EVALUATION OF BEACH EROSION UP-DRIFT OF TIDAL INLETS IN SOUTHWEST AND CENTRAL FLORIDA, USA

Mohamed A. Dabees [1] and Brett D. Moore [1]

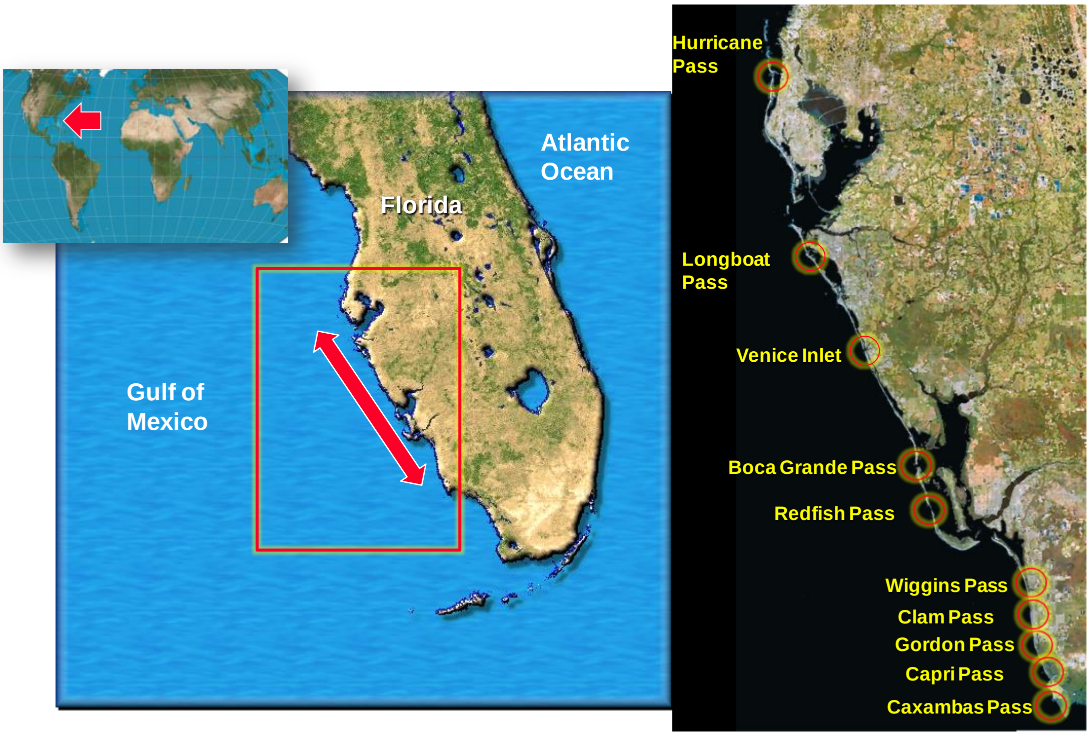
The paper discusses the analysis of up-drift beach erosion near selected tidal inlets due to natural evolution and anthropogenic influence. Large scale beach erosion adjacent to tidal inlets occurs due to mixed conditions of natural inlet evolution and anthropogenic change. Typically, beach erosion is expected on the downdrift side of many inlets as they can present a littoral barrier and cause sand deficit to the beaches downdrift. This paper focuses on beach erosion on the up-drift side of several selected inlets in Southwest and Central Florida, USA. The analysis includes evolution of the selected tidal inlets from the time they were naturally opened to existing conditions. The analysis of these case studies indicated the role of ebb shoal features in stabilizing shorelines adjacent to inlets. In cases where up-drift beach erosion occurred, ebb shoals features were significantly asymmetric in shape or depleted below their equilibrium volumes.

Keywords: Beach erosion; tidal inlets; long-term morphology, numerical modeling, Florida, Gulf of Mexico.

INTRODUCTION

Barrier Islands separated by tidal inlets form the majority of the gulf coast of southwest and central Florida. The dynamics and time scale of tidal inlets and barrier island evolution present a challenge to coastal management near inlets. The shoreline and beach plan form near inlets are primarily influenced by wave current interaction over ebb shoal deltas within the inlet area of influence. Tidal inlet morphologic features such as ebb shoals and flood shoals are part of an interactive sand-sharing system that evolves toward and around dynamic equilibrium under sediment transport produced by waves and tidal currents.

This paper presents analysis of chronic beach erosion problems near tidal inlets in Southwest and Central Florida on the Gulf of Mexico coastline. **Figure 1** shows the regional coverage of the study area and included inlets. The predominant sand transport along that part of the coastline is from north to south.



[1]Humiston & Moore Engineers, 5679 Strand Ct., Naples, FL, 34110,USA
Email, md@humistonandmoore.com

Figure1. Regional coverage of study area

Beach erosion near tidal inlets can be attributed to natural inlet evolution due to inlet opening or migration, inlet dynamics of wave /current interaction and storm events. Erosion near tidal inlets can also be attributed to anthropogenic change in cases where inlet and estuaries are modified, dredged or stabilized with structures for navigation or shore protection.

Typically, beach erosion is expected on the downdrift side of many inlets as they can present a littoral barrier and cause sand deficit to the beaches downdrift. Consequently, many beach management strategies focus on sand bypassing to the downdrift beaches to offset inlet related erosion, especially in cases of inlets with navigation jetties and frequent maintenance dredging. However, monitoring data of several inlets in the study area indicates erosion problems on the up-drift side. This paper focuses on beach erosion on the up-drift side of several selected inlets within the study area. The regional net sediment transport in the study area is southward. Thus downdrift is generally at the south side of inlets and up-drift is typically on the north side of inlets. **Figure 2** shows two types of erosion problems within the study area at Venice Inlet and Gordon Pass. The Venice Inlet case represents the typical downdrift erosion problem at a navigation inlet (Dabees et al 2011). The Gordon Pass case represents an erosion problem on the up-drift side of an inlet in the study area. This paper will investigate the cases where erosion occurs on the up-drift side of inlets.

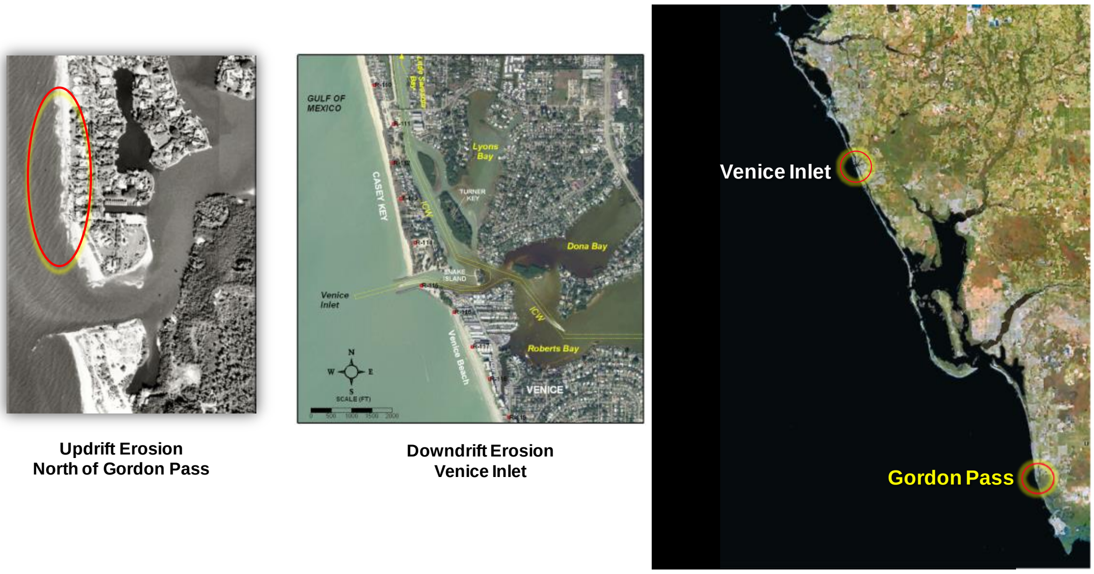


Figure 2. Examples of up-drift and downdrift erosion within the study area

CASE STUDIES

The paper discusses the analysis of up-drift beach erosion near selected tidal inlets due to natural evolution and anthropogenic influence. The analysis includes evolution of the selected tidal inlets from the time they were naturally opened to existing conditions. Numerical modeling of tidal flow, waves and sediment pathways was conducted at several temporal stages. These stages spanned over several decades to include conditions at the time of inlet opening where ebb shoals are not fully formed to mature ebb shoal conditions. For inlets that were subjected to dredging and/or terminal structures, the temporal stages included natural conditions prior to development, immediately following major construction of any coastal structures, and/or dredging events, as well as recent conditions reflecting the cumulative effects of all preceding major events. The analysis compared flow and sediment transport pathways for each inlet at the varying temporal stages to identify general factors that may have caused beach erosion up-drift of tidal inlets within the study area.

Natural Inlet Evolution

Large scale beach erosion adjacent to tidal inlets can occur due to natural inlet evolution such as the opening of a new inlet or channel migration. An example of natural inlet opening within the study area is discussed here through three case studies Hurricane Pass, Longboat Pass and Capri Pass.

Hurricane Pass represents a case where a new inlet is formed through a breach in the middle of a barrier Island. Longboat Pass and Capri Pass represent cases of natural inlet relocation through opening of an inlet up-drift of a pre-existing inlet. Hurricane Pass and Longboat Pass are located in central Florida, at the north part of the study area, while Capri Pass is located in southwest Florida at the south part of the study area (Figure 1).

Hurricane Pass

Hurricane Pass was opened by a major hurricane in 1921which breached Hog Island separating it into Honeymoon island to the north and Caladesi Island to the south. **Figure 3** shows the morphologic change from the inception of Hurricane Pass in 1921 until 1957. During that period, inlet evolution was controlled by natural physical processes of wave, sediment transport and tidal flow. The figure shows formation of the ebb shoal, flood shoal, main channel, and marginal flood channels (Dabees and Kraus, 2005). In this case since the inlet was opened in the middle of a barrier island on the open coast, the beach erosion occurred on both sides of the inlet. The sand eroded from the beach on both sides contributed to the formation of the ebb and flood shoal deltas.

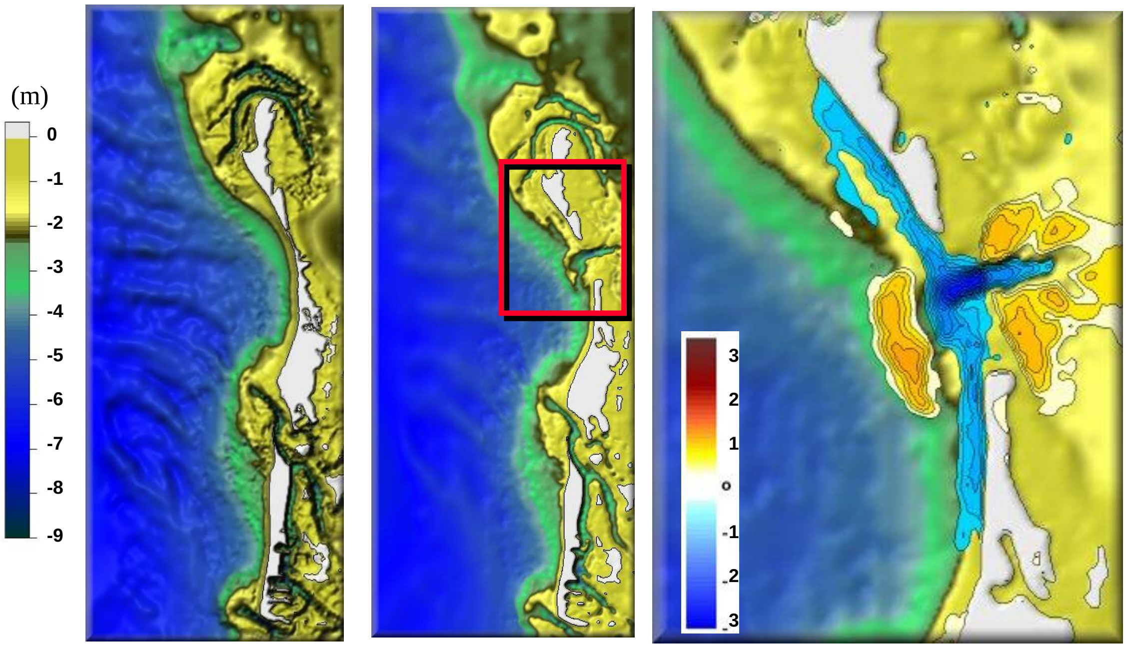


Figure 3. Hurricane Pass bathymetry and morphological change from 1921 to 1957

Longboat Pass

Longboat Pass is located between Anna Maria Island to the north and Longboat Key south. The earliest bathymetric data available are the 1876 and 1883 U.S. Coast and Geodetic Surveys. At that time, Longboat Pass was located approximately 500 meters south of its present location, as illustrated in Figure 4 (the federal channel authorized in 1977 is superimposed on this figure for illustrative reference). The survey of 1876 shows a single inlet and a large ebb shoal with a southwest orientation of the gulf channel. The 1883 survey of the bay indicates another inlet opening to the north creating a dual inlet system. Figure 4 shows the inlet conditions in 1876 and 1957 and shoreline comparison superimposed on the 1957 aerial photo. The inlet configuration in the early 1900's following the opening of the inlet up-drift of the precedent consisted of a two-channel system.

Because the original inlet was more restrictive, the newer inlet became more dominant as it gradually captured a larger share of the tidal prism. This dual inlet process continued until the south inlet closed in the 1950s. Onshore movement of the ebb shoal at the closed inlet provided a large volume of material to the down-drift beach (Longboat Key) and formation of the active ebb shoal to the north. Formation of the new ebb shoal caused significant erosion on the north side of inlet, along the south end of Anna Maria Island. Comparisons of 1880s and 1955 surveys indicate over 2 million cubic meters eroded from the beach and nearshore shoals along Anna Maria Island to form the Longboat Pass shoal system (Dabees and Kraus, 2008). Closure of the old inlet in the early 1950s and the onshore migration of the ebb shoal resulted in formation and growth of a sand spit at the north end of Longboat Key. The seaward advance of the shoreline at the south side of the inlet coupled with the shoreline retreat on the north side created a shoreline offset between the two sides of the inlet.

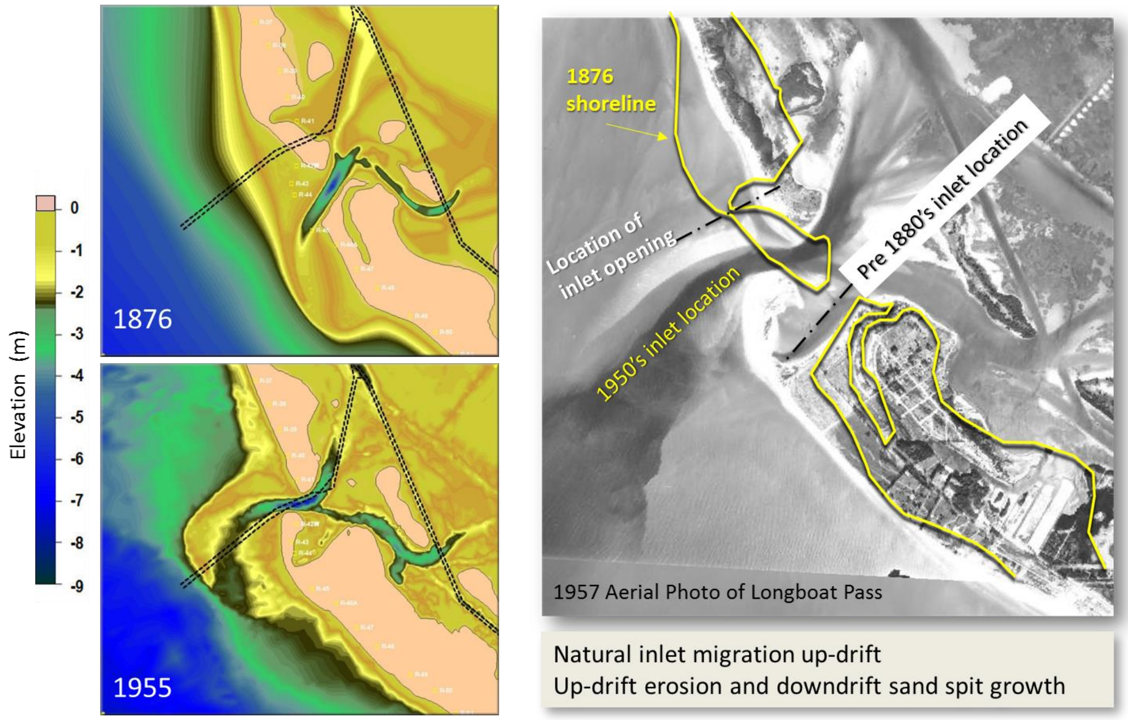


Figure 4. Longboat Pass bathymetry and shoreline change from 1876 to 1957

Figure 4 shows the natural evolution, inlet migration and shoreline change from 1876 to 1957. The figure shows the up-drift beach erosion following the natural relocation of the inlet north of the previous location of the inlet and its ebb shoal.

Capri Pass

Capri Pass is a tidal inlet in southwest Florida at the north side of Marco Island. Similar to Longboat Pass, the inlet was opened on the up-drift side of another inlet (Big Marco Pass) in the 1960's. Figure 5 shows the inlet configuration in 1969 two years after Capri Pass was opened and comparison of recent conditions represented by 2011 aerial photos with the 1965 shoreline before Capri Pass opened. The opening of Capri Pass created a dual inlet system of Capri Pass and Big Marco Pass separated by a small island (Coconut Island) and by a large and complex ebb shoal system (Dabees and Kraus, 2004). Similar to the Longboat Case, the reduction of tidal prism of the original inlet resulted in onshore migration of its large ebb shoal rendering the pass more restrictive to tidal flow. The newer inlet became more dominant as it gradually captured a larger share of the tidal prism. This dual inlet process continued until the south inlet closed in the 2000's. Onshore movement of the ebb shoal at the closed inlet provided a large volume of material to the down-drift beach (Marco Island) and formation of the active ebb shoal to the north. Formation of the new ebb shoal caused significant erosion on the north side of Capri Pass, along the south end of Sea Oat Island creating the up-drift beach erosion as shown in Figure 5, which compares the 1965 and 2011 shorelines.

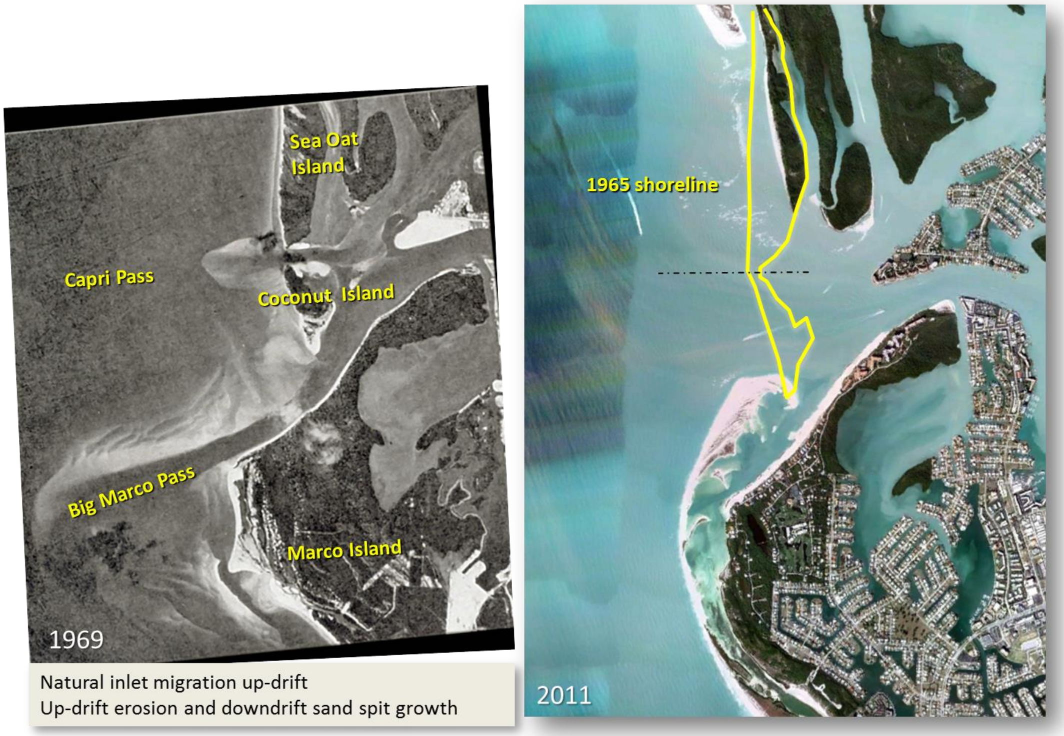


Figure 5. Capri Pass inlet and adjacent beaches 1960's to present conditions

Numerical modeling and data analysis at all inlets included in this study were done to evaluate the physical processes that cause beach erosion on the up-drift side of some inlets.

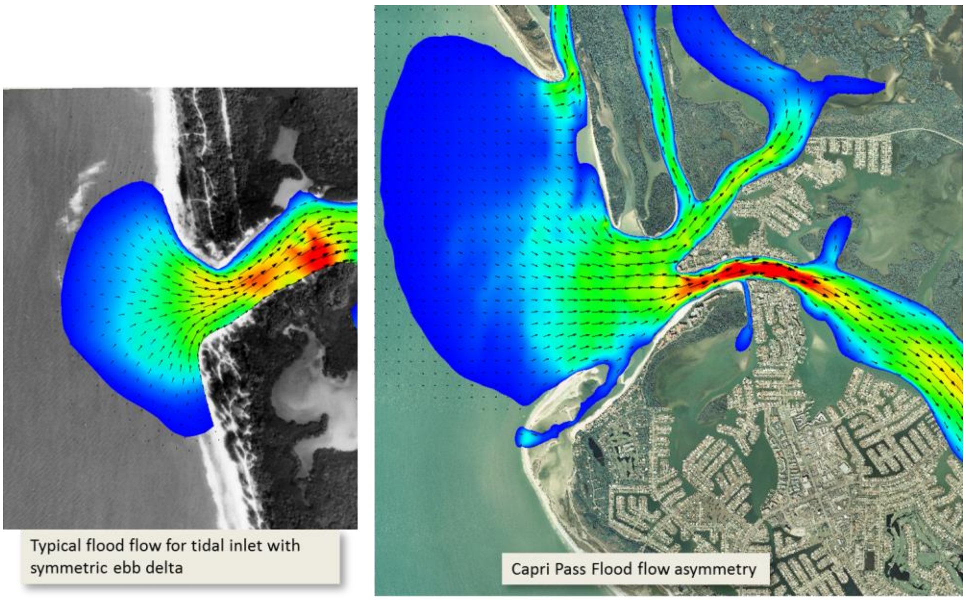


Figure 6. Tidal flood flow velocities at a typical inlet compared to Capri Pass

Figure 6 shows a comparison of flood flow velocities at a typical tidal inlet with symmetric ebb delta and the flood flow at Capri Pass. The figure shows the up- drift to downdrift symmetry of the flood tidal flow in the case of the typical inlet with symmetric ebb shoal delta and similar shoreline positions on both sides of the inlet. However, in cases where large offsets of shoreline positions and asymmetric ebb shoal deltas as in Capri Pass, the flood flow asymmetry results in increased flow velocities along the up-drift beaches.

Examples of natural evolution within the study area were discussed here through three case studies Hurricane Pass, Longboat Pass and Capri Pass. The analysis of these inlets was focused on periods influenced mainly by natural evolution. The Hurricane Pass case provided background on morphology change following natural opening of a tidal inlet. As shown in the Hurricane Pass case the morphology change near the inlet included nearshore beach erosion at up-drift and downdrift beaches. The beach erosion provided sand supply for formation of the flood and ebb shoal morphologic features to support the natural balance between the tidal prism and littoral drift influencing the inlet. Once the formation of inlet morphologic features nears the equilibrium volumes, beach erosion rates due to inlet processes are gradually reduced.

The Longboat Pass and Capri Pass demonstrated cases where beach erosion on the up-drift side along with large scale accretion on downdrift sides occurred. The up-drift beach erosion occurred due to the ebb shoal asymmetry and shoreline positions relative to inlet location. In such cases the ebb shoal asymmetry was created through natural processes a new inlet opening next to an existing inlet with a mature ebb shoal delta.

Anthropogenic Change

Large scale beach erosion adjacent to tidal inlets also occurs due to mixed conditions of natural inlet evolution and anthropogenic change. Anthropogenic change affecting inlet evolution may include bay and shoreline development, inlet structures, and cumulative effects of inlet and ebb shoal dredging for inlet maintenance and/or beach nourishment.

Ebb shoals typically contain substantial quantities of beach-quality material and offer a potentially significant economic advantage as a borrow source over offshore sources because of proximity to the beach. However, ebb shoals are part of an interactive morphologic system that evolves towards dynamic equilibrium under sediment transport produced by waves and tidal currents. Mature ebb shoals allow a maximum amount of sand to bypass an inlet to the downdrift beach. Mehta, et al. (1996) reviewed the acting processes, listed inlets in Florida where ebb shoals have been mined, and identified needs for predictive technology to assess the consequences of ebb-shoal mining.

Dredging of inlets for navigation channel maintenance and mining of ebb shoals for beach nourishment interrupts natural bypassing and may contribute to inlet-related beach erosion. Cialone and Stauble (1998) reviewed eight ebb-shoal mining projects on the Atlantic and Gulf coasts. Their analysis indicates varying responses ranging from beneficial to detrimental. The main detrimental impact was chronic downdrift beach erosion at some sites. Detailed analysis of cumulative effects of dredging on evolution of tidal inlets within the study area is discussed in Dabees and Kraus (2008), Dabees and Moore (2010), and Dabees et al (2011). In this paper examples of erosion on the up-drift side of tidal inlets are discussed through two case studies within the study area, Wiggins Pass and Gordon Pass.

Wiggins Pass

The case study of Wiggins Pass is for an inlet in southwest Florida without stabilization structures which is maintained for navigation through dredging. Wiggins Pass has a natural channel depth of approximately 2.5m and relatively small ebb shoal (approximately 400,000 m3). The inlet was first studied in 1980 (USACE 1980) and was first dredged by Collier County, Florida, in 1984. Before the first dredging, the critical depth for navigation at the seaward limit of the ebb channel was approximately 1.8 m MWL at a distance greater than 250 m offshore.

The top part of **Figure 7** shows the contour map of the inlet system in the 1970’s and 2000’s. The 1970’s show conditions prior to initial dredging of the inlet and the 2000’s show conditions of Wiggins Pass prior to the 2007 maintenance dredging. The 1970’s conditions show a near symmetric ebb delta while the 2000’s conditions, after frequent dredging (average 2-year interval since 1984) show significant southward migration of ebb shoal features and depletion of ebb shoal features north of the inlet channel. In recent years, shoaling has typically occurred rapidly after dredging is completed resulting in shallower navigation depths than those which existed prior to the initial dredging of the inlet in 1984. The frequent dredging depleted the up-drift lobe of the ebb shoal and resulted in chronic beach erosion, inlet channel migration, and ebb shoal migration to shallower water. To safeguard navigation, more emergency dredging and expanded dredging templates were implemented, which exacerbated the problem. Detailed wave and sediment transport modeling was done to identify morphologic features and sediment pathways for conditions before the 1984 initial dredging and present conditions. The modeling was done to evaluate dredging effects on channel and inlet evolution.

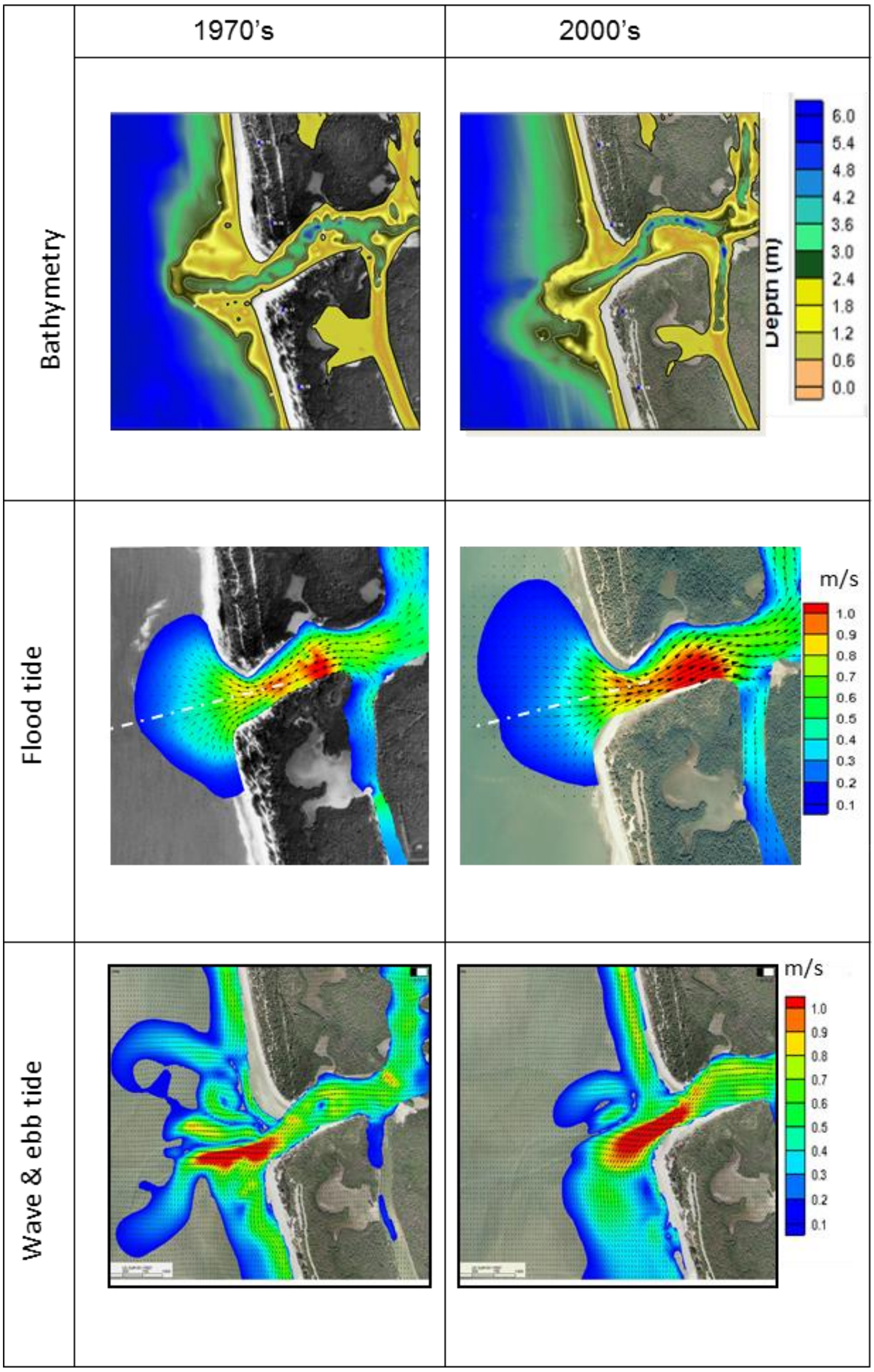


Figure 7. Wiggins Pass conditions and model results for 1970's and 2000's conditions.

Model results illustrated in Figure 7 show detailed maximum flood velocities for an average tide at Wiggins Pass for conditions of 1970’s and 2000’s. The comparison of the two conditions shows the asymmetry of nearshore flood tide flow in the 2000’s conditions. Detailed wave and sediment transport modeling using CMS simulated wave and current interaction and sediment pathways for both conditions. The model results indicate the effects of erosion of the ebb shoal bar and shoreline retreat on the north side of the inlet. The 1970’s condition indicates how the shoal provided a pathway for littoral transport to bypass the inlet and shelter the shoreline from direct wave action. The shoal therefore provided a level of natural shoreline erosion control and reduced sediment transport into the inlet.

The comparison of wave/ current flow for the ebb tide condition and northwest waves indicates the effect of cumulative dredging on ebb shoal evolution and resulting nearshore morphology change. For the 1970’s condition the symmetric ebb shoal lobes provided channel banks on both sides to extend the ebb jet seaward. The ebb currents created the symmetric ebb shoal by allowing sediment carried by the ebb jet to be deposited on both the north side as well as south side of the inlet. Cumulative effects of the dredging depleted the north side of the ebb shoal. The absence of an adequate ebb shoal on the north side of the channel allowed the momentum of wave driven currents to force the ebb jet to the south. This resulted in southward migration of the shoal, and as the ebb jet migrated south, the majority of sediment carried by the currents was deposited on the south side of the inlet. Additionally, the model results show the increase in flow velocities in the north side of the inlet causing the shoreline retreat north of the inlet.

Gordon Pass

Gordon Pass is located in the City of Naples, Florida. It is part of a federally authorized navigation project. This inlet has been stabilized with a terminal groin and a jetty on the north and south banks of the pass, respectively in the 1960's. Historical survey data show that from 1930’s to 1957 prior to the commencement of dredging, the Gordon Pass shoal system had been growing. This growth was in response to increases in tidal prism from the closure of an inlet that existed approximately 1 mile south of Gordon Pass in the 1940’s, and from development of tributary waterways, primarily along Naples Bay and the Port Royal Canal system. The data also shows that the inlet ebb shoal began decreasing in volume in the 1990’s as a result of the cumulative navigation maintenance dredging. From 1960 to 2003, the inlet was dredged 7 times at an average interval of approximately 7 years. The study shows that the cumulative effects of management of the inlet system through maintenance dredging and downdrift beach disposal have been insufficient in addressing the erosion of adjacent beaches to the inlet.

The top part of **Figure 8** shows the contour map of the inlet system in the 1930’s, and present conditions. The 1930's represent conditions prior to any development in the bay and inlet system. The figure is based on the earliest bathymetric data available from the 1930’s by the U.S. Coast and Geodetic Surveys. The surveys of the 1930’s have provided means to quantify the natural morphologic features at that time and includes the conditions in the nearshore and on adjacent beaches. At that time there was no apparent offset between the shorelines north and south of the pass. The adjacent beaches to Gordon Pass had a wide shallow swash zone on both sides of the inlet. The wide tidal swash and ebb shoal features provided a natural means to bypass sand from one side of the inlet to the other.

In the early 1960’s Gordon Pass became an authorized Federal Navigation Channel, and the inlet channel was stabilized with a jetty at the south side to reduce sand loss back to the inlet as a result of anticipated sand placement of dredged sand on Keewaydin Island. At that time a rock groin field already existed north of the inlet. Since the initial dredging in 1962, the inlet has been maintained with periodic dredging on an average 7-year interval.

Figure 8 shows example comparison of simulated flow due to tides and waves for natural conditions (1930's) and existing conditions (2000's) for Gordon Pass, Naples, Florida. As discussed in the previous case, the model results indicate the asymmetry in flow patterns and increased flow velocities nearshore for the 2000's conditions compared to 1930's conditions. This asymmetry resulted in increased magnitude of longshore current on the up-drift side of the inlet as shown in the figure.

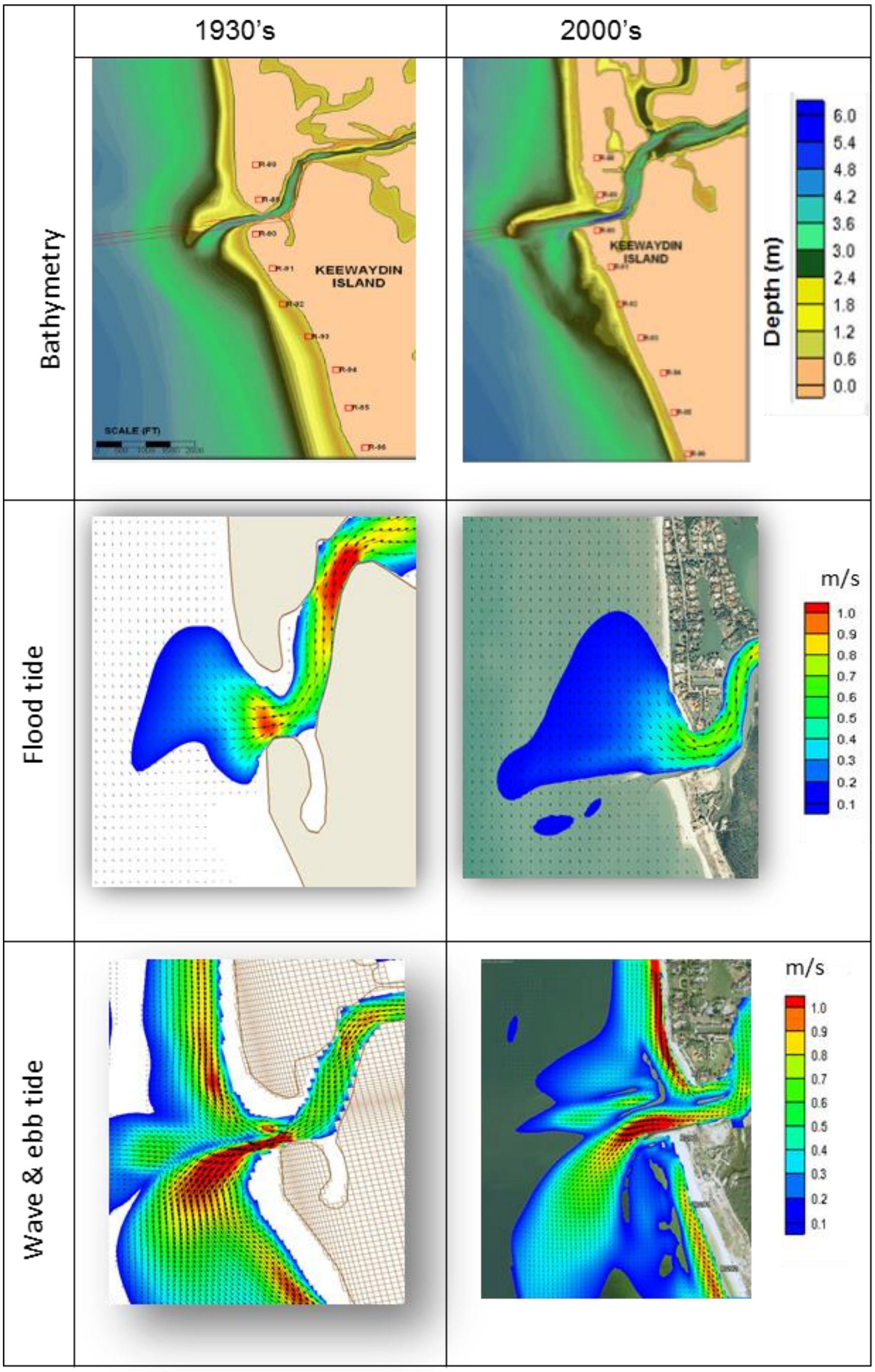


Figure 8. Gordon Pass conditions and model results for 1930's and 2000's conditions.

CONCLUSIONS

This paper discusses beach erosion on the up-drift side of tidal inlets in southwest and central Florida. Typically beach erosion is expected on the downdrift side of many inlets as they can present a littoral barrier and cause sand deficit to the beaches downdrift. The analysis of these case studies indicated the role of ebb shoal features of stabilizing shorelines adjacent to inlets. In cases where up-drift beach erosion occurred, ebb shoals features were significantly asymmetric in shape or depleted below their equilibrium volumes. Ebb shoal asymmetry was also evident for inlets that opened up-drift of an older mature inlet, cumulative effects of inlet and ebb shoal dredging, or inlets with terminal structures that influence natural flow and sediment transport patterns. The opening of a new inlet through natural inlet evolution or through inlet management practices may create the ebb shoal asymmetry that can lead to up-drift beach erosion. Data and model results for each of the discussed cases are analyzed to understand common factors that contribute to up-drift beach erosion. The goal of the analysis is to evaluate long-term effects of inlet management practices as well as concepts such as depth over-dredging and up-drift advanced dredging designed to reduce dredging frequency. The data and analysis indicate that in some cases the navigation maintenance dredging helps to stabilize the channel location. However, in other cases where frequent dredging and/or mining large portions of ebb shoals for beach nourishment may alter the configuration of the ebb shoal morphologic features. This may contributes to morphologic responses such as channel migration and beach erosion.

ACKNOWLEDGMENTS

This study was conducted by Humiston and Moore Engineers, Naples, Florida. The authors would like to acknowledge the support of West Coast Inland Navigation District, Florida Department of Environmental Protection, Comax Partners, and Collier County throughout the design and permitting process for the various projects which necessitated this analysis. The authors would also like to acknowledge the Coastal Inlets Research Program, U.S. Army Corps of Engineers (USACE) for the developments and technical support of inlet and coastal modeling tools utilized in this analysis.

REFERENCES

Cialone, M.A., and Stauble, D. K. 1998. Historical Findings on Ebb Shoal Mining. *J. Coastal Research*. 14(2), 537-563.

Mehta, A.J., Dombrowski, M.R., and Devine, P.T. 1996. Role of Waves in Inlet Ebb Delta Growth and Some Research Needs Related to Site Selection. *J. Coastal Res.*, SI 23, 121-136.

Dabees, M. A. and Kraus, N. C. (2004): Evaluation of Ebb-Tidal Shoals as a Sand Source for Beach Nourishment: *Proc. 17th Conf. on Beach Preservation Technology FSBPA*, Tallahassee, FL, 21pp

Dabees, M. and Kraus, N. C. (2005): General Methodology for Inlet reservoir Model Analysis of sand Management Near Tidal Inlets. *Proc. Coastal* Dynamics 2005, 14pp.

Dabees, M. A. and Kraus, N. C. (2008): Cumulative Effects of Channel and Ebb Shoal Dredging on Inlets in Southwest Florida. *Proc. International Conf. on Coastal Engineering 2008*, pp. 2303-2315.

Dabees, M. A., and Moore, B. D. (2011) Inlet Evolution Modeling of Multiple Inlet Systems In Southwest and Central Florida. Journal of Coastal Research, Special Issue 59.

Dabees M. A., Moore, B.D., and Humiston, K. (2011) Evaluation of Tidal Inlets Channel Migration and Management Practices in Southwest Florida , *Proc. Coastal sediments 2011, WS*.