COE estimates.

PBS&J (2009)
An estimate of the longshore sediment transport potential for St. Johns County was completed as part of a PBS&J study for St. Johns County. The study utilized a WIS hindcast database for the period 1980-1999. It was noted in the report (PBS&J (2009)) that the volume transport formulation in the USACE Coastal Engineering Manual (CEM), Equation III-2-7b was utilized for computation. A range of WIS stations (408 to 421) were queried to determine which wave data set was the closest and most applicable to each point on the shoreline for the calculations. Between R-60 and R-70, where it was noted that the local shoreline is aligned with the overall shoreline trend (azimuth ~ 77°), the estimated net sediment transport rate in a southerly direction was found to be in the range of 200,000 c.y./yr, comparable to estimates

made in the Taylor (1996) study. Spatial variations were found similar to the study performed by Brown (2002).

Summary of Historical Estimates

The estimated rates of longshore transport vary significantly due to differences in the data sets and methods used although insufficient details are provided in the many studies to determine reasons for the differences and/or even how the computations were made. All data sets and methodologies utilized show a clear southward directed net sand transport which appears reasonable based on historical information of drift rates in Northeast Florida. No studies identified in this literature search correlated tidal currents with sediment characteristics to obtain rates of tidal transport.

Analysis of Transport Rates for Present Study

Estimates of longshore transport made for the present study boundaries of the sediment budget are based on the Littoral Drift Rose (LDR) concept (Walton 1973, Walton and Dean 1973) where drift magnitude (away from inlet influence) is dependent on shoreline orientation. Three recent wave information sets as well as the previous work of Walton (1973) have been investigated to assess the reasonableness of the drift magnitudes and angular rotations of the LDR's to both past estimates but also to shoreline changes realized in the study area. The three recent hindcast model wave information sets and corresponding time periods investigated are as follows:

- Surfbreak Engineering 54 year hindcast wave information set for St. Johns County 1953 through 2007 (10 m depth at various grid locations throughout St. Johns County)

- WIS Wave Hindcast Program 20 year hindcast wave information set for Station 2024 1956 through 1975 (18 m depth at Latitude 29.75 N, Longitude 81.00 W)

- WIS Wave Hindcast Program 20 year hindcast wave information set for Station 417 1980 through 1999 (20 m depth at Latitude 29.91653 N, Long 81.08334 W)

The CERC equation for sediment transport as utilized by the Corps of Engineers program SEDTRAN was utilized along with linear wave theory to calculate the littoral drift at wave breaking for a range of values of shoreline outward azimuth angles to construct LDR's for the various data sets. In a first approach to the problem of assessing the proper littoral drift climate for the sediment budget area, magnitudes were considered of secondary importance compared to the rotational aspects of the wave climate. Reasons for not assessing magnitudes in the first approach are that the wave information sets have been computed in different manners, i.e. the Surfbreak Engineering data set was developed in 10 m of water with friction incorporated from deeper water to the 10 m depth while the WIS wave information data sets did not incorporate frictional reduction and were taken in deeper water, and the LDR from Walton (1973) incorporated a simplified frictional reduction scheme across the entire profile (see Walton (1973)). As will be seen later, magnitudes and directional aspects of the LDR are taken into consideration when choosing the final LDR based on agreement with shoreline change information provided via the FDEP surveyed shoreline as well as other historical shoreline data. Further explanation and examples of LDR usage can be found in Walton

(1973), Walton and Dean (1973), and Walton and Dean (2010). The value of littoral drift at a given point is based on the orientation of the azimuth of the outward normal to the shoreline at the location of interest with a corresponding value of littoral drift as:

$$Q = Q_{max} \cdot \sin\left(2 \cdot (\beta_N - \alpha_T)\right)$$

where $\beta_N =$ azimuth of the outward normal to the shoreline and $\alpha_T =$ azimuth of the null point for the LDR , and where a positive value represents transport to the right when looking offshore and a negative value represents transport to the left when looking offshore. For looking at directional aspects of the wave climate, the magnitude Q_{max} has been arbitrarily set equal to one.

The variability of the directional aspects in the wave climate shown by the three hindcast wave information sets and one transformed SSMO data set is shown in Figure 4.3.1. As seen in Figure 4.3.1, the directionality of the wave climate is vastly different, dependent on which data set is chosen. A particular problem in all of the hindcast data sets can be noted for the relatively stable (with regard to shoreline azimuth orientation) beaches to the north of the inlet (i.e. outward normal shoreline orientation β_N ~ 75 to 77 degrees). This particular azimuth orientation of the shoreline lies in vicinity of a LDR null point (see Walton (1973) for definition of LDR) for the hindcast data. Consequently, the estimates of longshore transport for the hindcast data are showing either an extremely small southerly directed net littoral drift (in comparison to Q_{max}, the maximum net littoral drift found on the LDR) or, in one of the hindcasts, a northerly directed net littoral drift. Historical estimates and knowledge of sediment transport along this area of coast all suggest a strong southerly directed transport based on downdrift erosion history south of the St. Johns River south jetty, hence further historical shoreline change information was utilized along with LDR theoretical considerations and the wave information sets and SSMO data set to assess a reasonable LDR for the boundaries of the sediment budget study. The results of this further study to determine the LDR utilized herein are described in Appendix D and provide a modified LDR as follows:

$$Q = \hat{Q}_{max} \cdot \sin\left(2 \cdot (\beta_N - \hat{\alpha}_T)\right)$$

where $\widehat{Q}_{max}$ = 428,000 m^3/yr and α_T = 55 degrees. The corresponding LDR utilized in this study for determining littoral drift at boundaries of the sediment budget area is shown in Figure 4.3.2.

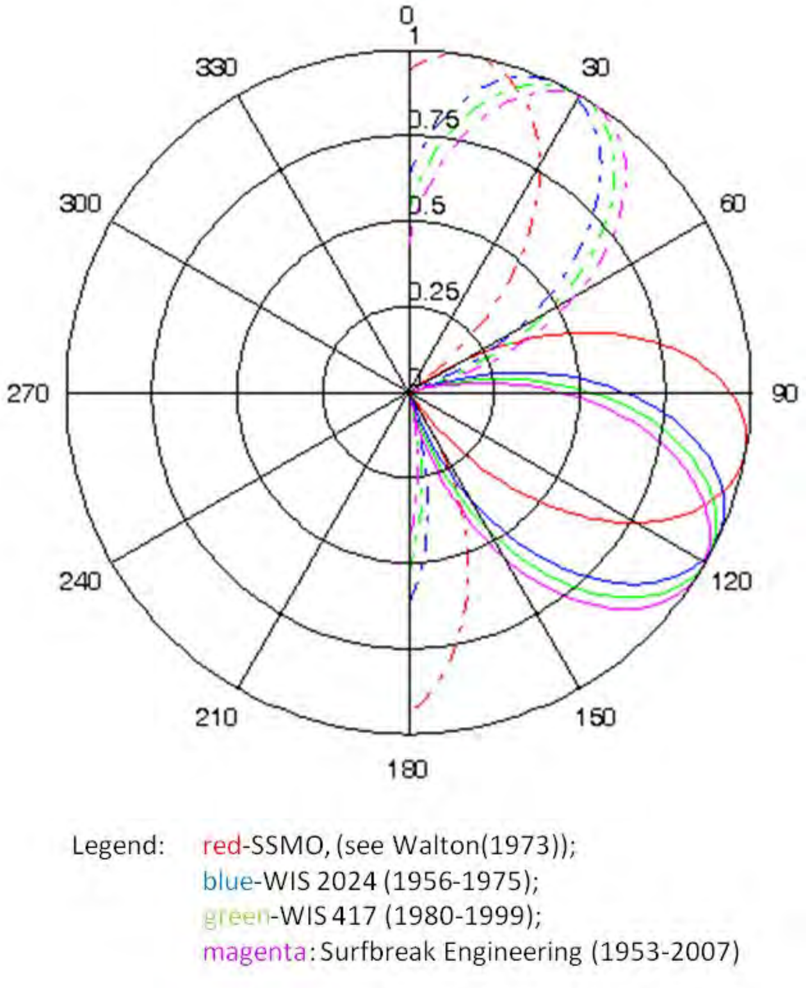
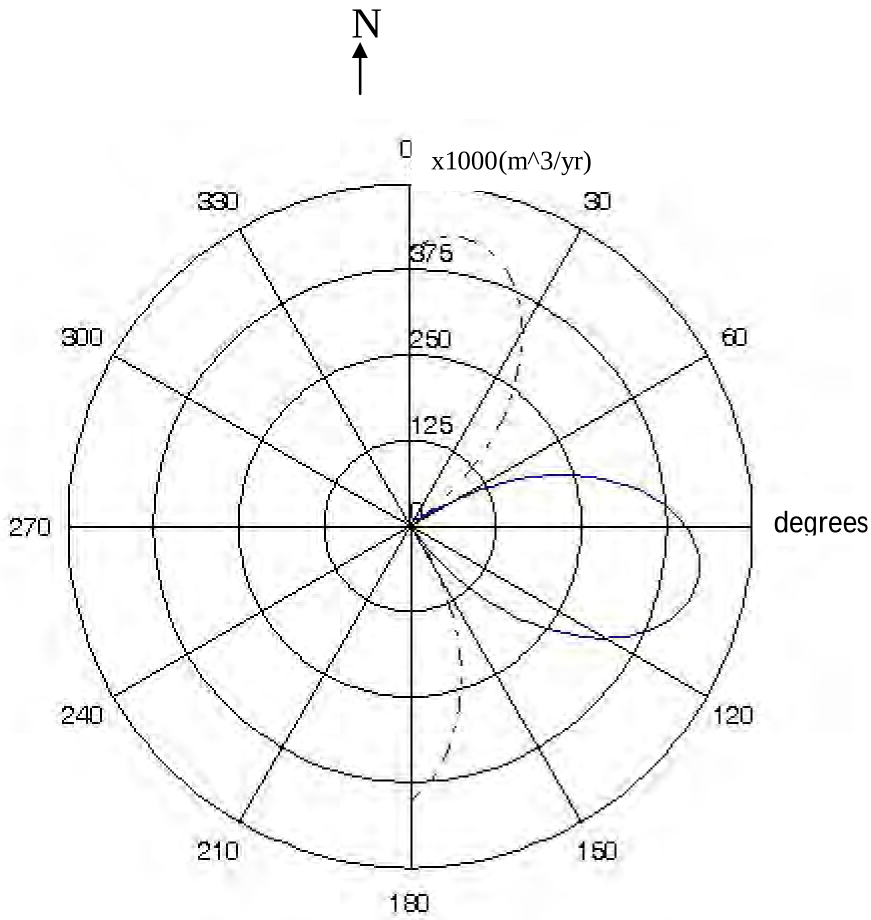


Figure 4.3 1 Littoral Drift Rose for Net Littoral Drift of Various Wave Information Data Sets (with Drift Magnitude Arbitrarily assumed Qmax=1).



Legend: Solid blue represents net southward directed transport
Dashed blue represents net northward directed transport.
(see Walton(1973)).

Figure 4.3 2 Littoral Drift Rose Estimate for Net Littoral Drift at St. Augustine Environs; $\boldsymbol{Q_{max} = 428{,}000\ m^3/yr}$ and $\boldsymbol{\alpha_T = 55\ degrees}$.

4.4 Shoreline Equilibrium Beach Profile Assessment for Present Study

Shoreline changes and offshore contour changes and their responses to inlets can often be assessed in terms of beach equilibrium beach profile analysis. As an example, steepening of profiles near an inlet due to inlet draw-down of sand may be viewed in terms of the "A" value as represented in the equilibrium beach profile (EBP) theory (i.e. see Dean and Dalrymple (2002), Walton and Dean (2007), and Walton (1996)). If there is a drawdown of sand due to the inlet, it might be expected that for a natural inlet, beach profiles would be steeper near to the inlet and hence the "A" coefficient of EBP theory would show this drawdown as a continuously increasing value of "A" as one approaches the inlet.

For the present study the beach profile signatures as represented by the EBP "A" coefficient were investigated for the St. Johns County shoreline using the complete county FDEP surveys available since 1972 when the FDEP data collection program began.

The "A" coefficient is related to the depth and offshore distance via the relationship provided in Dean and Dalrymple (2002) as:

$$h = Ay^{2/3}$$

where h = water depth and y = distance offshore. The "A" coefficient is found to be in units of $length^{1/3}$. The "A" coefficient can be thought of as a "surrogate" for an estimate of a representative quartz grain size in the beach profile at a given location via a non-linear relationship between "A" and D50 ,the median grain size (see for example Table 7.2, Dean and Dalrymple (2002)). As can be seen in the above equation, a larger "A" coefficient is representative of a steeper beach with corresponding larger (quartz) grain size, hence the "A" coefficient is representative of the overall characteristics of the beach profile at a given location. In the present study the "A" coefficient has been calculated via linear least squares analysis (see Walton and Dean (2007)), at each FDEP offshore profile in the county (where offshore data was obtained) for the surveys with reasonably complete county coverage. The survey dates of the data sets utilized were for 1972, 1986, 1999, 2003, and 2007. The 2007 data was augmented by data taken in 2008 for a limited number of ranges (~12) in the vicinity of St. Augustine Inlet. . For the early surveys, profiles were taken offshore at every third monument such that "A" coefficients can be calculated at every third monument location. In later surveys, the "A" coefficients could be obtained along the offshore profile transects at every monument location. Results of the profile analysis are shown in Appendix E where both the "A" coefficient versus Range for the entire county are shown as crosses while a low pass filtered signal of the raw computed "A" values is also provided on the figures as a solid line to help in possible interpretation of the signal. South of the inlet, the shoreline is more complex due to effects of Matanzas Inlet located in the vicinity of R-195 to R-199, hence figures were also graphed for the shoreline north of St. Augustine Inlet from R-1 to R-120 which are additionally provided in Appendix E. No clearly discernable trends over the shoreline or over time were observed which may be due to the interaction coquina and sand observed throughout this area although such speculation lacks further evidence.

4.5 Ebb Shoal Volumes and Changes Assessment for Present Study

An overview of past computations of ebb shoal volumes has been discussed previously. As the subject of ebb shoal growth is important to the overall picture of inlet stability and sediment budget, calculations were performed in the present study of St. Augustine Inlet to provide a check on past inlet ebb shoal calculations as well as to assess if the ebb shoal complex (both new and old inlet) is stable, growing or decreasing in size. Raw data survey coverage as well as interpreted contour plotting are shown for each of the four survey periods in Figures 4.5.1 through 4.5.8. The plotted data have a converted horizontal datum where necessary (to the most recent NAD 83 horizontal datum) to provide consistency in the survey horizontal locations of data and monument locations although vertical datum has been left as per original survey in the figures.

Two different approaches were utilized to assess the ebb shoal changes. The first approach was to compute the volume of material in the ebb shoal for a given survey date directly as per Dean and Walton (1973) method. An advantage of this method is that the computation can be extended to the limits of the survey as necessary. As this method is based on some subjective interpretation of "no inlet" bathymetry, a second method was also utilized whereby the direct differences in the data were utilized to calculate whether the ebb shoal complex was growing or deflating in the interval between the survey dates. A disadvantage of the two survey methods is that the change can only be computed in the region where the two surveys overlap although the method had the advantage of not requiring any subjective decisions on "no-inlet" contour estimation. The following paragraphs will first address the one survey method of ebb shoal volume (Dean and Walton (1973)) followed by the two survey direct difference method. As the methods and the survey coverage for different times are different, results will also not necessarily be consistent as will be noted in the summary of findings.

One Survey Ebb Shoal Volume Approach

The following table is a comparison of ebb shoal calculations based on the Dean and Walton (1973) approach for three ebb shoal survey periods (1924, 1972-74, and 2009). The 1924 and 1972-74 survey periods were based on NOAA surveys, while the 2009 survey was provided by the FDEP-BBCS based on FDEP survey and data from contract hydrographic surveyors of the FDEP. The 1972-1974 survey will be referred to as the 1974 survey for convenience herein. An attempt was made to assess the ebb shoal volume in a consistent manner for each survey. An additional survey made by the COE in 1937 was utilized but results are not presented herein due to the limited area of the COE coverage. Data do not always cover the same area, have gaps, and non-overlapping regions hence data interpretation for inlet management and understanding is therefore complex and open to interpretation. Interpretation of the ebb shoal volume was made in accordance with the procedure used in Dean and Walton (1973) although resolution of various grid spacings were utilized to determine an optimum spacing that would provide consistent results with grid spacings somewhat larger and smaller than the chosen grid spacing. Variability in the findings does exist due the subjective nature of the area chosen, as well as the availability of survey data for the area chosen and the quality and quantity of the data.

An attempt was made in the present study to compare previous findings of ebb shoal volumes based on the work of Walton and Adams (1976) and Marino (1986) for the 1970's time horizon using the same alongshore survey limits. Findings in the present study suggested the ebb shoal volume of the St. Augustine Inlet (at that time horizon) to be approximately $113.3 \cdot 10^6$ c.y. which is in reasonable agreement with both the Walton and Adams (1976) and Marino (1986) findings although somewhat higher.

As the survey limits of the raw data in the various historical surveys noted were not consistent, Table 4.5.1 is shown below showing a somewhat reduced ebb shoal volume based on the alongshore distance noted in the table. Results from the 1937 survey have not been provided in Table 4.5.1 due to concerns regarding the small footprint of the 1937 survey data area as noted previously as well as the fact that the two surveys are only 12 years apart. It is again noted that the 2009 tidal ebb shoal survey of the FDEP and FDEP contractors is limited in that it extends northward to only approximately R-116 and additionally has a number of survey area gaps where no data was obtained or provided although the survey was extended to the R-112 range using previous profile survey data collected by the FDEP.

Two Survey Ebb Shoal Volume Difference Approach
The second approach to ebb shoal volume change analysis was to estimate the differences in the volume of sand contained in the ebb shoal based on consistent survey coverage in the two survey time periods. As survey coverage for different surveys is different, the present approach provided an analysis of volume difference between surveys only in the regions of common survey coverage, i.e. where the surveys overlapped. Additionally, only the subaqueous portion of the overlap was considered for the results provided herein as surveys with both subaqueous and sub-aerial regions were combined for some survey periods and differences would not be as meaningful for the combined surveys (i.e. due to inconsistent regions of subaerial topography). Figures 4.5.9 through 4.5.11 show the data and overlap areas and Figures 4.5.12 through 4.5.14 show the data overlap areas outlined in "+" signs over the 1972 bathymetric contours. In this method, the areas where survey overlap occurred were gridded and interpolation to the same grid intersections was accomplished to provide a consistent mapping of depth differences over the region of survey intersection. Volume differences within each grid cell were then calculated knowing both the grid cell area and the average difference between grid cell interstices for the grid cell. Table 4.5.2 provides a summary of the volume differences for various survey time periods. In this method a positive change represents an increase in ebb shoal volume from the previous survey to the latter survey while a negative change represents a decrease in ebb shoal volume.

Findings based on the one survey ebb shoal volume approach are as follows:
The ebb shoal volume in the present calculations for the post inlet period of the 1970's is in reasonable agreement with earlier findings by Walton and Adams (1976), Marino (1986), and Marino and Mehta (1986) although it is much larger than the shoal volume noted in the IMP Taylor Engineering (1992) report and larger than the equilibrium ebb shoal volume that would be expected by the ebb shoal volume – tidal prism relationships of Walton and Adams (1979) based on tidal prism measurements noted previously.

The ebb shoal may have been growing to some extent prior to the Taylor Engineering (1992) IMP report as previous computations by Marino (1986) and Taylor Engineering (1992) have suggested although such growth does not appear to be continuing at present; rather, the ebb shoal appears to be decreasing in size, a part of which is due to ebb shoal dredging but a part of which appears to be based on an earlier increase in ebb shoal volume (above the equilibrium volume that would be present with the natural inlet) due to the construction of the new COE inlet. Based on the findings herein, a near equilibrium ebb shoal volume for this inlet may have been reached or exceeded prior to 2010 although variability from equilibrium may exist over time due to changes in both tidal prism and wave action. The ebb shoal appears to have increased in volume after the new inlet was cut which may have lead to the large ebb shoal volume found in earlier studies by Walton and Adams (1976) and Marino (1986) as well as in the present calculations. Tidal prism-ebb shoal volume relationship can be found in the Walton and Adams (1976) data graph wherein it is shown that St. Augustine Inlet had an excessively large ebb shoal for its tidal prism when compared to most other inlets. The results discussed here must remain somewhat speculative due to the gaps and large longshore spacing of data in the 2009 survey.

There are reasons why one might expect a larger ebb shoal at St. Augustine Inlet after the new inlet was constructed (and possibly larger than the equilibrium ebb shoal volume). This reasoning is as follows:

- The sweeping motion and bifurcating of the historical channel prior to the COE new channel as well as the location of the new channel by the COE to the north of the historic channel location allowed a larger alongshore spatial planform to collect sand on which has insufficient wave action to rapidly move the (excess over equilibrium) large volumes of sand back to the shore;

- The more recent COE inlet channel was constructed (and maintained) to be more hydraulically efficient (via jetty construction and continued channel maintenance) than the natural channel and aligned more normal to the shoreline, consequently jetting sand further offshore than the historic channel would (for the same tidal prism);

- The somewhat anomalous shoreline orientation in the St. Augustine area which tends to amplify the projected ebb shoal volume.

- By definition, an equilibrium ebb shoal volume results when, averaged over a suitable period, the sand volumes transported seaward by the ebb tidal currents and the sand volumes transported landward by the combination of waves and flood currents are equal. The seaward sand transport depends on the seaward directed currents, the sand availability, and other factors. The landward transport depends primarily on the waves and the geometry of the "platform" represented by the ebb shoal. This platform must be sufficiently shallow and of sufficient extent that the waves at the site can transport the sand shoreward. In the case of St. Augustine Inlet, the north and south jetties are quite short and low, thereby resulting in a greater sand supply to the inlet than if the jetties were longer and sand tight. It is hypothesized that, at equilibrium, this greater sand supply and thus the need for a greater landward sand transport results in the need for a greater ebb tidal shoal plan area at a shallower depth than would be the case if the jetties were longer and sand tight. Thus, according to this hypothesis, the equilibrium tidal shoal volume for "leaky jetties" is greater than for "sand tight" jetties.

Some of these points are discussed further along with some rough calculations made in Appendix F and provide support to the heuristic arguments noted herein.

Findings based on the two survey ebb shoal volume difference approach are as follows:
The volume of the ebb shoal increased from the early survey period 1924 (prior to COE inlet construction) to the 1970's (as might be expected due to the construction of the new COE inlet in the 1940's). Since the 1970's, the ebb shoal appears to have deflated somewhat (after ebb shoal dredging is taken into account) which suggests that the construction of the new COE inlet increased the ebb shoal volume above an equilibrium level in the initial years after construction although in more recent times offshore wave action may be carrying this excess (above equilibrium) ebb shoal sediment onshore.

Of the two methods utilized herein, both are consistent in showing an increase in volume from the 1920's to the 1970's and a decrease thereafter. The findings herein are different than the results of Taylor Engineering (1997) with regard to quantities for the early period (Taylor Engineering has not assessed the 1972-1979 period) although similar conclusions are reached with regard to the fact that the ebb shoal complex (old and new combined inlet shoals) grew as a result of the new COE inlet, consequently causing a loss of sand to surrounding beaches. Additional (indirect) evidence for this ebb shoal growth during the pre to post COE inlet construction is provided in the Taylor Engineering (1997) report which notes an increase in the ebb tidal prism (based on numerical modeling studies) from pre to post COE inlet which, when combined with the Walton and Adams (1976) tidal prism-ebb shoal volume relationships, would also suggest a growth in the ebb shoal complex. Again, as mentioned previously, the results discussed herein must remain somewhat speculative due to the gaps and large longshore spacing of data in the 2009 survey.

Table 4.5.1 Ebb shoal volume based on one survey ebb shoal volume approach.

Year	from Range	to Range	Grid Spacing (ft)	Volume (Observed – Idealized) (c.y.)
1924	112	152	500	100.6*10^6
1970s	112	152	500	113.3*10^6
2009	112	152	500	102.2*10^6

Note: 2009 Volume includes 7*10^6 c.y. removed from ebb shoal in 2000's and remaining material placed on beach to the south at time of survey.

Table 4.5.2 Ebb shoal volume difference based on two survey approach.

Year1	Year 2	from Range	to Range	Overlap Area (ft^2)	Volume Difference (c.y.)
1924	1970s	112	152	3.33*10^8	6.92*10^6
1970s	2009	112	152	3.33*10^8	9.81*10^6

Note: 2009 Survey includes ebb shoal dredging and beach placement of 7*10^6 c.y.

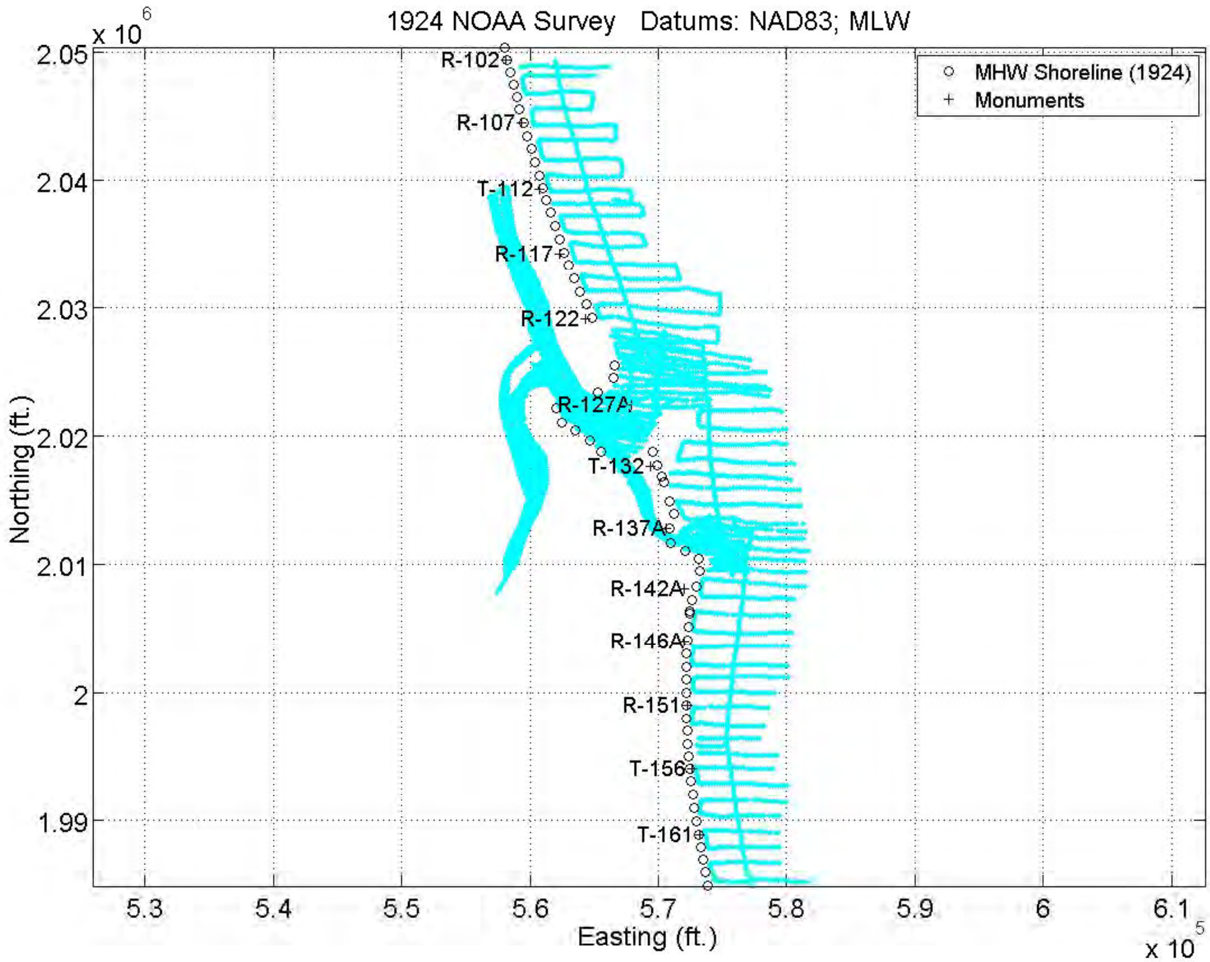


Figure 4.5 1 1924 Raw Data Survey

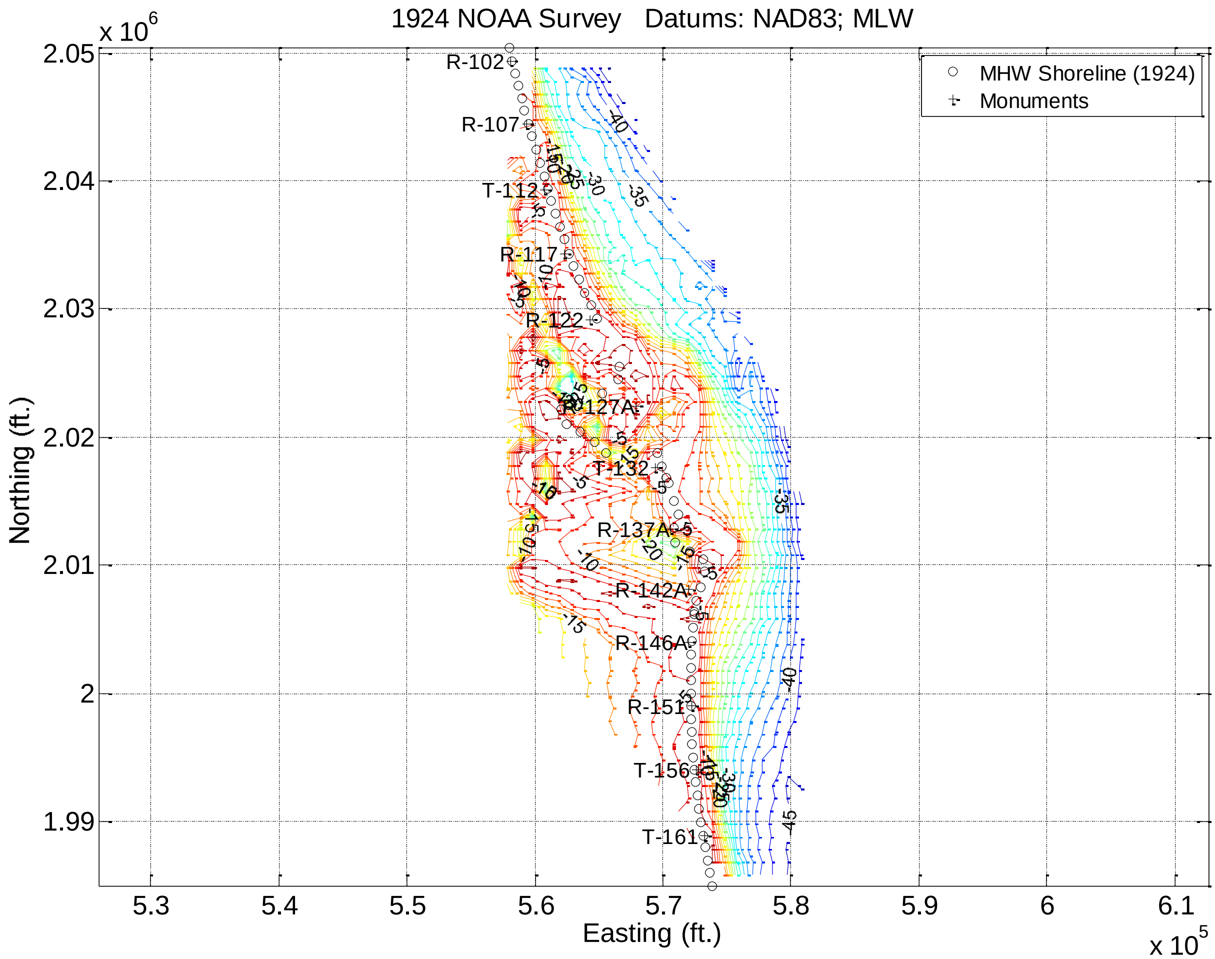


Figure 4.5 2   1924 Contoured Data

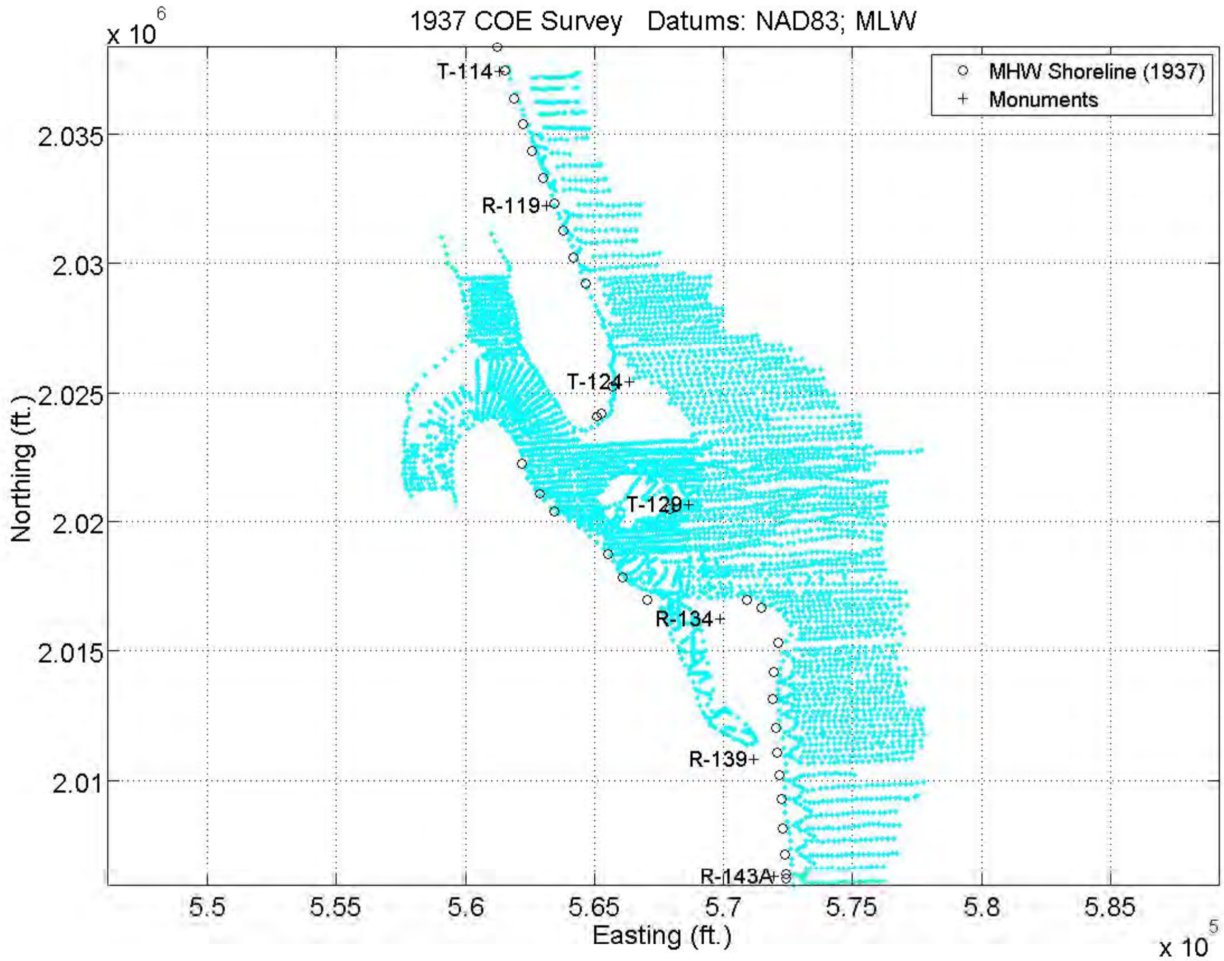


Figure 4.5 3 1937 Raw Data Survey

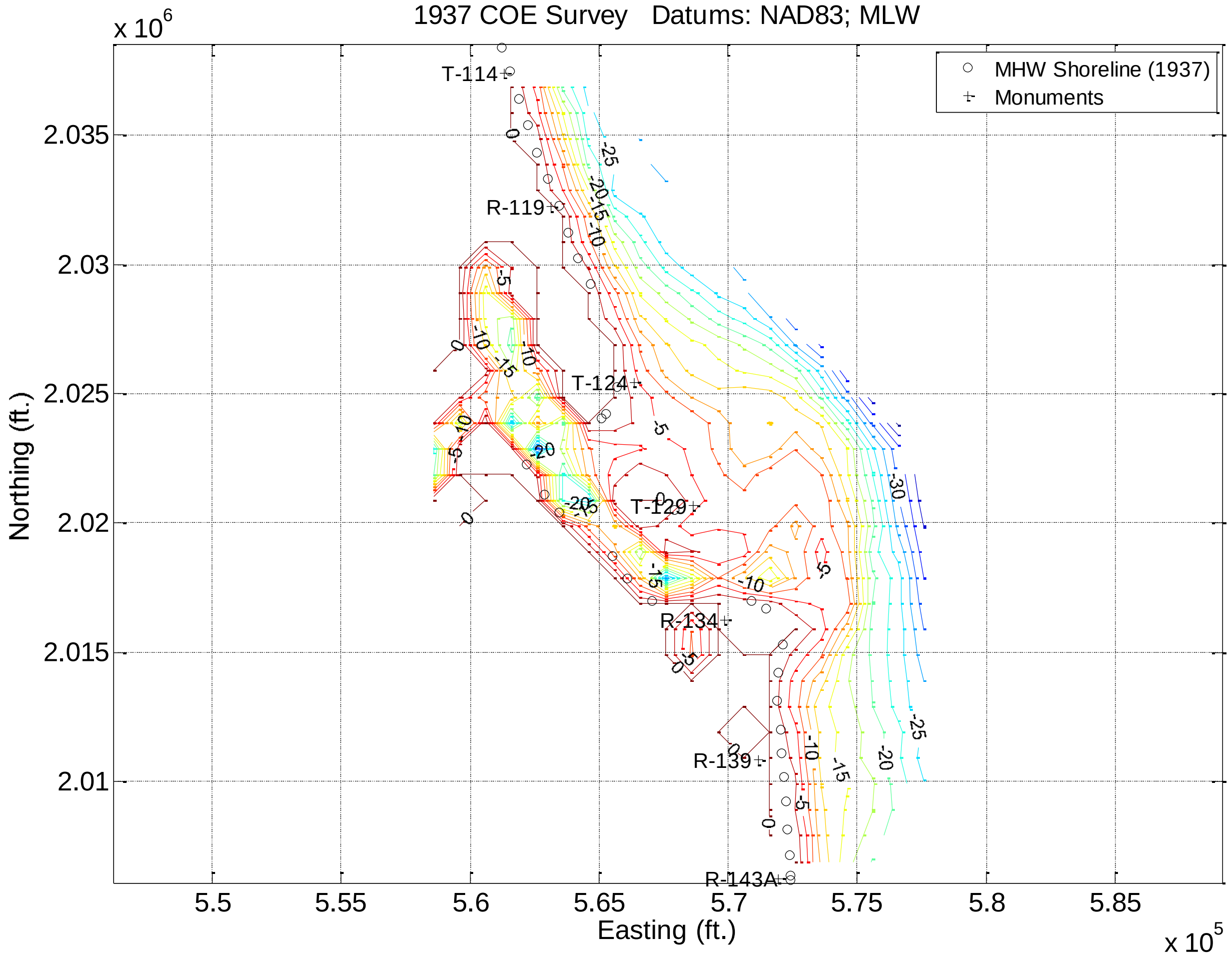


Figure 4.5 4 1937 Contoured Data

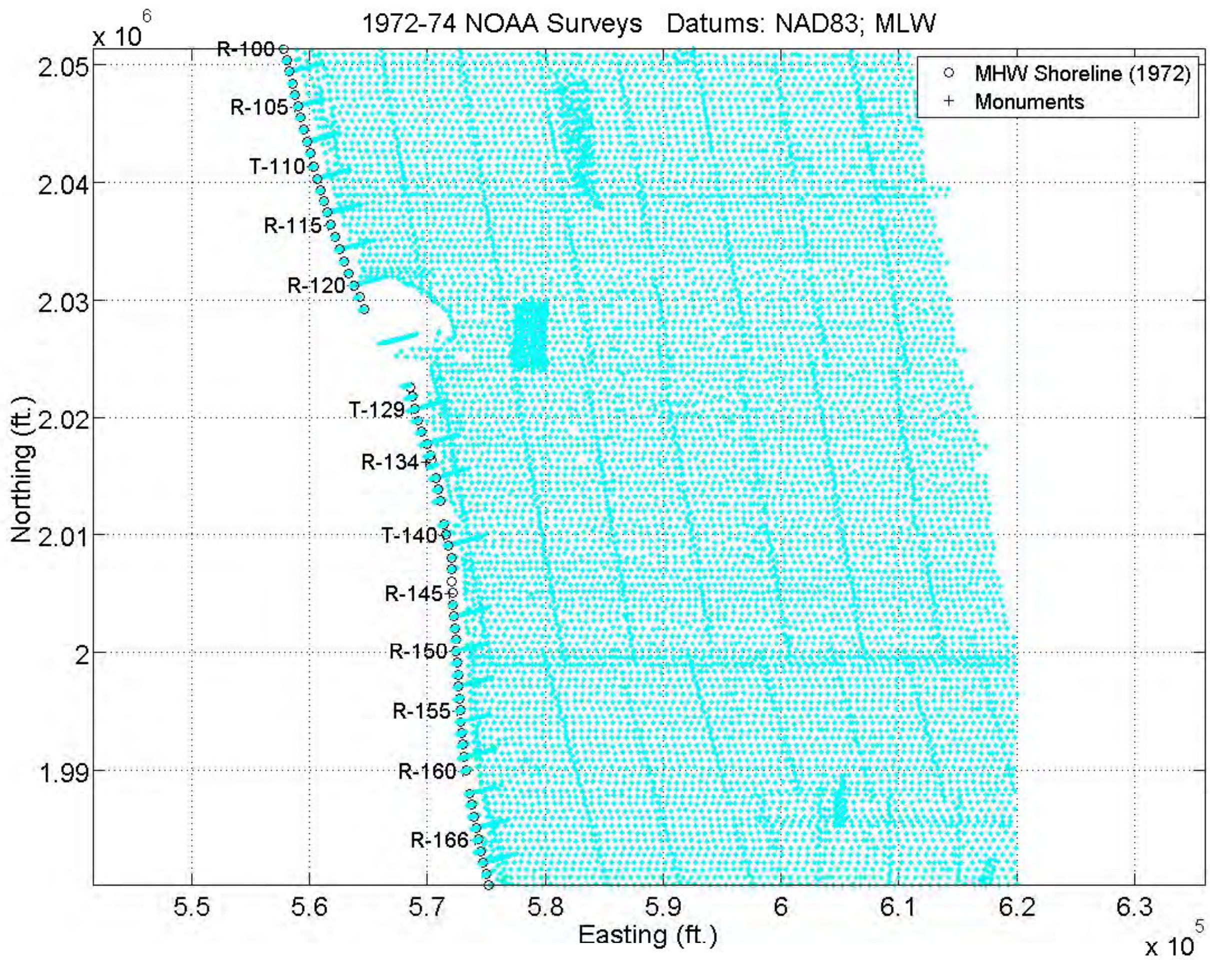


Figure 4.5 5   1972-1974 Raw Data Survey

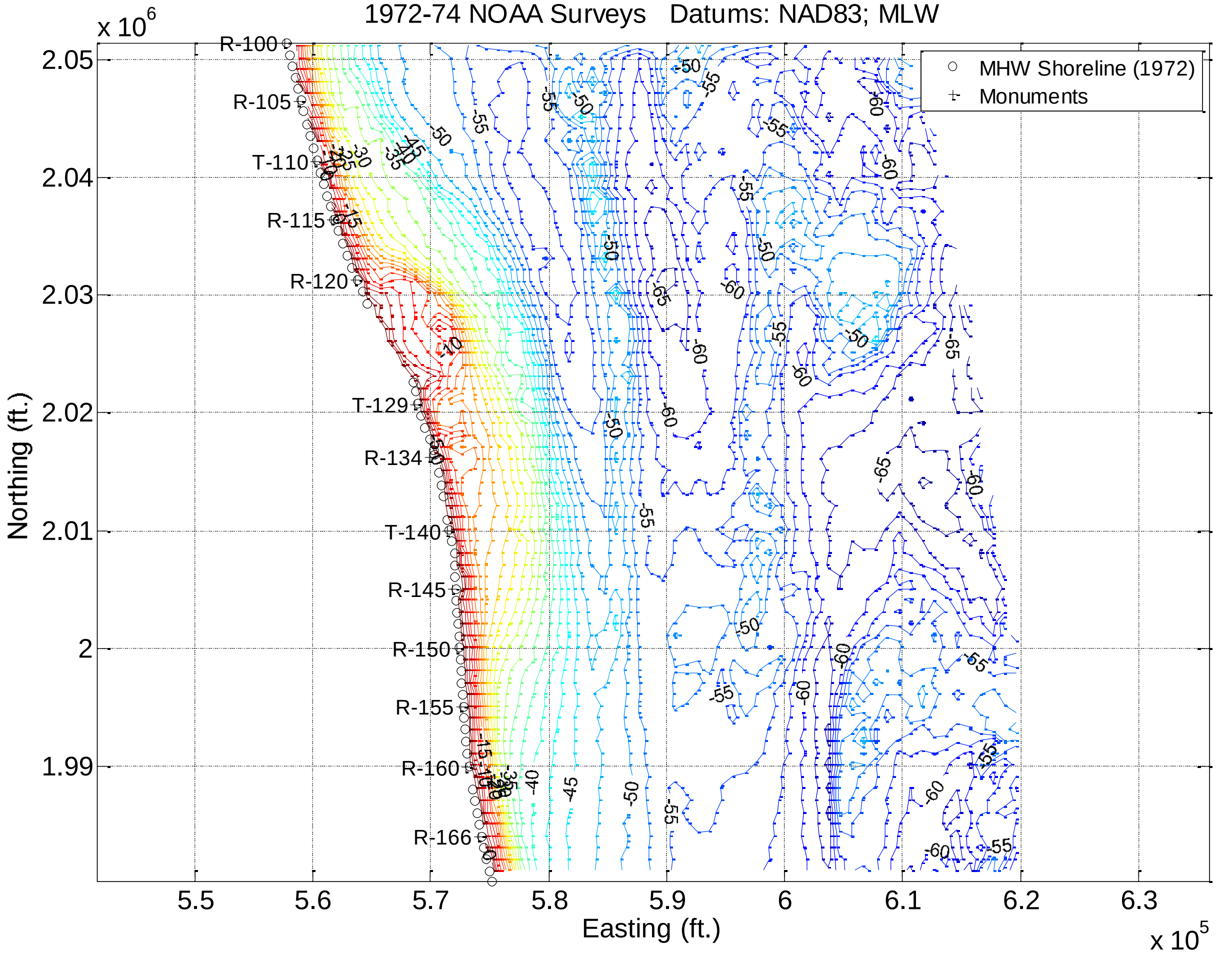


Figure 4.5 6   1972-1974 Contoured Data

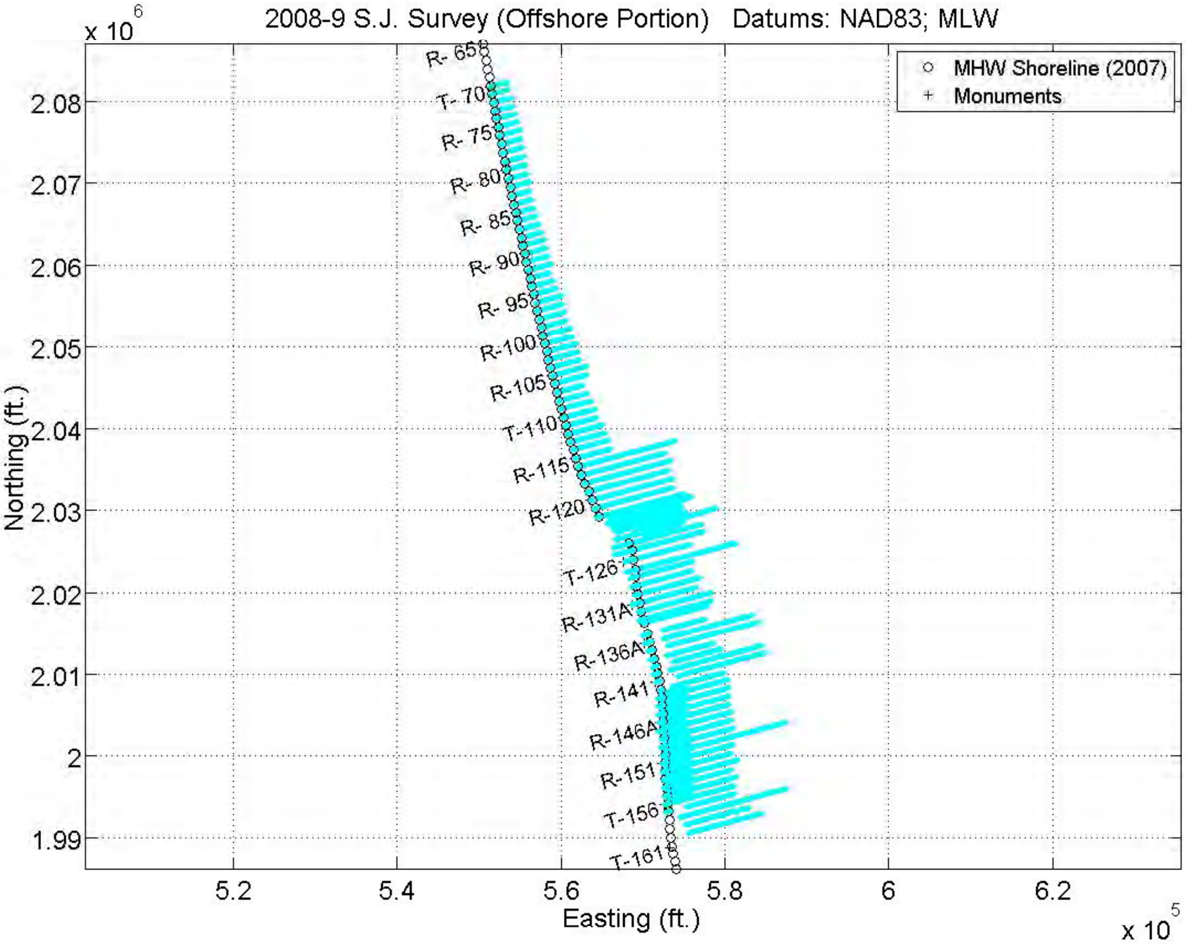


Figure 4.5 7 2009 Raw Data Survey

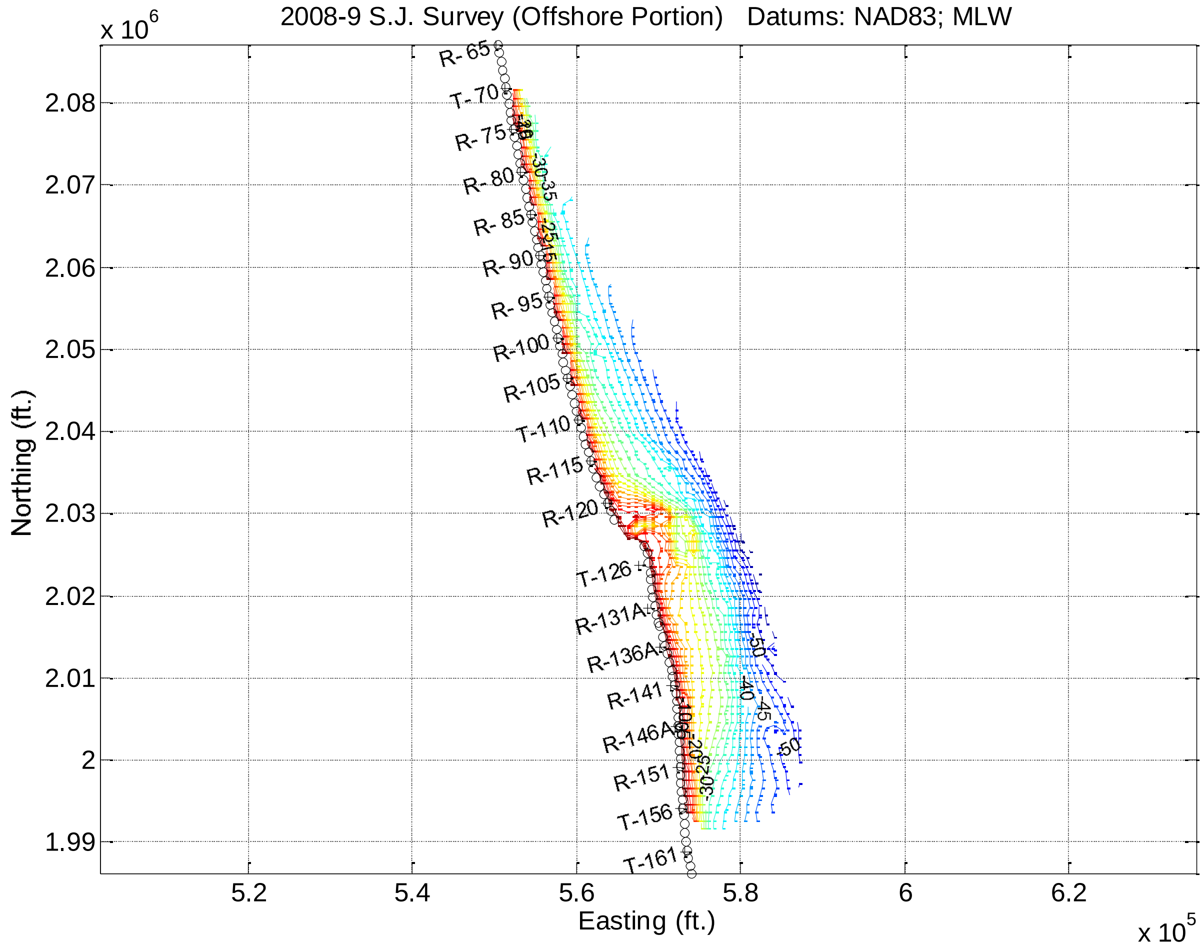


Figure 4.5 8 2009 Contoured Data

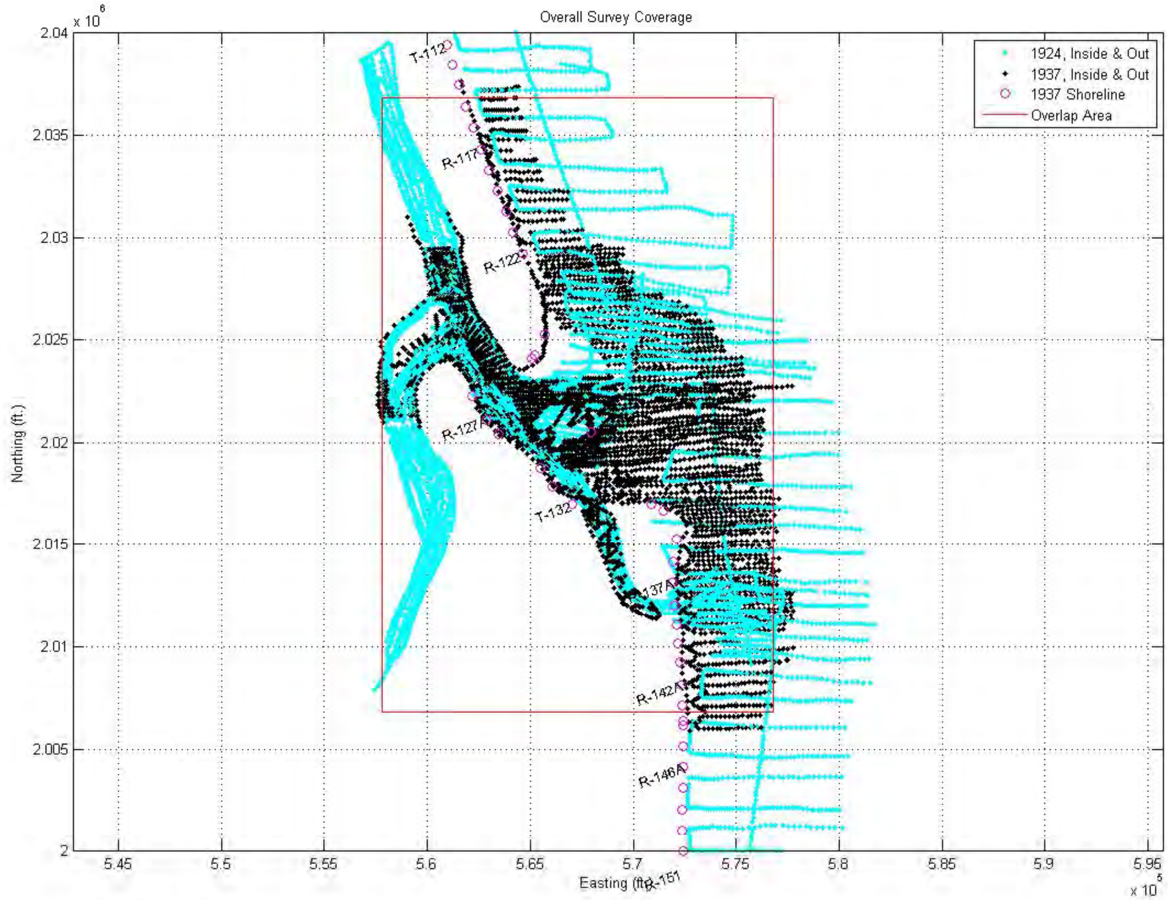


Figure 4.5 9 Survey Coverage and Overlap Area, 1924 and 1937 Surveys.

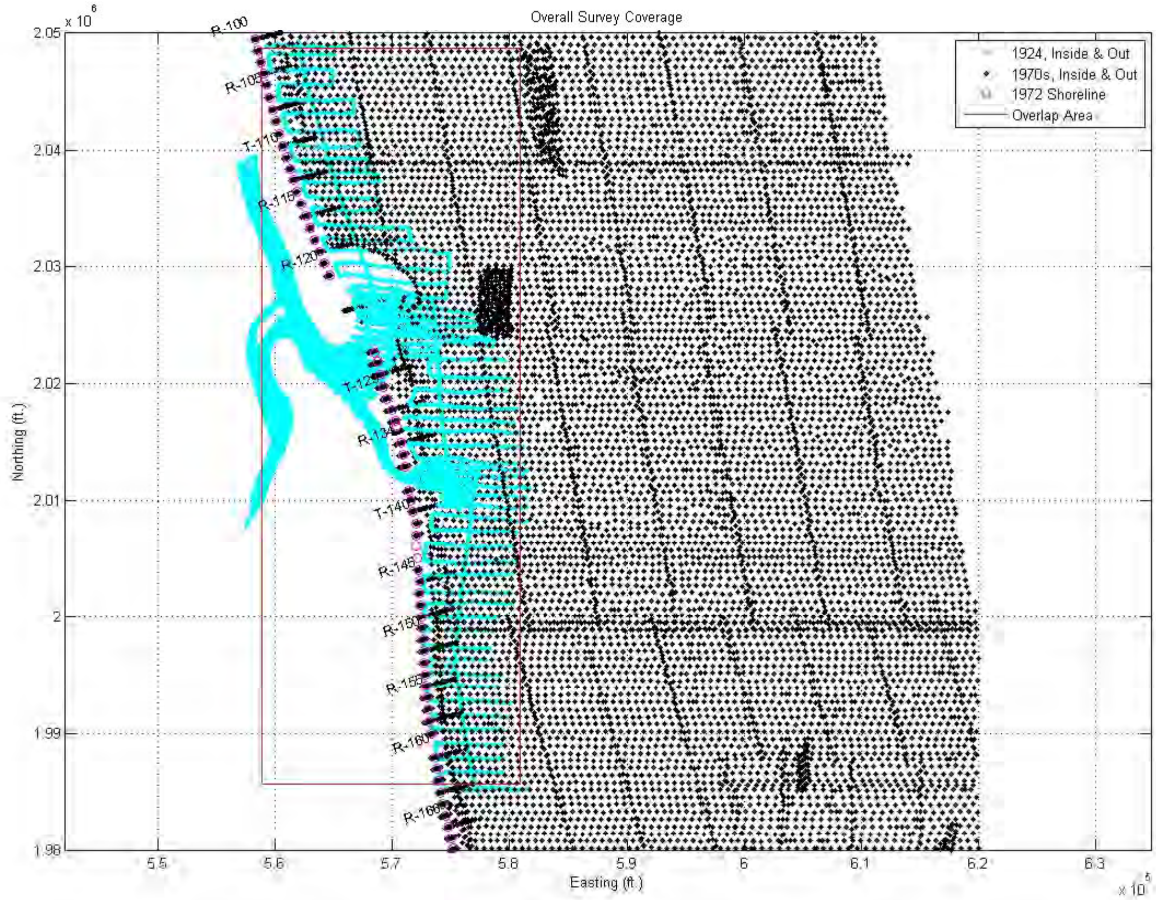


Figure 4.5 10 Survey Coverage and Overlap Area, 1924 and 1972 Surveys.

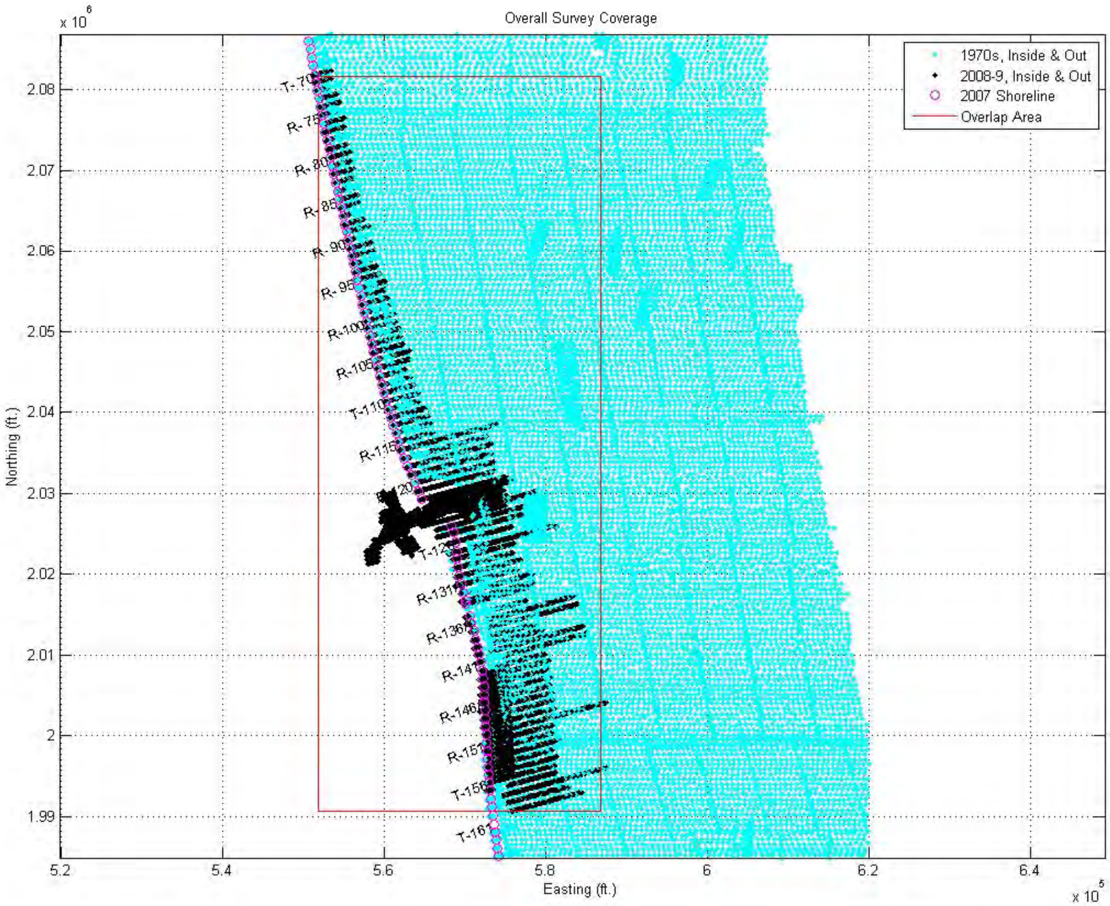


Figure 4.5 11 Survey Coverage and Overlap Area, 1972 and 2009 Surveys

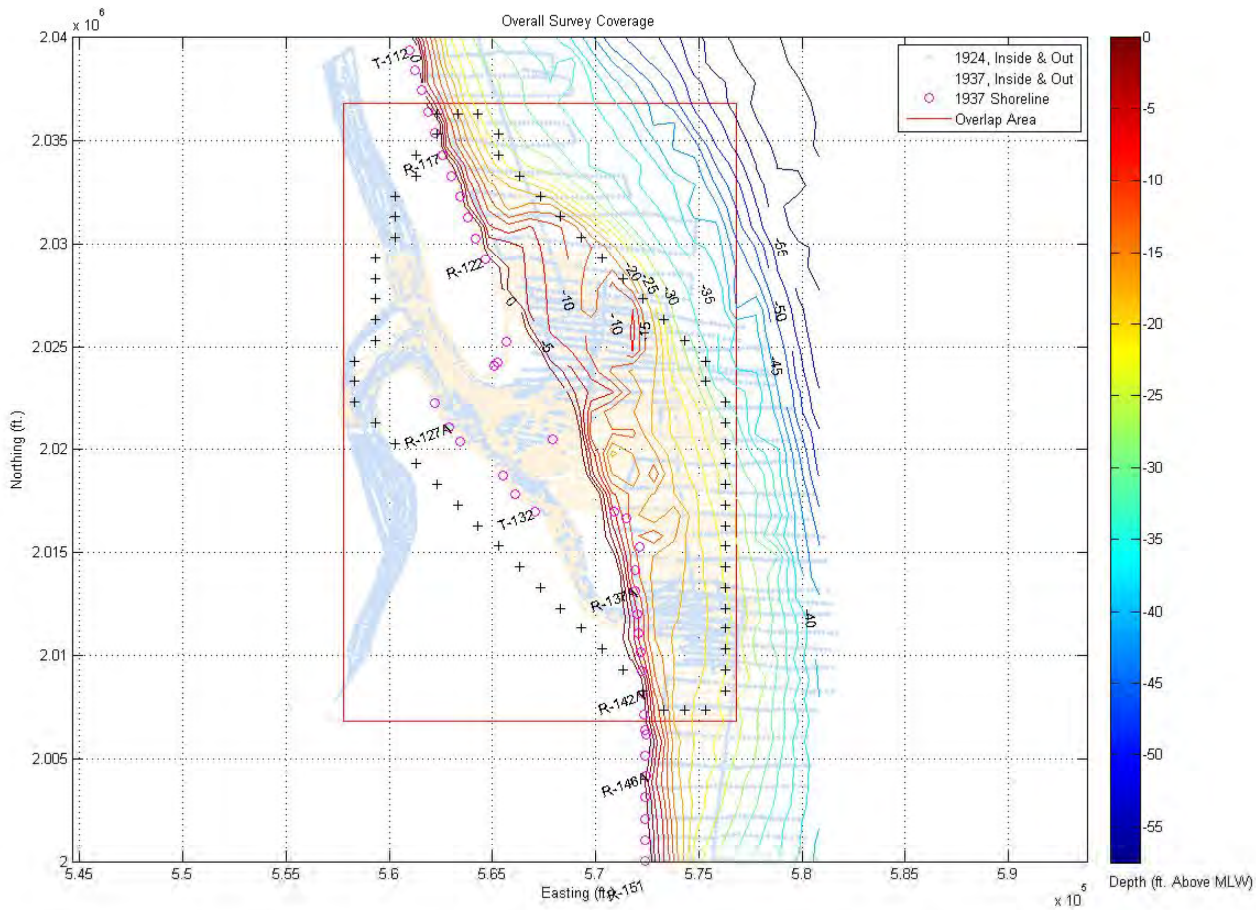


Figure 4.5 12 1972 Bathymetry with Outline of Overlap Area designated by "+", 1924 and 1937 Surveys.

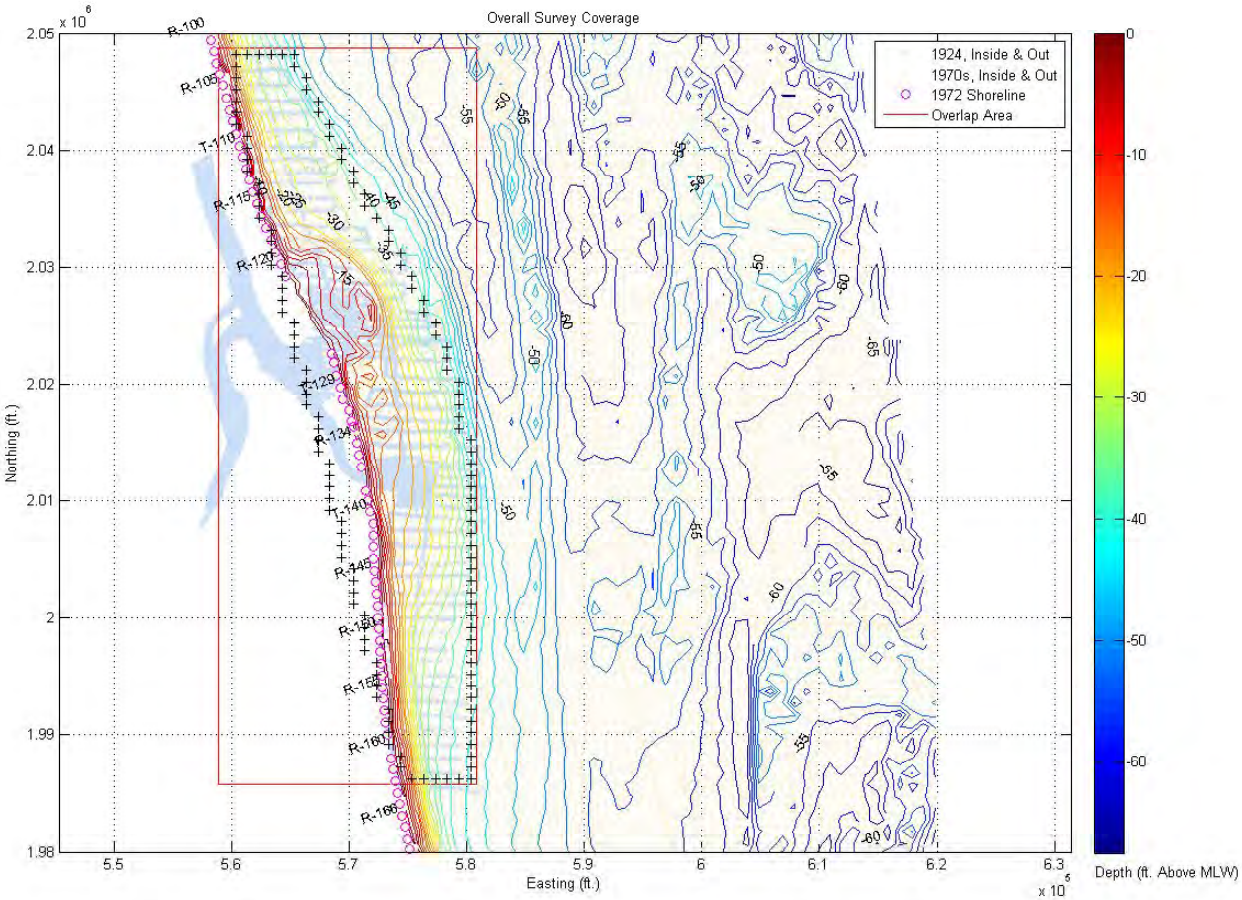


Figure 4.5 13   1972 Bathymetry with Outline of Overlap Area designated by "+", 1924 and 1972 Surveys.

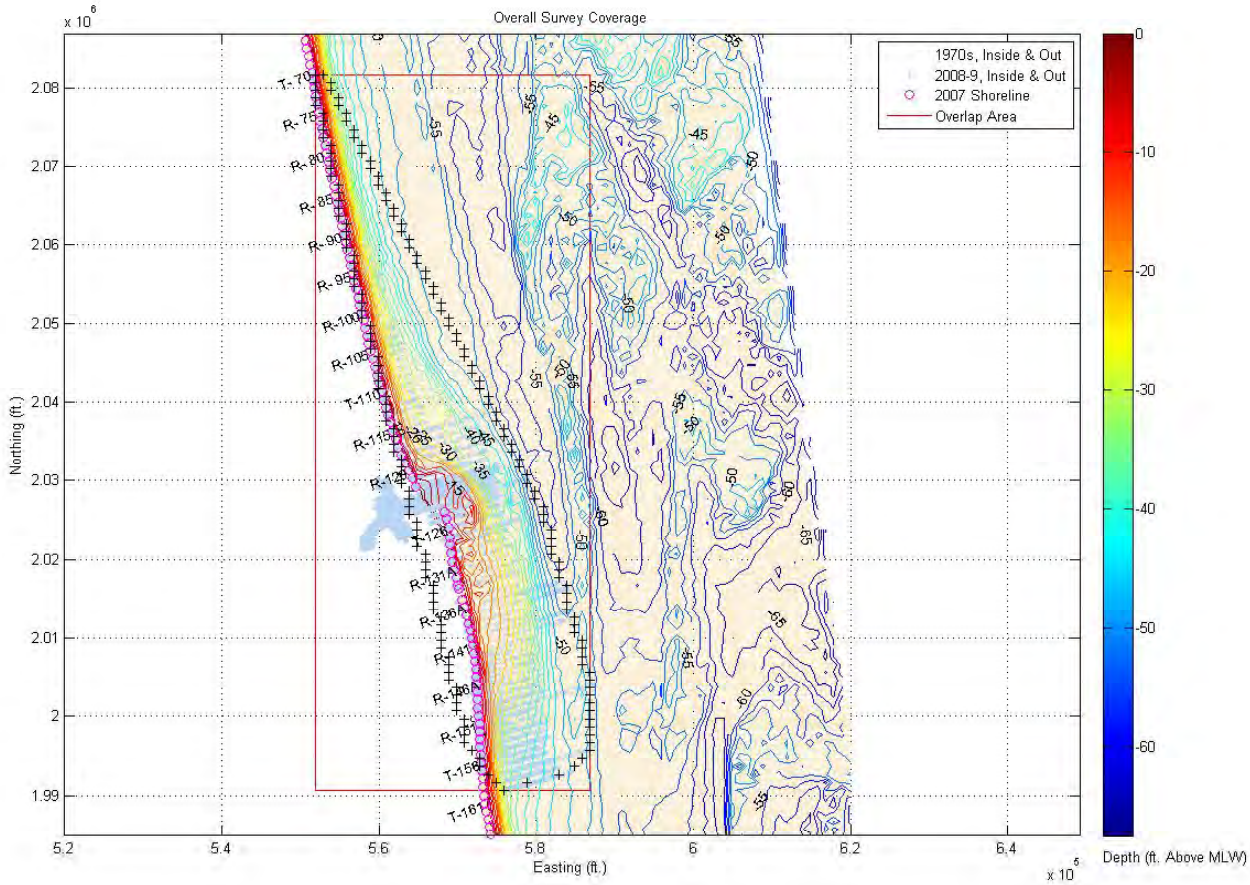


Figure 4.5 14 1972 Bathymetry with Outline of Overlap Area designated by "+", 1972 and 2009 Surveys.

4.6 Field Measurements of Tidal Prism and Currents (Surfbreak Engineering Sciences)

In the course of the present study the FDEP with assistance from FSU-BSRC requested Surfbreak Engineering Sciences (SES) to collect field information on tides, tidal prism, currents, and flood and ebb current patterns for St. Augustine Inlet. The report of Surfbreak Engineering Sciences is attached as Appendix G although the findings provided by the study are discussed below and utilized (where possible) in calibration of the hydrodynamic model.

SES computed tidal prism from peak discharge measurements (per Appendix G) as $1.34 \cdot 10^9\ ft^3$ (= $3.81 \cdot 10^7\ m^3$) within 1.5 percent of previously reported tidal prism reported in Taylor Engineering(1996) suggesting that the volume of sand within the ebb shoal has not changed appreciably since that time period.

4.7 Analysis of MHW Shoreline Data for Shoreline Change Trends

Shoreline MHW positions are available from the FDEP for time periods ranging from the late 1800's to the present. The quality of the surveys and the position of the MHL shoreline is subject to error dependent on the time period, type of survey, and the survey crew procedures. As an example, the earliest surveys of Mean High Water Line in the 1800's and early 1900's made by the U.S. Coastal Survey were done by plane table surveys and are typically of the debris line on the beach made by high water during the period of the surveys. More recent FDEP MHW shoreline data are of much higher quality but only exist from the 1970's onward. Although error is inherent in the MHW line position, the knowledge provided by this database of MHW positions represents the best information available on which to estimate shoreline change rates.

For the present study, annually averaged (either via least squares or end rate method) and cumulative (via summation with Range ($= \sum_{R1}^{Ri} \frac{dy}{dt}(i)$) annually averaged shoreline change rates have been estimated at each of the Monument-Range lines in the county. As monuments are approximately 1000 feet apart, a summation approach is shown here rather than an integration (which would provide units of ft^2/yr.) Due to the noise in shoreline change data, it was found that cumulative (via summation) shoreline change rates (which tend to integrate out the noise in shoreline change rates over a region) were the more useful for interpretative purposes. The derivative of the cumulative annually averaged (via summation) shoreline change rate plot (i.e. slope of plot) provides an annually averaged shoreline spatial change rate over limited regions of interest where the slope is approximately linear. The shoreline change rates are shown in a variety of figures for use in interpretation of inlet influence zones and shoreline change and inlet change interpretation throughout the county. The cumulative annually averaged shoreline change rates provided in the plots are, as noted above, summations of the annual average shoreline change rate at monuments (starting summation at monument R-1) and not integrated areas, therefore the vertical units on the figures are shown as ft/yr. An approximation to the true cumulative area integration may be produced approximately by multiplying the vertical axis magnitude by 1000 feet (i.e. the approximate distance between the monuments) although a discrepancy would exist starting at the inlet area where an offset would be expected due to the discontinuous nature of the shoreline there.

Figure 4.7.1 provides a view of the cumulative (via summation) historical change rate from the late 1800's to approximately 1970 as well as the more recent time period from 1970 to 2008. Although the 1970 time point is after the new COE inlet was dredged, the change rates provided by the span of time between the earliest survey and 1970 are believed to be reasonably representative of the pre-COE inlet period while still including sufficient accurate shoreline information for the least squares analysis procedure. As can be seen in the figure, during this time span, the north side of the inlet was accreting at a reasonably higher rate in the area north of R-70 although still accreting (abeit at a lower rate) to the south of R-70. This suggests that the area north of the inlet but south of R-70 was historically undergoing more recessional stress that that further to the north. Foster et al. (2000) have noted submerged coquina and/or bedrock outcrops in the nearshore zone acting as a "headland" feature extending from about R-15 to R-75 which may be the reason for this higher recessional stress to the south of approximately R-70.

South of the inlet during this same period, the general shoreline encounters a dramatic change from one of advancement on the south side of the inlet to that of a somewhat stable or slightly recessional shoreline from R-175 southwards with one exception. The exception is that of the bump encountered in the cumulative plot (i.e. vicinity of R-135 to R-140) near to where the old inlet (pre COE inlet) appears to provide an "attachment/feeder" zone from the inlet ebb shoal.

For the more recent time period, Figure 4.7.1 suggests that the advancement rates have decreased over the entire shoreline south of R-30, although there is still a zone of advancement north of approximately R-80 and the south side of the inlet is again advancing north of approximate R-190 (with one exception being the bump at the new location of the ebb shoal "attachment/feeder point" which is in the vicinity of R-131 and further north of the pre-COE inlet location). As has been noted previously, the relocation of the ebb shoal "attachment-point" due to the new COE inlet is rationale for the present recessional stress on the beaches at the junction of the south boundary of Anastasia S.P. and the City of St. Augustine Pier/Seawall/Park complex. Material bypassed naturally by the old pre-COE inlet moving onto the shoreline in the area spanned by the southern portions of Anastasia S.P. and the northern portions of the City of St. Augustine Beach [Pier/Seawall/Park complex] caused a "shoreline bump" allowing a shoreline seaward of the general shoreline trend at the approximate R-135 to R-140 area. The creation of the new COE inlet further to the north caused this shoal attachment point (seaward projected shoreline bump) to move northward leaving the southern portions of Anastasia S.P. and the northern portions of the City of St. Augustine Beach in what appears now to be a zone of sand divergence (i.e. material to the north of this location moves primarily northward and south of this location material moves primarily southward). The location of reversal is not believed to be stationary but is expected to fluctuate somewhat at times to north and south of the noted ranges.

The next set of figures is for the time period from the early 1970's to 1999 where the shoreline change rates have been estimated from the end point method using only the more accurate

FDEP MHW survey data. Figures 4.7.2 through 4.7.4 show the annually averaged MHW change rates and cumulative (via summations as opposed to integrated) annually averaged MHW change rates versus Monument-Range location north of the inlet for time periods from 1972 through 1999 where 1999 represents the last survey date prior to the major initiation of beach nourishment on the south side of the inlet using beach quality material dredged from the inlet ebb shoal complex. Figure 4.7.2 shows a noisy shoreline change rate north of the inlet for the various survey periods. It is noted that the overall shoreline north of the inlet remains relatively stable although there is somewhat of an recessional signal as one approaches the inlet. It is apparent that estimated rates for data from the shorter time intervals have significantly higher noise level than those from the longer time intervals although cumulating the results helps to reduce the apparent noise to effectively provide a more clear picture of recession/advancement trends. Cumulative (via summation) plots for the area north of the inlet are shown for two of the time periods as Figures 4.7.3 and 4.7.4. In the cumulative plots both the raw data and a "smoothed" low pass filtered version of the raw data are provided although throughout most of the region, the differences between the "smoothed" and "raw" data are small. Figure 4.7.3 suggests that for the time period from 1972 to 1986, the shoreline was advancing north of approximately R-90 with the highest advancement rates (largest positive slope) generally being north of approximately R-20. From the same Figure, it is noted that any inlet induced recessional effects on the north side of the inlet appear to be contained primarily to the area south of approximately R-90 although, as has already been mentioned, such recessional effects may be due to recessional stress induced by submerged coquina and/or beachrock outcroppings further to the north. For the time period from 1972 to 1999, Figure 4.7.4 shows a generally recessional trend north of the inlet with an increasing recessional rate (possibly due to submerged coquina and/or beach rock and due to inlet induced erosion) to the south of approximately R-90.

Figure 4.7.5 provides annually averaged MHW change rates south of the inlet for the same time periods ranging from 1972 through 1999 where again the standard deviation of the data spanning the longer time interval is smaller than those of the data spanning the shorter time intervals. Figures 4.7.6 and 4.7.7 show cumulative (via summation) plots for the beaches south of the inlet for the time periods 1972-1986 and 1972-1999, both prior to major nourishment of the south beaches using beach material dredged from the ebb shoal complex. Similar trends are seen in both figures with advancement north of approximately R-130, recession from approximately R-131 to R-150, and advancement south of approximately R-150 all the way to Matanzas Inlet area (approximately R-196 to R-199) although it is noted that advancement for the longer time span of 1972-1999 is significantly reduced to the south of approximately R-150 compared to that of the 1972-1986 period.

The last set of shoreline change figures (Figures 4.7.8, 4.7.9, and 4.7.10) are for the most recent time period just preceding the major beach nourishment and re-nourishment projects through 2007. Figure 4.7.8 shows the total shoreline change during the time interval from 1999 through 2007 and shows the major advancement in the area from approximately R140 to R160 south of the inlet due to the beach nourishment projects ongoing during this period as expected. The somewhat surprising fact though is that although over 4,200,000 c.y. of beach material were placed during this period, the shoreline is still showing a net landward displacement of MHW south of the nourished area (i.e. south of approximately R-160) suggesting that much of the placed material had not moved significantly southward as of 2007.

From Figure 4.7.9 it can be seen that over the time span of 1999 to 2007, the shoreline north of the inlet has experienced primarily advancement to the north of approximately R-20, while being generally stable from approximately R-21 to R-60 and recessional south of approximately R-60. Over the shorter time period from 1999 through 2003 when the first nourishment project was placed, the shoreline north of the inlet shows an recessional trend north of approximately R-20, and an recessional trend south of approximately R-20 with the recession decreasing from approximately R-70 to R-100 and then increasing toward the inlet south of approximately R-100.

From Figure 4.7.10 it can be seen that during the same 1999-2007 time span, the area south of the inlet experienced advancement to the north of approximately R-150 while a somewhat mild recession trend occurred south of approximately R-150. For the shorter time interval from 1999 to 2003 the shoreline south of the inlet experienced advancement over its entire distance with the most dramatic advancement being in the area of the placed beach nourishment.

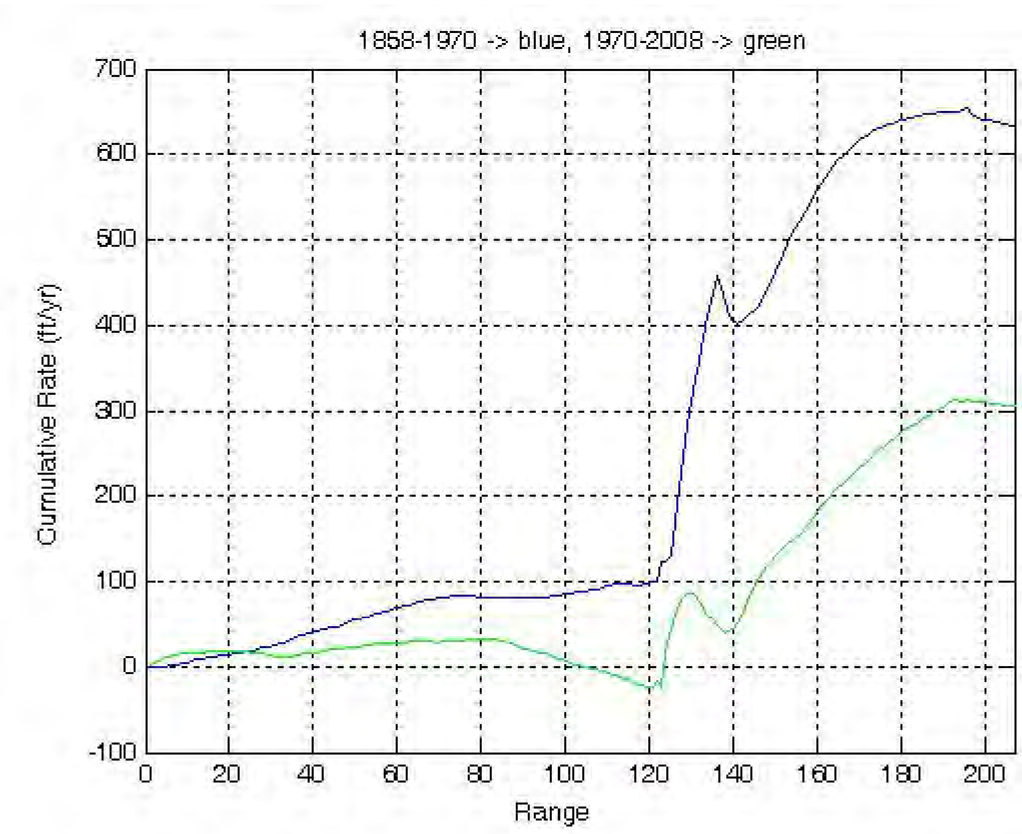


Figure 4.7 1 Historical Cumulative (Via Summation) Annually Averaged MHW Change Rates based on Least Squares Analysis of Multiple Data.

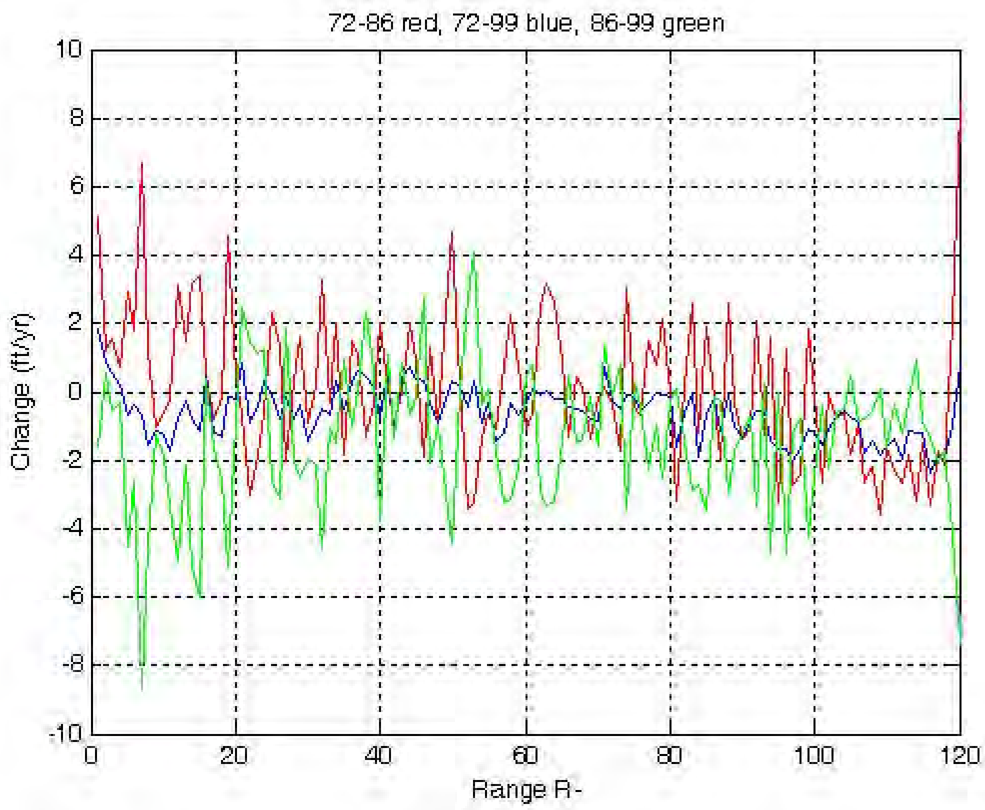


Figure 4.7 2 Annual Average MHW Change Rate (North of Inlet) for 1972-1999 Based on End Point Analysis.

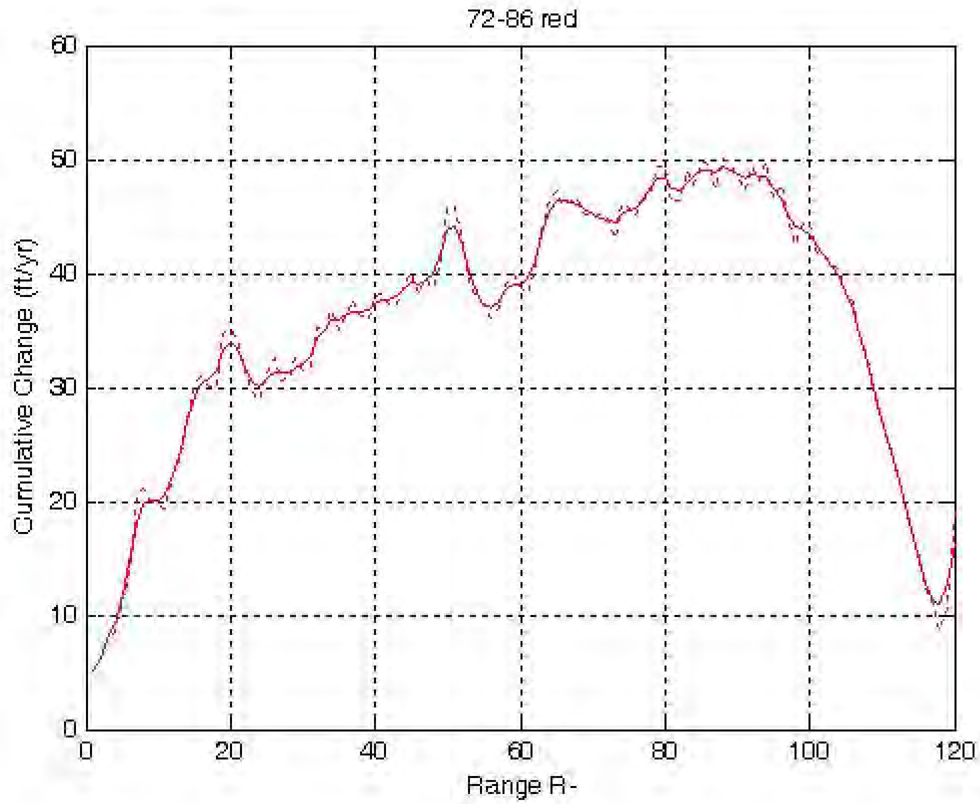


Figure 4.7 3 Cumulative (Via Summation) Annually Averaged MHW Change Rates (North of Inlet) for 1972- 1986 Based on End Point Analysis.

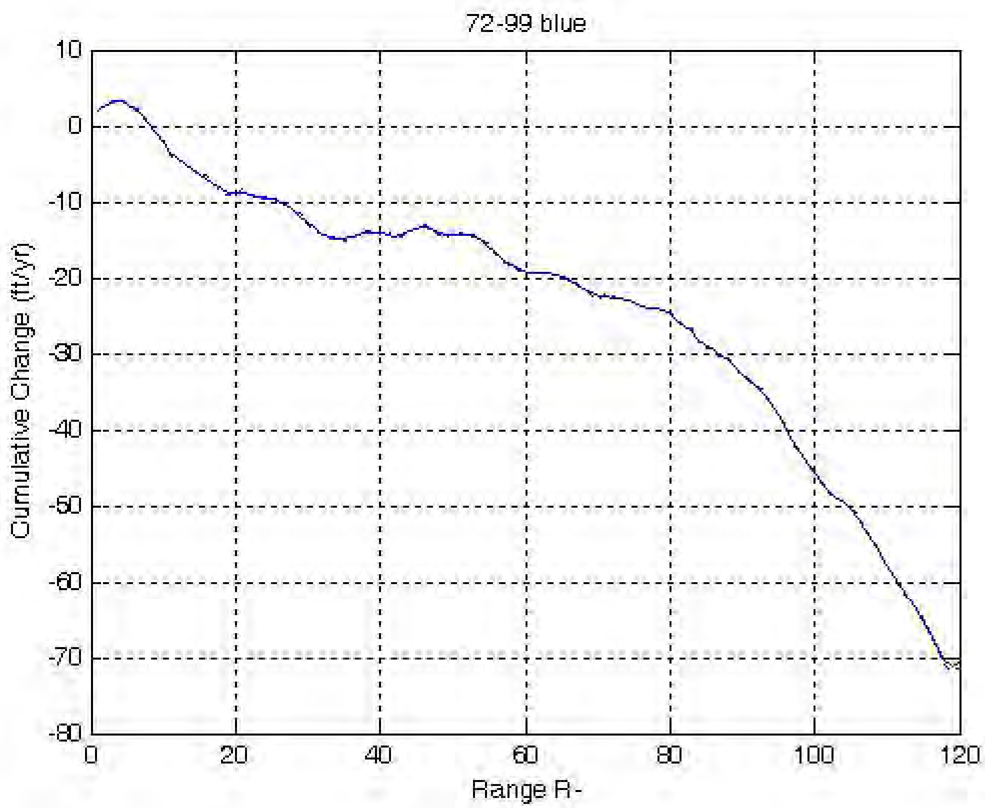


Figure 4.7 4 Cumulative (Via Summation) Annually Averaged MHW Change Rates (North of Inlet) for 1972-1999 Based on End Point Analysis.

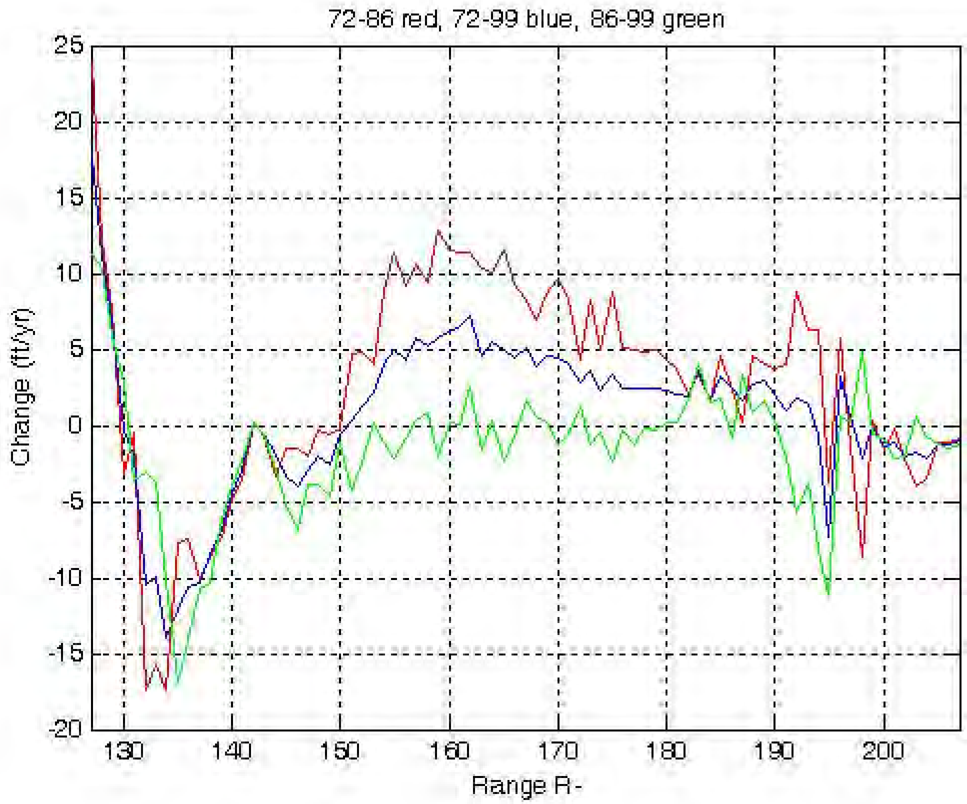


Figure 4.7 5 Annually Averaged MHW Change Rates (South of Inlet) for 1972-1999 Based on End Point Analysis.

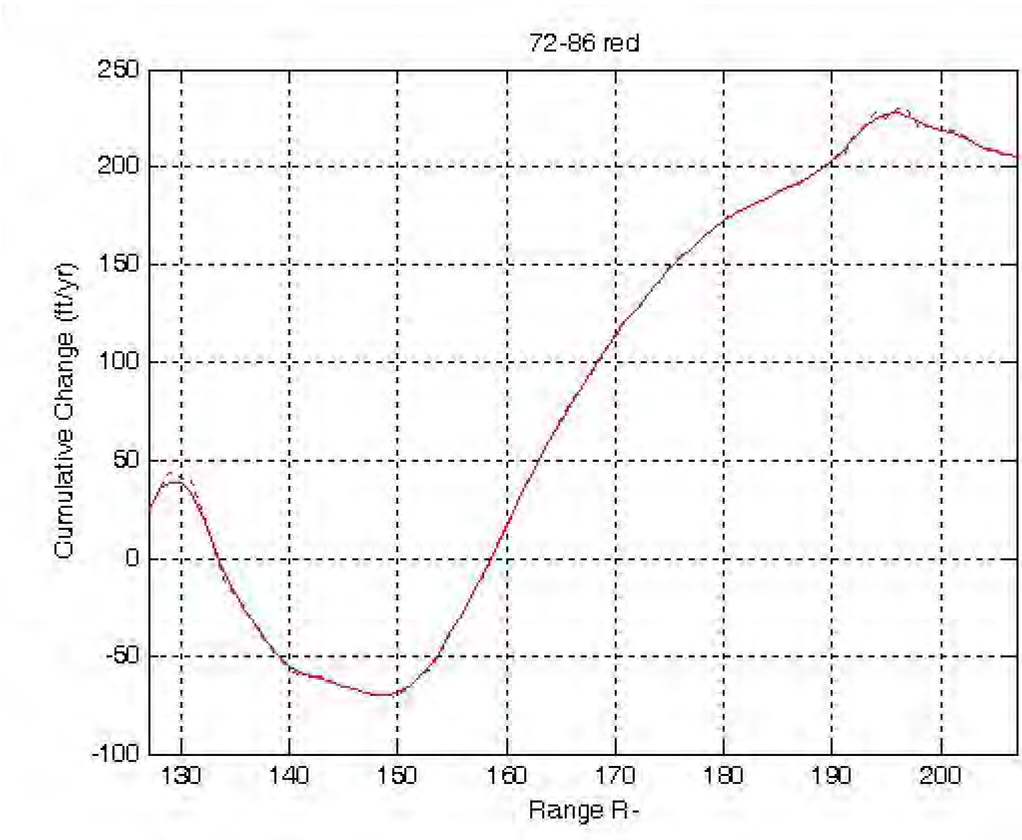


Figure 4.7 6 Cumulative (Via Summation) Annually Averaged MHW Change Rates (South of Inlet) for 1972-1986 Based on End Point Analysis.

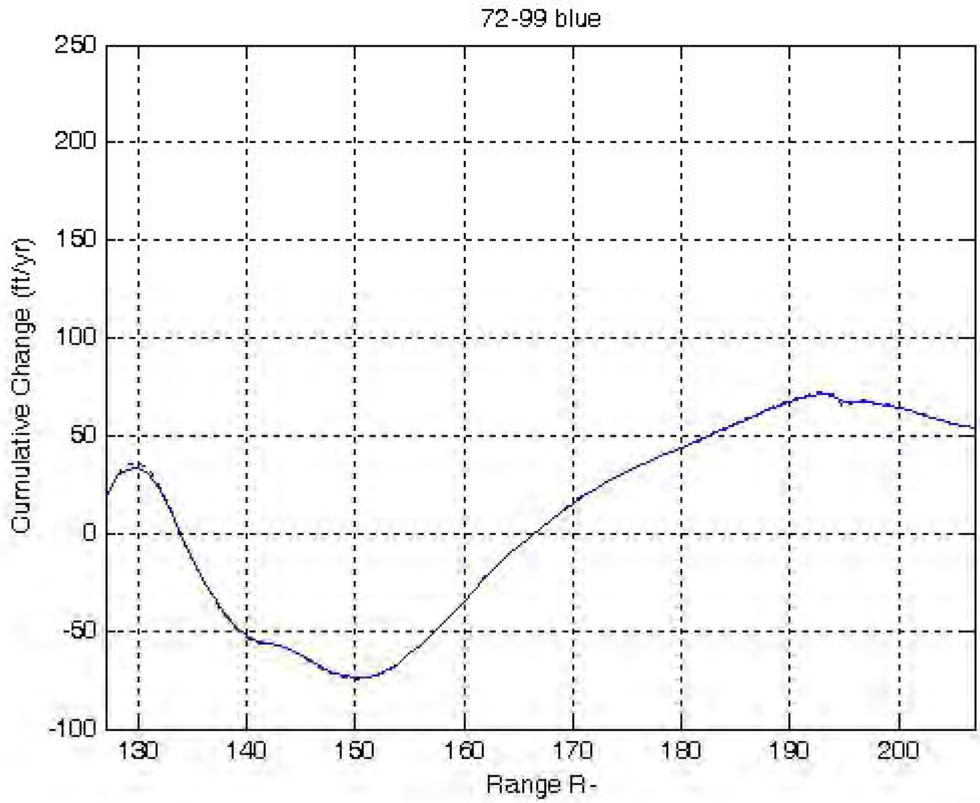


Figure 4.7 7 Cumulative (Via Summation) Annually Averaged MHW Change Rates (South of Inlet) for 1972-1999 Based on End Point Analysis.

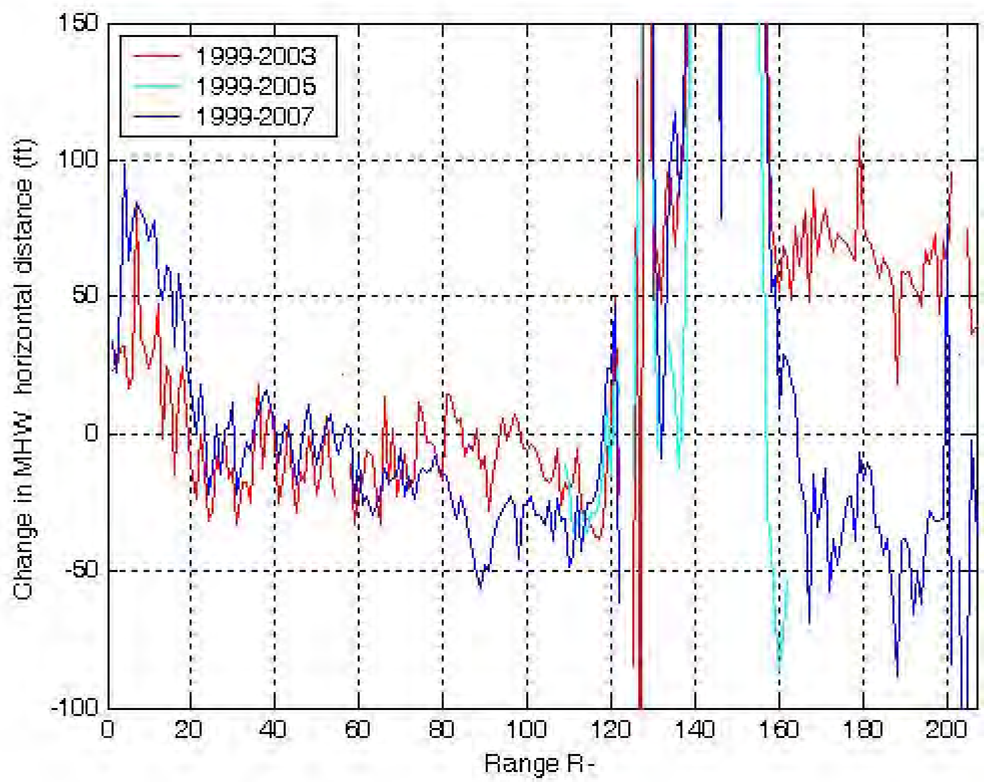


Figure 4.7 8 MHW Change Horizontal Distance for 1999-2007 Based on End Point Analysis.

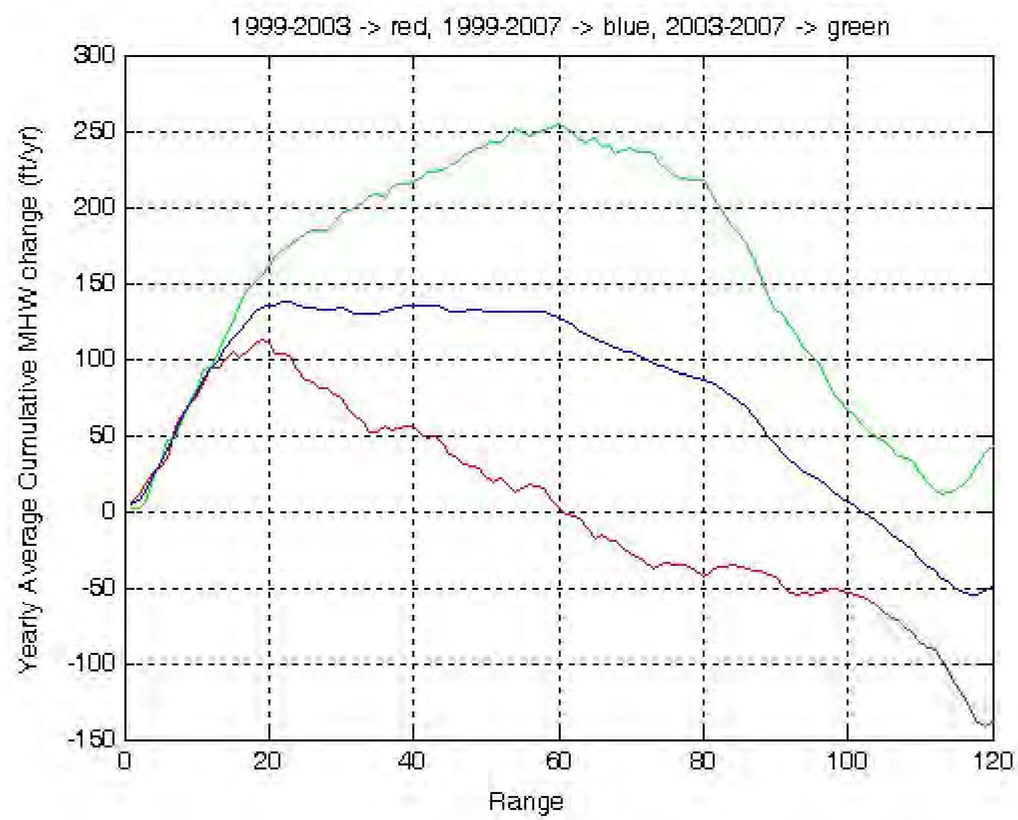


Figure 4.7 9 Cumulative (via Summation) Annually Averaged MHW Change Rates (North of Inlet) for 1999-2007 Based on End Point Analysis.

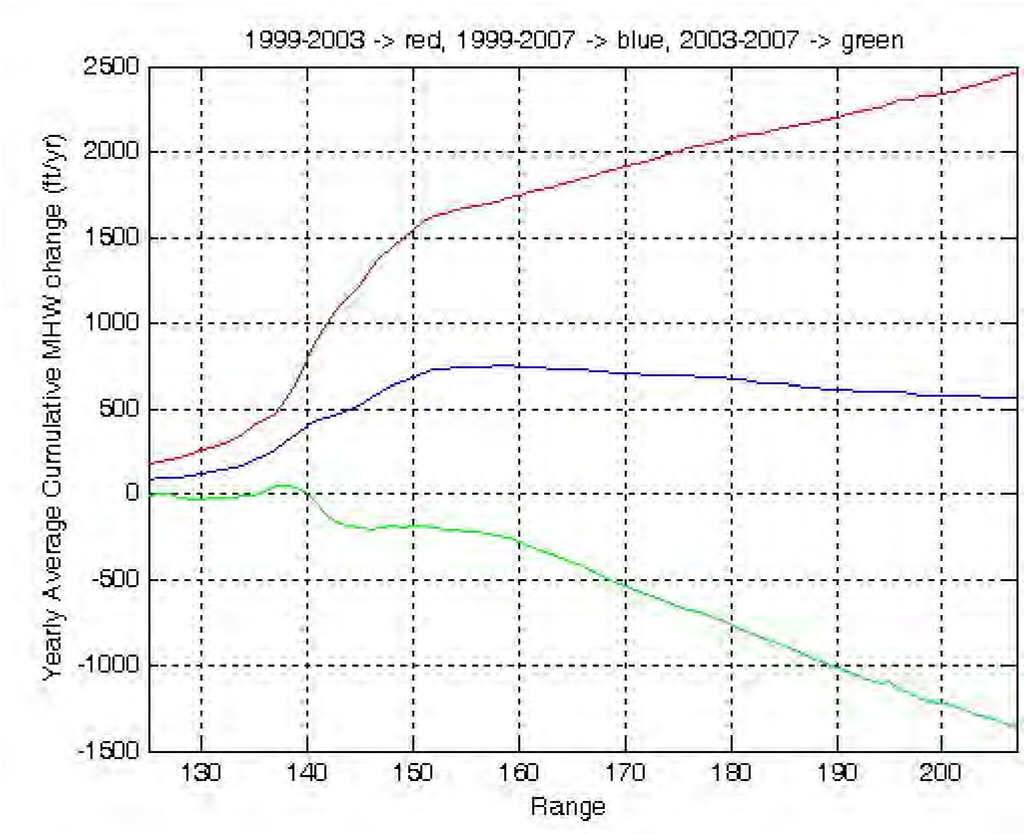


Figure 4.7 10 Cumulative (Via Summation) Annually Averaged MHW Change Rates (South of Inlet) for 1999-2007 Based on End Point Analysis.

4.8 Analysis of Profile and MHW Shoreline Data for Volumetric Change Trends

Recent North Side Change and Interpretation

Survey profile data and MHW shoreline data obtained from the FDEP shoreline history web site was utilized to assess volumetric changes to interpret volumetric change trends herein. A profile assessment has been provided separately as Appendix H which showed that the survey profile data were biased in regard to the offshore portions of the surveys and did not provide reasonable agreement with shoreline change information on which to make a rational assessment of sediment budget for most surveys. An assessment showing correlation between volumetric computations and planform areas computed from MHW was also made for sediment budget regions and provides a similar lack of correlation as noted later in the sediment budget discussion section of this report. Only the most recent survey dates of 1999 and 2007 which provided the smallest bias (0.24 feet) and trends provided by this profile change information are discussed herein.

Problems on correspondence between north side profile survey information and MHW shoreline information (for the 1999-2007 period) is expanded on here. Typically, an expectation of a rough linear relationship is provided between MHW (i.e. mean high water) shoreline change and profile based volumetric change on a sandy shoreline exposed to the same wave climate by the following equation (expressed as an integration between any two shoreline positions where the x represents distance along the shoreline):

$$\int \left(\frac{dy}{dt}\right) \cdot (h_c + D)\, dx = \int \frac{dA}{dt} \cdot dx \qquad (4.8.1)$$

with $\frac{dy}{dt}$ = MHW change over time span of interest, $h_c + D$ = vertical distance of active profile where h_c typically represents depth of profile closure and D represents the subaerial vertical portion of the active profile (i.e. dune or berm height), and $\frac{dA}{dt}$ represents the area change (between profiles at a given location). *Note that the A in this equation represents an area and is different (with different units) than the "A" factor previously discussed in the equilibrium beach profile computations.* Equation 4.8.1 can be applied over any time span of interest to assess the validity of the correspondence. Figure 4.8.1 represents the left side of the above equation starting at the north end of the county (for an assumed $h_c + D$ = 27 ft.) for the time period 1999 to 2007 while Figure 4.8.2 represents the right side of the above equation for the same time period (with an assumed offshore profile closure at -18ft depth). As can be seen by the different shapes of the two figures, there is clearly not an approximate linear correlation between the MHW change data and the offshore profile change data even in this time period where profile bias is minimal, further substantiating the difficulty in using the profile data alone to interpret accretion/erosion trends on the north side of St. Augustine Inlet.

An attempt at interpreting Figure 4.8.2 (which provides the cumulative volume change for the time period 1999 to 2007 from the north end of St. Johns County (~R-1) to the vicinity of the St. Augustine Inlet north jetty (~R-122)) is provided in Figure 4.8.3 here. The cumulative (i.e. integrated) change signal was utilized herein as it provides a smoothed signal compared to the noisy change signal seen from profile to profile. The ordinate axis is the FDEP survey range monument number while the abcissa is the cumulative volume change between the two surveys out to -18 feet of water, an approximate closing depth of water away from the inlet (i.e. see Dean (2002)). Other cumulative volume calculations were made for depths of (-6, -12, and -30 feet) and provided in Figures 4.8.4, 4.8.5, and 4.8.6 although the -18 foot depth will be utilized to show the general trends noted in this study. It can be seen in Figure 4.8.3 that the shoreline is generally stable (approximate flat curve) at the north end of the county (for about 2+ miles) during the time interval between April 1999 to September 2007 although the county shows an overall erosive signal during the same time period. The slope of the cumulative volume diagram provides the average area of erosion/accretion for the time period between surveys and normally would be expected to be proportional to the shoreline change during the same time period for a typical shoreline as noted previously. The present discussion will focus on four regions of the shoreline, R-30 to R-50 having approximate slope = s1, R-50 to R-80 having approximate slope = s2, R-80 to R-100 having approximate slope = s3, and, R-100 to ~R-117 having approximate slope = s4. As the negative (erosional shoreline) slope decreases (i.e. gets larger in [negative] magnitude), the more that section of the shoreline is eroding. It is found that s3 ~= s1 suggesting that large magnitudes of erosion exist on either side of the region extending from R-50 to R-80 where a low erosional rate (and minimal slope s2) is seen to prevail. Southward from R-100, the erosional slope increases in the s4 region which is the area influenced by St. Augustine Inlet. As the regions on either side of the s2 slope area are shown to have slopes greater than that of slope s2, it is not entirely clear that erosion north of R-100 is influenced by St. Augustine Inlet, but rather, may be due to headland effects projected to be coquina or beach rock outcroppings as noted in Foster et al. (2000). This hypothesis is speculative at present due to data concerns and lack of a jet probe survey to hard bottom of the beach and offshore north side of St. Augustine inlet.

Volumetric change data estimated from MHW shoreline change for the periods noted (using MHW shoreline files of the FDEP shoreline data web site) can also be interpreted to provide similar conclusions. Change trends for the north side of St. Augustine Inlet from the north County Line of St. Johns County southward to the inlet show different patterns than the volumetric (profile) trends noted above although, somewhat similar inferences can be made with regard to inlet effects. For the change signal provided in Figure 4.8.1, it is noted that there is a strong accretion signal up to about Range R-20, then a very stable shoreline between Range R-20 and R-60. Near Range R-60 the area changes from a somewhat stable (on average) region to a mildly recessional region with recession/erosion increasing southward from R-80 but slightly decreasing as the north jetty of St. Augustine Inlet is approached. The trend of an increasing recession/erosion southward from R-60 which is enhanced after R-80 is consistent with the downdrift shoreline effects due to a headland effect (projected to be coquina or beach rock outcroppings) as noted in Foster et al. (2000). The shoreline projection beyond the general trend of the shoreline, although very subtle, is apparent via close inspection of the shoreline using hydrographic charts for the area.

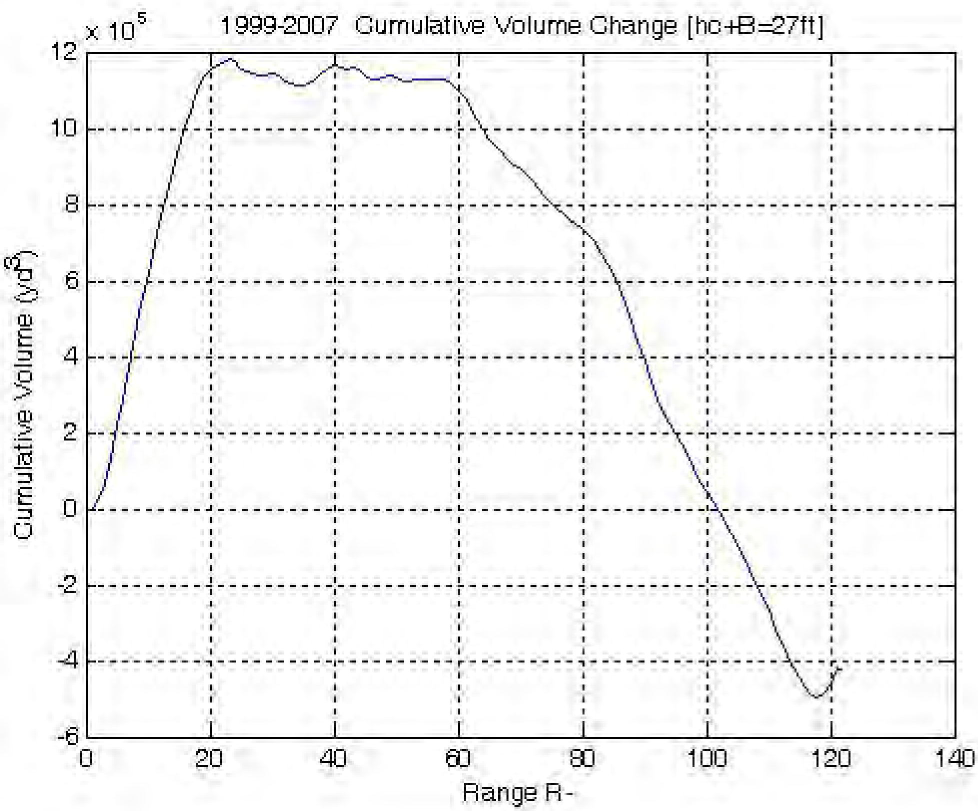


Figure 4.8 1 Cumulative Volume Change for 1999-2007 from MHW shoreline data, North Side of St. Augustine Inlet (assumed $\boldsymbol{h_c} + \boldsymbol{D}$=27ft).

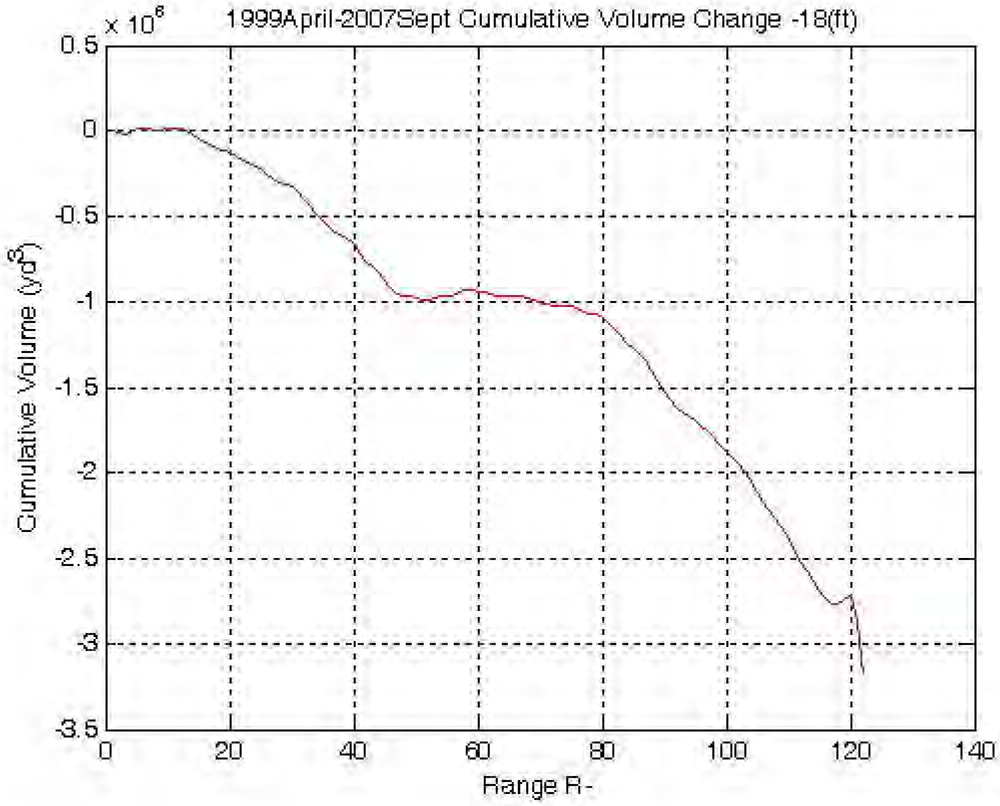


Figure 4.8 2 Cumulative Volume Change for 1999-2007, North Side of St. Augustine Inlet (profile cutoff at -18ft); Based on Integration of Profile Change.

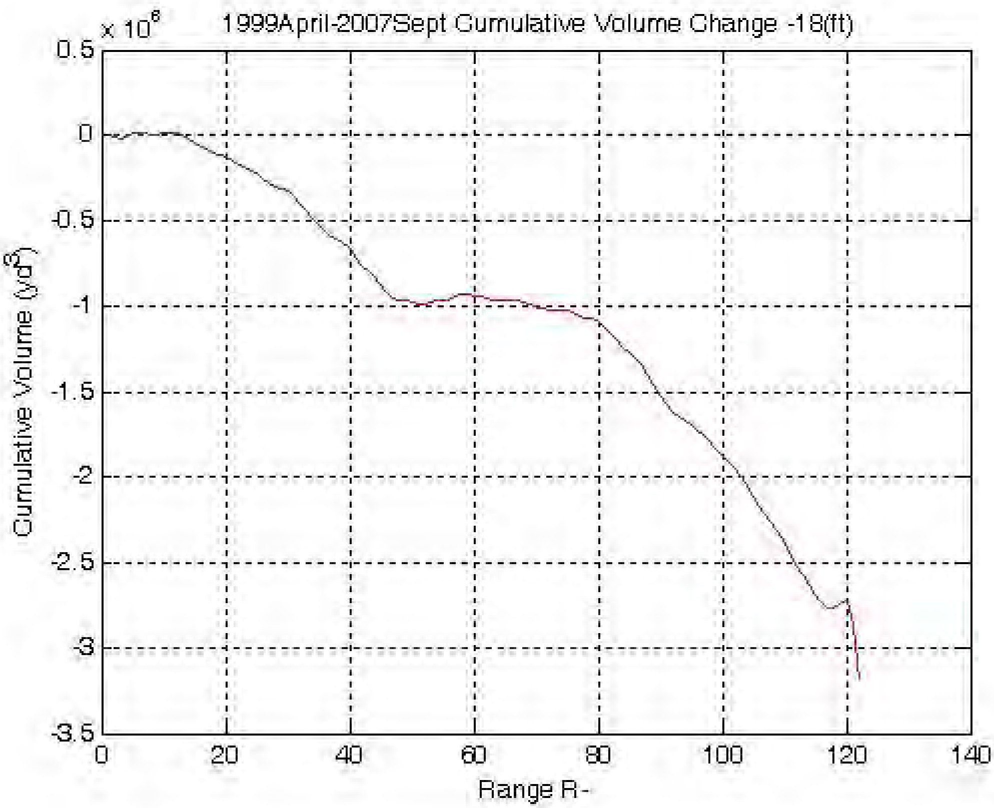


Figure 4.8 3 Cumulative Volume Change for 1999-2007 with trend lines, North Side of St. Augustine Inlet (profile cutoff at -18ft); Based on Integration of Profile Change.

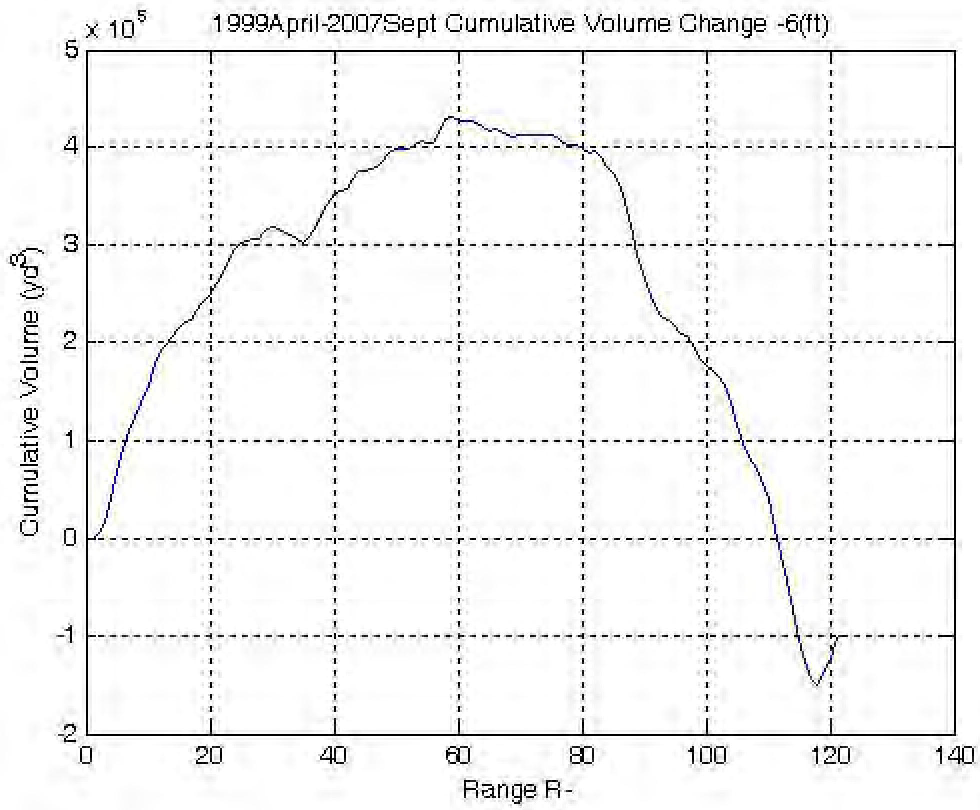


Figure 4.8 4 Cumulative Volume Change for 1999-2007, North Side of St. Augustine Inlet (profile cutoff at -6ft); Based on Integration of Profile Change.

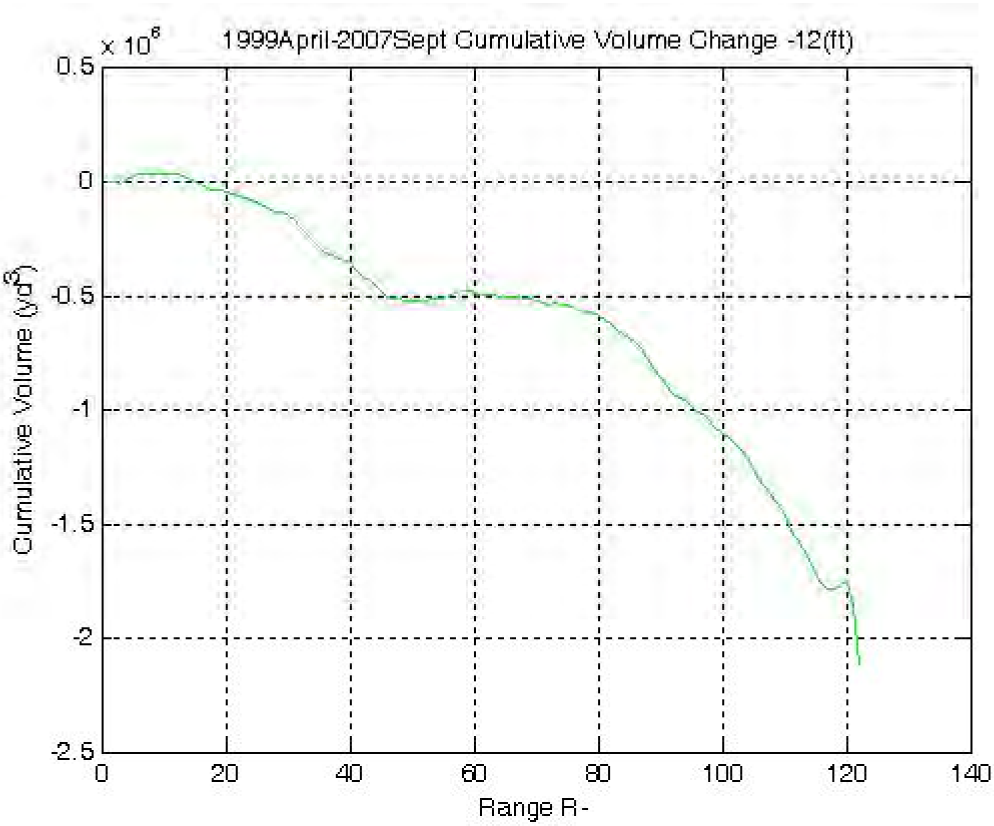


Figure 4.8 5 Cumulative Volume Change for 1999-2007, North Side of St. Augustine Inlet (profile cutoff at -12ft); Based on Integration of Profile Change.

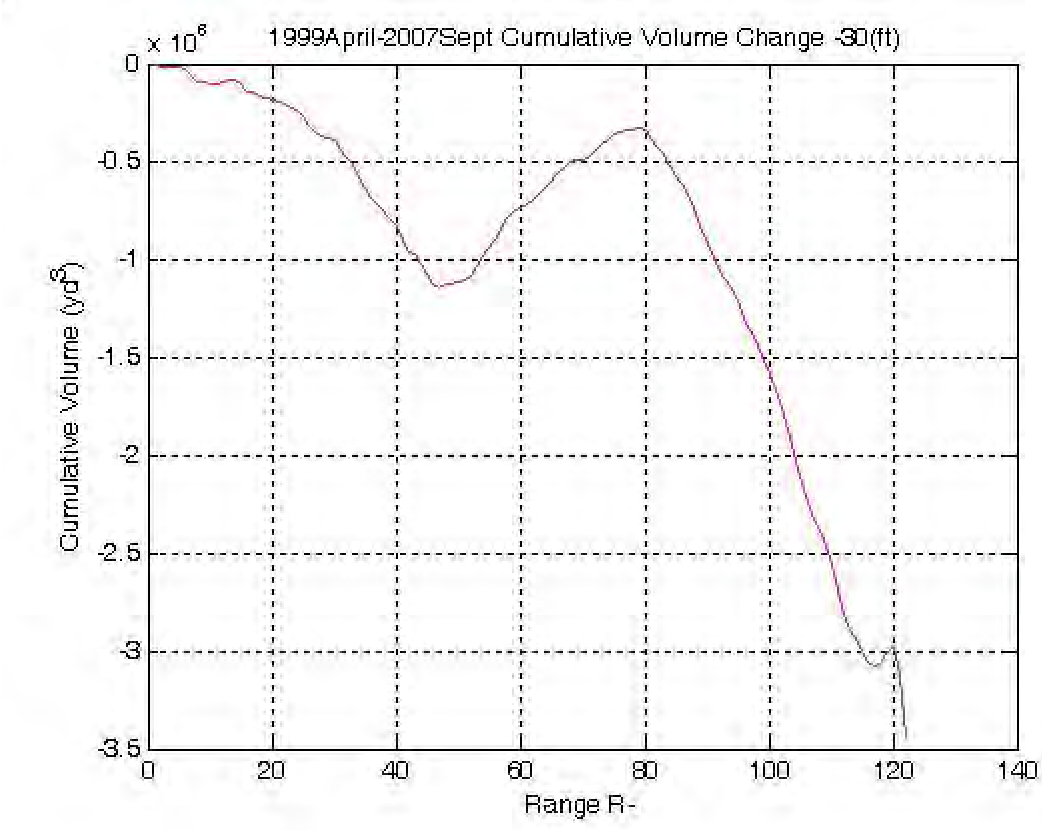


Figure 4.8 6 Cumulative Volume Change for 1999-2007, North Side of St. Augustine Inlet (profile cutoff at -30ft); Based on Integration of Profile Change.

Recent South Side Change and Interpretation

Survey profile data and MHW shoreline data was also obtained from the FDEP shoreline history web site for the south side of St. Augustine Inlet and an assessment made of this FDEP collected data. The previously discussed overall assessment of the survey profile data noted that survey profiles in most cases were biased in regard to the offshore portions of the surveys and did not provide reasonable information on which to make a rational assessment of sediment budget. The most recent survey dates of 1999 and 2007 provided the smallest bias (0.24 feet) and trends provided by the information between these two surveys are discussed herein for the south side of St. Augustine Inlet. Equation 4.8.1 can again be utilized to investigate the results.

Figure 4.8.7 represents the left side of the above equation starting at approximately R-123 south of St. Augustine Inlet and extending to the south end of the county (for an assumed $h_c + D$ = 27 ft.) for the time period 1999 to 2007. As only the nourished portion of the beach is available for survey profile volumetric information, a zoomed Figure 4.8.8 shows the same data as Figure 4.8.7 only for the limited portion of the area south of the Inlet for which survey information exists for the time period in question. Figure 4.8.9 represents the right side of the above equation for the same time period (with offshore profile closure at -18 ft). In this area a reasonable linear relationship exists for the MHW computed change and the volumetric profile change for this particular time period where survey bias is small.

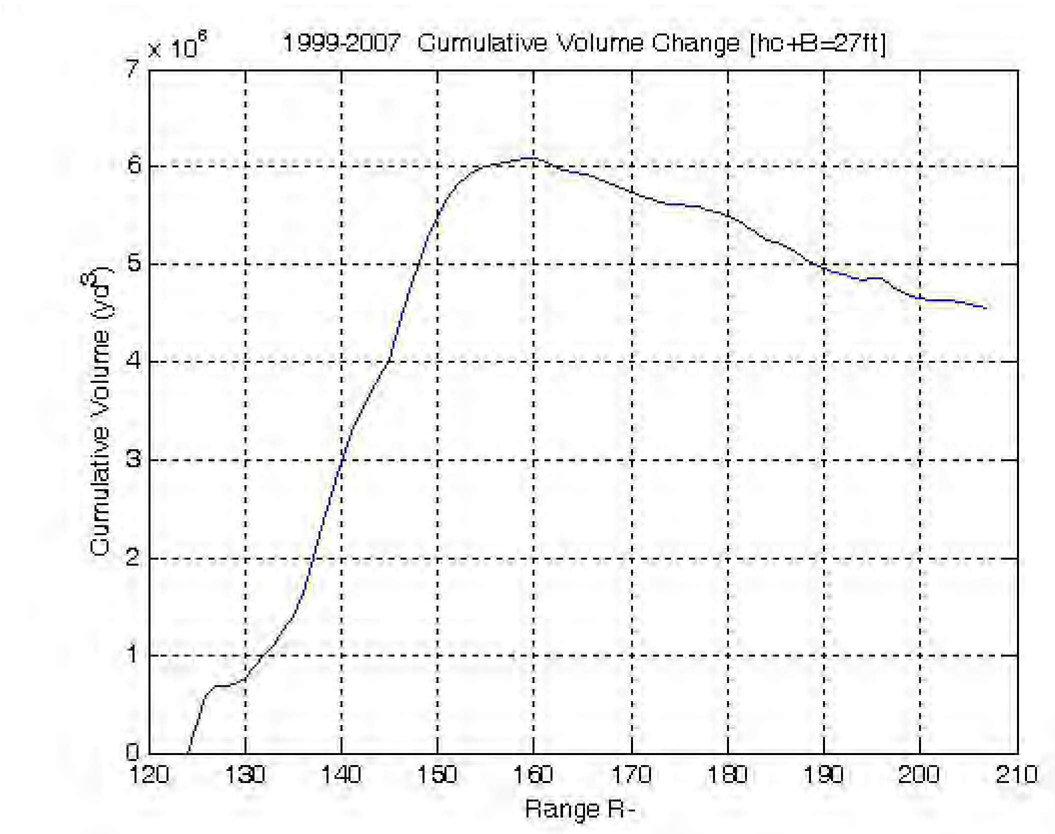


Figure 4.8 7 Cumulative Volume Change for 1999-2007 from MHW shoreline data, South Side of St. Augustine Inlet (assumed $\boldsymbol{h_c} + \boldsymbol{D}$ =27ft). Includes Nourishment Projects.

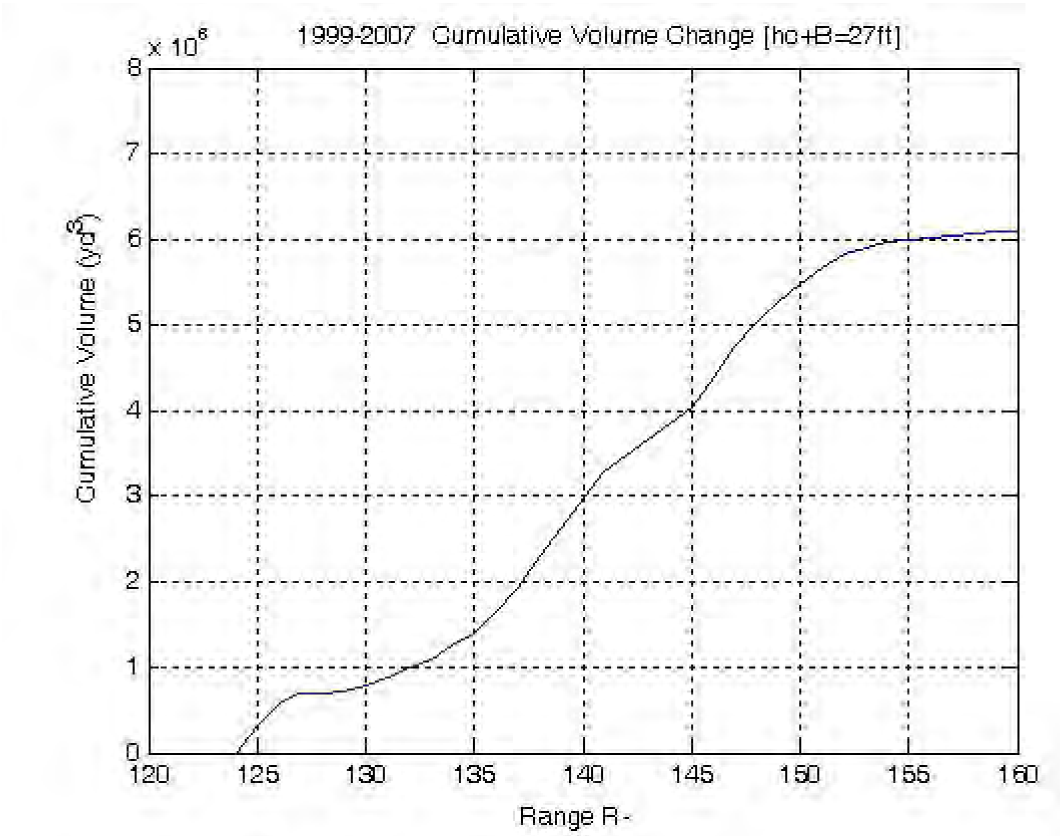


Figure 4.8 8 Cumulative Volume Change for 1999-2007 from MHW shoreline data, South Side of St. Augustine Inlet, R-123 to R-157; (assumed $\boldsymbol{h_c + D}$=27ft). Includes Nourishment Projects.

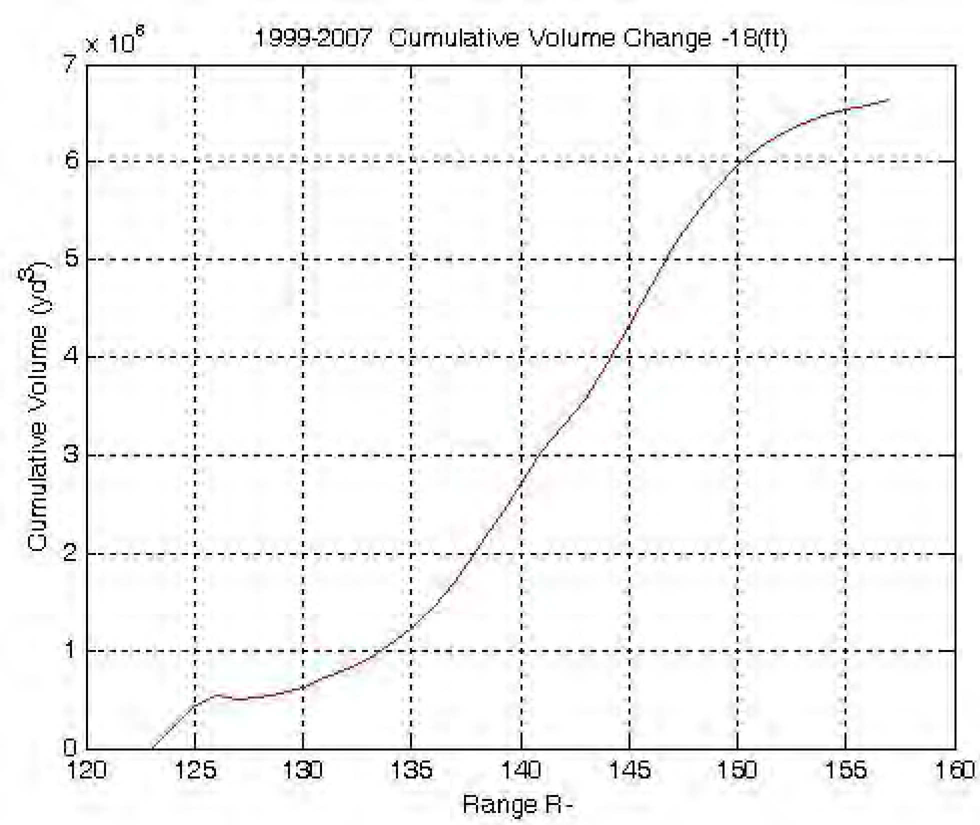


Figure 4.8 9 Recent Cumulative Volume Change for 1999-2007, South Side of St. Augustine Inlet (profile cutoff at -18 ft.); Based on Integration of Profile Change; Includes Nourishment Projects.

As noted above, Figure 4.8.9 provides a cumulative volume change for the portion of St. Johns County starting from the south jetty (~R-123) of St. Augustine Inlet to the southern terminus of the surveyed region at R-157. The cumulative (i.e. integrated) change signal was utilized herein as it provides a smoothed signal compared to the noisy change signal seen from profile to profile. The ordinate axis is the FDEP survey range monument number while the abcissa is the cumulative volume change between the two surveys out to -18 feet of water, an approximate closing depth of water away from the inlet (i.e. see Dean (2002)). Other cumulative volume calculations were made for depths of (-6, -12, and -30 feet) and provided in Figures 4.8.10 through 4.8.12 although the -18 foot depth will be utilized to show the general trends noted in this study. The slope of the cumulative volume diagram in this figure provides the area of erosion/accretion for the time period between surveys and normally would be expected to be proportional to the shoreline change during the same time period for a typical shoreline. As the slope is generally positive in Figure 4.8.9, the area is generally accretional as expected due to the placement of nourishment material (in two different episodes) over the region south of the inlet and some movement of the placed material. The volume of material in the region where the nourishment was placed contains about $5.0 \cdot 10^6$ c.y. of sand in 2007 or about 71% of the sand placed in this area from the two nourishments while the remainder (29% of sand placed or ~ $2.0 \cdot 10^6$ c.y.) appears to have moved northward to the area north of ~ R-137 (discounting potential material transfer between the -18 foot contour and the offshore shoal region).

Change data for the periods noted were also obtained using the MHW shoreline files of the FDEP shoreline data web site. For the change signal, the cumulative change volume was computed as per Figure 4.8.7 discussed previously for the same time period 1999 to 2007. Figure 4.8.7 shows the Range versus the yearly average cumulative change signal integrated with Range rather than distance. The ordinate axis is the FDEP survey range monument number while the abscissa is the annual averaged cumulative change (based on MHW change) between the two surveys.

Trends shown by change calculations made using the MHW data for the south side of St. Augustine Inlet from the south jetty of St. Augustine Inlet (~R-123) southward to the Flagler County line (~R-209) show similar patterns as the volumetric changes made using profile data within the surveyed nourishment area but, beyond ~R-157, the shoreline suggests a limited recessional trend of ~4 ft/yr. This area south of ~R-157 was historically either stable or accretionary and may again reach this state when sufficient nourishment material moves southward and bypassing of Q_{net} takes place on a more regular basis.

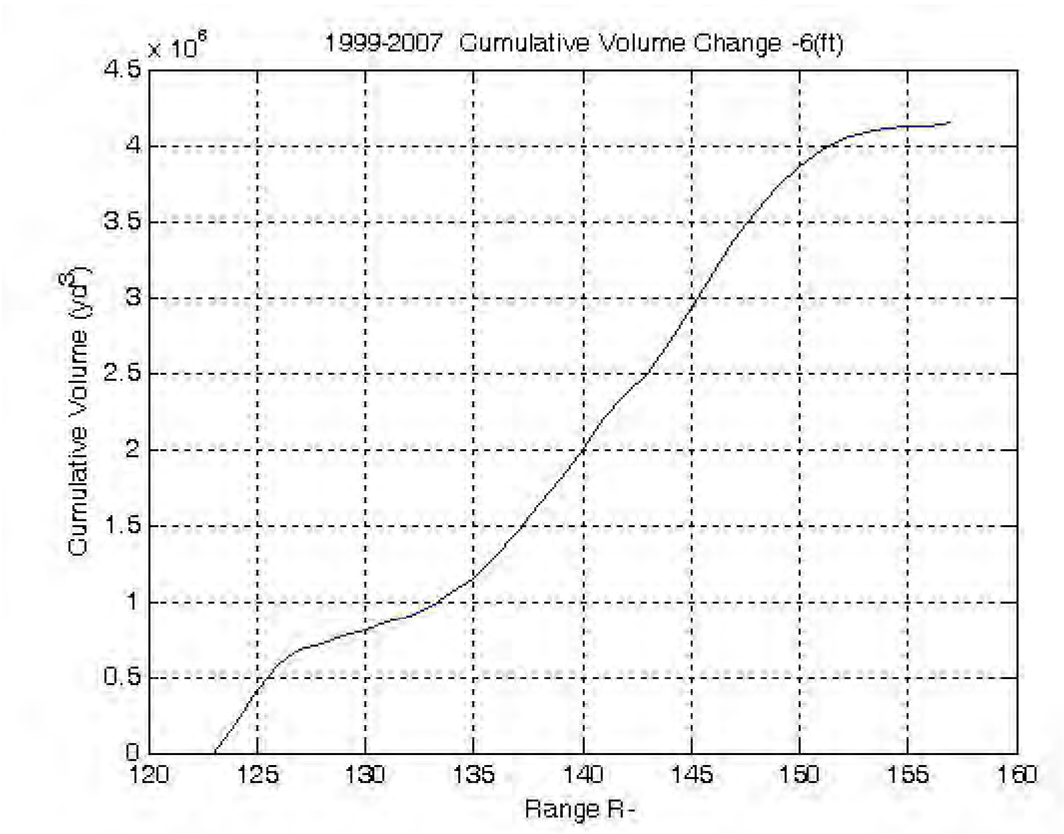


Figure 4.8 10 Recent Cumulative Volume Change for 1999-2007, on South Side of St. Augustine Inlet (profile cutoff at -6 ft.); Based on Integration of Profile Changes. Includes Nourishment Projects.

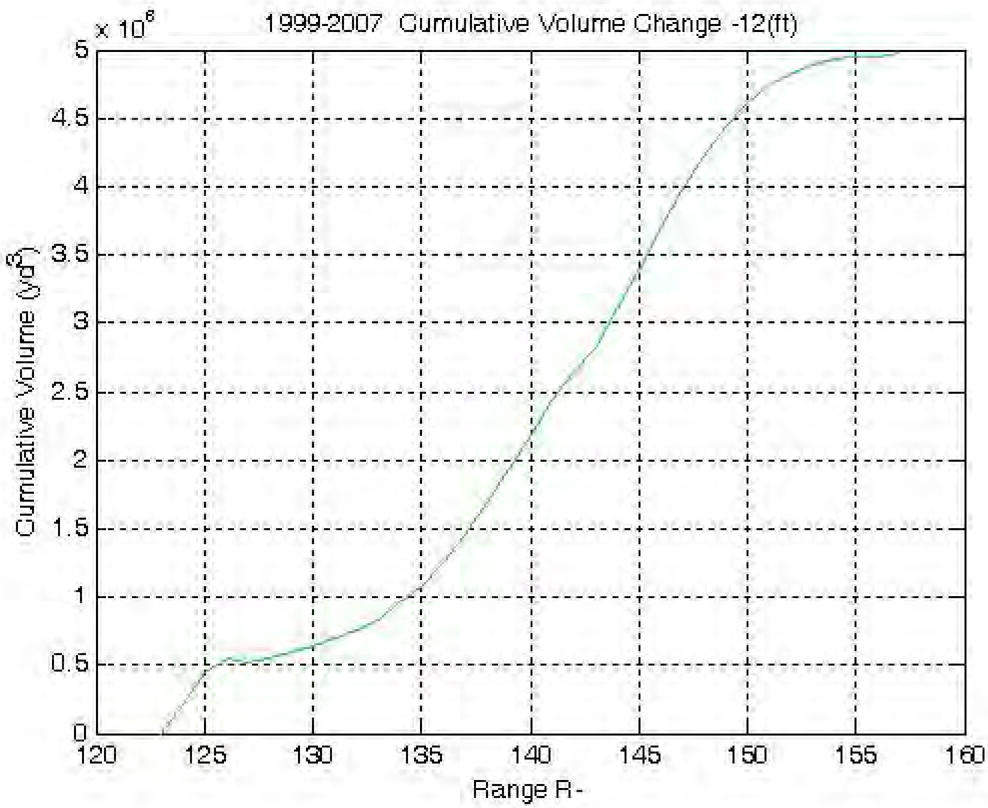


Figure 4.8 11 Recent Cumulative Volume Change 1999-2007, South Side of St. Augustine Inlet (profile cutoff at -12 ft.) Based on Integration of Profile Changes. Includes Nourishment Projects.

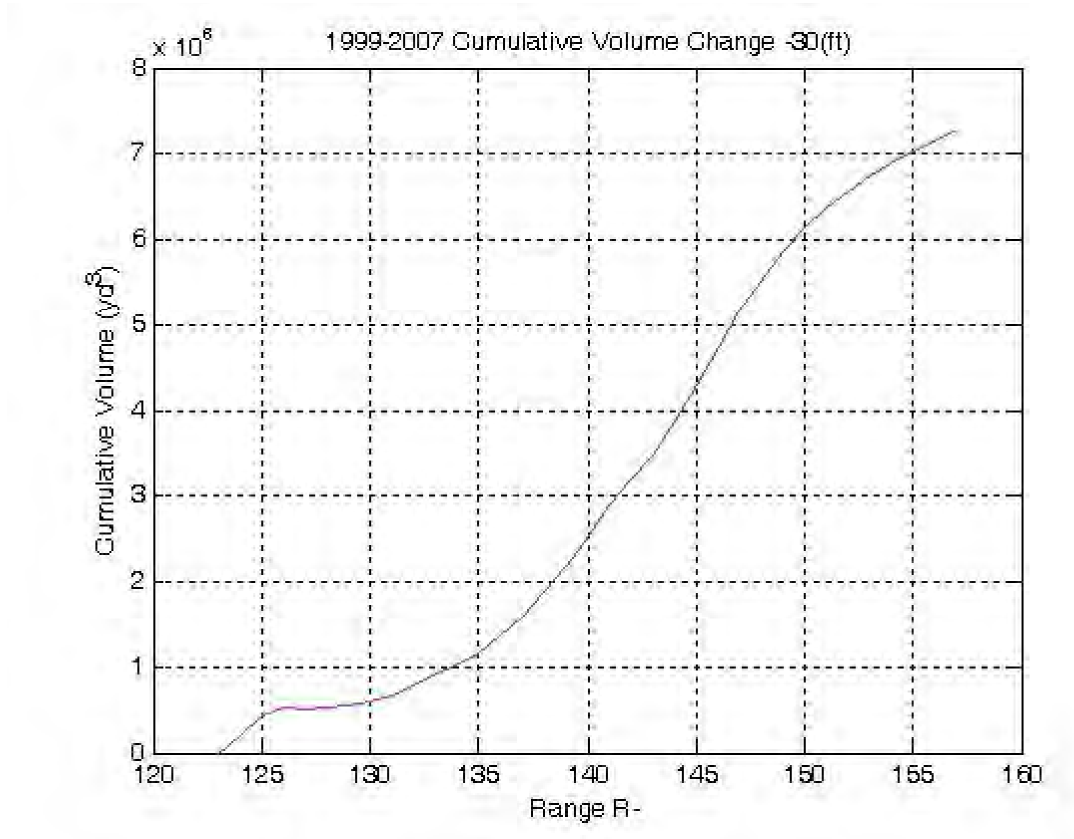


Figure 4.8 12 Recent Cumulative Volume Change for 1999-2007, South Side of St. Augustine Inlet (profile cutoff at -30 ft.); Based on Integration of Profile Changes. Includes Nourishment Projects.

4.9 Nodal Point Location South of Inlet and Even-Odd Analysis Discussion

The shoreline change data from 1972 to 1999 were analyzed to identify, if possible, the northerly nodal point location south of St. Augustine Inlet.

The conservation of volume equation at a horizontal point (x, y) is

$$\frac{\partial z}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = 0 \qquad (4.9.1)$$

in which z is the sand elevation at the point of interest, t is time, x is the longshore coordinate directed positively to the right as an observer looks seaward (ie, to the south for the shoreline under consideration), y is the cross-shore coordinate directed positively seaward and q_x and q_y are the unit sediment transport components in the x and y directions, respectively. Integrating in the cross-shore direction from y_1 to y_2 yields

$$\frac{\partial Q_x}{\partial x} + \frac{\partial V}{\partial t} + q_{y,2} - q_{y,1} = 0 \qquad (4.9.2)$$

in which Q_x is the total longshore sediment transport between y_1 and y_2, V is the sand volume per unit shoreline length between y_1 and y_2, and $q_{y,1}$ and $q_{y,2}$ are the unit transports in the y direction at locations y_1 and y_2, respectively.

To proceed further in an application in which the longshore sediment transport is to be based on shoreline change rates, $\frac{\partial y}{\partial t}$, it is necessary to assume values for the unknowns $q_{y,1}$ and $q_{y,2}$. For purposes herein, we will consider these to be zero at the upland and offshore survey limits. It is also necessary to apply the profile translation method which considers that the profile responds to a volume change by translating a horizontal distance, Δy without change of form over a vertical dimension, $h_* + B$. Thus, the volume change ΔV is proportional to the shoreline change Δy by $\Delta V = (h_* + B)\Delta y$. In these equations, h_* is the so-called closure depth and B is the berm height. Applying the profile translation method and the assumptions regarding $q_{y,1}$ and $q_{y,2}$, Eq. (4.9.1) is

$$\frac{\partial Q_x}{\partial x} + (h_* + B)\frac{\partial y}{\partial t} = 0 \qquad (4.9.3)$$

and the longshore sediment transport at any location, $Q(x)$ can be determined as

$$Q_x(x) = Q_x(x_R) - (h_* + B)\int_{x_R}^{x} \frac{\partial y}{\partial t} dx \qquad (4.9.4)$$

in which $Q(x_R)$ is the transport rate at a reference location, x_R.

The shoreline change rates over the period 1972 to 1999 are presented in Figure 4.9.1versus distance south of Monument R-123. Note that for purposes of all calculations herein, the spacings between monuments, Δx, were considered to be at a nominal value of 1,000 feet. Although the actual spacings differ from this value, use of the actual spacings would not change the sediment transport or nodal point locations materially.

Eq. (4.9.4) in summation form and the shoreline change rates in Figure 4.9.1 were applied for the following three values of $h_* + B$ and three values of $Q(x_R)$: $h_* + B$ = 20 ft, 25 ft, and 30 ft, and $Q(x_R)$ =-100,000 yd^3/yr, - 50,000 yd^3/yr and 0 yd^3/yr, where as noted previously, negative values denote transport to the north.

The reference value, x_R, was taken as 0 at Monument R-123. Note Monument R-123 is the monument immediately south of the south jetty at St. Augustine Inlet.

Figure 4.9.2 presents the calculated net transport rates, $Q(x)$, vs distance southward from Monument R-123 for a value of $h_* + B$ = 25 feet and the three values of $Q(x_R)$ noted previously. It is seen that as indicated by Eq. (4.9.4), the three curves are the same except for the displacement by $Q(x_R)$ and that for the results in Figure 4.9.2, nodal points exist only for a value of $Q(x_R)$ = 0 in which the most northerly nodal point occurs for x = 14,000 ft which is at Monument R-137.

Figure 4.9.3 presents the calculated net transport rates, $Q(x)$, vs distance southward from Monument R-123 for a reference value of $Q(x_R)$ = - 50,000 yd^3/yr and the three values of $h_* + B$ noted previously. It is seen that as indicated by Eq. (4.9.4), the effects of different $h_* + B$ values is to scale the effects of the shoreline change rates and is relative minor for the range of $h_* + B$ values considered here. For the results in Figure 4.9.3 ($Q(x_R)$ = - 50,000 yd^3/yr), a nodal point exists only for a value of $h_* + B$ = 30 feet in which the most northerly nodal point occurs for x = 26,000 ft which is at Monument R-149. For conditions examined herein, Table 4.9.1 summarizes the locations of all northerly nodal points for those cases where they exist.

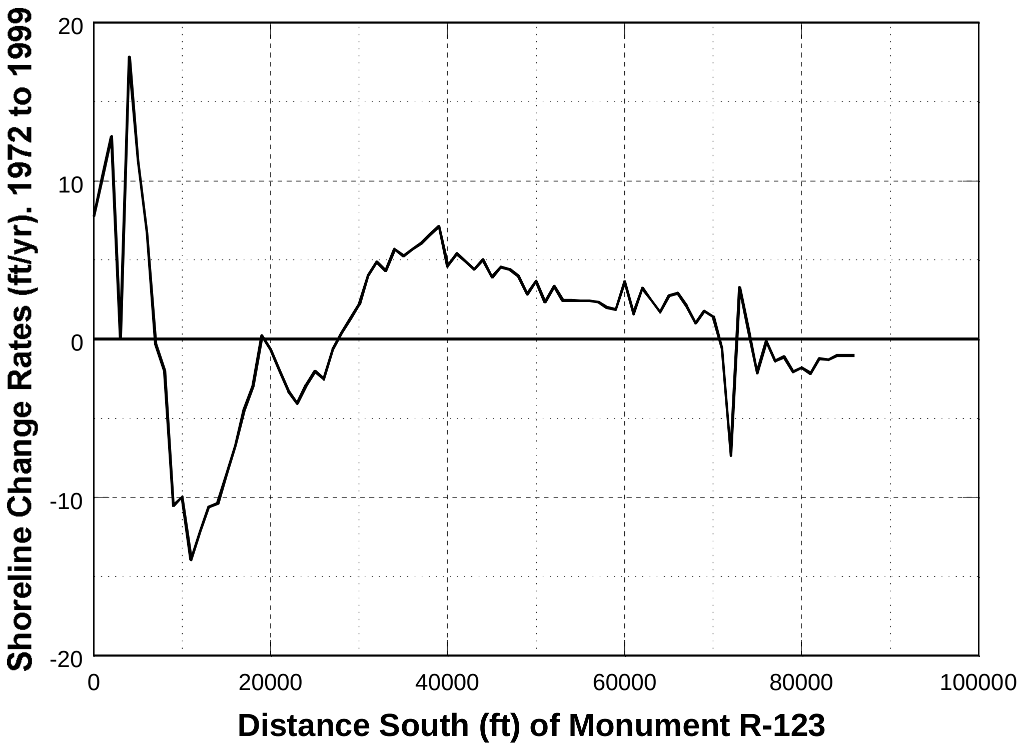


Figure 4.9 1 Shoreline Change Rates for Period 1972 to 1999 in St. Johns County vs Distance South of Monument R-123.

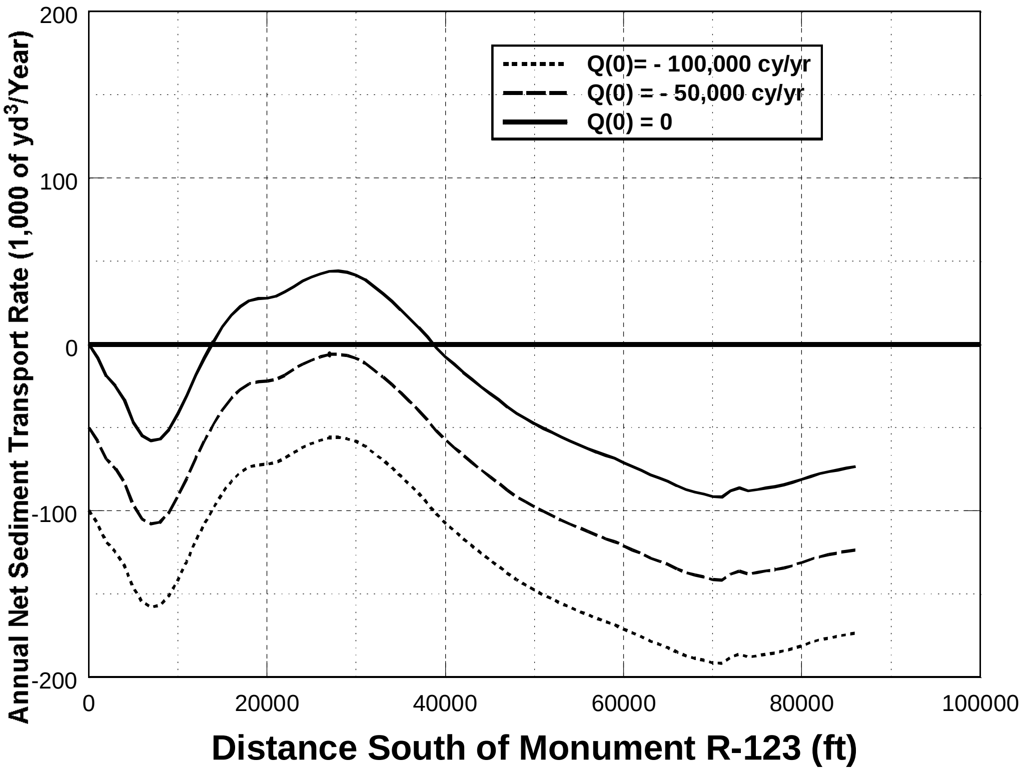


Figure 4.9 2 Net Sediment Transport Rates vs Distance South of Monument R-123 in St. Johns County for Three Assumed Transport Values at Monument R-123 and a value of $h_* + B$ = 25 feet.

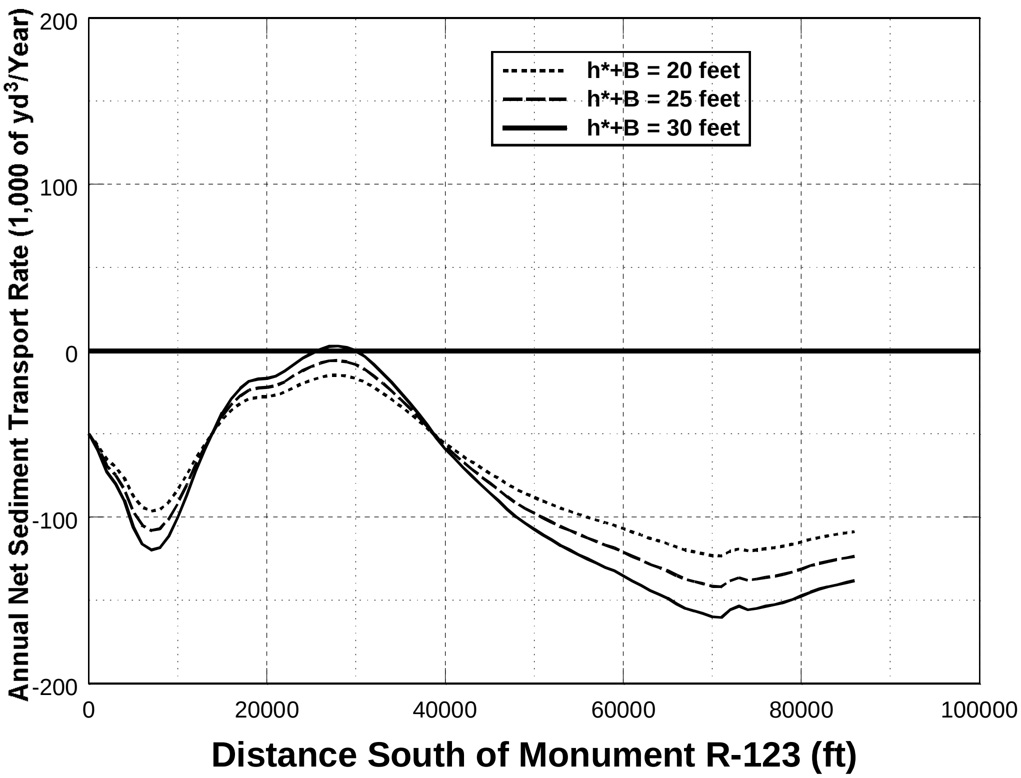


Figure 4.9 3 Net Sediment Transport Rates vs Distance South of Monument R 123 in St. Johns County for Three Assumed Values of $h_* + B$ and a Reference Value $Q(x_R)$ = - 50,000 yd^3/yr.

Table 4.9 Calculated Northerly Nodal Point Locations South of St. Augustine Inlet

$h_* + B$ (ft)	Location of Northerly Nodal Point x_{Node} (ft) for $Q(x_R) = Q(R-123)$		
	-100,000 yd^3/yr	- 50,000 yd^3/yr	0 yd^3/yr
20	No Nodal Point	No Nodal Point	14,000 (Monument R-137)
25	No Nodal Point	No Nodal Point	14,000 (Monument R-137)
30	No Nodal Point	26,000 (Monument R-149)	14,000 (Monument R-137)

This analysis of nodal point location has employed the profile translation method and the assumption that cross-shore sediment transport does not contribute to shoreline changes. As seen in Figures 4.9.2 and 4.9.3, the result of these computations is an unrealistic northerly net transport at the southerly end of the region considered and thus, onshore transport needs to be introduced into considerations to provide a realistic southerly transport at the southerly end of the region considered. The interpretation of this unrealistic northerly net transport direction can be easily modified if onshore sediment transport occurs in this general area[1]. As indicated by Eq. (4.9.2), the onshore transport effect is cumulative and, if $q_{y,2}$ were reasonably uniform, the onshore transport would not affect the results as much in the vicinity of the northerly nodal point as near the southerly limits of the region considered. The effect of an onshore sediment transport ($q_{y,2} < 0$) would be to shift the nodal point to the south or, if of sufficient magnitude and with $Q(x_R) = 0$, to result in the lack of a calculated nodal point. If one considers cross-shore sediment transport to be onshore north of the computed nodal point, the actual nodal point would be farther north than that calculated, perhaps $x_{Node} \approx$ 10,000 ft. For the case of $Q(x_R) = 0$, x_{Node} = 10,000 ft, and $h_* + B$ = 25 feet, this would amount to an average $q_{y,2}$ = - 4.2 yd^3/ft/yr over this distance. In view of the analysis and discussion provided herein, it is believed that a northerly net transport direction exists somewhere north of the City of St. Augustine pier and park complex. As discussed previously, this nodal point is believed to vary depending on wave climate.

4.10 Even- Odd Analysis of Shoreline in the Vicinity of St Augustine Inlet

The "Even-Odd" method is a procedure by which a signal can be unambiguously separated into even and odd components about a selected origin. In the application here, the signal is the Mean High Water (MHW) shoreline changes from 1972 to 1999 in St. Johns County. These shoreline changes are presented as Figure 4.10.1 in which the origin of the longshore coordinate is selected at Monument R-123 and the monument spacings are considered to be 1,000 feet. Interpolation was employed where data were missing.

Consider a function, $f(x)$, for which it is desired to determine the even and odd components about a reference $x = x_R$. It is easily shown that the even component, $f_{Even}(x_R + x)$ and odd component, $f_{Odd}(x_R + x)$ are given by

$$f_{Even}(x_R + x) = \frac{f(x_R + x) + f(x_R - x)}{2}$$

$$f_{Odd}(x + x_R) = \frac{f(x_R + x) - f(x_R - x)}{2}$$

The methodology described above was applied to the shoreline change data presented in Figure 4.19.1. Results are presented in Figure 4.10.2 in which the abscissa is presented as $x - x_R$ with x_R the longshore coordinate of Monument R-123. Two simplifications were made in this application:

[1] In fact, the northerly end of Anastasia Island has accreted by onshore sediment transport.

(1) It was considered that the monument spacings were uniform at 1,000 feet. Although the spacings differ somewhat from this value, use of the actual values would not materially affect the results, and

(2) The origin for the Even-Odd analysis was taken at Monument R-123 which is the monument immediately south of St. Augustine Inlet.

The Even-Odd results are most significant in cases where the physical processes leading to the function $f(x)$ produce a strong anti-symmetry and/or symmetry about the selected longshore origin (for the case of an inlet, at the inlet). This is the case at many of Florida Inlets (Dean and Work, 1993). However, this is not the case for St. Augustine Inlet where the immediate downdrift shoreline has advanced a considerable amount. The cause of this advancement appears to be the sheltering of the shoreline by the substantial ebb tidal shoal and also possibly to change in inlet location. In view of the above comments and the findings for the even-odd analysis developed for this inlet, *it appears that the even-odd analysis approach does not provide meaningful findings in the case of the St. Augustine Inlet complex.*

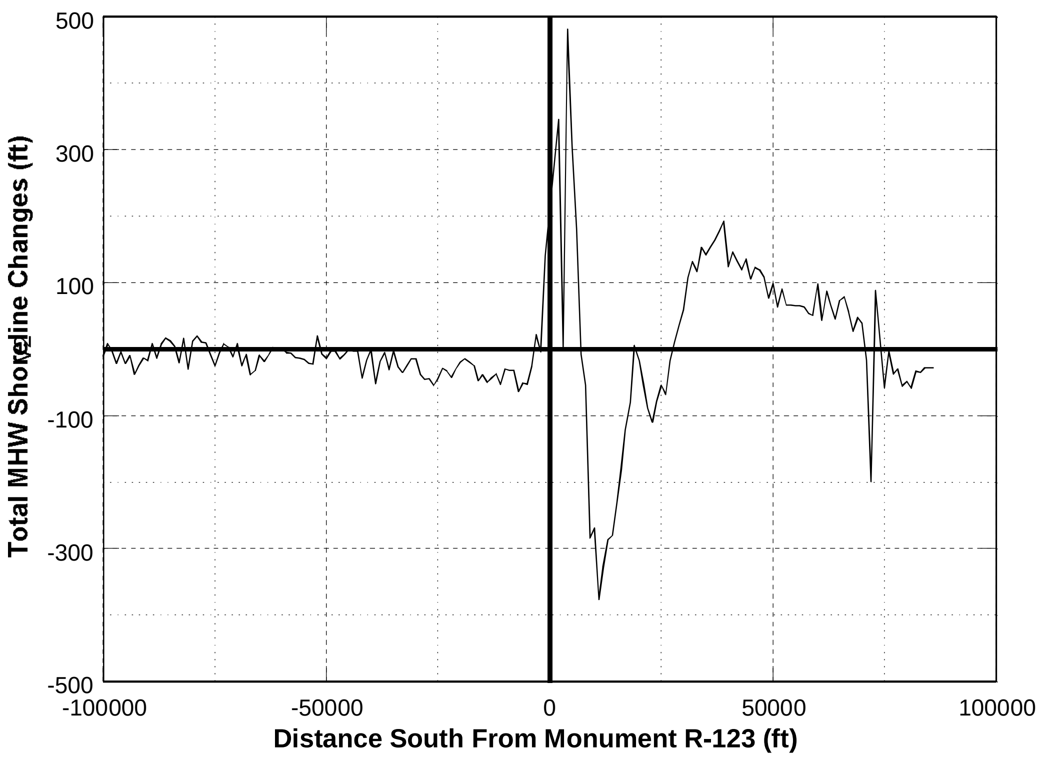


Figure 4.10 1 Total MHW Shoreline Change, 1972 to 1999. St. Johns County

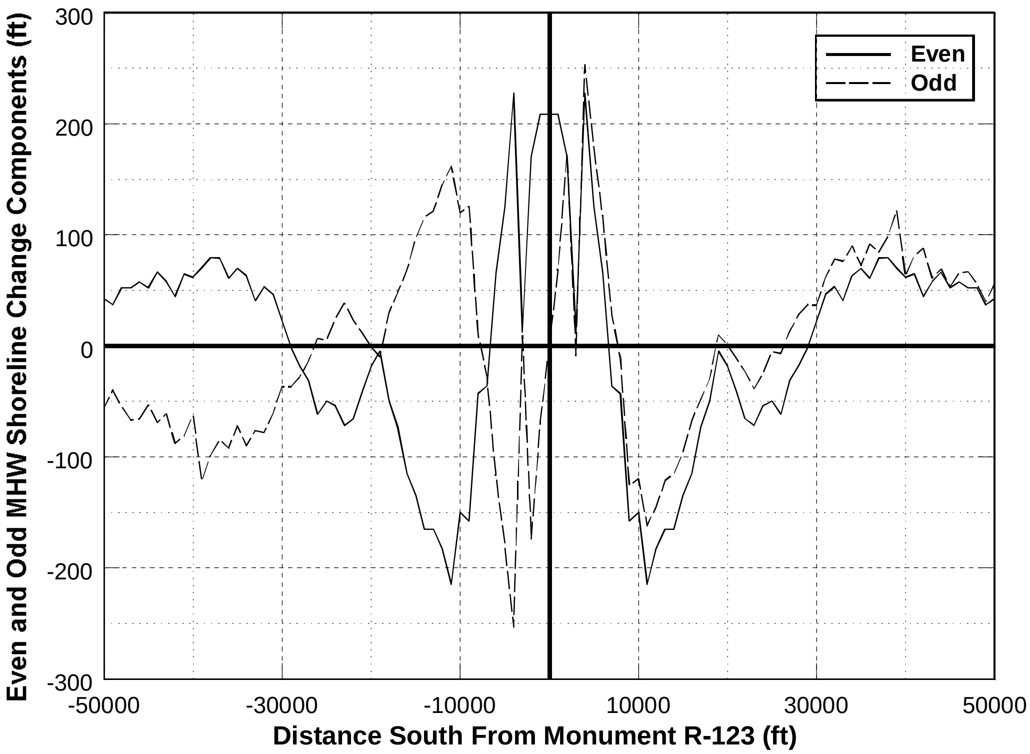


Figure 4.10 2 Even-Odd Analysis Results of MHW Shoreline Changes in Vicinity of St. Augustine Inlet. 1972 to 1999.

5. Sediment Budget

5.1 Zone of Influence (ZOI) Due to Tidal Flood Flow and Wave Analysis

Flood Flow Analytic Estimation

An approximate Zone of Influence due to flood flow currents in the vicinity of St. Augustine Inlet can be found via a knowledge of the tidal prism, and a knowledge of expected maximum velocity ($= u_{max}$) in the inlet channel using the following approach:

Tidal Prism = $P \approx \int_0^{T/2} u_{max} \cdot Area \cdot dt \approx (u_{max} \cdot Area \cdot T)/\pi$ hence

Channel Cross Sectional Area =$Area \approx P\pi/Tu_{max}$

Now using continuity to equate the flow at the inlet throat to the area for the arc at the distance r from the apex of the shoreline and the center of the channel to the ZOI of the inlet:

$u_{max} \cdot Area = u_r \cdot h_{avg} \cdot (\pi r)$ where $h_{avg} = (2/\pi) \cdot mr$ where $m =$ bottom slope.

Assuming $m \cong 0.007$ using a distance out to $h = 60\ ft$ calculated via Equilibrium Profile Theory findings (with the equilibrium beach profile factor $A \cong 0.145\ ft^{1/3}$) , and requiring that $u_r/u_{max} = 0.01$ (i.e. a current velocity equal or less than 0.03 ft/sec, the radius r can be found to be approximately $r \cong 21{,}400\ ft \cong 4.06\ miles$ using the work of Ozsoy and Unluata (1982) with corrections to the applicable equations. This is in accord with the northern limit of inlet influence determined for the sediment budget in the present report although it has been shown below that via the use of numerical models and more realistic parameters based on measured currents, that the expected hydrodynamic ZOI is considerably less. With regard to the tidal current being able to initiate sediment motion, a more reasonable velocity would be closer to 1 (ft/sec) thus suggesting that the tidal current ability to intitiate sediment motion is constrained to be within 1 mile of the inlet.

Numerical Modeling Results- Hydrodynamics

Numerical modeling has been accomplished in past studies as well as the present study utilizing different models with somewhat different assumptions and changes in boundary conditions. Results of the numerical models with regard to a hydrodynamic Zone of Influence are noted below:

- Taylor Engineering -Inlet Management Plan (IMP) (1992)

Taylor Engineering (1992) utilized a two dimensional depth integrated numerical hydrodynamic model called TRANQUAL as detailed in their inlet management plan (IMP) to evaluate various plans using different structural jetty configurations. Although the model was run with the best bathymetry that could be utilized at the time, it must be realized that there have been minor changes in offshore bathymetry on the north side of the inlet since this study was completed. As such, it would not be expected that the hydrodynamic situation in the nearshore zone would have changed much since that study. The resulting model grid for the IMP study using the TRANQUAL model shows a grid system with boundaries approximately 10,400 feet north of the inlet on the north side of the inlet and approximately 20,600 feet south of the inlet on the south side of the inlet. On both sides of the inlet during the spring flood flow runs with peak flood flow, velocities are shown to be miniscule at the boundaries and hence the inlet hydraulic influence due to spring tidal flows is well within the chosen boundaries. As ebb currents are more constrained to a narrower jet core on the ocean side (with high currents in the ebb jet core) which is well away from the shoreline, alongshore current influence of the ebb jet is expected to be much less than that of the flood flow findings. It is clear as the requirement for a good boundary scheme for running a model must be that the boundary numerical scheme incorporates the velocities at the boundary, the choice of boundary scheme in the model was adequate and the ZOI lies well within the chosen region for the sediment work in the present report.

- PBSJ Engineering

PBSJ Engineering (2009) utilized a two dimensional depth integrated finite element numerical hydrodynamic model called ADCIRC as detailed in their report to evaluate potential inlet effects on the shoreline. The model was run with recent bathymetry (at the time of the study) It would not be expected that the hydrodynamic situation in the nearshore zone would have changed significantly since that study. The resulting model grid for the PBSJ study using the ADCIRC model shows a grid system with boundaries similar to the Taylor Engineering IMP. On both sides of the inlet during the spring flood flow runs with peak flood flow, velocities are shown to be miniscule at the boundaries and hence the inlet hydraulic influence due to spring flood tidal flows is well within the boundaries chosen. As ebb currents are more jet like on the ocean side with the high currents in the ebb jet core which is well away from the shoreline, alongshore current influence of the ebb jet is expected to be much less than that of the flood flow findings. As noted previously for the Taylor model also, the requirement for a good boundary scheme for running a model must be that the boundary numerical scheme incorporate the velocities at the boundary, hence the choice of boundary scheme in the model was adequate and the ZOI lies well within the chosen ZOI for the sediment work in the present report.

PBSJ Engineering also submitted work to the FDEP regarding numerical modeling of wave effects utilizing the two dimensional wave model STWAVE often utilized and supported by the Corps of Engineers. Results of the STWAVE runs show changes in wave heights due to the dredging of the outer bar for nourishment material to again be well within the boundaries of the model which as before is much less than the ZOI for the sediment budget boundaries utilized in the present study.

- Jacksonville District Corps of Engineers

In 2009, the Corps of Engineers performed a study using STWAVE to establish the limits of wave and bed shear stress change from the pre-dredge ebb shoal planform to the post-dredge ebb shoal planform. Details of the findings from this report (USACE 2009) show that the wave and bed shear stress effects for both pre and post dredging ebb shoal conditions are well within the boundaries of the sediment budget chosen ZOI in the present report.

- BSRC-ADCIRC Modeling

Due to grid stability problems in using the ADCIRC model, results to date of ADCIRC modeling are not considered reliable and will not be discussed within this report.

- BSRC – STWAVE Modeling

Modeling with STWAVE+ and the Surfbreak Engineering Grid

Incoming waves from offshore propagating to the shoreline are generally refracted in relation to the contour changes and become significant in the inlet area where the bathymetry is shallow over the ebb shoal. The present study attempted to explore wave angle changes for various wave angles due to refraction over the ebb shoal at various longshore locations near the St. Augustine Inlet of St. Johns County using a grid created for St. Johns County in an earlier study by Surfbreak Engineering that addressed hindcast waves in St. Johns County. The Wave Model utilized in this exploratory study was STWAVE+, a modified version of STWAVE 3.3 developed by Dally and Osiecki (2004). The model included the effects of bed friction on wave energy transformation within its domain and utilized factors of energy reduction based on the findings for the wave hindcast study of St. Johns County by Surfbreak Engineering for the FDEP. Results of this analysis are provided in Appendix I. Findings of the exploratory study using the Surfbreak Engineering grid were that:

- Wave refraction is significant over the ebb shoal area at 5 meters and less depth as might be expected although alongshore change in wave direction due to wave refraction does not appear to extend north of R-100 on the north side of the inlet except for very severe wave angles from the south in which the effect is very minimal; and

- Wave refraction for a wave propagating normal to the shoreline (0 degrees angle) is less significant than for waves propagating from angles of 45 and - 45 degrees. As most waves propagate at small angles, and predominant wave action is from the northward quadrant, only limited wave influence would be expected north of approximately R-100.

Modeling with CMS-STWAVE and BSRC Created Grid

BSRC also created a grid extending to the shoreline for use in STWAVE modeling with the CMS model (Corps of Engineers model and model interface as distributed in the SMS package). This grid was created using a bathymetric data composite of FDEP survey data, NOAA survey data, Corps of Engineers survey data, and recent aerial photos. The primary data utilized was the FDEP 2009 survey data although due to gaps in the data set, the data was augmented with data from the other sources noted above and blended into the areas where no up to date survey information was available. Results from CMS-STWAVE data runs are provided and discussed in the numerical modeling section of this report.

5.2 Sediment Budget Boundaries and Data

Although the present study has made the utmost attempts to check survey datum and data quality to the extent that it can be checked within existing limitations (i.e. data was received from three different government agencies as well as consulting engineer companies), BSRC cannot vouch for data or datum accuracy. Questions have come into play concerning the quantity of the data for various surveys. Often surveys have closely spaced data along survey lines (typically oriented perpendicular to the shoreline trend in the area) although there may be a lack of data along perpendiculars to the survey lines where the data may change appreciably. Datum is not always specified to a land based vertical datum and consequently, changing water levels effect the datum plane location. Given these data and datum limitations, it is important to assess potential error due to some of these limitations although, in some instances, insufficient information exists to address the potential error and answers provided simply remain as estimates without quantifiable errors.

The first *potential* source of error discussed is due to vertical bias problems in profile surveys. As discussed in Appendix H, the vertical bias in many of the earlier surveys was sufficiently large that it is questionable if meaningful results can be obtained from these data. In the more recent surveys of 1999 and 2007 a bias of 0.24 feet was found in the offshore portions of the survey which falls within an often cited potential error of 1 foot due to hydrographic surveying. If one considers that the offshore portion of a survey line extends to (on the order of) 800 feet which is reasonable for the St. Augustine area (where this distance was found to range from approximately 700 to 1000 feet), a total error even this small and within hydrographic survey error can be estimated to be approximately 0.24*(800) c.f. per lineal foot or approximately 7.1 c. y. per lineal foot of shore. Over 30 FDEP ranges (~ 1000 ft. per range) this amounts to an error of approximately 210,000 c. y. For a typical hydrographic survey wherein the offshore error could be as high as 1 foot, this error would be on the order of 840,000 c.y. for an area spanning over 30 FDEP ranges.

A second *potential* source of error is due to survey error in datum over a region. As the ebb shoal survey coverage in the most recent surveys extended over 720 million sq. ft., a simple datum error of 0.25 feet between surveys would lead to an error of approximately $6.7 \cdot 10^6$ c. y. (i.e., approximately the same amount dredged from the ebb shoal from 2001 through 2005). Thus, any sediment budget projected estimate results are subject to potentially large errors which should be kept in mind when assessing study results. Results of datum error would amount to the area of survey coverage multiplied by the vertical datum error.

A third *potential* source of error exists when developing changes in volume between survey time periods where the survey coverage does not cover the same spatial region. Due to a lack of data coverage in the surveys, results cannot be included within the estimate but could change answers substantially if large changes occur in these regions. Unfortunately a lack of data in these situations does not allow reasonable estimates of error to be developed. Given the error possibilities within the surveys and standard hydrographic survey capabilities, as well as earlier limitations in the 1970's NOAA and 2009 FDEP ebb shoal survey of St. Augustine, the present estimates of sediment budget must be considered speculative and further sediment budget refinement must await better data collection at St. Augustine Inlet.

Although studies cited and work herein have provided various potential boundaries for addressing the sediment budget, the limitations of data do not allow complete well defined synoptic data sets to address the erosion concerns on both the beaches to the north and south of the inlet. Additional data limitations have been discussed previously but will again be noted due to the constraints and limitations on sediment budget estimates addressing present sediment budget at St. Augustine Inlet. The 1970's NOAA survey has limited inshore coverage over the ebb shoal. The 2009 FDEP ebb shoal survey has very limited longshore data collection over the ebb shoal and has numerous gaps in coverage on the inshore of portions of the ebb shoal and limited coverage to the north of the inlet (only extending northward to Range R-116). Limitations in beach profile surveys such as lack of profile closure have also been mentioned previously and in Appendix H to this report. Justification for using the MHW data over a long time interval is provided by the lack of correlation between sediment volume change rate computed via profile data and sediment volume change rate computed via MHW shoreline data (i.e. see Appendix J figures where perfect correlation would be shown by points lying on a 45 degree line).

Although ebb shoal surveys collected by Taylor Engineering sub-consultant during the short time frame of ebb shoal dredging have closer spacing over the portion of the ebb shoal surveyed, the surveys do not provide comprehensive coverage of changes to both the old and new ebb shoal, and additionally extend over a very short time interval of ebb shoal dredging, hence are primarily limited to estimating changes in the recent ebb shoal dredging areas but not to the entire old inlet and new inlet ebb shoal complex. Due to potential error (i.e. datum error, closure error, limited data coverage error, data gap error, etc.) of survey data change estimates over large regions as previously discussed, it is believed that data sets spanning less than approximately 20 years in length are of limited value in addressing ebb shoal dynamics of such a large inlet complex as the St. Augustine Inlet. A shorter time interval such as the 1999 to 2007/2009 period although desirable from the stand point of less vertical bias in survey profile data, have the negative aspect of being over a short time period, and additionally, extend over the period in which major ebb shoal dredging and beach nourishment occurred, thus complicating the picture of natural versus man-created coastal processes. The constraints mentioned here suggest that it is impossible to address a totally meaningful sediment budget at the present time although a sediment budget will be constructed herein for the purposes of an updated inlet sediment management plan. Recommendations for inlet management provided in a later section of this report will take into account that at present, there is still considerable uncertainty in a realistic sediment budget for the inlet.

Previous work and studies have suggested that inlet effects do not extend northward of approximately R-100 based on both inlet numerical modeling and previous inlet data based estimates. Additional justification for not choosing a boundary north of R-100 is provided in Appendix K where offshore normal orientation diagrams for the 1972, 1986, 1999, and 2007 surveys show curvature change of the shoreline as would be expected by inlet influence to be south of R-100.

South side boundary of the sediment budget was chosen as R-156 due to the extent of erosion problems on the south side of the inlet and limitations in many of data sets to the nourishment area. Additional reasons for the chosen south side boundary are that the shoreline to the south of R-156 shows considerable gain (not inclusive of nourishment) since the 1970's study as can be determined from the MHW shoreline changes from 1972 to 2007 FDEP shoreline data, and that the shoreline orientation south of this location suggests that the shoreline is undergoing accretion which is believed due to the onshore transport of sand from the remnant offshore ebb shoal platform in this area (as can also be inferred from offshore normal orientation diagrams for the 1972, 1986, 1999, and 2007 surveys in Appendix K).

The various data sets were investigated in attempts to provide a reasonable sediment budget with the decision to utilize what is believed to be the best available data at present to address inlet management concerns while recognizing that no present data set is both synoptic and comprehensive in coverage as discussed previously. Recognizing that the best early survey of the ebb shoal (although not sufficiently comprehensive and lacking in nearshore information) was the early 1970's NOAA survey, it was determined to utilize data from this time horizon and from the most recent FDEP 2009 survey to evaluate data in the region where FDEP shoreline and profile data does not exist. Additionally, recognizing that a comprehensive synoptic survey covering both the ebb shoal complex and FDEP monumented range lines does not exist for the post ebb shoal dredging period, and that bias and lack of profile closure in earlier FDEP profile data sets rules out using profile data from the 1970's and 1980's period, a decision to utilize FDEP mean high water (MHW) survey information to develop a sediment budget was made.

Various permutations of data sets were tried in an attempt to make a reasonable sediment budget closure for the inlet system within the boundaries discussed above without success although the best estimate is presented herein using the following information:

Net Longshore Transport at Boundaries R-100 and R-156

Net longshore transport and a Littoral Drift Rose (LDR) for this region have been discussed in a previous section of the report and the values provided for the boundaries were computed to be +402,000 c.y./ year for R-100 and +495,000 c.y./year for R-156 (i.e. the net sand transport is believed to be southward at both of these locations with a somewhat larger transport at the south boundary due to a different shoreline orientation.

R-100 to R-122

MHW change information from the 1986 to 2007 FDEP shoreline survey. Annually averaged MHW shoreline change information for the entire planform area from both the 1984 and 1986 surveys (as compared to the 2007 survey) were very close in magnitude, therefore confirming the desirability of using this data. When utilized with an overall depth of closure and berm height of 27 ft. the region provided an estimate of -38,000 c.y./yr erosion over the time interval between the surveys.

R-124 to R156

MHW change information from the 1986 to 1999 FDEP shoreline survey was utilized. As MHW change and profile area change are not expected to correlate in areas of recent beach nourishment, the 2007 MHW shoreline change data was not used here. When utilized with an overall depth of closure and berm height of 27 ft. the region provided an estimate of -65,000 c.y./yr erosion over the time interval between the surveys.

R-122-R124

Values of volume change from this area were computed via closure of the sediment budget as -74,000 c.y./yr. Graphical explanation of the sediment budget is provided in Figures 5.2.1 and 5.2.2. To assess the sediment budget closure number noted above for the region between the FDEP MHW/profile survey information, both the NOAA 1972 survey and the FDEP2009 survey were utilized. Neither survey is comprehensive nor is the data from either of the surveys provided for the same points. In the case of the 1972 NOAA survey, data provided in Latitude, Longitude, and depth information files were interpolated to a grid and lines were established through the data approximating 2009 FDEP survey data lines and developed inter-survey lines. As the 2009 FDEP survey data was provided to BSRC in northing, easting, and depth files, all data was reduced to offshore and depth data similar to that of the FDEP surveys. Both files were reduced to the same vertical datum. Volumetric change rate computations of the seaward side of the inlet in the sediment budget closure area (= dV2) with the 1972 NOAA hydrographic survey and the 2009 FDEP survey information suggested a volumetric change rate of +235,000 c.y./yr., very different from the sediment budget closure rate noted above, but due to the survey limitations in both surveys, the former estimated closure number of -74,000 c.y./yr is utilized herein.

Previously noted evaluation of the *entire* ebb shoal complex (as defined via Dean and Walton 1973 methodology) suggested that the ebb shoal complex overall has decreased in size in recent times while the sediment budget analysis presented suggests that the volume of sand in the region of the *new inlet* flood and ebb shoals is undergoing small changes. It has been noted herein that south of R-156, onshore transport from the remnant "old" ebb shoal appears to be moving onshore. As noted in an earlier section of this report, a heuristic rationale (which does not take into account onshore transport from the old ebb shoal) suggests an expected increase in inlet ebb shoal volume due to the new inlet construction in the early years of inlet construction. Although the present sediment budget results remain somewhat qualitative until comprehensive synoptic data sets for the entire region of the upland and bathymetric change out to depth of closure are available, the results appear to be reasonable in light of processes know to be occurring and what might be expected to occur from a change in inlet location of over 2 miles. Additional findings important to future inlet management suggest that the north jetty is bypassing a somewhat greater quantity of sediment than the net sediment transport. This material is being trapped within the inlet. Much of the material bypassed around the inlet primarily reaches the north portion of the S.P. area, but due to transport reversal in the S. P. area at times, it is not all reaching the area where extensive erosion is presently occurring. Due to the nature of the uncertainties in longshore sediment transport quantities, volumetric analysis, and shoreline change analysis, an alternate sediment budget has been prepared in Appendix S of the report based entirely on volumetric analysis (i.e. no longshore sediment transport values estimated) with the added assumption of a null point in sediment transport at R-137 which is necessary for solution of sediment budget transport rates. This may be viewed as an alternate solution to the sediment budget if profile data is to be assumed accurate.

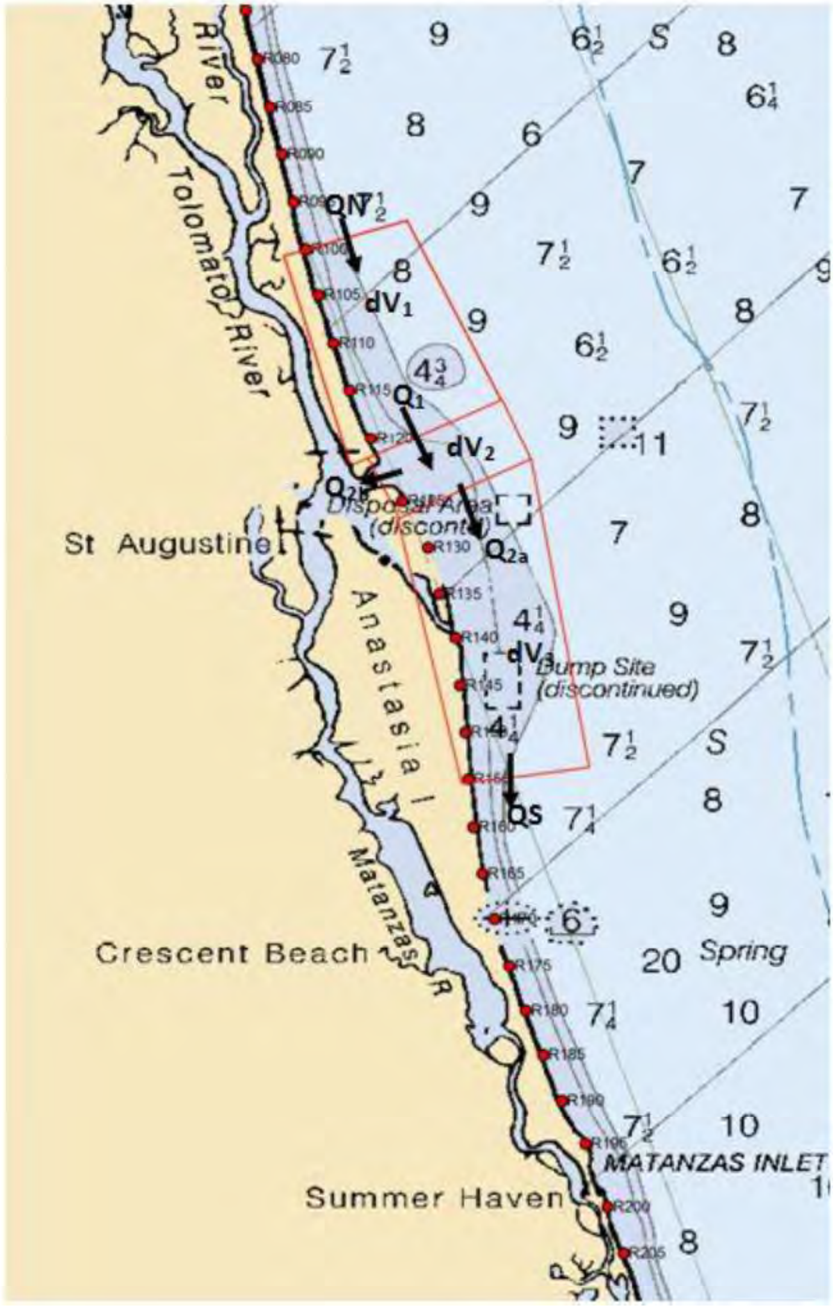
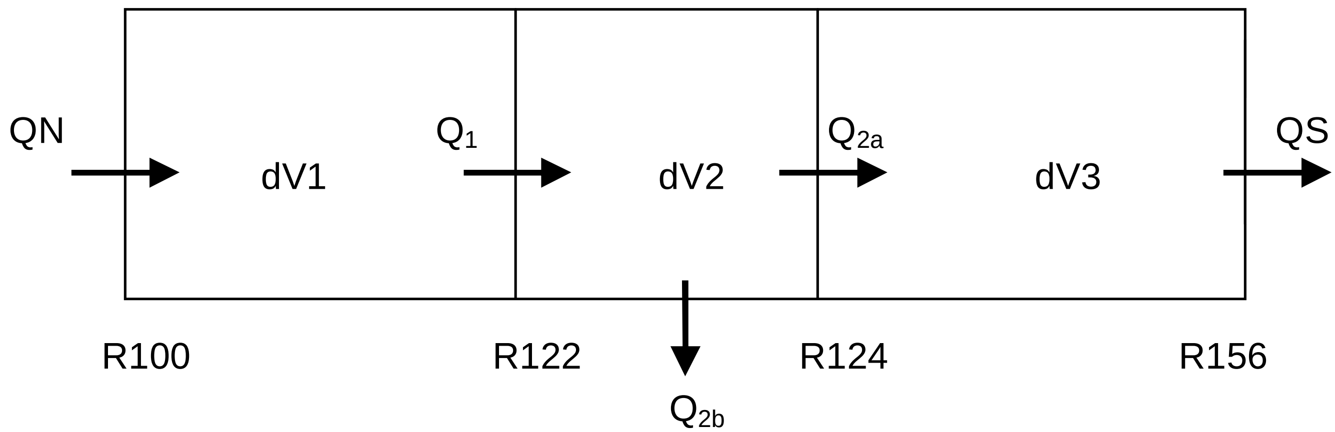


Figure 5.2 1. Sediment Budget Boundaries at St. Augustine Inlet.



Equations for Sediment Budget (with rates in thousands of c.y./year) :

QN - Q1 = dV1

Q1 - (Q2a + Q2b) = dV2

Q2a –QS = dV3

where
QN = 402
QS = 495
Q2b = 84
dV1 = -38
dV3 = -65

and therefore:
Q1 = 440
Q2a = 430
dV2 = -74

Figure 5.2 2 Sediment Budget Schematic for St. Augustine Inlet.

6. CMS-SMS Numerical Model Analysis and Findings.

Findings from the CMS-SMS numerical modeling are presented in Appendix R.

7. Recommendations/Conclusions

Recommendations for updating the State Inlet Management Plan of St. Augustine Inlet and possible structure modifications/additions, dredging, and placement of material south of the inlet are provided below in three sections referred to as: north side of inlet (i.e. North Beach), the ebb and flood shoal complex, and the south side of inlet (i.e. South Beach). A final recommendation for consideration is provided in final comments.

North Side of Inlet (North Beach)

To reduce erosion on the north beaches, steps should be taken to tighten (i.e. make impermeable via grout or combination of grout and smaller stone) and raise the north jetty to a level approximately 2 feet above the natural beach profile template to the north of the north jetty. If the structure is found to be permeable, further sealing of the structure via grouting might also be considered. Further evaluation and monitoring of changes on the north and south beaches and of bypassing at the north jetty should be accomplished by the Corps of Engineers (with permitting oversight by the State) prior to considerations of any extensive lengthening of the north jetty beyond its present length. It is important to note that when the jetty was constructed, it extended 450 ft. seaward from the MLW shoreline at that time. At present time, the shoreline extends to near the jetty tip. Although lengthening of the north jetty would enhance trapping of sand on the north side of the inlet, it would also interfere with potential natural bypassing of the *net sediment transport* desired at the inlet. Until more high quality data is collected regarding the ability of the existing structure to trap sand in its fillet on high tides and water levels (i.e. preventing overwash into the inlet side of the jetty) it is not recommended to do any extensive lengthening of the north jetty. At a future time when more is known about the processes at the jetty, a limited lengthening of the jetty might then be considered.

Monitoring of the jetty fillet should consist of profile surveys on FDEP Range lines from the inlet at least as far northward as monument R-70 on a yearly basis and after significant storms, as well as a comprehensive tidal ebb shoal survey (discussed further below). Future lengthening of the north jetty may be warranted based upon this monitoring but any lengthening of the north jetty should be investigated with more comprehensive synoptic data to assess the effects of the jetty in preventing material from reaching the ebb shoal and consequent bypassing of sediment to the inlet south side.

Dredging of material reaching the Porpoise Point area should be accomplished as justified through periodic monitoring to by-pass or back-pass material which has been continuously building up in this area (and to flood shoals) to areas of inlet adjacent ocean shorelines suffering erosion. At present time it is recommended that the material from this area be back-passed to help alleviate erosion concerns on the North beaches.

Shoreline erosion due to St. Augustine Inlet appears as of 2009 to be limited to areas south of Range R-100. Recent year severe erosion in the South Ponte Vedra area and northward in St. Johns County (i.e. north of range R-100) does not appear to be due to effects of maintenance dredging of the St. Augustine ebb shoal based on known coastal processes. Reasons for this assessment are discussed in the following paragraphs.

FDEP ***recently*** added "critical erosion areas" of R-84 to R-94 and R-109 to R117 of St. Johns County to the critically eroded beaches list, hence it has not previously been an area of State concern prior to the USACE dredging of the ebb shoal although it should be noted that the South Ponte Vedra (SPV) beaches may have been undergoing erosion during past time periods (well before the dredging of the ebb shoal for the St. Augustine Beach nourishment project) although the adjacent beaches to either side were not considered of a critical nature. This observation is based on the National Shoreline Study of the U.S. Army Corps of Engineers (USACE (1971)) which delineated SPV beach as a ***critical erosion area*** as far back as 1971 (see Fig 2d, page d6 of National Shoreline Study, Regional Inventory Report, South Atlantic-Gulf Region, 1971). It should be noted that the area of coast in the northernmost "critical erosion area" is an area where homes have been built very close to the shoreline (seaward of the 100 year Coastal Construction Control Line), likely due to the limited lot spacing available between the ocean and Highway A1A in this area and to the fact that the Hurricane Dora “cut” line moved more landward in this area than in other areas. It is likely that erosion occurring in such areas is more noticeable and judged more significant than that occurring in areas which have built further back from the shoreline allowing for natural dune buildup and natural fluctuations of the shoreline to occur.

The newly designated state "critical erosion areas" have been suggested (by homeowners in this area) to be eroding now due to the two recent dredging events of the ebb shoal of St. Augustine Inlet (occurring from September 2001 through November 2005). The present study through literature research and engineering sediment budget analysis has not produced any evidence to support the contention that the ebb shoal dredging has been the cause of erosion in the South Ponte Vedra (SPV) area although it is noted that sufficient data to clearly ascertain the cause of recent erosion in this area does not exist at present. Specific arguments to suggest that the northernmost erosion was not induced by the recent ebb shoal dredging events are as follows:

- COE STWAVE study (see USACE report entitled "DRAFT REPORT -Influence of St Augustine Ebb Shoal Excavation on Near-shore Wave Climate and Sediment Pathways, St. Johns County, Florida", July 2009) has conducted bottom stress calculations with and without dredging of the ebb shoal for the St. Augustine Beach nourishment project to assess changes. It was found (for the pre versus post project-2003 bathymetry) that no significant change in longshore currents or excess bed stress (and consequent change in capability to transport sand in longshore direction) were noted in the area of concern North of R-100.

- Cumulative planform area changes based on MHW shoreline changes (see Appendix L) show trends of erosion in the SPV area higher than for an area southward and closer to the inlet. This is contrary to known coastal processes at an inlet (jetty or channel/shoal/sink) whereby erosion/accretion effects decrease/increase in a continuous manner as distance from the inlet increases (see arguments in Appendix M.1 and Appendix M.2).

- A study by PBS&J (PBS&J (July 2009)) does not show any significant effects (i.e. changes in wave height) of inlet dredging of the ebb shoal for the St. Augustine Beach nourishment project. Details of the study are in PBS&J (July,2009) as well as response comments filed to FDEP in response to the PBS&J study.

- PBS&J response comments to PBS&J July 2009 study show (Fig. 1.2) that considerable areas in the St. John's area were experiencing recession from 2003-2007 (dredging period), not just the SPV & Vilano areas. This study also finds that areas to north of SPV clearly are not in the influence of recent St. Augustine Inlet ebb shoal dredging concerns (see comments provided to FDEP in response to study response comments by South Ponte Vedra and Vilano homeowners and Olsen and Associates Engineering).

- Historical shoreline analysis (Foster, et al 2000) suggests that the area of concern has been erosional during the period of 1972-1999 prior to the ebb shoal dredging, while the area to the north is somewhat stable believed due to effective outcropping of coquina from R-15 to R-75.

- PBS&J response comments to homeowner/Olsen comments on PBS&J (July 2009) study provide an equilibrium beach profile analysis (EBP) that suggests effects of inlet do not reach beyond approximately R-90 on the north side of inlet as interpreted solely via "A" factor (reinterpreted to grain size) changes (see comments provided to FDEP in response to study response comments by South Ponte Vedra and Vilano homeowners and Olsen and Associates Engineering).

- PBS&J response comments to homeowner/Olsen response comments on PBS&J (July 2009) study provide a shoreline azimuth angle orientation with distance diagram for north side of the inlet that suggests effects of inlet do not reach beyond approximately R-95 on the north side of inlet as interpreted by the change in the outward azimuth angle with distance (see comments provided to FDEP in response to study response comments by South Ponte Vedra and Vilano homeowners and Olsen and Associates Engineering)**.**

- A Taylor Engineering refraction study utilizing the REF/DIF model prior to initial dredging of the ebb shoal (Taylor 1999) suggests that the wave height change due to the dredging is constrained to the near inlet region, south of the SPV area of concern.

- A Taylor Engineering refraction study utilizing the REF/DIF model prior to second (re-nourishment) dredging of the ebb shoal (Taylor (2005)) suggests that the wave height change due to the dredging is constrained to the near inlet region, south of the SPV area of concern.

- BSRC STWAVE+ modeling work (cases with and without dredging of the ebb shoal per the original dredging activity) utilizing various wave directions and wave heights does not show significant changes in wave angle except close to the inlet, i.e. south of R-100.

- BSRC tidal hydrodynamics modeling with the CMS-SMS numerical model on tidal current strength (cases with and without dredging of the ebb shoal per the original dredging activity) for the St. Augustine Beach nourishment project did not show significant changes in current strength except close to the inlet, i.e. south of R-100.

- Data analysis of the original ebb shoal borrow area based on Taylor surveys suggests that borrow pit area of dredging was deflating prior to dredging (or that survey information is incorrect). As the surveys did not cover the entire ebb shoal but only a limited portion of it (i.e. the dredging area), it is not clear that sediment budget assessment of dredging can be provided which would allow reasonable assessment of the dredging effects for a useful geomorphic model to be calibrated or verified. This conclusion suggests that the utility of running a geomorphic model for the St. Augustine Inlet area based on available data at present may be of limited value.

- Changes in cumulative yearly shoreline change rates between the periods 1858-1970 and 1970 to 2008 suggest a stabilization and decreased erosion rate north of the south end of SPV area, consistent with inlet processes not impacting the SPV area.

- BSRC investigation (see Appendix N) of the old vegetation line approximate MHW shoreline, and line of construction from the most recent FDEP aerial photos in the area of SPV Beach area suggest that the shoreline erosion experienced in this area in recent years is not connected with the dredging of the St. Augustine tidal ebb shoal, but rather appear to be an artifact of aggravated erosion due to cutback of the shoreline during Hurricane Dora and/or other storms.

- Investigation of oscillatory effect of the north shoreline utilizing an analytical model, suggests that shoreline oscillatory effects due to inlet bypassing do not provide rationale for erosion experienced in the SPV Beach area (see Appendix O).

As noted above, an abundance of modeling and shoreline evidence has consistently provided information that suggests the dredging effects of the ebb shoal from the first two dredging periods were constrained to the near-field dredged area of the ebb shoal with minor secondary effects in the vicinity of the inlet. There has been no evidence provided by either of the two major consulting companies that have studied these effects suggesting that the COE dredging caused problems in the northermost (SPV) erosional area. Additionally, the USACE (2009) study confirms the findings of these consultant studies (at least as regards the historical 2003 and 2005 dredging of the south lobe of the ebb shoal borrow area). *This is not to be construed as a finding that the continued dredging of the north lobe of the ebb shoal will not have some detrimental effects on shorelines to the north of the inlet should it continue at rates similar to the reported episodes, nor does it suggest that the inlet itself is not having any adverse effect on the (Vilano) beaches in the near vicinity of the inlet.* Clearly the recommendation provided to improve the north jetty trapping of material now feeding the

Porpoise Point area will improve the long term stability of the beaches to the north and further data collection and study will show the merits of possible future lengthening of the north jetty to stabilize this area.

The localized erosion noted in recent years in the South Ponte Vedra area may also be related to coquina outcroppings offshore that may affect localized wave and surge action in the area of South Ponte Vedra area causing elevated surges that are conducive to higher upper beach erosion in the area although this is purely speculative and without sufficient evidence at this time. In this regard *it is recommended that a jet probe study be conducted by the Corps of Engineers on the north side of St. Augustine Inlet extending from 1 mile north of to 1 mile south of the SPV Beach erosional area to ascertain potential hard bottom effects on the historically erosional shoreline in this area*.

Although as stated above, it is not clear that any definitive evidence exists to suggest that the recent COE ebb shoal dredging has caused a problem on the northernmost erosional area (South Ponte Vedra) beaches, present BSRC recommendations are to constrain dredging on the tidal ebb shoal to the south lobe of the ebb shoal with maximum dredging volumes not to exceed the estimated net southward littoral drift rate " Q_{net} (c.y./yr)" times the dredging interval "dt (years)" where dt is not to exceed three years (but preferably one year dredging interval if practical cost-wise). The dredging should be done with intent to modify alignment of the channel to a more (natural) southerly direction and somewhat more parallel to the shoreline (i.e. similar to the historical pre COE inlet channel). The amount both dredged and placed should be monitored at yearly intervals. Additional material necessary for stability of beaches to the south side of the inlet might be derived from the historical remnant ebb shoal platform area on the south side of the inlet in areas where shoreline is now *naturally* accreting.

<u>Ebb and Flood Shoal Complex</u>

A necessary requirement for future better understanding of the St. Augustine Inlet complex is to collect more comprehensive (and synoptic) survey data on the inlet complex and its environs. A recommendation herein is to reinforce the previous Taylor Engineering (1997) recommendation of a comprehensive monitoring plan for the inlet. In the Plan Element 4 of that document, numerous recommendations are made that provide for a comprehensive monitoring of the inlet complex to include extensive ebb and flood shoal surveys, as well as beach surveys. Typically the COE only provides channel and near channel surveys but needs to resume *and extend* past (1940's and earlier surveys) practices of providing extensive and comprehensive survey data of the inlet. For an example of a survey of the ebb shoal complex, one can refer to the 1862 US Coast Survey of St. Augustine Inlet, although this survey did not extend far enough southward to cover the complete southern lobe of the ebb shoal. A comprehensive hydrographic survey today would need to extend at least southward to FDEP monument R-160 and preferably to R-180. Additional beach surveys can be utilized to extend an ebb shoal survey to the north and south (from approximately R-70 to R-180). Additional to the noted monitoring plan, it is recommended that prior to dredging of the ebb shoal for beach nourishment and at least at every three years, profile surveys should be conducted of the St. Johns County shoreline (at least as far northward as R-70) along with a "comprehensive" ebb and flood shoal survey of the St. Augustine Inlet complex for future improved sediment budget estimation.

Intent to dredge the tidal ebb shoal area should refrain from dredging on the north lobe of the ebb shoal but rather concentrate on the south side of the channel and preferably attempt to reestablish a natural historical channel over the ebb shoal somewhat similar to that which existed prior to the new COE channel. In this regard a preliminary suggestion for dredging is to utilize the area in Figure VII.1 shown as "5S" in the south ebb shoal area with intent to help establish the channel to migrate in a more southerly direction and allowing the ebb shoal to wrap around the inlet as it did historically. It is beyond the scope of the present study to determine dredging quantities available from this area, grain size analysis, and analysis for the effects on the State Park area, and further study would need to be made prior to the use and permitting of this area. At present, the south beach is furnishing large volumes of material to the area of the south jetty where it is either stored in the (accreting) beach just south of the south jetty, and reintroduced into the inlet flushing to both inner shoals south of the inlet channel and to the outer shoal complex. The effective moving of material from the southern portion of the ebb shoal complex to the area presently nourished will be needed to provide a continuing flow of sand to the State Park area and prevent breakthrough of the barrier at the site of the old natural channel (i.e. Salt Run). Short of a structural approach on State Park lands (discussed in the South Beach recommendations), it is believed to be the only course of action deemed reasonable.

South Beach

Due to the mid 1940's creation of the new COE inlet channel to the north of the historical inlet channel location, and the consequent northward shifting of the bypass bar attachment area on the south side of the inlet, the location of the present City of St. Augustine Beach pier, facilities, and park (along with seawall/revetment complex) are seaward of where the shoreline would be in its new non-natural state, thereby forming an unnatural promontory. As such, the pier, seawall, revetment, and park facilities and buildings will always be undergoing significant erosion stress. Sand will continue to be needed to protect these facilities as well as the state park area directly to the north of Pope Road where a future potential breakthrough of the barrier island could occur if sufficient protection is not provided, either in the form of sand and an enhanced dune system alone (as previously noted in the Taylor Engineering (1997) recommendation), or structures in the form of a low profile groin system combined with sand nourishment. Effects of different bypassing intervals on the downdrift beach are discussed in Appendix Q where it is noted that the longer maintenance intervals cause increased recession/erosion of the downdrift shoreline during the maintenance cycles. An unfortunate aspect of the present scheme of sand nourishment only with placement every three years is that the amount of sand placed on the beach will of necessity need to be larger than the previously discussed volume (=$Q_{net} \cdot dt$ where Q_{net} ~= 402,000 c.y./yr) due to the portion of material moving northward and to the seaward projection of this portion of the shoreline (now acting as a headland). It is estimated from previous work herein that approximately 29% of the material placed is moving northward hence requiring the amount placed to be approximately $1.41 \cdot Q_{net} \cdot dt$ (i.e. $1.41 \cdot Q_{net} \cdot dt$/(1.00-0.29) to account for northward transport of material in volume placed). Depending on future beach nourishment configurations, an added amount will be required to maintain the promontory/hardened area as noted above due to readjustment and spreading of the beach fill. Further arguments concerning added nourishment required due to the offset armored area are provided in

Appendix P and suggest a necessary annualized volume placement required to maintain the stabilized area as 700,000-800,000 c.y./yr. Based on actual performance of the ebb shoal placed beach material in 2001-2003 and 2005, an estimated yearly maintenance figure would be approximately 700,000 c.y./yr if no additional structures are built (see Appendix P).

As noted above, a possible addition (unappealing esthetically and possibly uneconomically viable) to the existing inlet management approach of sand placement alone would be to build low profile groins along the State Park and in the vicinity of the City of St. Augustine Park/seawall/revetment area to reduce the alongshore sand movement to both the north and south from the zone of sand divergence. If such a concept is considered, the structures should be filled with sand at time of construction (at least in the region of existing nourishment placement). Such structures would help to retain fill in these highly erosional areas, moderating the effects of headland retreat and slowing longshore sediment transport in the zone of divergence by locally realigning the shoreline to reduce littoral drift. Structures would not eliminate erosional stress in the area but only slow down the losses presently occurring with nourishment alone (see Appendix P). If such a solution were to be considered, the design of the groin system should include careful consideration of the consequences on adjacent shorelines to ensure that addressing erosion issues in one area would not worsen the situations in adjacent areas. Further design considerations of such a system are beyond the scope of the present study and would by necessity require a joint approach between the Corps of Engineers (i.e., the responsible party for inlet maintenance and the south jetty), and the State of Florida beach management agencies (i.e. FDEP-Parks, FDEP- BBCS).

Additional Recommendations

It is additionally recommended that the State of Florida approach Congress for funding of a Section 111 study for St. Augustine Inlet. At present USACE (1979) concludes that the Federal Navigation project is responsible for approximately 80% of the erosion in St. John's County although the present study would suggest this figure is higher (although due to the sparse nature of the available data and fact that much of the data is not synoptic, a fair percentage of Federal costs is not possible at present). Part of a Section 111 Study (or study precursor) should be the collection of synoptic detailed surveys of the ebb shoal complex at St. Augustine Inlet (prior to and after all dredging/nourishment episodes), and the digitization of all historical COE surveys of the inlet channel and inlet complex. Such data collection and digitization is well beyond the scope of the existing study. As the State of Florida has considerable economic and beach preservation interests at stake in the outcome of a Section 111 study, it is also recommended that a panel of at least two to three Florida coastal engineering experts be appointed by the State of Florida who would serve on a State oversight committee to assess the ongoing performance of the Corps of Engineers study. These coastal engineering experts should be intimately involved in an overview of all data collected by the Corps of Engineers (or their contractors) as well as being involved in all study components and study findings of the Section 111 study to be performed by the Corps of Engineers.

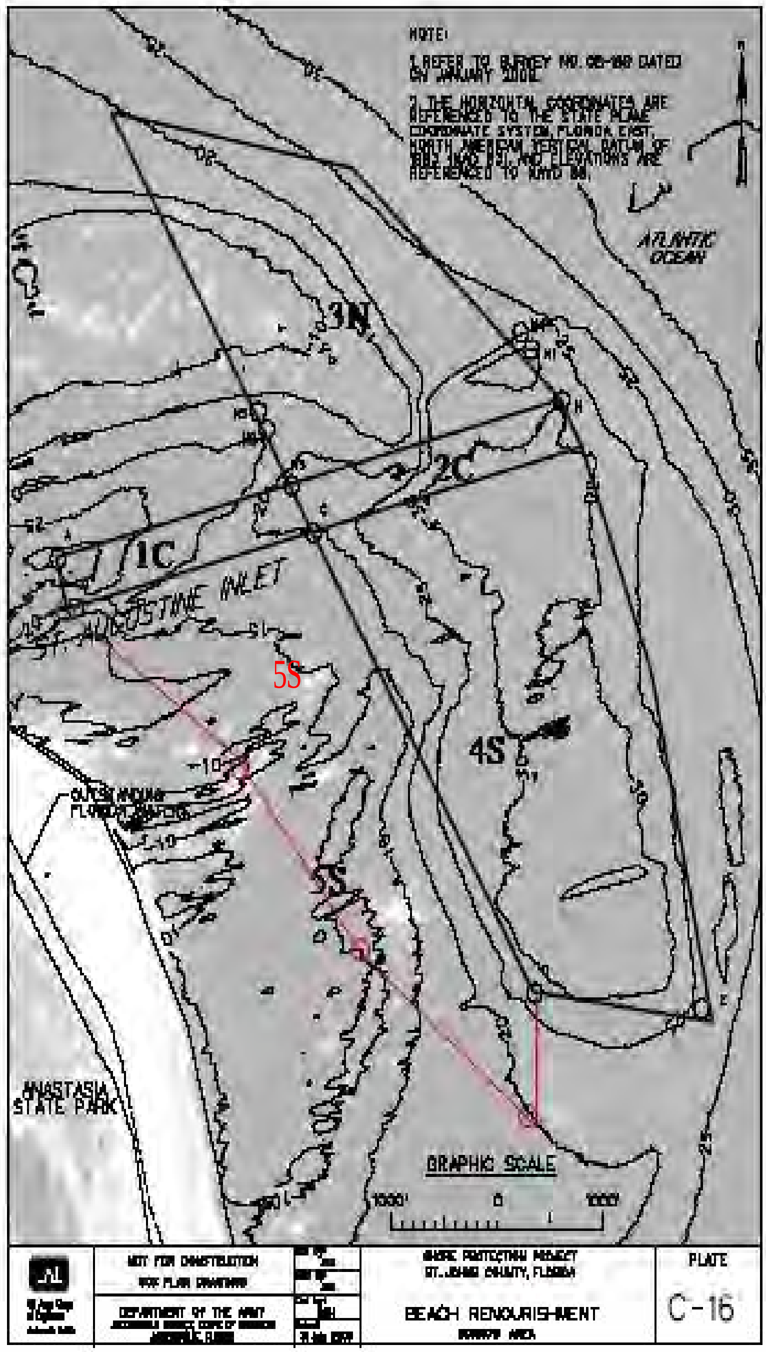


Figure 7. 1 Preliminary proposed ebb shoal area to consider for dredging superimposed on original COE permit area.

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