Morphodynamics of Two Anthropogenically Altered Tidal Inlets: New Pass and Big Sarasota Pass, West-Central Florida

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Morphodynamics of Two Anthropogenically Altered Tidal Inlets: New Pass and
Big Sarasota Pass, West-Central Florida

By

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Morphodynamics of Two Anthropogenically Altered Tidal Inlets: New Pass and Big Sarasota Pass, West-central Florida

Tanya M. Beck

Abstract

Time-series aerial photographs from 1943 to 2006, including three bathymetry surveys from 1888, 1953, and 2006, are analyzed and compared. The locations of three morphological features, including that of shoreline, offshore bars, and channel orientation, are delineated over the historical aerial photos in order to examine the morphodynamics of the system. Anthropogenic alteration of the New Pass and Big Sarasota Pass system is a crucial factor in controlling the morphodynamics.

Both New Pass and Big Sarasota Pass are mixed-energy tidal inlets with New Pass illustrating a straight morphology and Big Sarasota Pass a highly offset morphology. The sediment bypassing at New Pass can be explained by a modified ebb tidal delta breaching model with the breaching initiated by frequent channel dredging. The sediment bypassing at Big Sarasota Pass is different from that at New Pass, in that it is transported across the entire shallow ebb tidal delta with minor interruptions. This particular morphology, without a deep channel in the distal part of the ebb tidal delta, has been maintained by natural processes over at least the last 65 years. The shoreline in the vicinity of both
inlets fluctuates as much as 200 m in a time scale of only few years. The
advance and retreat of the shoreline at the southern tip of Lido Key is influenced
by the frequent Lido Key beach nourishment. A large portion of the sediment is
eventually transported onto the Big Sarasota Pass ebb tidal delta. The northern
Siesta Key headland has experienced erosion since the 1960s. Downdrift of the
headland, a persistent shoreline accretion was observed over the last 40 years,
the pattern of which is related to the location and timing of the swash bar
attachment.
Introduction

Tidal inlets play an important role in nearshore processes along barrier island coastlines. Escoffier (1940, 1977) describes an inlet as a short, narrow waterway which connects a bay, lagoon, or estuary to a larger body of water, facilitating exchange of water, sediments, nutrients, and pollutants. The presence of an inlet along the coastline traps a considerable amount of sand, thereby creating the potential for erosion of the adjacent beaches (Dean and Dalrymple, 2002). For example, Dean (1988) suggested that 80% of the east coast of Florida’s shoreline erosion can be directly linked to tidal inlets. Understanding the processes of tidal inlets and their influence on morphologic change provides crucial insight into regional behavior of barrier island coastlines. Coastal inlets, particularly those in Florida, tend to be heavily modified by anthropogenic activities. Therefore, a comprehensive understanding of inlet morphodynamics is also essential for coastal management.

A tidal inlet presents a break in an otherwise continuous barrier island, interrupting the pathway of longshore sediment transport driven by obliquely incident waves. The longshore moving sand may be redistributed both landward and seaward by flooding and ebbing tidal currents, forming flood and ebb tidal deltas. In other words, tidal inlets effectively act as sediment traps for longshore moving sand. Therefore, the balance between longshore sediment transport and
the strength of tidal flow dictates the morphological characteristics of tidal inlets (Bruun, 1960; Hayes, 1979).

The morphodynamics of many coastal systems are often characterized in terms of relative dominance of wave or tidal forcing (Hayes, 1975; 1979). Davis and Hayes (1984) developed a morphodynamic classification of coastal systems, emphasizing barrier-islands (Figure 1). The low-energy Florida Gulf of Mexico coast is located near the origin of Figure 1. Therefore, a small change in either tidal range or wave height will cause a substantial change in morphology (Davis and Barnard, 2003). This delicate balance between the relative forcing of tides and waves results in all varieties of coastal morphodynamics ranging from tide-dominated to wave-dominated systems along the Florida Gulf coast.

![Figure 1. Davis and Hayes (1984) morphodynamic classification of barrier-inlet systems including the limit of barrier island formation.](image)
Davis and Gibeaut (1990) applied the Davis and Hayes (1984) classification to tidal inlet morphodynamics along the west-central Florida coast (Figure 2). They identified four types of tidal inlet systems including tide-dominated, mixed energy straight, mixed energy offset, and wave-dominated tidal inlets. Tide-dominated inlets typically have a deep and stable channel with extensive ebb and flood tidal deltas. Wave-dominated inlets are characterized by unstable and migratory channels with a typically small and asymmetric ebb tidal delta. In some cases the ebb tidal delta may even be absent. Under mixed energy settings, the morphological characteristics associated with both wave and tide forcing are apparent. Dependent upon the particular pattern of sediment bypassing, mixed energy inlets may exhibit either a straight or offset morphology.

Figure 2. Classification of tidal inlets along the west-central coast of Florida (from Davis and Gibeaut, 1990).
Comprehensive understanding of sediment bypassing at tidal inlets is essential in inlet and barrier-island morphodynamics. Fitzgerald (1988) developed three models for mechanisms and patterns of sediment bypassing (Figure 3). The three major mechanisms for inlet sediment bypassing include: 1) inlet migration and spit breaching, 2) landward migration of bar complexes at stable inlets, and 3) ebb tidal delta breaching. The trend of bypassing under models 1 and 3 is rather apparent and tend to be event related. As the inlet channel is further and further skewed downdrift driven by longshore sediment transport, the decreasing inlet hydraulic efficiency may lead to breaching. As the newly breached inlet establishes itself, the part of barrier island (model 1) or ebb tidal delta (model 3) that was at the updrift side of the inlet, becomes effectively “bypassed” to the downdrift side of the new inlet. The trend of bypassing under model 2 with a stable channel is not as obvious as models 1 and 3. Complex and case specific movement of channel margin linear bars and swash bars constitute the sediment pathways.
Figure 3. Models of inlet sediment bypassing (from Fitzgerald et al., 1978). 1) inlet migration and spit breaching; 2) stable inlet processes; and 3) breaching of ebb tidal delta by relocation of main ebb-channel.

In contrast to numerous studies on inlet hydrodynamics and stability (Bruun, 1978; Metha and Ozsoy, 1978; Van de Kreeke, 1972; 1988; Aubrey and Giese, 1993), detailed mathematical modeling of long-term and large-scale morphology change at inlets is a relatively new area of research (De Vriend, 1996a, and b). Resolving fine-scale processes of sediment transport in the vicinity of a tidal inlet is very difficult. In addition, large-scale morphology change requires computation at a much larger temporal scale than those used in hydrodynamic and sediment transport computations. As an alternative, 'aggregate' modeling of large-scale geomorphic features based on a small number of attributes has been attempted (Stive et al., 1998; Kraus, 2000).
Kraus (2000) developed a reservoir model of ebb tidal delta evolution and sand bypassing. A large-scale aggregate model based on fundamental attributes can utilize a much larger spatial resolution as well as longer time scales that are associated with the entire morphological form of an ebb shoal (Kraus, 2000). An integral assumption included in the model is that the longshore transport defines the type and amount of sediment of which the ebb shoal is composed. A general set of initial assumptions for aggregate models included in Kraus (2000) are 1) Mass is conserved, 2) Morphological forms and the sediment pathways are identifiable throughout evolution of the feature (Figure 4A), 3) Stable equilibrium of the individual morphologic form(s) exist (Figure 4B), and 4) Changes in meso- and macro-morphological forms are reasonably smooth.

Figure 4. Large-scale aggregate sediment bypassing model of inlet system (Kraus, 2000). A is a conceptual model, and B is the sediment budget of the aggregate model.

Recent improvements in surveying, remote sensing, and data analyses technology allow for better quantification of both inlet processes and the resultant morphology for development of predictive relationships and further improvement upon numerical models (Fitzgerald et al., 2003). Fitzgerald et al. (2003) discussed the applications of updated measurement technology, including Light Detection and Ranging (LIDAR), side-scan sonar, acoustic Doppler current
profilers (ADCP), and Ground Penetration Radar (GPR) in comprehensive inlet studies. In addition, Fitzgerald et al. (2003) also emphasized the application of Geographical Information System (GIS) tools in compilation and analysis of large datasets. Detailed topographic, bathymetric, hydrodynamic, and other geophysical data collected using the aforementioned technology is typically limited to a short time frame. In contrast, a large amount of historical data on tidal inlets, especially in Florida, is available through time-series aerial photos. These aerial photos can be accurately and efficiently rectified using GIS technology. This allows a semi-quantitative analysis of morphological changes over an extensive time scale.

The West-central Florida coastline has 29 barrier islands, 30 tidal inlets, and the most diverse morphology of any barrier system in the world (Davis, 1989). A large range of tidal inlets, in terms of their morphodynamics, is found along this coast. Davis and Gibeaut (1990) and Gibeaut and Davis (1993) summarized the morphological characteristics of ebb tidal deltas along this coast. Dean and O'Brien (1987) examined the interaction between tidal inlets and the adjacent shoreline along the Florida west coast. Davis and Barnard (2000) analyzed the influence on the anthropogenic modifications in the back-barrier area on tidal inlet stability. Wilhoit (2004) investigated the morphodynamics of Bunces Pass, a pristine tide-dominated inlet situated near the mouth of Tampa Bay. Wang et al. (2007) examined the hydrodynamics and morphodynamics of a heavily structured and wave-dominated inlet at Blind Pass in Pinellas County.
Mehta et al. (1976) examined various factors controlling the hydrodynamics and sediment transport processes at both Johns Pass and Blind Pass.

New Pass and Big Sarasota Pass are situated along the microtidal, low-wave energy coast of West-central Florida (Figure 5). The two closely spaced inlets carry a relatively large tidal prism, on the order of $10^7$ m$^3$ each, draining a large portion of Sarasota Bay. Based on the classification (Figure 2) of Davis and Gibeaut (1990), New Pass inlet has a mixed-energy straight morphology and Big Sarasota Pass has a mixed-energy offset morphology. Both inlets have relatively stable main channels and large ebb tidal deltas. Several inlet management studies for each inlet were conducted to investigate inlet stability and potential sand resources of ebb tidal deltas (CPE, 1993).

Objectives

This study focuses on analysis and comparison of time-series aerial photographs of these two inlets from 1943 to 2006. Three bathymetry surveys from 1888, 1953, and 2006 are also compiled for analysis and comparison. All the data are digitized and compiled using ArcGIS 9.2. Digital aerial photos are of high geometric capability and are a useful source of data because the study area has low topographic relief (Fitzgerald et al., 2003). CMS-Wave (Lin et al., 2006) is used to examine wave propagation patterns over the ebb tidal delta complex. The objectives of this paper are to examine 1) the various factors controlling the morphodynamics of the two inlets, 2) interaction between the inlets and the
adjacent beaches, and 3) morphodynamic response of the inlets and the adjacent beach to anthropogenic modifications.

Figure 5. General study area map.
Study Area

Located along the western Florida Gulf of Mexico coast, New Pass and Big Sarasota Pass serve the southern portion of Sarasota Bay, immediately south of the Tampa Bay Estuary (Figure 6). The Intercoastal Waterway hydraulically links Sarasota Bay to Tampa Bay to the north and Little Sarasota Bay to the south. New Pass separates the 16-km long Longboat Key to the north and the 4-km long Lido Key to the south. Big Sarasota Pass separates Lido Key and a long barrier island system to the south. Siesta Key, a drumstick barrier, is located at the north end of this barrier system. The general study area coastline has a northwest to southeast orientation. Most of the tidal prism that flows through New Pass and Big Sarasota Pass likely comes from the southern portion of Sarasota Bay. Longboat Pass, the third inlet serving Sarasota Bay, is located at the northern end of the bay 16 km north of New Pass. This long distance, in addition to a possible restriction caused by Long Bar (Figure _), should limit the interaction between New Pass-Big Sarasota Pass and Longboat Pass in terms of morphodynamics on a decadal scale. The water body to the south of New Pass and Big Sarasota Pass is rather narrow and restricted. The closest tidal inlet to the south is Venice Inlet, approximately 22 km from Big Sarasota Pass. The interaction between Venice Inlet and the two study inlets is minimal.
Figure 6. Regional map showing major estuaries including Tampa Bay and Charlotte Harbor.
Meteorological Conditions

Due to the limited fetch of the Gulf of Mexico, waves are controlled by both regional and local meteorological conditions. Also, because the microtidal nature of the greater study area, the tidal range may be significantly influenced by meteorological conditions. Therefore, local and regional meteorological conditions may have substantial influence on the inlet morphology. There are two distinct seasonal weather patterns associated with the low latitude of the study area (Davis and Barnard, 2003). The Bermuda High dominates the regular summer pattern with gentle easterly winds. High energy events during the summer are associated with passages of tropical storms, however, a direct hit by a hurricane strength tropical storm is uncommon. The last such storm that passed within 40 km from the study area was an unnamed hurricane in 1946.

During the winter season, the frequent passage of frontal systems is the main source for high wave-energy events. The sustained and relatively strong northerly wind after the frontal passage is the major cause of southerly longshore sediment transport (Davis and Barnard, 2003; Elko et al., 2005).

The distribution of wind speed and direction measured during 2007 at Venice Inlet is summarized in Figure 7. Throughout much of the year, wind speeds are typically less than 6 m/s, shown in orange in Figure 7. The predominant wind direction is from the northeast usually with a slow speed. The
influence of cold front passages is apparent as indicated by the secondary mode (shown in light blue color) approaching from the northwest, often proceeded by a strong pre-frontal wind from a southerly direction. The pre-frontal wind, although can be quite strong, typically only lasts a short period of time (Tidwell, 2005). This can also be implied from the much narrower light-blue bar in Figure 7. It is worth noting that there was no passage of significant tropical storms during 2007.

Figure 7. Wind rose diagram showing percentage distribution of measured wind speeds in 2007 at the NOAA Venice Inlet Station.
Wave Climate

The overall wave energy along this coast is low with average breaker heights for west-central Florida estimated to be 25-30 cm (Tanner, 1960; Davis and Andronzco, 1987). Figure 8 is a summary of hindcast wave conditions from 1994 to 1999 based on the Wave Information Study (WIS) by the US Army Corps of Engineers. The data illustrated are from WIS station 274, which is located in 18m of water depth approximately 26 kilometers offshore to the west of the study area. Most of the time the significant wave height is less than 1 meter, approaching from an easterly direction (Figure 8). These offshore directed waves have a minimal effect on the nearshore processes of the inlets. The relationship between wave conditions and the passages of cold fronts is apparent with higher waves approaching from the west-northwest direction (Figure 8). These highly oblique waves have a significant impact on the nearshore processes and the resultant inlet morphology.

Wave-induced sediment transport in the study area is episodic, controlled by the high-energy events associated with cold front passages. The wind and waves during these events typically are incident from a northerly direction, driving a southward longshore sediment transport, as also found by numerous previous studies (Davis and Barnard, 2003; Elko et al., 2005). However, during the rest of the year, wave forcing should not be significant. On a smaller temporal scale, the
sea breeze during the summer season may generate modest waves in the nearshore. However, their effect on sediment transport is insignificant.

Figure 8. Wave rose diagram of WIS wave hindcast data from 1994-1999 (station 274).
Tidal Regime

Two months of tide and current measurements were conducted simultaneously at New Pass and Big Sarasota Pass by this study using two side-looking ADCPs. The locations of the measurements are shown in Figure 9. Details of this hydrodynamic study are beyond the scope of this thesis. Data are briefly summarized to provide general characteristics of the tidal regime in the following section.

Tides in the region are classified as mixed-tropical tides with a microtidal range (Davis and Barnard, 2003). The spring tide is typically diurnal with a range of roughly 0.8 m, while the neap tide is semi-diurnal with a range of 0.3 to 0.4 m (Figure 10A). Although the diurnal spring tidal range is nearly twice as much as the semi-diurnal neap tidal range, the peak velocities through both channels are largely similar due to a similar rate of water level change. During spring tide the rising phase occurs over a longer period of time than the falling phase, resulting in a much stronger ebb flow at both inlets (Wang et al., 2007). Ebbing velocities at both inlets typically reach or surpass 1.5 m/s during spring tide, and flood velocities typically peak at 1.0 m/s (Figure 10B). Both spring and neap flooding tides at Big Sarasota Pass lead New Pass by 20 to 60 minutes; however, the falling tide is largely in phase (Figure 11).
Based on estimation by CPE (1993), the tidal prism through New Pass is roughly $1.1 \times 10^7$ m$^3$ and the Big Sarasota Pass prism is approximately twice that of New Pass at $2.1 \times 10^7$ m$^3$. The tidal prism during spring tide calculated based on the flow measurement from this study yielded a similar tidal prism.

Figure 9. Location of the side-looking ADCPs.

Figure 11. Tidal phase difference at New Pass and Big Sarasota Pass.
Sediment Characteristics

Sediments along the Gulf coast of Florida are dominated by fine quartz sand with varying amounts of shell debris (Evans et al, 1985). There is little to no riverine input of sediment to the coastal system, and unconsolidated sediment cover rapidly thins in the offshore direction (Brooks et al, 2003a; Twichell et al, 2003; Davis and Kuhn, 1985). At the inlet and adjacent shoreline, sediment is mainly composed of fine to very fine quartz sand with varying amounts of gravel-sized shell and negligible amounts of biogenic mud.

Sixty surface sediment samples were collected on the flood tidal delta, in the main channel, and on the ebb tidal delta for this study. Details of the sediment analysis are beyond the scope of this thesis, however, general characteristics of surface sediment samples are presented for the study area. Figure 12 shows the location and mean sediment grain size (phi) of the sediment samples. Figure 13 shows the carbonate concentrations, which effectively illustrate the fractions of sediment other than the fine to very fine quartz sand. In the inlet channel, sediment varies greatly in mean grain size from 0.16 mm (2.64 phi) to 10 mm (-3.32 phi), with carbonate concentration varying from roughly 2% to 100%. The coarse, shelly sediments are channel lag deposits consisting of predominantly biogenic shell hash, found mostly in the deepest part of the channel thalweg. The fine quartz sand with minimal shell content is mostly found
along the slope of the channel, where large sand waves are often observed. A variety of sediment textures are found in between the above two end members. Flood tidal delta sediment characteristics are relatively uniform with a mean sediment grain size ranging from 0.13 mm (2.94 phi) to 0.20 mm (2.32 phi) with little to no shell material. The finer sediments have a small content of organic mud, which is the primary source of mud sized grains in the greater study area. The mean sediment grain size on the ebb tidal deltas varies over a greater range than that on the flood tidal delta, varying from 0.15 (2.74 phi) to 0.3 mm (1.74 phi) controlled by the various amount of shell debris. Field observations indicated that the shell debris tend to distribute in a patchy pattern.
Figure 12. Surface sediment grain size in phi scale. Samples collected in 2006 for the Sarasota Inlet Management Plan.
Figure 13. Surface sediment carbonate percentage. Samples collected in 2006 for the Sarasota Inlet Management Plan.
Trend and Rates of Longshore Sediment Transport

The net and gross rates of longshore sediment transport play a significant role in inlet stability and morphology. Walton (1976) estimated net and gross longshore sediment transport rates for West-central Florida based on estimated breaking wave conditions. Most of the southerly transport occurred in the winter months, influenced by the passage of cold fronts. Walton’s (1976) estimate has been used in various inlet management studies (CPE, 1993); however, the uncertainty associated with Walton’s calculations is unknown. In addition, Walton’s (1976) regional estimation does not resolve local variation in longshore sediment transport, especially in the vicinity of tidal inlets in this study.

Probably, a more accurate way to estimate trends of longshore sediment transport rate, along a complicated barrier-inlet coast, is through analysis of time-series morphology change. The southerly net longshore transport is clearly illustrated by the orientation of numerous morphological features. This study focuses on resolving morphology change through analysis and comparison of rectified time-series aerial photos. Trends and patterns of longshore sediment transport can be inferred from the morphology analysis.
Anthropogenic Activities at New Pass and Big Sarasota Pass

A hurricane in 1848 opened New Pass creating a wide gap separating Longboat Key with Siesta Key (Harvey, 1982). The age and origin of Big Sarasota Pass are unknown although the age of adjacent Siesta Key has been documented at about 3000 BP by Stapor et al (1988). This makes Siesta Key one of the oldest barrier islands on the west central Florida coast. The prograding beach/dune ridges on Siesta Key are at least 2000 years old, implying that an inlet has existed at that location since that time.

Anthropogenic activities have played a significant role in the evolution of both New Pass and Big Sarasota Pass over the last century. As a matter of fact, the very existence of the clearly defined New Pass and Big Sarasota Pass is attributed directly to the artificial creation of Lido Key. World War II marks a period of extensive settlement along this coast as well as a change in the approach and intensity of anthropogenic modifications to the natural system.

Historical records extend back to the first Europeans traveling along the coastline noting features such as the locations of major inlets, including the observation of Boca Sarasota as an entrance into Sarasota Bay (Figure 14). The oldest maps in this area of the coast date back to the early 1800s, and included Fishery Point, a fishing town located on the north side Sarasota Key (now known as Siesta Key) along the channel of Big Sarasota Pass.
Figure 14. Map of important geographical features.
Since the opening of New Pass in 1848, both New Pass and Big Sarasota Pass carried a significant portion of the tidal prism of southern Sarasota Bay. The inlets were separated by grass flats and a group of small mangrove islands known as the Cerol Isles (CPE, 1993b). A historical map of Sarasota dating back to 1888 illustrates that both the size and orientation of New Pass and Big Sarasota Pass are generally similar to the present.

Much of the initial dredge and fill activities in Sarasota Bay were conducted along the back-bay area. The first bridge, now known as the Siesta Key Bridge, was built in 1917 connecting the mainland to Sarasota Key (Figure 14). The Hanson, Nettie and Louise Bayous were dredged to create the first platted subdivision with canals in Sarasota named Siesta. Sarasota Key later becomes known as Siesta Key.

In 1912, John and Charles Ringling purchased much of the land surrounding both inlets and along the bayside including the Cerol Isles. Beginning in the late 1910s and early 1920s, John Ringling built Ringling Causeway from the mainland to the Cerol Isles, and then further connected them to Longboat Key. Along the Ringling Causeway a series of artificially expanded islands were built over originally mangrove islands or grassflats. Seaward from the mainland, the three most prominent artificial islands are Cedar Key, Bird Key, and St. Armands Key (Figure 14). The construction of this causeway and artificial islands may have altered the bay circulation and the tidal prisms of New Pass and Big Sarasota Pass.
The most substantial modification to the natural system was the creation of Lido Key. Lido Key was built by filling in the Cerol Isles with dredged material excavated from Sarasota Bay. Lido, Italian for beach, was chosen as a Mediterranean themed name for the newly created island. In 1926, the city of Sarasota dredged New Pass and placed the material along the north side of Lido Key. The nearly 60 acre extension of north Lido Key, also known as “City Island”, substantially changed the New Pass channel configuration (Figure 14).

It was not until the post-war 1940s and 1950s that the coast really began to develop and grow in population. The last major change to the bay was the creation of Bird Key in 1959 (Figure 14). The new subdivision was more than twenty times the original size from 14 acres to approximately 300 acres. This caused substantial degradation to the bay fisheries and caused an environmental uproar over the development. No further development of bay property has been approved since then. Both the Lido Key and south Longboat Key coasts were developed into popular winter resort destinations and residential villages by the early 1960s.

Associated with the increasing development was a series of nonintegrated efforts to stabilize both the bayside and Gulf-side shoreline to protect from wave and current induced erosion. Sea walls were built around much of the bay, as is common in west-central Florida. Also, seawalls were constructed along the southern side of both inlets, along with additional reinforcement with rip-rap and groin fields. This effectively halted the southerly migration of the inlets. Along the Gulf beaches, groin fields were also used as a shoreline protection measure.
In contrast to hard engineering structures, that dominated before the mid-1960s, dredging and beach nourishment became the primary shore protection measure. In 1964, New Pass was authorized as a Federal navigation project and was dredged and realigned perpendicular to the overall shoreline trend (USACE, 1968). The dredged material was placed on Lido Key to help alleviate erosion along the central and south beaches. Since 1964, channel dredging at New Pass and subsequent beach nourishment have become a regular method for navigational channel maintenance and beach erosion control. Table 1 lists the date and sand volume of each dredge event, and the location of the associated beach nourishment. The central beach of Lido Key has been identified as an erosional “hot spot” since the 1960’s (USACE, 1968). Lido key has been renourished a total of 11 times with eight of the projects using material from the maintenance dredging of New Pass (CPE, 1993b). The first nourishment was in 1964 when 93,000 m$^3$ of sand were dredged from the New Pass channel and placed onto Lido Key (CPE, 1993b). The most recent nourishment of Lido Key occurred in 2003.

In 1964, the Army Corps of Engineers decided against selecting Big Sarasota Pass as a priority navigation inlet because of its large and complex ebb tidal delta (CPE, 1993a). Due to the large offset at Big Sarasota Pass, the ebb tidal delta is perceived by north Siesta Key residents as providing a major sheltering from northerly approaching waves. Any attempt to dredge the large ebb delta was strongly opposed by the Siesta Key community. As a result, Big
Sarasota Pass and its ebb tidal delta have never been dredged. Also, north Siesta Key has never been nourished.

Table 1. Historical inlet dredging and nourishment projects on both Longboat Key and Lido Key. Note most of all New Pass dredged material is placed on the downdrift Lido Key.

<table>
<thead>
<tr>
<th>Year</th>
<th>Source</th>
<th>Dredged Quantity (m$^3$)</th>
<th>Quantity placed on Lido Key (m$^3$)</th>
<th>Quantity placed on Longboat Key (m$^3$)</th>
</tr>
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<td>2003†</td>
<td>New Pass</td>
<td>93910</td>
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<td></td>
</tr>
</tbody>
</table>

* - U.S. Army Corps of Engineers (April 1984)
** - CPE (1991)
† - Sarasota CO. (2005)
- Modified from CPE (1992)

In summary, the anthropogenic activity at New Pass and Big Sarasota Pass differs significantly in that the New Pass channel is dredge of frequently, while no dredging activities have occurred at Big Sarasota Pass. Most of the dredged material is placed along the Lido Key beaches, directly updrift of Big Sarasota Pass. However, there are similar anthropogenic modifications to both inlets, including construction of sea walls and groin fields along the downdrift side of the channel. Also, neither inlet has jetties, which are fairly common at other developed inlets in Florida.
Methodology

The primary goal of the study is to understand the morphodynamics of the two closely spaced inlets through the analysis of time-series rectified aerial photos. Aerial photos and navigation maps were digitized and rectified using ESRI ArcGIS software. All images were rectified using land-feature control points on each aerial image over a referenced digital orthophoto. The Digital Orthophoto Quarter Quad (DOQQ) was obtained from the Land Boundary Information Service (LABINS) of the Bureau of Survey and Mapping, Florida. DOQQ imagery has an image resolution of 1 meter per pixel, and a horizontal accuracy of 0.18 m. All DOQQ images are in compliance with the National Map Accuracy Standards (NMAS).

Distinguishable fixed features, including road intersections, seawall corners, and building corners were selected in all aerial photos for control points, and an example is illustrated in Figure 15. At least six control points selected for the rectification. Emphasis was placed on the features located near the inlet. This was done to ensure the highest accuracy of referencing in the vicinity of the features of interest. Also, for most of the cases, a considerable portion of the image is covered by water, and selecting control points over this featureless area is difficult. Therefore, the accuracy of the rectification decreases over relatively
wide water bodies, e.g., along the western (Gulf) and eastern (bay) boundaries of many photos. Appendix I includes all the rectified aerial photos.

Figure 15. Example of reference control points selected for aerial photo and navigation map georectified images.
After the images are rectified, they can be easily overlain and compared to examine morphologic change. Furthermore, in order to quantify the changes of important morphologic features, including shoreline, updrift edge of the channel, and offshore bars, these features are delineated using a digitizing tool in a GIS. Shoreline positions were determined manually, based on the color change between land pixels and shallow water pixels. Considering that tidal ranges are typically less than 0.6 m, the influence of tidal fluctuation on the location of the shoreline should not be significant for a study at this scale. In addition, a section of a stable and natural shoreline in the backbay was digitized as a control. If the digitized stable shoreline remains at a similar location for the time-series aerial photos, then this may indicate that the uncertainty in shoreline position associated with the water-level fluctuation is not significant for this analysis. The crests of offshore bars were delineated through visual interpretation of the brightest pixels on an image taken on a clear day, or offshore breaking waves found in an image taken on a day with higher wave action. The updrift edge of the channel, including the channel margin linear bar, was digitized as an indicator of the channel location and orientation. This feature was chosen over the channel thalweg to indicate channel location and orientation because the latter was impossible to identify in the aerial photos.

Comparison of the digitized shorelines provides information on the trends of beach erosion and accretion. Information on the morphodynamics of the ebb tidal delta can be inferred by the orientation change of the main channel over the delta. Based on Fitzgerald (1988) and Elko and Wang (2007), the nearshore bar
may provide an important sediment pathway from the beach to the ebb delta complex. Therefore, the offshore bar is delineated in this study to investigate the relationship of the offshore bar and the trend of sediment bypassing to the ebb tidal delta. Also, in order to examine the driving mechanism for sediment bypassing over the ebb tidal delta, wave propagation modeling is conducted. Anthropogenic modifications, including bay area changes, beach nourishment, and inlet dredging activities, are linked to the time-series morphology changes.
Morphology of New Pass and Big Sarasota Pass

Time-series aerial photos of New Pass and Big Sarasota Pass, from 1943 to 2006, are rectified and analyzed. In addition, three bathymetric datasets are examined, including two from rectified navigational maps in 1888 and 1953 and one from recent a survey in 2006. The focus of this analysis is on sediment bypassing mechanisms and pathways based on investigations of various morphological features in the inlet system. The features investigated include the inlet channel, the offshore bar, shoreline along the adjacent beach, and the ebb tidal delta. In the following, time-series evolution of the above features is discussed largely on a decadal scale. Anthropogenic modifications play a significant role in the morphological evolution and are emphasized throughout the discussion. Generally, there are two types of anthropogenic modifications. Before the mid-1960s, hard engineering structures, for example sea walls, groin fields, and dredge-and-fill in the bay, are the dominant activities. Following the late-1960s, the above activities were largely replaced by beach nourishment and inlet maintenance dredging. The only available data that illustrates minimal anthropogenic modifications is the navigational map from 1888.
Location and Orientation of the Inlet Channel

New Pass

The location of the New Pass channel, delineated from the 1888 navigational map, is considerably north of the present location (Figure 16). The channel is curved toward the south, apparently influenced by net littoral drift in the southerly direction. This indicates a greater degree of wave influence of the inlet before anthropogenic modifications. The first dredging of New Pass was in 1926 with the intention of increasing hydraulic stability (CPE, 1993b).

The location of the New Pass channel, delineated from the first aerial photo in 1943, is considerably south of the 1888 location. The channel has migrated up to 260 meters southward. Furthermore, the 1943 image shows a relatively straight channel (Figure 17), in contrast to the curved channel in 1888. The channel is not as visible in the 1957 aerial photo. However, a relatively straight channel over the ebb tidal delta is illustrated. Overall, during the 1940s and 50s, New Pass had a predominantly mixed-energy straight morphology with a long and straight channel margin linear bar.
Figure 16. New Pass channel location and orientation from 1888 to 2005 illustrated over the 2005 aerial photos.
Figure 17. New Pass channel aerial photos from 1888 to 1998.
The overall orientation of the entire channel, delineated from the 1960 aerial photo (Figure 18), is substantially different from that in the 1940s and 1950s due to the different ebb tidal delta morphology. However, the part of the channel between the barrier islands remains at a similar location. The substantial change of the channel orientation over the ebb tidal delta is the result of two factors. As typical of west-central Florida coast, dredge and fill activity in the back-barrier bay was quite active in the 1950s (Davis and Barnard, 2003). For this study area, this dredge and fill activity is largely concluded by the construction of Bird Key in 1959. These activities resulted in a decrease of bay area, and therefore a decrease in the tidal prism.

Figure 18. Channel orientation of New Pass in 1960.
The second reason for the curved 1960 channel is related to the passage of Hurricane Donna. Hurricane Donna struck South Florida in early September of 1960, and moved up the state near and landward of the west-central coast (Figure 19). Donna was a category 4 hurricane on the Saffir-Simpson scale that moved very slowly across the state. After the storm had passed, Longboat Key was declared as a disaster zone. The storm removed old docks, wharves, and boathouses from the bay. The track of the cyclone landward of the shoreline and the counterclockwise rotation of the storm would have generated predominantly offshore winds with a strong northerly component. It is reasonable to believe that the slowly moving storm allowed sufficient time to generate high waves approaching from the north. The offshore wind was likely the reason for minimal morphological evidence associated with storm surge. This event, in conjunction with the decreasing tidal prism, is likely the reason for the substantial southward growth of the ebb tidal delta and the curve of the channel.
In addition to the migrating shoal causing navigation problems at New Pass, Lido Key was experiencing severe erosion during the 1960s. This prompted the city of Sarasota to petition the US Army Corps of Engineers’ assistance in maintaining their inlets. The first maintenance dredge was in 1964 and subsequent dredges are listed in Table 1. The shore-perpendicular orientation of the channel, as clearly illustrated in the two example aerial photos from 1971 and 1972 (Figure 20), apparently resulted from the maintenance dredging.

Figure 20. Aerial photos from 1971 and 1972 are two examples illustrating the straight morphology and prominent channel linear bar on the north side of the main channel.

The New Pass channel has remained largely perpendicular to the shoreline since 1964 due to the well scheduled dredging of the main channel (Figure 15). In general, the channel location and orientation have been controlled by anthropogenic activities. Therefore, any attempt for the channel to migrate south is interrupted by the maintenance dredging.
Big Sarasota Pass

The Big Sarasota Pass at the present location is documented to as far back as the 1700s. The navigation map from 1888 positions the main channel of Big Sarasota Pass adjacent to Fishery Point. An inlet adjacent to Fisher Point was also documented in the 1700s. This suggests that the main channel has been relatively stable. Due to the long history of the inlet, it is assumed to have carried much of the prism for Sarasota Bay before the opening of New Pass (CPE, 1993a). Its domination was believed to have extended into the early 1900s before the massive dredge and fill construction by John Ringling (CPE, 1993a).

The location and orientation of the main channel of Big Sarasota Pass has largely been stable since 1943, except for portion just south of Lido Key (Figures 21 and 22). In 1888, the main channel was positioned approximately 200 meters to the northwest. The influence of the net southward longshore sediment at Big Sarasota Pass is illustrated by the narrowing of the portion of the channel just south of Lido Key (Figure 22). In the 1943 aerial photo, the main channel extends through roughly the middle of the ebb tidal delta and is relatively straight. In contrast, in the later aerial photos, the distal channel curving to the south indicates an increased influence by the southward longshore sediment transport (Figure 23). Unfortunately, there are no aerial photos available from the early 1960s to illustrate the influence of Hurricane Donna.

In summary, both New Pass and Big Sarasota Pass have remained at the similar positions since 1943, likely due to the stabilization of the shoreline along
the south side of the inlet channels. New Pass channel orientation is strongly
influenced by the regular maintenance dredging, preventing the seaward portion
of the channel from curving to the south. The stable channel morphology of Big
Sarasota Pass, on the other hand, has not been influenced by dredging. The
seaward portion of the channel is shallower than the dredged New Pass channel.

Figure 21. Example of delineated updrift edge of inlet channel at Big Sarasota
Pass in 1943.

A variety of events, both natural and anthropogenic, may have influence
on tidal flow patterns and tidal prism. These events include the closure of
Midnight Pass (approximately 10 km south of Big Sarasota Pass) in 1983, the
maintenance dredging of New Pass, and the dredging of the Intracoastal
Waterway. However, these modifications did not seem to have identifiable
influence on the channel locations between the barrier islands.
Figure 22. Big Sarasota Pass channel location and orientation from 1888 to 2005 illustrated over the 2005 aerial photos.
Figure 23. Big Sarasota Pass aerial photos from 1888 to 2005.
Shoreline Change

Substantial erosion and accretion in the vicinity of the inlet can be observed from the rectified time-series aerial photos. In the following discussion, a net southward sediment transport is assumed. Therefore updrift of each inlet is the north side, and downdrift is the south side. In the following sections, the delineated shoreline gathered from all the aerial photos are illustrated on a roughly decadal scale. For clarity the entire study area is illustrated as three subsections, 1) New Pass (updrift and downdrift), 2) Big Sarasota Pass (updrift), and 3) Big Sarasota Pass (downdrift).

New Pass

During the 1940s little shoreline change occurred at the updrift of New Pass (Figure 24). Figure 24 includes shoreline change from aerial photos in 1943, 1945, 1947, and 1948. Along the updrift side of the channel there is some erosion of the spit that extends east into the channel. Along the southwestern tip of Longboat Key there is a small amount of accretion from 1945 to 1948. It is important to note that during the 1940s there is no offset between the updrift and downdrift shorelines around New Pass.

Downdrift of New Pass, an attachment point appears to be inside the channel, resulting in a bulge along the downdrift side of the inlet. This protruding feature is distinguishable into the late 1950s. Downdrift of the attachment along
northern Lido Key, rapid shoreline erosion is observed. There appears to be a significant flood marginal channel along northern Lido Key.

Figure 25 illustrates shoreline change from 1948 to 1957. Updrift of New Pass the shoreline eroded and the spit inside the inlet remained unchanged. However, shoreline downdrift of the inlet had changed substantially. The 1952 image illustrates a partially emergent set of swash bars close to the shoreline at the north end of Lido Key. The substantial shoreline advance in 1957 suggests that these swash bars had attached to the northern tip of Lido Key, providing a significant amount of sediment to the north end. Apparently the attachment only benefited a limited section of the shoreline as severe erosion just south of the attachment is measured. A groin field was installed along the central Lido Key in order to slow the erosion.

Substantial shoreline change is observed in the 1960s, resulting from the combination of the passage of Hurricane Donna and the first New Pass dredging (Figure 26). The 1960 aerial photo, taken two months after Hurricane Donna, illustrates a significantly different overall inlet morphology with a large curved ebb shoal. The updrift shoreline has further eroded in the 1960 and 1961 images as compared to 1957. The 1960 and 1961 images show that the attachment point at northern Lido Key was smoothed with some sediment transported downdrift. The smoothing of this attachment point affects only a short stretch of the shoreline, as the severe erosion around the groin field of central Lido Key persists.
Figure 24. Shoreline change at New Pass from 1943 to 1948.
Figure 25. Shoreline change at New Pass from 1948 to 1957.
Figure 26. Shoreline change at New Pass from 1957 to 1969.
Extensive changes to the New Pass system occurred between 1961 and 1969 and are best illustrated by the dramatic shoreline change both updrift and downdrift of the inlet (Figure 26). It is reasonable to believe that the first dredging of New Pass, and nourishment of the downdrift beach in 1964, had a significant influence on the morphology. Along the updrift side of the inlet a substantial amount of sediment had accumulated. Comparing the 1961 and 1969 aerial photos, the shoreline advanced approximately 150 m to a position similar to that of the 1940s. The spit inside the inlet acquired a significant amount of sand along the lagoon side. This is likely the result of artificial fill associated the accelerated development of the area.

The downdrift shoreline accreted substantially at the north tip of Lido Key during the 1960s, creating a large offset between Longboat Key and Lido Key. The bulge inside the New Pass channel, as observed in the 1950s photos, has eroded along with significant erosion of 100 m at the north Lido Key headland. This dramatic morphology change is likely influenced by the 1964 dredging of New Pass. The dredging artificially created a situation similar to the “ebb delta breaching” as described by Fitzgerald (1988). Following the dredge, a portion of the previously downdrift side of the ebb tidal delta collapsed onshore resulting in the shoreline gain observed in the 1969 photo.

The aerial photo from 1971 shows an apparent marginal channel separating the channel linear bar from the updrift shoreline on south Longboat Key (Figure 27), between the 1971 and 1972 aerial photos. There was substantial shoreline erosion of about 70 m directly updrift of the inlet. Directly
downdrift of the inlet there is significant shoreline erosion of up to 140 m between 1969 and 1971. The central Lido Key beaches have accreted which may in part be the result of an extensive beach renourishment project in 1970. Shoreline erosion along the northern Lido Key was observed between 1971 and 1972.

New Pass was dredged twice in the 1970s, in 1974 and 1977, during the same year the aerial photos were taken. Comparing the 1972 and the 1974 photos, the shoreline directly downdrift and updrift of the inlet gained up to 50 m (Figure 28). The shoreline advance continued to 1977 with an additional 50 m of shoreline gain. It is worth noting that the 50 m represents a maximum value of the spatially variable shoreline changes. The central Lido Key beaches show extensive accretion when comparing the 1974 and 1977 photos. This is apparently the result of the placement of 300,000 m$^3$ of dredged material on Lido Key.
Figure 27. Shoreline change at New Pass from 1969 to 1972.
Figure 28. Shoreline change at New Pass from 1972 to 1977.
Dredging of New Pass and subsequent nourishment continued into the 1980s with approximately 211,000 m$^3$ of sediment placed on Lido Key. Comparing the 1977 photo with those in the 1980s, the updrift shoreline is relatively stable with gains and losses within 40 m (Figure 29). The shoreline along the inner channel remains unchanged in part due to the structuring of the south side of the channel with a continuous seawall. Between 1977 and 1983 the northern Lido Key headland was severely eroded, with a shoreline retreat of over 100 m, to a position where there was no longer an offset between south Longboat Key and north Lido Key. Also, following the 1977 beach nourishment, north Lido Key had experienced a shoreline retreat of over 100 m by 1983. However, comparing the 1983 and 1986 photos, substantial shoreline gain was observed at the headland beach. It is worth noting that the 1985 dredging, as visible in the 1986 photo, followed a further southward orientation (Figure 29). As typical of a post-dredging response, the swash bars over the previous downdrift ebb tidal delta are migrating and attaching to the shoreline as is visible in the 1986 aerial photo. This resulted in substantial shoreline gain. Some alongshore spreading of the recently attached material can be identified in the 1986 aerial photo.
Figure 29. Shoreline change at New Pass from 1977 to 1986.
The 1990s saw the greatest amount of dredging in New Pass, with almost 1.12 million m\(^3\) of material removed (Table 1), in addition to an offshore dredging in 1998. Approximately 910,000 m\(^3\) of sediment were placed on Lido Key. About 300,000 m\(^3\) of sediment from the 1990 and 1993 New Pass dredging were placed onto south Longboat Key to mitigate the erosion.

Substantial changes occurred between 1986 and 1990 (Figure 30). Over 50 m of shoreline erosion occurred along the updrift beach. Tremendous shoreline accretion of up to 150 m occurred at the downdrift beach. This created an offset at New Pass. The updrift shoreline erosion continued to 1993 with another 50 m of shoreline retreat. At the downdrift beach, a portion of the accretion was eroded with a shoreline retreat of approximately 50 m. Further downdrift the shoreline advanced. This trend continued to 1998 and is probably the result of downdrift migration of the attachment point, which may be related in part to the artificially controlled southward alignment of New Pass. The updrift shoreline advanced from 1993 to 1998, likely resulted from the 1993 south Longboat Key nourishment.

Since 1998, shoreline change in the vicinity of New Pass has been relatively stable (Figure 31). A notable change occurred along the inlet channel at the updrift side between 2004 and 2005 with an up to 50 m shoreline retreat. In response, rock T-groins were placed along this shoreline to inhibit any further erosion.
Figure 30. Shoreline change at New Pass from 1986 to 1998.
Figure 31. Shoreline change at New Pass from 1998 to 2006.
Big Sarasota Pass

Due to the large offset at Big Sarasota Pass and its immense ebb tidal delta, it is difficult to illustrate the entire system in one figure. Therefore, Big Sarasota Pass is separated into two parts, updrift and downdrift, for better resolution of shoreline changes. Some of the aerial photos did not cover the entire Big Sarasota Pass system.

Big Sarasota Pass shoreline change also begins with aerial photos from the 1940s including 1943, 1945, and 1948. The 1943 aerial photo has a higher brightness than the rest of the aerial photo dataset, and therefore it is difficult to distinguish features. Also, the lack of constructed features adds to a greater uncertainty in the rectification as shown by the offset in the back bay shoreline (Figure 32). However, the overall trend in the shoreline change along the updrift side of Big Sarasota Pass can still be identified. Comparing the 1945 and 1948 aerial photos, the southern tip of Lido Key had accreted with a shoreline advance of up to 110 m. The spit inside the channel along the updrift side also grew in size and extended further north.
Figure 32. Shoreline change updrift of Big Sarasota Pass from 1943 to 1948.
Downdrift of Big Sarasota Pass there is an apparent swash bar attachment at the Siesta Key headland as shown in the 1943 aerial photo (Figure 33). However the extensive beach erosion had occurred at the headland by 1948. The beaches south of the headland, which were already somewhat developed, had also eroded quite substantially, roughly 150 m to the edge of the developments. By 1948 extensive groin fields were exposed at the shoreline along north Siesta Key.

Comparing 1948 and 1952 photos, the southern tip of Lido Key had accreted substantially with a shoreline gain of up to 130 m. A considerable amount of this accretion was eroded by 1957, followed by another tremendous shoreline gain of up to 160 m by 1969 (Figure 34). The exact reason for these large and rapid shoreline fluctuations is not clear. Coincidentally, heavy development occurred in the late 1960s resulting in a large amount of structures on the newly accreted yet very dynamic beach at the southern tip of Lido Key. The spit inside the channel along the updrift side had remained mostly unchanged. Much of the flood tidal delta of Big Sarasota Pass, known as Bird Key, had been filled in and developed between 1959 and 1960 (Figure 35).
Figure 33. Shoreline change downdrift of Big Sarasota Pass from 1943 to 1948.
Figure 34. Shoreline change updrift of Big Sarasota Pass from 1948 to 1969.
The channel shoreline along northern Siesta Key experienced significant erosion between the late 1940s and 1957 (Figure 36). The beach that is visible in the 1940s photos has largely disappeared by the 1950s. At this point many of the homeowners had constructed sea walls to protect their property from the persistent erosion along the channel shoreline. In addition to the almost continuous sea wall, some groin fields were also installed along the inlet as is visible in the 1957 aerial photo. These efforts had essentially anchored the downdrift or east side of the Big Sarasota Pass channel.

Downdrift of the inlet, comparing 1948 and 1957 (the 1952 photo did not include the downdrift beach), the headland at Siesta Key experienced shoreline advance of up to 60 m. This accumulation may be the result of the deposition of sediment transported from the eroding shoreline inside the channel. This trend of accumulation had dramatically changed by 1969. The Siesta Key headland experienced severe erosion with up to 200 m shoreline recession comparing the
1957 and 1969 aerial photos (Figure 36). The erosion can be attributed to the depletion of sediment supply due to the artificial anchoring of the shoreline along the channel. By 1969, the entire headland is heavily structured with groin fields, seawalls, and rip-rap placed along the shoreline in an effort to stop and mitigate the erosion. The ebb shoal has grown and is now bypassing and attaching in the form of swash bars further downdrift. This resulted in a shoreline gain of over 130 m at the attachment point between 1957 and 1969. However, the accumulation caused by the attachment is rather local with limited alongshore spreading during this time frame. This is illustrated by the severe erosion of the shoreline updrift and downdrift of the attachment.

The large variation in shoreline position along southern Lido Key, such as that observed in the 1950s and 1960s, continues through the 1970s and 1980s. The updrift south Lido Key beach had eroded significantly with up to 170 m of shoreline retreat from 1969 to 1976 (Figure 37). Much of the development along this stretch had exposed seawall and rip-rap at the shoreline as is visible in the 1976 aerial photo. Reversing this severe erosive trend, the beach experienced accretion in 1977 and continued to 1983. This may be related to the sand supply from the 1977 and 1982 Lido Key beach nourishment.
Figure 36. Shoreline change downdrift of Big Sarasota Pass from 1948 to 1969.
Figure 37. Shoreline change updrift of Big Sarasota Pass from 1969 to 1983.
Shoreline position at the downdrift Siesta Key headland had remained unchanged with little to no sediment accretion during the 1970s and 1980s (Figure 38). However, over the 1970s and 1980s a significant amount of sediment had accreted at the downdrift northern Siesta Key beach. This accretion is due to a combination of attachment point migration and some alongshore spreading of the accumulation at the attachment point.

Comparing the aerial photos from 1983 to 1990, the shoreline at the southern tip of Lido Key has advanced nearly 100 m (Figure 39). After 1990, this beach experiences an overall erosional trend with the shoreline retreating to a position similar to 1983. Figure 40 shows the shoreline change at the downdrift Big Sarasota Pass from 1983 to 1999. Except for the aerial photo from 1999, all of the photos during this period of time did not extent beyond the Siesta Key headland. The shoreline at the Siesta Key headland remained relatively stable due to the structures. Compared to the aerial photos in the 1970s, the 1999 photo illustrates that the beach ridges that were formed through the attachment of swash bars have been vegetated. This suggests that over the last 30 years this portion of the beach has been accretionary, apparently benefiting from the sediment bypassing.
Figure 38. Shoreline change downdrift of Big Sarasota Pass from 1969 to 1983.
Figure 39. Shoreline change updrift of Big Sarasota Pass from 1983 to 1999.
Figure 40. Shoreline change downdrift of Big Sarasota Pass from 1983 to 1999.
The shoreline advance along southern Lido Key, resulting from the 2001 and 2003 beach nourishment (Table 1), is apparent when comparing the 1998 and 2004 photos (Figure 41). Subsequent beach erosion can be identified in the 2005 and 2006 aerial photos. The southward longshore sediment transport is clearly illustrated by the 2004, 2005, and 2006 aerial photos. A portion of the eroded sand on southern Lido Key beaches apparently was deposited at the southern tip. Along the downdrift shoreline, the attachment of the swash bars continued in the 2000s (Figure 42). The low-altitude 2005 aerial photos illustrate the complicated morphology of the swash bars. The exact point of attachment can be related to the position of a particular migrating swash bar. This may be the reason for the variation in attachment locations.
Figure 40. Shoreline change updrift of Big Sarasota Pass from 1999 to 2006.
Figure 41. Shoreline change downdrift of Big Sarasota Pass from 1999 to 2006.

Legend
- BP_1999
- BP_2004
- BP_2005
- BP_2006

Meters
0 125 250 500 750 1,000
Offshore Bar

The offshore bar that is discussed here is that which directly interacts with the ebb tidal deltas of each inlet. The hypothesis here is that these bars serve as important pathways for sediment bypassing. On many aerial photos, these offshore bars can be traced updrift to a merging point with the shoreline, as illustrated in Figure 43. In the following discussion, this merging point is referred to as the detachment point of the offshore bar. The crest of the offshore bar was traced to identify any trends of bar movement.

![Image](image)

Figure 43. Example of offshore bar detachment point and attachment point.

The digitized offshore bar crest updrift of New Pass is illustrated in figure 44. Generally, the cross-shore distances of the bar crest increases towards the ebb tidal delta. Overall, no apparent time-series trend can be identified. The offshore bar updrift of Big Sarasota Pass shows a similar morphology as that
updrift of New Pass (Figure 44). However, the detachment point of the offshore bar on Lido Key seems to relate to the nourishment activities.

Figure 44. Offshore bar locations for south Longboat Key from visible aerial photos of New Pass. A general trend is not apparent.
Figure 45. Offshore bar locations for Lido Key from visible aerial photos of New Pass and Big Sarasota Pass. A general trend is not apparent.
Ebb Tidal Delta and Wave Refraction

Both New Pass and Big Sarasota Pass are associated with large and active ebb tidal deltas. These two ebb tidal deltas are relatively closely spaced, but with substantially different overall morphologies. The wave refraction over these ebb deltas strongly influences the sediment bypassing patterns. As discussed above, the inlet morphodynamics is strongly influenced by southerly longshore sediment transport. In the greater study area, the net longshore sediment transport is largely controlled by the passages of cold fronts.

Mehta (1996) discussed several case studies of federally maintained inlets, including New Pass. He suggested a need for extensive research on the recovery of ebb tidal deltas and the interrelationship with the stability of adjacent beaches. A wave refraction study is emphasized as a key component of the recommended research.

In the following, the steady-state spectrum CMS-Wave model, developed by the Army Corp of Engineers (Lin et al., 2006), is used to investigate the wave refraction patterns over the ebb tidal delta. CMS-Wave is a spectral wave shallow water propagation model. Wave data collected from the 1994-1999 WIS dataset were examined and three representative waves were selected for use in this study. Basic wave characteristics, including wave height, period, and direction, were input into a wave generation program in SMS (Surface Water
Modeling System), a comprehensive modeling interface that runs CMS-Wave. The wave generation tool in SMS creates the spectral wave input conditions used in CMS-Wave under user parameters. Bathymetry used in this model was collected in 2005 and in 2006 using RTK GPS and a precision single beam echo sounder (CPE 2005; CEC 2006). The 2-D finite difference model, which handles wave refraction and diffraction, propagates the spectral wave over a rectilinear grid generating a 2-D visual output as well as numerical results. Results include wave height, period, direction, breaking dissipation, and radiation stresses.

The characteristics of the two ebb tidal deltas are clearly illustrated by the high resolution survey (Figure 45). The Big Sarasota Pass ebb tidal delta is substantially bigger than the New Pass ebb tidal delta. In contrast to the very asymmetrical Big Sarasota Pass ebb tidal delta, the New Pass ebb tidal delta is relatively symmetrical but slightly skewed toward the south. The main channel through New Pass is relatively short and straight, while the channel at Big Sarasota Pass is much longer and sinuous.
Three representative wave conditions were selected based on regional meteorological and wave conditions (Figures 7 and 8). The main goal is to examine wave refraction patterns over the complex ebb tidal deltas under simplified conditions. Although a large number of modeled runs were conducted, only the simpler cases, excluding tide influences and therefore wave-current interactions, are discussed below. The first of the three idealized wave
conditions is a 1.0 m wave approaching from the north-northwest, representing an average post-frontal wave condition. The second wave condition is a 2.4 m wave approaching from due west, representing a very energetic storm wave condition (Figure 8). The third wave condition is 1.2 m wave approaching from the south, representing a relatively high energy wave condition.

Figure 47 illustrates an incoming wave from a north-northwest direction, representing a typical wave condition accompanying a cold front passage. Wave refraction around the ebb deltas is apparent with higher waves on the northern flank of the delta and smaller waves along the southern flank of the delta due to sheltering. The wave height dissipation is closely related to the bathymetry, with less dissipation in deeper water and more dissipation in shallow water.
Figure 47. Wave propagation of a 1.0 m wave height with a 5 s period approaching from a north-northwest direction.

Figure 48 represents a relatively energetic wave condition from a distant storm. The wave propagates toward the east from the center of the Gulf of Mexico. The wave refraction over the ebb deltas and the divergence of the wave direction just downdrift (south) of each delta are illustrated. This divergence point relates to the persistent shoreline erosion in the north-central portion of Lido Key as discussed above. The refracted wave vectors of both ebb tidal deltas suggest the southerly trend of longshore sediment transport. Wave sheltering along the downdrift portion of the ebb deltas is evident. Significant wave energy reduction
is modeled at both the New Pass and Big Sarasota Pass attachment locations. This indicates a process-response bypassing and attaching mechanism.

Figure 48. Wave propagation of a 2.4 m wave height with an 8 s period approaching from due west.

Figure 49 represents a prefrontal wave condition incident from the south. The protruding Siesta Key and the large Big Sarasota Pass ebb delta produced a large shadow zone with a smaller refracted wave. Although Siesta Key is impacted by much of the wave energy, the rest of the littoral system is mostly sheltered from the dissipated and refracted waves. A divergence of the wave vectors can still be identified at the north-central area of Lido Key under a southerly approaching wave. This further explains the erosional hotspot in central Lido Key. In other words, the wave divergence occurs under both
northerly and southerly approaching wave as well as shore normal waves. Also, under a southerly approaching wave, a localized, relatively high wave is modeled at the headland at Siesta Key. This suggests that the persistent erosion and the headland is related to the southerly approaching wave and the skewed Big Sarasota Pass channel.

Figure 49. Wave propagation of a 1.2 m wave height with a 6 s period approaching in from the south.

The modeling efforts also indicated that the large variation of the shoreline at the tip of southern Longboat Key, the southern tip of Lido Key, and Siesta Key is related to the complex wave-current interaction in addition to the wave refraction pattern discussed above. Detailed discussion of this modeling effort is beyond the scope of this thesis.
Discussion

The processes controlling the morphodynamics of tidal inlets are complicated, including meteorological, tidal, and wave forcing. These forces are highly variable in space and time and are difficult to quantify. In addition, they interact with each other actively. A simplified approach is to examine the morphological changes through an evaluation of a relative energy level. The following qualitative discussion on the morphodynamics of New Pass and Big Sarasota Pass follows the above relative energy level approach.

Anthropogenic alteration is a crucial factor when examining historical morphologic changes along such a modified and extensively developed coastline. Structures, dredge and fill in the bay, dredging of the channel, and nourishment activities, all have tremendous influence on the sediment bypassing system. The influence of anthropogenic activities is clearly illustrated by morphodynamics of New Pass and Big Sarasota Pass.

Both New Pass and Big Sarasota Pass are mixed-energy tidal inlets with New Pass illustrating a straight morphology and Big Sarasota Pass a highly offset morphology. Also, New Pass is dredged regularly, whereas Big Sarasota Pass has never been dredged. A substantial amount of bypassing occurs at both inlets based on the analysis of historical photos. However, the pathways and
mechanism of the bypassing are different at New Pass as compared to Big Sarasota Pass.

The bypassing at New Pass can be explained by the modified model 3, i.e. ebb tidal delta breaching, of Fitzgerald (1978). The ebb tidal delta breaching here is initiated by channel dredging as opposed to natural processes described in Fitzgerald (1978). Channel realignment essentially cuts through the ebb tidal delta, serving the same purpose as ebb tidal delta breaching, modifying the hydrodynamics. Typically after the channel dredging a portion of the downdrift ebb tidal delta migrates onshore and attach to the Lido Key headland, therefore, completing the bypassing.

A conceptual model of the New Pass bypassing system is illustrated in Figure 50, in terms of relative forcing. The red arrows indicate the pathway of sediment bypassing around the inlet. Different morphological features are dominated by different processes. The sediment supply along the updrift shoreline as well as along the offshore bypassing bar is driven by wave forcing. This is especially true during the passages of cold fronts. This portion of the coast, as outlined in yellow, is mostly dominated by wave forcing. As the net longshore sediment transport reaches the ebb tidal delta, the sediment is redistributed by tidal flow. This portion of the ebb tidal delta along the updrift side of the inlet, as outlined in orange, is modified by both waves and tides. Downdrift of the inlet channel, the complex swash bars tend to migrate onshore. This portion of the ebb tidal delta is outlined in yellow, and is dominated by wave forcing. The relative updrift and downdrift side of the ebb tidal delta is controlled
by the channel dredging. In other words the channel realignment allows a substantial portion of the sediment on the ebb tidal delta to switch from the updrift side to the downdrift side.

The sediment bypassing at Big Sarasota Pass does not follow Fitzgerald’s (1978) models. Due to the shallow distal part of the ebb channel, it seems that the sediment is transported across the entire shallow ebb delta without major interruption of a deep channel. This particular morphology, without a deep channel in the distal part of the ebb delta, has been maintained by natural processes over at least the last 65 years.

A conceptual model of sediment bypassing at Big Sarasota Pass is illustrated in Figure 51. The red arrows indicate the pathway of sediment bypassing around the inlet. The sediment supply along the updrift shoreline as well as along the offshore bypassing bar is driven by wave forcing. The frequent beach nourishments at Lido Key influence the Big Sarasota Pass system by artificially supplying a large amount of sediment to the ebb tidal delta. This anthropogenic influence contrasts the maintenance dredging activity at New Pass. This portion of the coast, as outlined in yellow, is mostly dominated by wave forcing. As the net longshore sediment transport reaches the ebb tidal delta, the sediment is redistributed by tidal flow. This portion of the ebb tidal delta along the updrift side of the inlet, as outlined in orange, is dominated by both waves and tides. Downdrift of the inlet channel, the complex swash bars tend to migrate onshore. This portion of the ebb tidal delta is outlined in yellow, and is dominated by wave forcing.
Figure 50. Illustration of pathways of natural sediment bypassing at New Pass.
Figure 51. Illustration of pathways of natural sediment bypassing at Big Sarasota Pass.
The shoreline in the vicinity of both inlets fluctuates as much as 200m in a time scale of only few years. The shoreline fluctuation is controlled by both wave and tide forcing in addition to artificial supply from beach nourishment. The shoreline at the southern tip of Longboat Key at the updrift side of New Pass is relatively stable. At the downdrift side the shoreline position fluctuates dramatically depending upon the exact location and timing of the attachment. This is controlled by the timing of the dredging and the timing of the collapse of the downdrift side of the ebb tidal delta. Typically when the ebb delta collapses, the downdrift shoreline advances substantially to a point where there is a notable offset between Longboat Key and Lido Key. Following the onshore migration of the collapsed ebb delta, the sediment is quickly eroded restoring the straight morphology at New Pass.

The results from the wave modeling indicate that there is a divergence zone in the central part of Lido Key. The divergence occurred under a variety of wave conditions. This explains the severe erosion at central Lido Key and the classification of this beach as an erosional “hotspot”. Over the years a tremendous amount of sand has been placed along this stretch of the beach. Most of the nourished sand was transported south onto the Big Sarasota Pass ebb tidal delta.

The shoreline in the vicinity of Big Sarasota Pass is substantially influenced by the frequent Lido Key beach nourishment. Specifically, the advance and retreat of the shoreline at the southern tip of Lido Key is directly related to nourishment activity. A considerable portion is transported along the
shoreline and deposited at the southern tip of Lido Key. This process can cause shoreline to fluctuate on the order of 200 m. A large portion of the sediment is eventually transported onto the ebb tidal delta. Another important pathway for the sediment to reach the ebb tidal delta is along the offshore bar. The detachment of the offshore bar from the beach and the attachment to the ebb tidal delta can be identified from some of the aerial photos.

Two fairly persistent trends at the downdrift shoreline of Big Sarasota Pass are identified. The northern Siesta Key headland has experienced erosion since the 1960s after the sand supply from the inner channel of Big Sarasota Pass was terminated by the construction of sea walls. Over the last 40 years, no accumulation was observed at that point. However, downdrift of the headland, a persistent shoreline accretion was observed over the last 40 years. The pattern of shoreline advance is related to the location and timing of the swash bar attachment.
Conclusions

- Both New Pass and Big Sarasota Pass are mixed-energy tidal inlets with New Pass illustrating a straight morphology and Big Sarasota Pass a highly offset morphology.

- The shoreline in the vicinity of both inlets fluctuates as much as 200 m in a time scale of only few years. The shoreline fluctuation is controlled by both wave and tide forcing in addition to artificial supply from beach nourishment.

- The sediment bypassing at New Pass can be explained by a modified ebb tidal delta breaching model. The breaching is initiated by channel dredging. After the channel dredging a portion of the downdrift ebb tidal delta migrates onshore, creating a notable offset between Longboat Key and Lido Key. This sediment is quickly eroded restoring the straight morphology.

- At Big Sarasota Pass, the sediment is transported across the entire shallow ebb tidal delta with minor interruptions. This particular morphology has been maintained by natural processes over at least the last 65 years.
Two fairly persistent trends at the downdrift shoreline of Big Sarasota Pass are identified. The northern Siesta Key headland has experienced erosion since the 1960s after the sand supply from the inner channel of Big Sarasota Pass was terminated by the construction of sea walls. Downdrift of the headland, a persistent shoreline accretion was observed over the last 40 years, the pattern of which is related to the location and timing of the swash bar attachment.

The results from the wave modeling indicate that there is a divergence zone in the central part of Lido Key. The divergence occurs under a variety of wave conditions. This explains the severe erosion at central Lido Key and the classification of this beach as an erosional “hotspot”.

Anthropogenic alteration, dredge and fill activity in the bay, dredging of the Intracoastal Waterway, shoreline stabilization, inlet maintenance dredging, and beach nourishment are critical factors when examining historical morphologic changes along an extensively developed coastline.
References


Coastal Planning & Engineering (CPE), 1993c. Wave Refraction and Sediment Transport Study of New Pass and Big Sarasota Pass, Sarasota County, Florida. Submitted to the City of Sarasota.


Appendix I – Rectified Time-series Aerial Photographs