APPENDIX 17

Inlet Management Study for Bunces Pass And Pass-A-Grille Inlet

INLET MANAGEMENT STUDY FOR BUNCES PASS AND PASS-A-GRILLE INLET
USF COASTAL RESEARCH LABORATORY

Study Components

1. Physical and historical data collection and analysis
   a. Document historical morphology of inlets and beaches (includes north Shell Key).
   b. Collect field data on existing inlet and beach morphology, sand characteristics, and currents for numerical model construction.

2. Numeric modeling and Sediment Budget to quantify:
   a. Wave and current characteristics of inlets.
   b. Sediment transport processes through the inlets.
   c. Morphological evolution of inlets, shoals, and adjacent beaches from months to 5 years into the future. Specific modeling scenarios to be determined with Technical Advisory Committee input during the project.
   d. Inlet – beach interactions along adjacent shorelines.
   e. Develop a sediment budget for the dual inlet system (sand quantities entering and leaving defined dual inlet system components).

3. Evaluate inlet management strategies that include:
   a. Maintenance dredging and ebb shoal borrow area dredging with focus on Pass-a-Grille ebb shoal as sand source for beach nourishment.
   b. Balancing the sediment budget (alternatives to balance the sand entering the system compared to sand lost from the system).
   c. Enhancing the performance and longevity of adjacent beach nourishments.

4. Case Study 1. Erosion and mitigation of north Mullet Key Beach
   a. Clarify and quantify processes that cause beach erosion
   b. Develop alternative mitigation measures to restore Ft. De Soto's North Beach

5. Case Study 2. Stability and evaluation of North Shell Key Pass channel
   a. Questions to address:
      i. How the Pass closed?
      ii. What sand sources caused the closure?
      iii. What conditions led to Pass closure?
      iv. What conditions could favor a sustained Pass?
      v. Will the channel stay open for an extended period of time?
      vi. How will an open channel influence circulation in the Preserve back bay?
      vii. How will an open channel impact sediment and water currents of Pass-a-Grille inlet?
      viii. How will an open channel impact Shell Key beach conditions?

Inlet Management Study for Pass-A-Grille and Bunces Pass, Pinellas County, Florida

Final Report

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Executive Summary

Pass-A-Grille and Bunces Pass inlet system is located at the mouth of Tampa Bay and is part of the inlet complex of the Tampa Bay entrance. The inlet system of Pass-A-Grille and Bunces Pass has experienced significant hydrodynamic and morphologic changes over the past 140 years. An inlet jetty, in addition to seawalls, was constructed to stabilize the northern side of Pass-A-Grille inlet. The south side of Pass-A-Grille inlet and the entire Bunces Pass are not structured.

Major hydrodynamic and morphologic changes at the Pass-A-Grille and Bunces Pass system include the closure of PAG South Channel, the development of the entire Shell Key Island that separates Pass-A-Grille inlet and Bunces Pass, and large-scale morphology change along northern Mullet Key associated with attachments of large sand bodies. One of the consequences of the development of Shell Key is the closure of the North Shell Key Pass at the southeastern corner of the Pass-A-Grille inlet. Despite the regional scale morphology changes, the main channels of Pass-A-Grille inlet and Bunces Pass have remained in similar locations with similar configuration over the past 140 years.

In this inlet management study, a series of sediment budgets was developed for the Pass-A-Grille and Bunces Pass inlet system. The patterns of sediment transport and morphology change are complicated with large temporal and spatial variations. The two inlets are parts of the inlet complex at the mouth of Tampa Bay and situated on the large Tampa Bay ebb shoal complex. Net onshore sediment transport in the morphology form of initiation, growth, onshore migration, and eventual shoreline attachment of large sand bodies played a significant role in longer-term sediment budget. This net onshore sand transport resulted in the development of the entire Shell Key and the attachment of a large sand body at the northern half of Mullet Key. The development of a longer-term sediment budget in this study focused on this net onshore transport over the past 50 years. Once Shell Key was developed and the attachment at northern Mullet Key was completed, substantial shoreline adjustment along the Gulf-facing beach occurred driven by longshore sand transport. The shorter-term sediment budget over the past 20 years developed in this study focused on the sand redistribution by longshore transport. It is worth emphasizing that due to significant temporal variations, caution should be exercised when applying the sediment budget developed here over a different time period, e.g., in the future.

The sediment budget associated with net onshore sand transport was developed over a 50-year period, from 1966 to 2016. Approximately 102,000 m^3/year of sand were gained at Shell Key, resulting in the formation of the entire island, and 60,000 m^3/year were gained at Mullet Key, leading to the beach accretion at the northern end.

Over the past 20 years, the entire Pass-A-Grille ebb shoal is receiving approximately 80,000 m^3/year of sand. This is in addition to the 40,000 m^3/year removed for beach nourishment projects. Therefore, accounting for the artificial sand removal, the Pass-A-Grille ebb shoal is gaining 120,000 m^3/year of sand, of which approximately 90,000 m^3/year, or 75%, are gained over the northern flank of the ebb shoal, and 30,000 m^3/year, or 25%, are gained over the southern flank. About 21,000 m^3/year of sand is gained from the beach along Long Key, and 1,000 m^3/year from the beach along Shell Key. Nearly 100,000 m^3/year of sand is gained through net onshore sand transport from the greater Tampa Bay ebb shoal. This balanced sediment budget at Pass-A-Grille inlet supports the rate and location of sand borrowing at the ebb shoal over the past 30 years. The sand borrowing has been conducted in the distal portion of the northern flank of the ebb shoal, at a rate of approximately 40,000 m^3/year. Based on the budget developed by this study, the northern flank of Pass-A-Grille ebb shoal would recover at roughly twice the above borrow rate. The borrowed sand was used to nourish Long Key, specifically Upham Beach at the northern end and Pass-A-Grille Beach at the southern end. The sediment budget here also support these nourishment locations.

The entire Bunces Pass ebb shoal is receiving approximately 34,000 m^3/year of sand over the past 20 years. No artificial sand removal or input took place at the Bunces Pass inlet system. Approximately 8,000 m^3/year, or 24%, are gained over the northern flank of the ebb shoal, and 26,000 m^3/year, or 76%, are gained over the southern flank. About 20,000 m^3/year of sand is gained from the beach along Mullet Key, and negligible amount from the beach along Shell Key. Roughly 14,000 m^3/year of sand are gained through net onshore sand transport from the greater Tampa Bay ebb shoal.

A numerical model, using the Coastal Modeling System (CMS) developed by the U.S. Army Corps of Engineers, was constructed and verified with extensive field measurements. The model run was conducted over a 1.5- to 2-year period to simulate medium-term changes during typical wave conditions. In addition, a short-term, 2-month run was conducted to simulate inlet changes during extreme storm conditions, synthesized based on the active 2004 hurricane season.

Eleven management alternatives for Pass-A-Grille and Bunces Pass inlet system are examined based on the historical morphology changes, *in-situ* field data, sediment budget, and the numerical model developed by this study. Both inlets are quite wide and deep with no major navigation issues in the past 70 years. The tidal prisms are 68.6×10^6 m^3 at Pass-A-Grille inlet and 48.3×10^6 m^3 at Bunces Pass. Since both inlets have a relatively large ebb shoal, 5,538,000 m^3 at Pass-A-Grille and 8,922,000 m^3 at Bunces Pass, this inlet management study focused on various dredging alternatives with goals of providing sand for beach nourishment. In addition, two special topics are investigated: the closure and potential re-opening of North Shell Key Pass and erosion along northern Mullet Key beach.

Alternative 1 represents the baseline no-action scenario, the results from which provide comparisons for other alternatives with the goal of examining potential deviations from the existing conditions. Based on the field measurements and modeling results, the ebb jet extends up to 1,500 m from the mouth at both inlets. The Pass-A-Grille ebb jet bends to the south while the Bunces Pass ebb jet bends to the north, resulting in a converging pattern of the two ebb jets. The flood flow follows a different spatial pattern as the ebb flow. Instead of a jet feature, the flood flow converges into the inlet. This converging flow pattern generates a relatively strong flow along the beach adjacent to the inlet, which plays a significant role at the erosional hotspots at both Mullet Key and Shell Key. Wave modeling results reveal that the wave height along the northern portion of Shell Key is considerably higher than along the adjacent shoreline under a variety of incident conditions, explaining the persistent erosive trend observed along that stretch of shoreline over the past 15 years. The wave modeling also reveals a divergent zone at northern Mullet Key, which leads to a longshore sand transport gradient and subsequently beach erosion.

Alternative 2 investigates the option of using the beach quality sand along the Pass-A-Grille channel margin linear bar for beach nourishment projects. The dredge pit extends along the channel margin linear bar to seaward of the terminal lobe, yielding roughly 600,000 m^3 of sand and creates a more distinctive and straight channel across the outer portion of the Pass-A-Grille ebb shoal. The ebb flow becomes more channelized by the dredging, with stronger flow in the dredged channel, accompanied by reduced flow speed along the two flanks of the ebb jet. The influence of the channel dredging on flood flow is not significant. The Alternative 2 dredge pit results in increased wave height at the northern corner of Shell Key, which has been accreting and extending eastward especially over the past 15 years and led to the closure of the North Shell Key Pass. The increased wave height may result in more active sediment transport and subsequently more beach accretion to the east. The models yields a sedimentation rate of 163,000 m^3/year in the entire dredge pit. At this rate, the 600,000 m^3 dredge pit will be filled in 3.7 years assuming that the sand source for the infilling will not be depleted. The increased water depth in the distal portion of the ebb shoal due to this channel dredging may have some impact on sediment bypass. However, since the pre-dredging water depth in the terminal portion is relatively deep, the initial impact to sediment bypassing is not expected to be significant. Alternative 2 is recommended as a Pass-A-Grille inlet management option due to the efficient dredge pit recovery.

The Alternative 3 scenario involves dredging the northern flank of the Pass-A-Grille ebb shoal. The design dredge pit, which is roughly 500 m alongshore and 1,000 m across shore and yields roughly 1,600,000 m^3 of sand, simulates a combination of several dredging events since the mid-1980s. The overall flood and ebb flow fields are similar to that under the existing condition. The influence of the large dredge pit to the wave field is largely confined to the pit and the immediate surrounding areas. Wave conditions near the shoreline remain similar to the baseline case. An annualized sedimentation rate of 25,000 m^3/year is computed by the model. With this rather modest infilling rate, the large Alternative 3 dredge pit will take roughly 64 years to fill. The relatively slow infilling rate, as compared to the sediment budget of the northern flank of ebb shoal discussed above, is influenced by the rather deep pre-dredging water. In other words, the dredge pit is receiving a portion of the sedimentation over the northern ebb shoal. Since the designed dredge pit is does not extend across the terminal lobe, it does not have significant influence on sediment bypass across the terminal lobe. Alternative 3 is recommended as an inlet management option due to its minimal influences on current and wave fields, as well as sediment bypassing. The large dredge pit examined here should be viewed as an upper limit design.

Alternative 4 scenario involves dredging and extending Bunces Pass channel, yielding roughly 1,100,000 m^3 of sand. Since no dredging has been conducted at Bunces Pass and its ebb shoal in the past, this alternative represents a new option. The overall flow field and the configuration of the ebb jet are similar to that under the existing condition, although the ebb jet through the dredged channel is narrower and more channelized. The influence of the channel dredging on flood flow is not significant. The Alternative 4 dredge pit has modest influence on the wave field, mostly limited to the offshore area. Wave conditions near the shoreline remain similar to the baseline case. Rather rapid sedimentation in the dredge pit, at an annualized rate of 405,000 m^3/year is predicted by the model. The Alternative 4 dredge pit would take slightly over 2.7 years to fill assuming adequate sand source is available in the nearby areas. Since the dredge pit cut through the entire shallow terminal lobe, considerable influence to the sediment pathway and obstruction to sand bypassing around the terminal lobe are likely to occur, at least during the 2.7 years before the dredge pit is filled. The model predicted landward migration of the shallow ebb shoal on the southern flank particularly under storm conditions. The severely eroding shoreline along the northern Mullet Key would benefit from this likely onshore sand transport, although it may take a few years for the sand to reach the beach. Alternative 4 is recommended for future consideration as a sand source for beach nourishment projects and an experiment to artificially initiate onshore sand transport to mitigate beach erosion along northern Mullet Key.

Alternative 5 involves dredging the relatively shallow outer lobe of Bunces Pass ebb shoal. The 200-m wide dredge pit extends approximately 1000 m in the alongshore direction across the Bunces Pass outer lobe, yielding 1,100,000 m^3 of sand. The overall modeled flood and ebb flow fields are similar to that under the existing condition. The influence of the dredge pit to the wave field is largely confined to the pit and the immediate adjacent areas. Wave conditions near the shoreline remain similar to the baseline case because the large area of shallow water between the dredge pit and the nearshore zone is not altered. Since the dredge pit is located at the terminus of the Bunces Pass ebb jet, and mostly surrounded by shallow water, rapid sedimentation, at 334,000 m^3/year, is computed by the model driven by ebb flow and wave breaking. The 1,100,000 m^3 dredge pit would be filled in 3.3 years assuming there is adequate sediment supply from the surrounding shallow area. Since the dredge pit cuts across a large portion of the shallow terminal lobe, considerable influence to the sediment pathway and obstruction to sand bypassing may occur initially. However, because the dredge pit would be filled in about 3 years, the influence on sediment pathway and subsequently sand bypassing may be limited to 2-4 years. The model predicted landward and southward (downdrift) migration of the shallow ebb shoal on the southern flank, which would benefit the eroding northern Mullet Key although it may take a few years for the onshore moving sand to accrete to and therefore widen the beach. Similar to Alternative 4, Alternative 5 is recommended for future consideration as a sand source for beach nourishment projects and an experiment to artificially initiate onshore sand transport to mitigate beach erosion along northern Mullet Key.

Alternative 6 scenario involves dredging the terminal lobe of the relict ebb shoal of the closed PAG South Channel, yielding roughly 1,000,000 m^3 of sand. The overall modeled flood and ebb flow fields are similar to that under the existing condition. The Alternative 6 dredge pit has minor influence on wave conditions near the shoreline or in the inlet channel. The CMS model yielded an annualized sedimentation rate of 76,000 m^3/year. At this infilling rate, the 1,000,000 m^3 dredge pit will take roughly 13 years to fill in. The sand will likely come from the two ebb shoals. Alternative 6 is a recommended inlet management option as a sand source for beach nourishment.

Alternative 7 scenario involves beach nourishment along two sections: Pass-A-Grille beach and north Mullet Key beach. The sand is borrowed from the Pass-A-Grille channel (Alternative 2, not recommended) and the relict ebb shoal of the closed PAG South Channel (Alternative 6, recommended). The Pass-A-Grille beach nourishment extends about 1.6 km north of the Pass-A-Grille inlet. The potential impacts of the borrow sites are summarized earlier. Pass-A-Grille beach nourishment has been successful in the last two decades based on monitoring studies (Wang et al., 2016, Roberts and Wang, 2012). The north Mullet Key beach is experience aggressive erosion in the past 15 years. However, due to an adequate buffer zone, the infrastructures landward have not been significantly impacted by the erosion. Since it is likely that the Outback Island will attach to the shoreline in the next 5 years or so, nourishment of northern Mullet Key beach may not be necessary unless the coast is hit by an energetic storm that breaches the island and threaten the infrastructures.

Alternatives 8, 9, and 10 examine the feasibility of three options of re-opening the closed North Shell Key Pass. Alternative 8 scenario represents an aggressive dredging option, with the re-opened North Shell Key Pass being 2.5 m deep and 80 m wide. This aggressive channel re-open alternative involves dredging over an area of 56,200 m^2, 15,800 m^2 of which are presently beach and dunes, and removal of approximately 140,000 m^3 of sand. The overall flood and ebb tidal flow field at Pass-A-Grille inlet and Bunces Pass are similar to that under the existing condition, indicating that the Alternative 8 re-opening of the North Shell Key Pass does not have significant influence on the two major inlets. The small dredged channel has negligible influence on the wave field, both regionally and locally. The model predicted modest improvement of the circulation in the northern portion of Shell Key Preserve. Based on the historic morphologic evolution and modeling results, the Alternative 8 channel would need to be dredged regularly. A 5-year maintenance dredging cycle is estimated based on the modeling results and sediment budget analyses.

Alternative 9 scenario simulates a very modest dredging operation that was conducted in 2013, which was closed within a year. The Alternative 9 dredged channel is 2.5 m deep and 20 m wide. The overall flood and ebb flow fields are similar to that under the existing condition. The small channel has negligible influence on the hydrodynamics of Pass-A-Grille inlet and Bunces Pass. The small dredged channel has negligible influence on the wave field, both regionally and locally. Based on the sediment budget analysis and historical data, the Alternative 9 channel will be completely filled in less than 2 years, requiring a maintenance dredging cycle of about 1 year, which is not practical. The small tidal prism of 900,000 m^3 provides limited benefits to the water circulation in the Shell Key Preserve.

Alternative 10 scenario, which was proposed by a local consulting company, represents a dredged channel of 1.8 m deep and 40 m wide, but with a different orientation as the two previous alternatives. The overall ebb and flood flow fields, as well as wave field, are similar to that under the existing condition. The water-circulation improvement only occurs in a small area in the north Shell Key Preserve. Based on two commonly used inlet stability analysis methods which examine two different aspects of inlet stability, the Alternative 10 North Shell Key Pass will not be able to stay open for an extended period of time. Results from sediment budget analysis indicate that this channel will be completely filled within 2 years. Therefore, an 1- to 2-year maintenance dredging cycle will be required for this alternative.

Alternative 11 scenario extends an existing channel along the Pinellas Bayway and connects with the channel along Oceanview Drive. Both sections of the existing channel appear to be dredged historically. The Alternative 11 connector channel would be approximately 600 m (1800 ft) long. It will provide vessel access to the Oceanview community. The Alternative 11 connector channel does not have any influence on current and wave fields, as well as on the morphology change patterns in comparison with the baseline case. Therefore, other than providing vessel assess for the community along Oceanview Drive to Bunces Pass, Alternative 11 has minimal influence to the Pass-A-Grille and Bunces Pass inlet system. It is beyond the scope of this study to investigate the permitting feasibility for the dredging of the connector channel.

1. Introduction and objectives of the study

The overall goals of this inlet management study are to provide an updated sediment budget for Pass-A-Grille and Bunces Pass inlets, and to identify and quantify the detailed sediment pathways in order to develop or update inlet management plans pursuant to Section 161.142, Florida Statutes. This study also provides an evaluation of inlet management implementation strategies based on field measurements and numerical modeling.

The overall approach of the study combines field measurements and numerical modeling, in addition to compiling existing data and knowledge. This study is conducted in close collaboration with various local, state, and federal agencies including FDEP, Pinellas County, and USACE (ERDC and Jacksonville District), and other potential stakeholders. To achieve the above overall research goals, this inlet management study includes the following three main tasks and subsequent subtasks:

1) Physical and historical data collection and analysis to:
    a. Document historical morphodynamics of the inlets and adjacent beaches (particularly the northern Mullet Key beach and northern Shell Key), and engineering activities;
    b. To provide up-to-date field data on inlet and adjacent beach morphology, sediment characteristics, and hydrodynamics for the grid construction, calibration, and verification of the numerical model, as well as to understand the present state of inlet and beach processes.
2) Numerical model study and application of CEM methodology to quantify:
    a. Wave and current field of the dual-inlet system of Bunces Pass and Pass-A-Grille;
    b. Sediment transport processes through the inlet channels, over the ebb and flood shoals, and along the adjacent beaches;
    c. Short (months to a year)- to medium-term (one to five years) morphological evolution of the inlet, ebb and flood shoals, and adjacent beaches;
    d. Interaction between inlet processes and beach processes along the adjacent shoreline; and
    e. Identify the inlet areas of influence and develop a sediment budget using the method provided in Rosati (2005) and the Coastal Engineering Manual (CEM)

(http://www.publications.usace.army.mil/USACE-Publications/Engineer-Manuals/u43544q/636F617374616C20656E67696E656572696E67206D616E75616C/).

3) Evaluation of inlet management implementation strategies including:
    a. Maintenance dredging and ebb shoal borrow area excavation: Pass-A-Grille ebb shoal has served as the borrow site for several beach nourishment projects in Pinellas County, while Bunces Pass has not been dredged;
    b. Balancing the sediment budget;
    c. Enhancement of performance and longevity of adjacent beach nourishment projects.
    d. Actions at Bunces Pass that may affect Mullet Key and evaluate various alternatives including potential need for staged retreat.

In addition to the above tasks, two local case studies are conducted to examine two areas with special considerations, as requested by Pinellas County. The first special case study concerns the erosion and potential mitigation measures of north Mullet Key beach. North Mullet Key beach has been eroding persistently and rapidly over the past 15 years. A major goal of the proposed study is to understand and quantify the processes that cause the beach erosion and to develop mitigation measures to restore this popular beach in the Ft. De Soto Park. A preliminary study conducted by the USF Coastal Research Lab (Sandoval, 2015) has shown that the morphological evolution of the Gulf-facing Mullet Key beach is controlled by a rather cyclic behavior of the swash-bar complexes over the large Bunces Pass ebb shoal. This study further quantify the above morphology evolution model based on numerical modeling, in addition to analysis of time series aerial photos.

The second special case study concerns the closure of the North Shell Key Pass and potential artificial re-opening of the pass. The recent closure of the North Shell Key Pass has raised some concern about the water quality in the northern portion of the Shell Key Reserve. Options of reopening the pass at the previous location have been explored. A recent reopening in 2013 lasted less than one year. In order to develop a sustainable solution, the following questions are addressed:

1) How did the North Shell Key Pass close?

2) What are the sand sources for the closure?

3) What are the hydrodynamic conditions that lead to the closure of the pass?

4) What are the hydrodynamic and sediment conditions that may favor the existence of a pass at that location?

This study aims at answering the above questions based on historical data (e.g., aerial photos and bathymetry data), measurement and modeling of flow and wave conditions in the vicinity of the pass. The existence of the inlet is analyzed in the context of the evolution of the entire Shell Key.

In the following, a detailed description of each task and the associated sub-tasks is provided, along with the collaborations with various stakeholders and agencies. The following also summarizes the execution and coordination of the Bunces Pass and Pass-A-Grille inlet management study.

A Technical Advisory Committee (TAC) was formed to ensure effective coordination and communication with the various stakeholders. The TAC includes representatives from FDEP, Pinellas County, the USACE Jacksonville District, Tampa Bay Watch, and a resident representative of the Tierra Verde community who is also a University of South Florida physical oceanography professor. In addition, a representative from a consulting company participated in the TAC. The TAC helped with collection of documents and data of past engineering activities from their agency files, including detailed records of inlet dredging and beach nourishment activities. A key task of the TAC is to advise on the numerical modeling alternatives and evaluation of inlet management implementation strategies. Regular meetings between USF researchers and TAC were held to ensure that the progress of the study and particularly the formulation of the modeling alternatives are directed with proper input from the stakeholders and agencies.

Overall, Task 1 of the study provides background knowledge of the greater study area and the project site. Deliverables from Task 1 include: 1) the literature research portion of the final report; 2) a series of databases on hydrodynamic, sediment, and morphologic conditions collected from existing studies; 3) a series of databases on present hydrodynamic, sediment, and morphologic conditions collected by this study, and 4) an up-to-date topographic and bathymetric survey data collected by this study in a format consistent with FDEP's *Monitoring Standards for Beach Erosion Control Projects, (FDEP, 2004).*

Task 2 of the study focuses on numerical modeling using the CMS and development of a sediment budget. The numerical models, CMS-WAVE and CMS-FLOW, developed by the USACE's CIRP (Coastal Inlet Research Program) is applied to model the inlet system of Pass-A-Grill Pass and Bunces Pass. CMS is broadly used by USACE for the modeling of inlet processes and morphology change. The Guidelines for Documenting Numerical Model Studies in Submittal to the FDEP Bureau of Beaches and Coastal Systems (BBCS, 2009) was followed in this part of the study.

The CMS model grid was constructed based on up-to-date bathymetry data obtained during this study. The modeling domain, including the seaward, landward, north, and south boundaries, as well as the grid resolution, was reviewed by the TAC. The USF researchers finalized the modeling domain and grid after the review, before the calibration-verification runs. The calibration-verification model runs were conducted over a 4-week period, over which field data were collected. The calibration-verification model runs were driven by measured boundary condition data (wave and tide). The calibration-verification modeling results were compared with the comprehensive field data to calibrate and verify the Pass-A-Grille and Bunces Pass CMS model. The calibration-verification modeling grid was further reviewed by the TAC. After the review, a production-run model grid was established.

The USF researchers worked closely with TAC to develop model run alternatives. Five dedicated computers in the USF Coastal Research Laboratory were used to run CMS models. The production and management alternative model runs are discussed in detail in the following sections. The detailed design of the alternative model runs was discussed among the USF researchers and TAC. The production runs are comprised of short-term and medium-term runs. The short-term runs focus on storm conditions and span a 2-month period. The medium-term runs span a 2-year period with the goal of simulating morphology change associated with various management alternatives such as dredging, beach fill, and modification of inlet structures.

In general, the alternative model runs are designed to address the following topics, including

1) Design alternatives of maintenance channel dredging: potential influences on inlet hydrodynamics, wave field, and sediment transport pathways.
2) Predicted rate of infilling of the dredge pit.

3) Potential influence of channel dredging or sand borrowing from ebb shoals to the nearshore wave field, and subsequent effects on sediment pathways and beach processes.

4) Design alternatives of other potential inlet management measures, such as jetty modifications or other structural methods.

A main goal of this inlet management study is to establish and verify a sediment budget for the Pass-A-Grille and Bunces Pass inlets. A major method used in the development of sediment budget is the volumetric change method provided in Rosati (2005) and the Coastal Engineering Manual. Development and verification of the Pass-A-Grille inlet and Bunces Pass budget are described in detail in the following sections.

Overall, task 2 of the project provides key tools for the inlet management at Pass-A-Grille and Bunces Pass inlets. The tools include a calibrated and verified numerical model of Pass-A-Grille and Bunces Pass inlet system, and a balanced sediment budget for the inlets and adjacent beaches with sediment pathways identified. Deliverables from Task 2 include: 1) input data for verified and calibrated inlet model; 2) final production grid of the numerical model and the design of production run alternatives; and 3) a balanced sediment budget of the inlets and the adjacent beaches.

Task 3 of the Pass-A-Grille and Bunces Pass inlet management study focuses on the evaluation of various inlet management implementation strategies. The comprehensive evaluation of the inlet management implementation strategies are based on 1) findings from analyses of existing data and engineering activities over the past seven decades; 2) field data collected by this study; and 3) results from CMS numerical modeling; and 4) the sediment budget. Generally speaking, the following inlet management strategies are evaluated, including: 1) frequency of maintenance dredging of the navigation projects that is cost-effective and enhances the performance and longevity of adjacent beach nourishment projects; 2) location, volume and frequency of ebb shoal borrow area excavation that provides supplemental beach nourishment fill material but does not destabilize the inlet systems, or increase beach erosion or storm damage to the adjacent beaches; and 3) based upon the evaluation of 1) and 2), the location and volume of material to be dredged from the inlet system and the frequency and location of beach placement that balances the sediment budget between the inlets and adjacent beaches. In addition, management strategies relating to the special case studies at north Mullet Key beach and North Shell Key Pass are discussed. Deliverables from Task 3 include: 1) the comprehensive evaluation of inlet management strategies, 2) the associated production-run model results of the alternatives analysis, 3) the associated sediment budget, and 4) local scale management options for north Mullet Key beach and North Shell Key Pass. Detailed discussion on the inlet management strategies is presented in the following sections.

The deliverables of this study include two main parts: digital data and a final report. All the digital data are delivered in a GIS environment, consistent with FDEP's *Monitoring Standards for Beach Erosion Control Projects, (FDEP, 2004).* The GIS databases that are compiled by this study include:

1) A Pass-A-Grille inlet and Bunces Pass data inventory including rectified time-series aerial photos (except the oblique ones), beach and nearshore profiles, hydrographic survey data, shoreline survey data, measured wind data, measured tide data, measured wave data, inlet current data, and bottom sediment data;
2) Morphologic, sedimentologic, and hydrodynamic field data collected during this study.
3) Maps showing a balanced sediment budget and sediment transport pathways.

This final report summarizes 1) present state of knowledge on the inlet processes at Pass-A-Grille inlet and Bunces Pass; 2) findings from analyses of existing data; 3) historical engineering activities and expected and unexpected consequences; 4) findings from field data collection by this study; 5) calibration and verification of the CMS modeling; 6) results from the production models runs on various alternatives; 7) comprehensive evaluation of inlet management implementation strategies; 8) a balanced sediment budget and sediment transport pathways established based on available understanding and data; and 9) specific management strategies at north Mullet Key beach and North Shell Key Pass.

As supplements to the final report, time series of graphic output of the key CMS model run results were compiled. In addition, movies of crucial modeled flow field, sediment transport patterns, and morphology evolution were made and provided separately.

Buttolph, A.M., Reed, C.W., Kraus, N.C., Ono, N., Larson, M., Camenen, B., Hanson, H., Wamsley, T., Zundel, A.K., 2006. Two-dimensional depth-averaged circulation model CMS-M2D: Version 3.0, Report 2, sediment transport and morphology change. *ERDC/CHL TR-06-9*, U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi, 149 pp.

Cialone, M.A. and Stauble, D.K., 1998. Historical findings on ebb shoal mining. *Journal of Coastal Research*, 14(2), 537-563.

Davis, R. A. and Hays, M.O., 1984. What is a wave dominated coast? *Marine Geology*, 60, p. 313-329.

Davis, R.A. and Gibeaut, J.C., 1990. Historical morphodynamics of inlets in Florida. Technical Paper 55, Florida Sea Grant College Program, 81 pp.

Davis, R.A., 1994. Barriers of the Florida Gulf Peninsula. In: Davis, R.A. (Ed.), *Geology of Holocene Barrier Island Systems*. Springer-Verlag, pp. 167–206.

Davis, R.A., 1997. Regional coastal morphodynamics along the United States Gulf of Mexico. *Journal of Coastal Research*, 13, 595–604.

Dean, R.G., 1971. *Hydraulics of Inlets*. COEL/UFL-71/019. Department of Coastal and Oceanographic Engineering, University of Florida, Gainsville.

Dean, R.G., 1988. Sediment interaction at modified coastal inlets: processes and policies. *Lecture Notes on Coastal and Estuarine Studies*, 29. Springer-Verlag, Berlin Heidelberg New York Tokyo, pp. 412–439.

Dean, R.G., 1993. Terminal structures at ends of littoral systems. *Journal of Coastal Research*, Special Issue 18, 195-210.

Dean, R.G., and Work P.A., 1993. Interaction of navigation entrances with adjacent shoreline. *Journal of Coastal Research*, Special Issue 18, 91-110.

Dean, R. G. and Dalrymple, R. A., 2002. *Coastal Processes with Engineering Applications*. United Kingdom: Cambridge University Press, p. 413-450.

Demirbilek, Z., Lin, L., Hayter, E., O'Connell, C., Mohr, M., Chader, S., and Forgette, C., 2015a. Modeling of Waves, Hydrodynamics and Sediment Transport for Protection of Wetlands at Braddock Bay, New York. *ERDC TR-14-8*, pp.122.

Demirbilek, Z., Lin, L., Ward, D.L., and King, D.B., 2015b. Modeling Study for Tangier Island Jetties, Tangier Island, Virginia. *ERDC TR-14-8*, pp.110.

Elko, N.A., Holman, R.A., Gelfenbaum, G., 2005. Quantifying the rapid evolution of a nourishment project with video imagery. *Journal of Coastal Research*, 21, 633–645.

Elko, N.A., Wang, P., 2007. Immediate profile and planform evolution of a beach nourishment project with hurricane influences. *Coastal Engineering*, 54, 54–79.

Escoffier, F. F., 1940. The stability of tidal inlets. *Shore and Beach*, 8, p.114-115.

FitzGerald, D. M., 1976. Ebb-tidal delta of Price Inlet, South Carolina: geomorphology, physical processes, and associated inlet shoreline changes. In Hayes, M.O. and Kana, T.W., (eds) *Terrigenous Clastic Depositional Environments*: Report No. 11-CRD, University of South Carolina.

FitzGerald, D.M., 1984. Interactions between the ebb-tidal delta and landward shoreline – price inlet, South-Carolina. *Journal of Sedimentary Petrology*, 54, 1303–1318.

FitzGerald, D.M., 1993. Origin and stability of tidal inlets in Massachusetts. In: Aubrey, D.G., Giese, G.S. (Eds.), *Formation and Evolution of multiple tidal inlet systems*. American Geophysical Union, Coastal and Estuarine Studies, No. 44, pp. 1–61.

Fitzgerald, D.M., 1996. Geomorphic variability and morphologic and sedimentologic controls on tidal inlets. *Journal of Coastal Research*, 23, 47–71.

FitzGerald, D.M., 2011. Morphodynamics and facies architecture of tidal inlets and tidal deltas. In: Davis, R.A., Dalrymple, R.W. (Eds.), *Principles of Tidal Sedimentology*. Springer-Verlag, New York Berlin Heidelberg pp. 25-43.

Gibeaut, J.C., 1991. Morphodynamic classification, evolution, and modeling of unstructured inlets in west-central Florida. *Ph.D. dissertation*, Department of Marine Science, University of South Florida, Tampa, FL, 192 pp.

Goda, Y., 1970. A synthesis of breaker indices. *Transactions of the Japanese Society of Civil Engineers*, Vol. 2, Part 2.

Grella, M.J., 1993. Development of management policy at Jupiter Inlet, Florida: An integration of technical analyses and policy constraints. *Journal of Coastal Research,* Special Issue 18, 239-256.

Hanson, H. and Kraus, N.C., 1989. GENESIS-Generalized model for simulating shoreline change. Vol. 1: Reference Manual and Users Guide. Technical Report CERC-89-19, Coastal Engineering Research Center, US Army Corps of Engineers, 247pp.

Hayes, M.O., 1979. Barrier island morphology as a function of tidal and wave regimes. In: Leatherman, S.P. (Ed.), *Barrier Islands: From the Gulf of St. Lawrence to the Gulf of Mexico*. Academic Press, New York, pp. 1–27.

Jarrett, J. T., 1976. Tidal prism – inlet area relationships. GITI Report no. 3, Department of the Army, Corps of Engineers, Vicksburg, Mississippi, 32p.

Kraus, N.C. and Rosati, J.D., 1998. Estimation of Uncertainty in Coastal Sediment Budgets at Inlets. *Coastal Engineering Technical Note* IV-16, pp. 12.

Kraus, N.C., 2009. Engineering of tidal inlets and morphologic consequences. In Y.C. Kim (ed.), *Handbook of Coastal and Ocean Engineering*, World Scientific, 867-901.

Larson L., Camenen, B., Nam, P.T., 2011. A unified sediment transport model for inlet application. *Journal of Coastal Research,* Special Issue 59, 27-39.

Lin L., Demirbilek, Z., Mase, H., 2011. Recent capabilities of CMS-Wave: A coastal wave model for inlets and navigation projects. *Journal of Coastal Research*, Special Issue 59, 7-15.

Li, H.; Lin, L., and Burks-Copes, K.A., 2013. Modeling of coastal inundation, storm surge, and relative sea-level rise at Naval Station Norfolk, Norfolk, Virginia, U.S.A. *Journal of Coastal Research*, 29(1), 18–30.

Loeb, W.A., 1994. Beaches of Pinellas County, Florida: A history of their comings and goings (circa 1950-present). USGS Open File Report 94-565.

Mehta, A.J. (editor), 1993. Beach/Inlet Processes and Management: A Florida Perspective. *Journal of Coastal Research*, Special Issue 18.

Montague, C.L., 1993. Ecological engineering of inlets in southeastern Florida: design criteria for sea turtle nesting beaches. *Journal of Coastal Research*, Special Issue 18, 267-276.

Nelson, W.G., 1993. Beach-inlet ecosystems of southeastern Florida: A review of ecological research needs and management issues. *Journal of Coastal Research*, Special Issue 18, 257-266.

O'Brien, M. P., 1931. Estuary tidal prism related to entrance areas. *Civil Engineering*, 1: p. 738-739.

O'Brien, M.P., 1969. Equilibrium flow areas of inlets on sandy coasts. *Journal Waterway Port Coast Ocean Engineering*, 95(1),43–52

Pacheco, A., Ferreira, O., Williams, J.J., Garel, E., Vila-Concejo, A., Dias, J.A., 2010. Hydrodynamics and equilibrium of a multiple-inlet system. *Marine Geology* 274, 32–42.

Reed, C.W., Brown, M.E., Sanchez, A., Wu, W., Buttolph, A.M., 2011. The Coastal Modeling System Flow Model (CMS-Flow): past and present. *Journal of Coastal Research*, Special Issue 59, 1-7.

Roberts, T.M. and Wang, P., 2012. Four-year performance and associated controlling factors of several beach nourishment projects along three adjacent barrier islands, West-Central Florida, USA. *Coastal Engineering*, 70, 21-39.

Roelvink, J.A. and Reniers, A.J.H.M., 2011. *A Guide to Modeling Coastal Morphology*. World Scientific Publishing Company, 292 pp.

Rosati, J.D. and Kraus, N.C., 1999. Formulation of sediment budgets at inlets. *Coastal Engineering Technical Note* IV-15, pp. 20.

Rosati, J.D. and Kraus, N.C., 1999b. Sediment Budget Analysis System (SBAS). *Coastal Engineering Technical Note* IV-20, pp. 14.

Rosati, J.D. and Kraus, N.C., 2003. Sediment Budget Analysis System (SBAS): Upgrade for Regional Applications. *ERDC/CHL CHETN-XIV-3*, pp. 13.

Salles, P., Voulgaris, G., Aubrey, D., 2005. Contribution of nonlinear mechanisms in the persistence of multiple tidal inlet systems. *Estuarine Coastal and Shelf Science* 65, 475–491.

Rosati, J.D., 2005. Concepts in sediment budgets. *Journal of Coastal Research*, 21, 307-322.

Sanchez, A., Wu, W., 2011. A non-equilibrium sediment transport model for coastal inlets and navigation channels. *Journal of Coastal Research*, Special Issue 59, 39-49.

Sánchez, A., Wu, W., Li, H., Brown, M., Reed, C., Rosati, J.D., and Demirbilek, Z., 2014. Coastal Modeling System: Mathematical Formulations and Numerical Methods. *ERDC/CHL TR-14-2*, pp. 104.

Seabergh, W. C., and Kraus, N. C., 1997. PC program for coastal inlet stability analysis using Escoffier method. Department of the Army, Corps of Engineers, *Coastal and Hydraulics Laboratory Technical Note*, 7p.

Stauble, D.K., 1993. An overview of southeast Florida inlet morphodynamics. *Journal of Coastal Research*, Special Issue 18, 1-27.

Tanner, W.F., 1960. Florida coastal classification. *Transactions – Gulf Coast Association of Geological Science* 10, 259–266.

Van de Kreeke, J., 1990. Can multiple inlets be stable? *Estuarine Coastal and Shelf Science*, 30, 261-273.

Van de Kreeke, J. Brouwer , R.L., Zitman, T.J., and Schuttelaars , H.M., 2008. The effect of a topographic high on the morphological stability of a two-inlet bay system. Coastal Engineering, Vol. 55, 2008, pp 319-332.

Walther, M.P. and Douglas B.D., 1993. Ebb shoal borrow area recovery. *Journal of Coastal Research*, Special Issue 18, 211-223.

Walton, T.L., JR., 1973. Littoral Drift Computations along the Coast of Florida by Means of Ship Wave Observations. *Coastal and Oceanographic Engineering Laboratory Technical Report No. 15*, University of Florida, Gainesville, Florida, 80 pp.

Walton, T.L., JR., 1976. Littoral Drift Estimates along the Coastline of Florida. *Technical Report No. 13*, Florida Sea Grant Program, 39 pp.

Wang, P., Tidwell, D.K., Beck, T.M., Kraus, N.C., 2007. Sedimentation patterns in a stabilized migratory inlet, Blind Pass, Florida. *Proceedings of Coastal Sediments 07*, ASCE Press, pp. 1377–1390.

Wang, P. and Beck, T.M., 2009. Modeling Coastal Processes at John's Pass and Blind Pass and Adjacent Beaches. *Technical Report*, Coastal Research Laboratory, University of South Florida, 157 pp.

Wang, P., Beck T.M., and Roberts T.M., 2011. Modeling regional-scale sediment transport and medium-term morphology change at a dual inlet system examined with the Coastal Modeling System (CMS): A case study at Johns Pass and Blind Pass, west-central Florida. Journal of Coastal Research, Special Issue 59, 49-60.

Wang, P. and Beck, T.M., 2012. Morphodynamics of an anthropogenically altered dual-inlet system: John's Pass and Blind Pass, west-central Florida. *Marine Geology*, 291-294, p.162-175.

Wang, P., Horwitz, M.H., and Cheng, J., 2016. *Inlet Management Study for John's Pass and Blind Pass, Pinellas County, Florida*. Final Report, Coastal Research Laboratory, University of South Florida, Tampa, FL.

Willmott, C. J. (1981). On the validation of models. *Physical Geography*, 2, 184–194.

Wu, W., Sanchez, A., Zhang, M., 2011. An implicit 2-D shallow water flow model for inlets and navigation projects. *Journal of Coastal Research*, Special Issue 59, 15-27.