Morphodynamics and Sediment Pathways of the John's Pass-Blind Pass Dual-Inlet System: Pinellas County, Florida

Mark H. Horwitz
University of South Florida, mhorwitz@mail.usf.edu

Follow this and additional works at: https://digitalcommons.usf.edu/etd

Part of the Geology Commons

Scholar Commons Citation

This Dissertation is brought to you for free and open access by the USF Graduate Theses and Dissertations at Digital Commons @ University of South Florida. It has been accepted for inclusion in USF Tampa Graduate Theses and Dissertations by an authorized administrator of Digital Commons @ University of South Florida. For more information, please contact digitalcommons@usf.edu.
Morphodynamics and Sediment Transport Pathways of the John’s Pass-Blind Pass Dual Inlet System: Pinellas County, Florida

by

Mark H. Horwitz

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy
Department of Geosciences
College of Arts and Sciences
University of South Florida

Major Professor: Ping Wang, Ph.D.
Bogdan P. Onac, Ph.D.
Nathaniel Plant, Ph.D.
Sarah Kruse, Ph.D.

Date of Approval:
June 22, 2017

Keywords: Inlet morphodynamics, sediment pathways, sediment bypassing, Blind Pass, John’s Pass, sediment budget, dual-inlet system, barrier island, west-central Florida.

Copyright © 2017, Mark H. Horwitz
DEDICATION

To my parents who would have reveled in this accomplishment.
ACKNOWLEDGEMENTS

I would like to thank Dr. Ping Wang for the insights into coastal processes he has shared with me, and for the memorable times in the classroom, lab and field that I have been fortunate enough to have had with him over the years. I would also like to thank the other members of my committee, Dr. Bogdan Onac (for the memorable field excursions to San Salvador), and Drs. Nathaniel Plant and Sarah Kruse for the mind provoking questions they posed during my comprehensive exams, and for the recommendations they provided that led to improving the quality and content of this manuscript. I would also like to thank Robert Brantly, Ralph Clark and Guy Weeks of the Florida Department of Environmental Protection for their technical input and for funding this study. Similarly, I would like to thank Andy Squires and John Bishop of the Pinellas County Natural Resources Division who also provided technical and logistical help during this study.
TABLE OF CONTENTS

LIST OF TABLES iii
LIST OF FIGURES iv
ABSTRACT xvii
CHAPTER 1 INTRODUCTION 1

CHAPTER 2 GENERAL BACKGROUND: TIDAL INLET HYDRODYNAMICS AND MORPHODYNAMICS 5
  2.1 Introduction 5
  2.2 Inlet Processes, Stability, Morphology and Morphologic Change 7

CHAPTER 3 STUDY AREA 35
  3.1 Location and Background Information 35
  3.2 Previous Studies 40
  3.3 Blind Pass Engineering History Summary 47
  3.4 John’s Pass Engineering History Summary 50
  3.5 Oceanographic Characteristics 54
    3.5.1 Wind Patterns 54
    3.5.2 Wave Patterns 56
    3.5.3 Tides 59

CHAPTER 4 METHODOLOGY 61
  4.1 Field Methods Introduction 61
    4.1.1 Wave Measurements 62
    4.1.2 Current Measurements 66
    4.1.3 Water Level – Tide Measurements 69
    4.1.4 Bathymetric Surveys 70
    4.1.5 Sediment Sampling 73
  4.2 Sediment Budget Formulation 74
  4.3 Numerical Modeling 76
    4.3.1 Overview of the Coastal Modeling System (CMS) 76
    4.3.2 Model Construction, Calibration, and Validation 80

CHAPTER 5 RESULTS 81
  5.1 Field Measurements 81
    5.1.1 Wave Conditions 81
<table>
<thead>
<tr>
<th>Section</th>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1.2</td>
<td>Current Through and in the Vicinity of the Inlets</td>
<td>86</td>
</tr>
<tr>
<td>5.1.3</td>
<td>Offshore and Backbay Tides</td>
<td>97</td>
</tr>
<tr>
<td>5.1.4</td>
<td>Bathymetric Characteristics</td>
<td>100</td>
</tr>
<tr>
<td>5.1.5</td>
<td>Sediment Characteristics</td>
<td>109</td>
</tr>
<tr>
<td>5.2</td>
<td>CMS Model Construction, Calibration and Verification</td>
<td>113</td>
</tr>
<tr>
<td>5.2.1</td>
<td>Model Grid Construction</td>
<td>113</td>
</tr>
<tr>
<td>5.2.2</td>
<td>Model Calibration</td>
<td>116</td>
</tr>
<tr>
<td>5.2.3</td>
<td>Model Verification</td>
<td>120</td>
</tr>
<tr>
<td>5.2.4</td>
<td>Model Calibration</td>
<td>126</td>
</tr>
<tr>
<td>5.3</td>
<td>Volumetric and Morphologic Change</td>
<td>133</td>
</tr>
<tr>
<td>5.3.1</td>
<td>John’s Pass and Blind Pass Ebb Shoal Volumes</td>
<td>133</td>
</tr>
<tr>
<td>5.3.2</td>
<td>Rates of Dredge Pit Infilling</td>
<td>137</td>
</tr>
<tr>
<td>5.3.3</td>
<td>Time-Series Ebb Shoal Volume Changes</td>
<td>145</td>
</tr>
<tr>
<td>5.4</td>
<td>Regional Sediment Budget and Sediment Pathways</td>
<td>153</td>
</tr>
<tr>
<td>5.5</td>
<td>Modeled Hydrodynamic and Morphologic Changes</td>
<td>176</td>
</tr>
<tr>
<td>5.5.1</td>
<td>Baseline Conditions Simulation</td>
<td>178</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Alternative 1</td>
<td>183</td>
</tr>
<tr>
<td>5.5.3</td>
<td>Alternative 2</td>
<td>197</td>
</tr>
<tr>
<td>5.5.4</td>
<td>Alternative 3</td>
<td>211</td>
</tr>
<tr>
<td>5.5.5</td>
<td>Alternative 4</td>
<td>224</td>
</tr>
<tr>
<td>5.6</td>
<td>Quantification and Distribution of North Boca Ciega Bay Tidal Prism</td>
<td>237</td>
</tr>
</tbody>
</table>

CHAPTER 6 DISCUSSION AND CONCLUSIONS

6.1 Discussion of Inlet Morphodynamics, Sediment Pathways and Bypassing

6.1.1 Historical Morphodynamics of the John’s Pass-Blind Pass Dual-Inlet System

6.1.2 Modern Morphodynamics of the John’s Pass-Blind Pass Dual-Inlet System

6.1.3 Sediment Pathways and Bypassing

6.2 Conclusions

REFERENCES

APPENDIX A TABLE OF ENGINEERING MODIFICATIONS

APPENDIX B FIGURE COPYRIGHT RELEASES

ABOUT THE AUTHOR
LIST OF TABLES

Table 1    North Boca Ciega Bay tidal prism    238
LIST OF FIGURES

Figure 1  Idealized drawing of a typical tidal inlet showing morphologic features and the dominant tidal current flow directions (modified from Schrader et al. 2000). 7

Figure 2  Asymmetry between ebbing and flooding currents exiting and entering an inlet (from Oertel, 1988). 10

Figure 3  Classification of inlet types found along the microtidal west-central Florida barrier island chain based on dominant forcing mechanism. (from Davis and Gibeaut, 1990). 18

Figure 4  Escoffier diagram showing relationship between mean velocity and channel cross-sectional area. (modified from Escoffier, 1940). 22

Figure 5  Sediment budget parameters in Equation 10 (from Rosati and Kraus, 1999). 30

Figure 6  Aerial image (2000) showing Sand Key, Treasure Island, and Long Key and the locations of John’s Pass and Blind Pass inlets. 35

Figure 7  John’s Pass 1988 dredge pit infilling (trapping) rate (from Walther and Douglas, 1993). 44

Figure 8  Time-series aerial photos of Blind Pass from 1926 to 2006.  Note the diminishment of the ebb shoal over the years and the severe downdrift beach erosion. 47

Figure 9  2010 aerial image of Blind Pass showing the numerous engineering modifications.  Also shown are T-groins installed along Upham Beach immediately south of the inlet, and the location of R-monument 143 for spatial reference. 47

Figure 10  Time-series aerial photos of John’s Pass from 1926 to 2010. 52

Figure 11  2010 aerial image of John’s Pass and adjacent Sand Key and Treasure Island shorelines showing numerous engineering modifications.  Also shown are the locations of R-monument 124, 127, and 129 for spatial reference. 53
Figure 12  Wind rose based on measurements made at the NOAA Clearwater Beach station CWBF1 (#8726724) from 2010 to 2014 (5 years).

Figure 13  Statistical wave conditions for the period 2000 through 2014 computed from WAVEWATCHIII for a numerically simulated wave station located ca 7 km offshore from John’s Pass.

Figure 14  Wave conditions measured ca 400 m offshore Blind Pass in 4 m water depth. The measurements were conducted from November 25, 2003 to February 26, 2005 with some gaps due to equipment maintenance. Upper panel shows significant wave height, and lower panel shows corresponding peak wave period.

Figure 15  Tide measurements collected from a site located ca 3 kilometers offshore from John’s Pass during the period July 23, 2008 to August 5, 2008.

Figure 16  Image of study area showing the locations of hydrodynamic sensors deployed during this study, and the boundary of the numerical modeling domain (red border).

Figure 17  Measured significant wave heights at the seaward boundary of the numerical modeling domain compared to WAVEWATCH III modeled significant wave heights for the period 6/7/2014 – 12/31/2014.

Figure 18  Measured wave peak periods at the seaward boundary of the numerical modeling domain compared to WAVEWATCH III modeled wave peak periods for the period 6/7/2014 – 12/31/2014.

Figure 19  Measured wave principal directions at the seaward boundary of the numerical modeling domain compared to WAVEWATCH III modeled wave principal directions for the period 6/7/2014 – 12/31/2014.

Figure 20  Survey vessel showing downward looking ADCP (left image) and RTK GPS equipment (right image) used to map current flow fields within John’s Pass and Blind Pass.

Figure 21  Image showing extent (red lines) of 2014 multibeam bathymetric survey coverage of the JPBPIIS.
Figure 22 Image showing extent of 2014 single beam bathymetric survey coverage of the northern portion of Boca Ciega Bay in red, and single beam surveys extending R-monument beach profile surveys in black.

Figure 23 Distribution of sediment samples (red triangles).

Figure 24 Volume change above four contours representative of the dry-beach, shoreline, nearshore, and entire profile for Sand Key beach profiles.

Figure 25 The four major coupled components of CMS. From the CMS Wiki page (http://cirpwiki.info/wiki/CMS).

Figure 26 Steering between CMS-Flow and CMS-Wave. From the CMS Wiki page (http://cirpwiki.info/wiki/CMS).

Figure 27 Significant wave height recorded at the numerical modeling domain boundary between June 2014 and June 2015.

Figure 28 Peak wave period recorded at the numerical modeling domain boundary between June 2014 and June 2015.

Figure 29 Rose diagram of significant wave height and direction recorded at the numerical modeling domain boundary between June 2014 and June 2015.

Figure 30 Rose diagram of peak wave period and direction recorded at the numerical modeling domain boundary between June 2014 and June 2015.

Figure 31 July 2014 wind record recorded near Clearwater Beach, Florida.

Figure 32 July 2014 air pressure record at the NOAA Clearwater Beach, Florida station.

Figure 33 Significant wave heights measured at the nearshore Triton PUV gauge (blue line) compared to the offshore ADCP significant wave heights (red line) for the period 6/8/2014 - 10/7/2014.

Figure 34 Dominant wave period measured at the nearshore Triton PUV gauge (blue line) compared to the offshore ADCP (red line) dominant wave period for the period 6/8/2014 - 10/7/2014.

Figure 35 Depth averaged current velocities measured using a U-ADCP deployed in the John’s Pass channel thalweg.
Figure 36  Vertical current velocity profiles measured using a U-ADCP deployed in the John’s Pass channel thalweg.

Figure 37  Depth averaged current velocities measured using a U-ADCP deployed in the Blind Pass channel thalweg.

Figure 38  Vertical current velocity profiles measured using a U-ADCP deployed in the Blind Pass channel thalweg.

Figure 39  Cross-channel distribution of tidal flow velocities measured at John’s Pass. Upper panel shows H-ADCP location and range (black line) of the measurement. Lower panel shows peak flood (blue) and ebb (orange) velocities measured during spring tide.

Figure 40  Cross-channel distribution of tidal flow velocities measured at Blind Pass. Upper panel shows location of H-ADCP and range (black line) of the measurement. The U-ADCP location is also shown. Lower panel shows peak flood (blue) and ebb (orange) velocities measured during spring tide.

Figure 41  Ebb stage flow field depth averaged velocities at John’s Pass.

Figure 42  Flood stage flow field velocities at John’s Pass.

Figure 43  Ebb stage flow field depth averaged velocities at Blind Pass.

Figure 44  Location of water level measurement gauges.

Figure 45  Tide water-level variations measured within the greater study area.

Figure 46  Two day tide from 8/10/2014 – 8/12/2014 during spring tide conditions, showing phase lag between offshore and inshore tide.

Figure 47  Bathymetry of the study area.

Figure 48  Detailed bathymetry of the John’s Pass ebb shoal based on July 2014 multi-beam bathymetric survey data showing 1988 and 2010 dredge pits, the channel margin linear bar (CMLB), swash bar attachment point, and locations of cross-sections shown in Figure 49.

Figure 49  Bathymetric cross-sections of the John’s Pass ebb shoal (refer to Figure 48 for cross-section locations).

Figure 50  Detailed bathymetry of the Blind Pass ebb shoal and channel based on July 2014 multi-beam bathymetric survey data, showing locations of cross-sections shown in Figure 51.
Figure 51  Bathymetric cross-sections of the Blind Pass ebb shoal (refer to Figure 50 for cross-section locations).

Figure 52  John’s Pass sediment sample locations showing mean grain-size in phi units, overlain on 2014 bathymetry.

Figure 53  Blind Pass Sediment sample locations showing mean grain-size in phi units, overlain on 2014 bathymetry.

Figure 54  Relationship between mean grain-size and carbonate content. Upper panel represents John’s Pass samples, and lower panel, Blind Pass samples.

Figure 55  The CMS “refined” wave grid for the entire numerical modeling domain.

Figure 56  The CMS “telescoping” flow grid for the entire numerical modeling domain.

Figure 57  Detail view of the “telescoping” CMS-Flow grid at John’s Pass illustrating increased resolution over the inlet, in the nearshore and ebb shoal.

Figure 58  Measured and modeled wave height just seaward of the closure depth (~4 m) using default friction coefficient provided by CMS-Wave.

Figure 59  Input water level and wave conditions, measured at the boundaries, for the numerical models.

Figure 60  Comparison between CMS simulated current velocities using different Manning’s $n$ values and measured velocity at John’s Pass. Positive values represent flood flow and negative values represent ebb flow.

Figure 61  Measured and modeled current velocity in John’s Pass main channel.

Figure 62  Measured and modeled current velocity in the Blind Pass main channel.

Figure 63  Modeled flow field during a peak spring ebbing event at both John’s Pass and Blind Pass.

Figure 64  Measured (upper panel) and modeled (lower panel) flow field during a peak spring ebbing event at John’s Pass.
Figure 65  Modeled flow field during a peak spring flooding event at John’s Pass.

Figure 66  Measured and modeled flow field during a peak spring ebbing event at Blind Pass.

Figure 67  Modeled flow field during a peak spring flooding event at Blind Pass.

Figure 68  Interaction of a southward longshore current and ebb jet at John’s Pass. Note eddy on the south side of the ebb shoal immediately offshore of Sunshine Beach.

Figure 69  Interaction of a southward longshore current and ebb jet at Blind Pass. Red squares are ADCP deployment locations.

Figure 70  Computed morphology change over a 10 month simulation period, at John’s Pass (upper panel) and Blind Pass (lower panel).

Figure 71  Synthetic bathymetry of the John’s Pass inlet region, constructed using 2014 R-monument beach and offshore profiles. The inlet ebb shoal and channel have been removed.

Figure 72  John’s Pass ebb shoal based on July 2014 survey data, overlain on the synthetic bathymetry shown in Figure 71.

Figure 73  Synthetic bathymetry of the Blind Pass inlet region, constructed using 2014 R-monument beach and offshore profiles. The inlet ebb shoal and channel have been removed.

Figure 74  Blind Pass ebb shoal as surveyed in July 2014, overlaying the synthetic bathymetry shown in Figure 73, with 20x vertical exaggeration.

Figure 75  Outline of 2010 dredge pits at John’s Pass (left image), and Blind Pass (right image).

Figure 76  Annualized infilling rates of the John’s Pass inlet channel dredge pit during the 4 years following the 2010 dredging.

Figure 77  Annualized infilling rates of the John’s Pass inlet terminal lobe dredge pit during the 4 years following the 2010 dredging.

Figure 78  Infilling patterns in the John’s Pass dredge pits during the first year post dredging from October 2010 to September 2011.
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>79</td>
<td>Infilling patterns in the John’s Pass dredge pits during the second year (10 months) post dredging from September 2011 to July 2012.</td>
</tr>
<tr>
<td>80</td>
<td>Annualized infilling rates of the Blind Pass dredge pit during the 4 years following the 2010 dredging.</td>
</tr>
<tr>
<td>81</td>
<td>Infilling of the Blind Pass dredge pit during the first year post dredging from October 2010 to September 2011.</td>
</tr>
<tr>
<td>82</td>
<td>Infilling of Blind Pass dredge pit during the second year (10 months) post dredging from September 2011 to July 2012.</td>
</tr>
<tr>
<td>83</td>
<td>Sedimentation and erosion patterns over John’s Pass ebb shoal between October 2010 and January 2011.</td>
</tr>
<tr>
<td>84</td>
<td>Sedimentation and erosion patterns over John’s Pass ebb shoal between October 2010 and September 2011.</td>
</tr>
<tr>
<td>85</td>
<td>Sedimentation and erosion patterns over John’s Pass ebb shoal between October 2010 and July 2012.</td>
</tr>
<tr>
<td>86</td>
<td>Sedimentation and erosion patterns over John's Pass ebb shoal between October 2010 and July 2014.</td>
</tr>
<tr>
<td>87</td>
<td>Sedimentation and erosion patterns over Blind Pass ebb shoal comparing bathymetry survey of September 2011 with that of October 2010.</td>
</tr>
<tr>
<td>88</td>
<td>Sedimentation and erosion patterns occurring between October 2010 and July 2012 over the Blind Pass ebb shoal.</td>
</tr>
<tr>
<td>89</td>
<td>Sedimentation and erosion patterns occurring between October 2010 and July 2014 over the Blind Pass ebb shoal.</td>
</tr>
<tr>
<td>90</td>
<td>Regional sediment budget of John’s Pass and Blind Pass system determined based on field data collected from October 2010 to June 2014.</td>
</tr>
<tr>
<td>91</td>
<td>Regional annualized sediment budget of John’s Pass and Blind Pass system determined based on field data collected from October 2010 to June 2014.</td>
</tr>
<tr>
<td>92</td>
<td>Sediment budget at John’s Pass determined based on field data collected from October 2010 to June 2014.</td>
</tr>
<tr>
<td>93</td>
<td>Annualized sediment budget at John’s Pass determined based on field data collected from October 2010 to June 2014.</td>
</tr>
</tbody>
</table>
Figure 94  Sedimentation patterns over John’s Pass ebb shoal determined based on field data collected from October 2010 to June 2014.

Figure 95  Annualized sedimentation pattern over John’s Pass ebb shoal determined based on field data collected from October 2010 to June 2014.

Figure 96  Sediment budget at Treasure Island determined based on field data collected from October 2010 to June 2014.

Figure 97  Annualized sediment budget at Treasure Island determined based on field data collected from October 2010 to June 2014.

Figure 98  Sediment budget at Blind Pass determined based on field data collected from October 2010 to June 2014.

Figure 99  Annualized sediment budget at Blind Pass determined based on field data collected from October 2010 to June 2014.

Figure 100  Detailed sediment budget at Blind Pass determined based on field data collected from October 2010 to June 2014.

Figure 101  Detailed annualized sediment budget at Blind Pass determined based on field data collected from October 2010 to June 2014.

Figure 102  Sediment budget at Long Key determined based on field data collected from October 2010 to June 2014.

Figure 103  Annualized sediment budget at Long Key determined based on field data collected from October 2010 to June 2014.

Figure 104  Figure 104. Input significant wave height at the seaward boundary for the 2-year production CMS model run.

Figure 105  Bathymetry for the Alternative 1 baseline run. This bathymetry was surveyed in 2014 by this study. Upper: John’s Pass and its ebb shoal; Lower: Blind Pass and its ebb shoal.

Figure 106  Modeled bathymetry change under baseline conditions at John’s Pass after 12 months (upper panel) and 24 months (lower panel).

Figure 107  Modeled bathymetry change at Blind Pass under baseline conditions after 12 months (upper panel) and 24 months (lower panel).
Figure 108  Bathymetry for the Alternative 1 simulation, which includes a
dredge pit excavated in the northeast portion of the John’s Pass ebb
shoal. The dredged sediment is placed as a berm in a dredge pit
excavated in 1969 seaward of Sunset Beach.

Figure 109  Initial and subsequent bathymetric profiles of the Alternative 1
dredge pit and placement berm. Profile locations are shown in
Figure 108.

Figure 110  Modeled morphology change for Alternative 1 after 1 year (upper
panel), and 2 years (lower panel).

Figure 111  Modeled morphology change for Alternative 2, after 1 year (upper
panel), and 2 years (lower panel), emphasizing the evolution of the
nearshore berm.

Figure 112  Difference between Baseline simulation and Alternative 1 wave
heights for three different incident wave directions. Upper panel
shows a SW incident wave (220 degree) with 1.1 m significant wave
height and 6.26 s peak wave period. Middle panel shows a W
incident wave (270 degree) with 1.5 m significant wave height and
8.20 s peak wave period.

Figure 113  Difference between Baseline simulation and Alternative 1 wave-
heights over the berm placed in the 1969 dredge pit for three
different incident wave directions. Upper: SW incident wave (220
degree) with 1.1 m significant wave height and 6.26 s peak wave
period. Middle: W incident wave (270 degree) with 1.5 m
significant wave height and 8.20 s peak wave period. Lower: NW
incident wave (310 degree) with 1.1 m significant wave height and
7.70 s peak wave period.

Figure 114  Modeled peak ebb flow velocities for the Baseline simulation (upper
panel), and Alternative 1 (middle panel). The lower panel shows
difference between Alternative 1 and Baseline simulation peak ebb
velocities.

Figure 115  Modeled peak flood flow velocities for the Baseline simulation
(upper panel), and Alternative 1 (middle panel). The lower panel
shows the difference between Alternative 1 and the Baseline case.

Figure 116  Input bathymetry for Alternative 2 showing the dredge pit and the
berm nourishment offshore Sunshine Beach (upper panel) and the
berm nourishment along Upham Beach (lower panel). Also shown
are the locations of bathymetric profiles shown in Figure 117.
Figure 117 Bathymetric profiles of the Alternative 2 dredge pit and nearshore berm placements. The locations of the cross section are shown in Figure 116.

Figure 118 Alternative 2 modeled morphology change at John’s Pass and at the Sunshine Beach berm nourishment after one year (upper panel) and two years (lower panel).

Figure 119 Alternative 2 modeled morphology change at the Upham Beach berm nourishment after one year (upper panel) and two years (lower panel).

Figure 120 Alternative 2 wave-heights relative to Baseline wave heights in the region in and adjacent to John’s Pass. Upper panel shows SW incident wave (220 degree) with 1.1 m significant wave height and 6.26 s peak wave period. The middle panel shows W incident wave (270 degree) with 1.5 m significant wave height and 8.20 s peak wave period, and the lower panel shows NW incident wave (310 degree) with 1.1 m significant wave height and 7.70 s peak wave period.

Figure 121 Alternative 2 wave-heights relative to Baseline wave heights in the region in and adjacent to Blind Pass. Upper panel shows SW incident wave (220 degree) with 1.1 m significant wave height and 6.26 s peak wave period. The middle panel shows W incident wave (270 degree) with 1.5 m significant wave height and 8.20 s peak wave period (middle panel), and the lower panel shows NW incident wave (310 degree) with 1.1 m significant wave height and 7.70 s peak wave period.

Figure 122 Modeled peak ebb flow velocities at John’s Pass for the Baseline simulation (upper panel), Alternative 2 (middle panel), and the difference between Alternative 2 ebbing current velocities and those from the Baseline simulation (lower panel).

Figure 123 Modeled peak flood flow velocities at John’s Pass for the Baseline simulation (upper panel), Alternative 2 (middle panel), and the difference relative to the Baseline simulation.

Figure 124 Modeled peak ebb flow velocities at Blind Pass for the Baseline simulation (upper panel), Alternative 2 (middle panel), and the difference relative to the Baseline simulation.

Figure 125 Modeled peak flood flow velocities at Blind Pass for the Baseline simulation (upper panel), Alternative 2 (middle panel), and the difference relative to the Baseline simulation.
Figure 126  Input bathymetry for the Alternative 3 simulation. Bathymetric profiles A and B are shown in Figure 127.

Figure 127  Alternative 3 bathymetric profiles showing pre- and post-dredging bathymetry at the John’s Pass (upper panel) and Blind Pass (lower panel) dredge pits. Profile locations are shown in Figure 126.

Figure 128  Infilling of the John’s Pass dredge pit for Alternative 3 case after 1 year (upper panel) and 2 year (lower panel).

Figure 129  Infilling of the Blind Pass dredge pit for Alternative 3 case after 1 year (upper panel) and 2 year (lower panel).

Figure 130  Modeled wave-height change at John’s Pass for Alternative 3, as compared to the existing condition (Alternative 1 baseline run). Upper: SW incident wave (220 degree) with 1.1 m significant wave height and 6.26 s peak wave period. Middle: W incident wave (270 degree) with 1.5 m significant wave height and 8.20 s peak wave period. Lower: NW incident wave (310 degree) with 1.1 m significant wave height and 7.70 s peak wave period.

Figure 131  Modeled wave-height change at Blind Pass for Alternative 3, as compared to the existing condition (Alternative 1 baseline run). Upper: SW incident wave (220 degree) with 1.1 m significant wave height and 6.26 s peak wave period. Middle: W incident wave (270 degree) with 1.5 m significant wave height and 8.20 s peak wave period. Lower: NW incident wave (310 degree) with 1.1 m significant wave height and 7.70 s peak wave period.

Figure 132  Modeled peak ebb flow velocities at John’s Pass for Alternative 3. Upper panel shows Baseline simulation velocities, middle panel shows Alternative 3 velocities, and the lower panel shows the difference between Alternative 3 and the Baseline case.

Figure 133  Modeled peak flood flow velocities at John’s Pass for Alternative 3. Upper panel shows Baseline simulation velocities, middle panel shows Alternative 3 velocities, and the lower panel shows the difference between Alternative 3 and the Baseline case.

Figure 134  Modeled peak ebb flow velocities at Blind Pass for Alternative 3. Upper panel shows Baseline simulation velocities, middle panel shows Alternative 3 velocities, and the lower panel shows the difference between Alternative 3 and the Baseline case.
Figure 135  Modeled peak flood flow velocities at Blind Pass for Alternative 3. Upper panel shows Baseline simulation velocities; middle panel shows Alternative 3 velocities, and the lower panel shows the difference between Alternative 3 and the Baseline case.

Figure 136  Input bathymetry for Alternative 4. Note the groin extensions in grey at John’s Pass (upper panel) and Blind Pass (lower panel).

Figure 137  Predicted morphology change at John’s Pass, as compared to the baseline case, for Alternative 4 case with extensions of north and south jetties after 1 year (upper panel) and 2 years (lower panel).

Figure 138  Predicted morphology change at Blind Pass, as compared to the baseline case, for Alternative 4 case with extensions of both north and south jetties after 1 year (upper panel) and 2 years (lower panel).

Figure 139  Alternative 4 wave-heights relative to Baseline wave heights in the region in and adjacent to John’s Pass. Upper panel shows SW incident wave (220 degree) with 1.1 m significant wave height and 6.26 s peak wave period. The middle panel shows W incident wave (270 degree) with 1.5 m significant wave height and 8.20 s peak wave period (middle panel), and the lower panel shows NW incident wave (310 degree) with 1.1 m significant wave height and 7.70 s peak wave period.

Figure 140  Alternative 4 wave-heights relative to Baseline wave heights in the region in and adjacent to Blind Pass. Upper panel shows SW incident wave (220 degree) with 1.1 m significant wave height and 6.26 s peak wave period. The middle panel shows W incident wave (270 degree) with 1.5 m significant wave height and 8.20 s peak wave period (middle panel), and the lower panel shows NW incident wave (310 degree) with 1.1 m significant wave height and 7.70 s peak wave period.

Figure 141  Alternative 4 modeled peak ebb flow velocities at John’s Pass. Upper panel shows peak ebb flow for the Baseline simulation. The middle panel shows peak ebb flow for Alternative 4, and the lower panel shows the difference between Alternative 4 and the Baseline simulation.

Figure 142  Alternative 4 modeled peak flood flow velocities at John’s Pass. Upper panel shows peak flood flow for the Baseline simulation. The middle panel shows peak flood flow for Alternative 4, and the lower panel shows the difference between Alternative 4 and the Baseline simulation.
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>143</td>
<td>Alternative 4 modeled peak ebb flow velocities at Blind Pass. Upper panel shows peak ebb flow for the Baseline simulation. The middle panel shows peak ebb flow for Alternative 4, and the lower panel shows the difference between Alternative 4 and the Baseline simulation.</td>
</tr>
<tr>
<td>144</td>
<td>Alternative 4 modeled peak flood flow velocities at Blind Pass. Upper panel shows peak flood flow for the Baseline simulation. The middle panel shows peak flood flow for Alternative 4, and the lower panel shows the difference between Alternative 4 and the Baseline simulation.</td>
</tr>
<tr>
<td>146</td>
<td>Area of north Boca Ciega Bay pre- and post-dredge and fill projects. Left panel shows pre-dredging land area, and right panel shows 2006 land area.</td>
</tr>
<tr>
<td>146</td>
<td>Spring tide water elevations at John’s Pass, and corresponding peak flood (positive values) and ebb (negative values) velocities at John’s Pass and Blind Pass. Measurements made with an upward looking ADCP located in the channel throat thalweg.</td>
</tr>
<tr>
<td>147</td>
<td>Interaction of the southward longshore current and the ebb jet at Blind Pass.</td>
</tr>
<tr>
<td>148</td>
<td>2014 bathymetry of the John’s Pass ebb shoal showing regions where 1-m (black contour), 1.5-m (blue contour) and 2-m (red contour) high waves would break.</td>
</tr>
<tr>
<td>149</td>
<td>Modeled sediment concentration at Johns Pass. Note the high sediment concentration in areas with wave breaking (modified from Beck and Wang, 2009).</td>
</tr>
<tr>
<td>150</td>
<td>Time series bathymetry of the Blind Pass inlet.</td>
</tr>
</tbody>
</table>

xvi
ABSTRACT

The morphodynamics of an inlet channel draining an estuary or bay are governed by a complex system of temporally and spatially varying physical processes, including wind, waves, tides, sediment transport, and both tide and wave driven currents. In addition, sediment availability and characteristics in conjunction with underlying geologic framework bear on the morphology and morphologic behavior of an inlet system. This study examines the morphodynamics, sediment transport patterns and time-series morphologic change of John’s Pass and Blind Pass, two structured tidal inlets that collectively make up a dual-inlet system sharing the tidal prism of northern Boca Ciega Bay, in Pinellas County, Florida.

To quantify wave and tidal forcing and response mechanisms an array of hydrodynamic sensors were deployed over a 12 month period at both inshore and offshore locations. In order to capture morphologic changes and quantify volumetric changes within the inlets, bathymetric surveys of the inlets were conducted in 2010, 2011, 2012, and 2014. Similarly, bi-monthly beach survey data for the same range of time was acquired in order to quantify volumetric changes along adjacent stretches of beach. In addition to gaining insights into sediment pathways based on morphologic and volumetric variability, those data were also used to develop a regional sediment budget along the studied stretch of coast.

To gain insights into the morphodynamics of the dual-inlet system, bathymetric and hydrodynamic data was used to develop a numerical model of the dual inlet system. Numerical model simulations based on existing or baseline conditions were compared with numerical
simulations employing synthetic bathymetric and hydrodynamic conditions in order to examine inlet behavior under a range of different morphological and hydrodynamic conditions.

John’s Pass is the dominant of the two inlets. It exhibits mixed-energy straight morphology and captures ca 81% of the available tidal prism. The inlet has a well-developed mature ebb shoal, and actively bypasses sediment from one side of the inlet to the other supplying sediment to the downdrift littoral system. Blind Pass captures less than 20% of the available tidal prism, and while also exhibiting mixed-energy morphologic characteristics has a less well developed ebb shoal that currently has not fully established a sediment bypassing system.

Both inlets channels and ebb shoals have been dredged on multiple occasions to provide sediment for the nourishment of nearby chronically eroding stretches of beach. Dredge pits excavated along the distal margins of the ebb shoals are infilling at rates substantially slower than expected due to limited sediment transport along those regions of the ebb shoal, while inlet channel dredge pits infill at rapid and expected rates. The objective of this study was to characterize the morphodynamics of the dual-inlet system with the aim of identifying sediment pathways and bypassing mechanisms, and quantify a balanced regional sediment budget in order to design more sustainable approaches to inlet management.
CHAPTER 1
INTRODUCTION

This study examines the morphodynamics of John’s Pass and Blind Pass, two tidal inlets that collectively make up a dual-inlet system sharing the tidal prism of northern Boca Ciega Bay, in Pinellas County, Florida. The morphodynamics of an inlet channel draining an estuary or bay are governed by a complex system of temporally and spatially varying physical processes, including wind, waves, tides, sediment transport, and both tide and wave driven currents. In addition, sediment availability and characteristics in conjunction with underlying geologic framework bear on the morphology and morphologic behavior of an inlet system.

While the combination of physical processes and geologic controls make tidal inlets one of the most dynamic and complex coastal environments, the complexity is often further exacerbated by engineering modifications made to the inlets, adjacent beaches and backbay regions. These modifications can include: (1) construction of jetties or terminal groins at inlet mouths designed to stabilize inlet channels, (2) dredging, filling and dissection of backbay regions yielding changes in the volume of water held within the bay and thus the tidal prism that the inlet system services, (3) maintenance dredging of inlet channels and/or mining of flood or ebb shoals that results in rapidly altering flow patterns in and around inlet channels, and sedimentation patterns, and (4) nourishment of adjacent beaches that results in changes to the coastal sediment
budget. While these influences occur on decadal time scales, long-term influences such as sea level and climate change certainly act to influence inlet behavior and morphology.

Tidal inlets often act as sediment sinks storing significant volumes of largely beach compatible sediment. This sediment is delivered to and transported away from the inlet by longshore transport processes. As will be discussed in Chapter 2, inlet processes directly influence the morphodynamics of adjacent stretches of beach. These influences, depending on specific conditions, either promote sediment deposition or contribute to erosion along updrift and downdrift beaches. In the case of erosional beaches, when in close proximity to an inlet, coastal management practices frequently include mining inlet channels and shoals to provide local sources of sand for those nearby beach fill projects. These practices often satisfy inlet channel maintenance dredging requirements while providing sediment to maintain critically eroding stretches of shoreline and coastal habitat.

Modern approaches to coastal management recognize that engineering modifications to inlet systems must be accomplished without adversely impacting the inlet or adjacent shorelines, and ideally, should be based on sustainable approaches. Inlet channel dredging and the beneficial use of the spoil material for beach fill is just one example. Unfortunately, past engineering practices were often conducted without a regional scale understanding of rates, patterns, and mechanisms of inlet geomorphic change, and thus yielded unintended negative impacts to other parts of the coastal system. These adverse consequences were not necessarily a failure of coastal management practices but rather a reflection of the complexity of inlet systems, and the difficulty and expense of assembling comprehensive databases through which sound management decisions can be made. With recent advancements in field measurement equipment and numerical modeling, some of those challenges mentioned above can now be addressed more quantitatively.
This dissertation resulted from an inlet management study (IMS) of John’s Pass and Blind Pass inlets conducted by the University of South Florida Coastal Research Lab, and funded by the Florida Department of Environmental Protection (FLDEP). Through a combination of recent and longer-term detailed hydrodynamic and morphologic measurements this study aims to provide new and more quantitative insights into the magnitude, rates, and patterns of geomorphic change within the John’s Pass-Blind Pass dual inlet system (JPBPIS). Additionally, numerical simulations of the JPBPIS are used to examine morphologic evolution of the inlet systems under various alternative management scenarios. And finally, quantified rates of post-dredging inlet shoal recovery, in conjunction with formulation of a balanced sediment budget, and identification of sediment transport pathways produced by this study will provide coastal managers and engineers with quantitative tools that will aid in developing more sustainable approaches to managing inlets, inlet sediment resources, and adjacent shorelines.

The preceding provided an overall introduction to this study. Chapter 2 will provide general background on tidal inlets and a review of pertinent literature available on the subject. Chapter 3 introduces the study area, its oceanographic and geologic characteristics, previous research focused at the JPBPIS as well as engineering modifications that have influenced the JPBPIS over the last several decades. Chapter 4 reviews the applied and theoretical approaches used in characterizing hydrodynamic conditions and morphology change and the approaches used to quantify a balanced sediment budget and identify sediment transport pathways within the JPBPIS. The construction of a numerical model simulating the JPBPIS is also described. Chapter 5 presents results of measured hydrodynamics and morphology, volumetric quantification of morphology change, and a balanced sediment budget of the JPBPIS are revealed. Numerical model simulation output of the dual-inlet system conducted under various hypothetical engineering
modifications is also presented. Chapter 6 discusses potential general applications of the results from the JPBPIS to other dual-inlet systems, and Chapter 7 presents conclusions of this study.
CHAPTER 2
GENERAL BACKGROUND:
TIDAL INLET HYDRODYNAMICS AND MORPHODYNAMICS

2.1 Introduction

An inlet is a channel connecting a barrier-backbay, lagoon, harbor or estuary to open-ocean. Inlets provide important pathways for the exchange of water, sediment, and nutrients between bays and open marine environments. They also provide critical access to and from open-ocean for commercial and recreational vessels. A tidal inlet refers to an inlet that is dominantly channeling flow driven by tidal processes with nominal riverine input. John’s Pass and Blind Pass, the subjects of this study, are tidal inlets connecting the northern portion of Boca Ciega Bay (the barrier backbay) to the Gulf of Mexico.

The primary mechanism driving flow through an inlet channel is water surface elevation differences between open-ocean and the backbay and the gradient that those elevation differences yield. The elevation differences occur as tides rise and fall. During a rising or flooding tide, the water level in the open ocean rises first, creating a gradient that drives flow into the backbay. During the falling or ebbing tide, higher water surface elevations in the backbay drive flow seaward through an inlet channel. The temporal variation between high and low tides in the ocean and backbay is referred to as tidal lag. The factors controlling the magnitude of current velocity flowing through an inlet channel include the area of backbay, tidal range, tidal lag, and cross-
sectional area of the inlet channel (LeConte, 1905; O’Brien, 1931; O’Brien, 1969). The tidal range and lag are directly proportional to current magnitude, while channel cross-sectional area is inversely related.

Inlet morphology evolves through the combined effects of tides, waves, and wave driven currents in conjunction with geologic controls, and sediment characteristics and availability (Fitzgerald, 1996). Those physical processes act simultaneously on sediment stored within the inlet channel and shoals, as well as sediment actively being delivered to the inlet through littoral processes, creating a complex system that is constantly adjusting in order to achieve a state of balance or at best dynamic equilibrium. Adjustments occur over a range of temporal scales, from seconds as tidal currents flow in and out of the channels while waves break simultaneously over the inlet’s ebb shoals, to years as inlet channels migrate in response to channel and shoal sedimentation processes, to decades as sea level changes. When natural processes fail to maintain open channels suitable for marine vessel passage, engineering modifications are often implemented designed to mitigate those inlet channel instabilities.

Historically, the primary concern of coastal engineers and managers has been the maintenance of safe passable inlet channels for vessel traffic. While this remains to be a primary management concern, more recent mandates include the management and beneficial use of inlet sediment resources, and ensuring that implemented inlet management strategies minimize impacts to updrift and downdrift beaches. Inlet processes can have substantial influence on adjacent and downdrift beaches. Dean (1988) estimated that 80% of beach erosion issues in Florida are attributed to adjacent inlet processes.
The following section examines fundamental inlet processes and stability, focusing on those relate to inlet morphology and morphologic change within the context of inlet-barrier island systems.

2.2 Inlet Processes, Inlet Stability, Morphology and Morphologic Change

In the case of west-central Florida tidal inlets, inlet channels provide a passageway between barrier islands for vessel traffic and the exchanging tidal flow between the backbay and Gulf of Mexico (GOM). The morphology of tidal inlets varies as a function of tidal range, wave climate, sediment supply, and antecedent geology (FitzGerald, 1996). Figure 1 depicts idealized morphologic features of a typical tidal inlet system. The ebb and flood tidal deltas, also referred to as ebb and flood shoals, are large sediment bodies lying on the seaward and

Figure 1. Idealized drawing of a typical tidal inlet showing morphologic features and the dominant tidal current flow directions. Adapted from Hayes and FitzGerald (2013). Reproduced with permission of the Coastal Education and Research Foundation.
landward ends of the inlet throat respectively. The ebb shoal represents the most dynamic and complex feature of the inlet system. Forming the most seaward portion of the inlet system, ebb shoal morphology is strongly influenced by interacting wave and tidal (dominantly ebbing) processes in conjunction with the volume of sediment delivered to the inlet through littoral processes relative to the volume transported seaward by ebbing currents (Oertel, 1975). As will be discussed later in this chapter, it is along the ebb shoal that sediment is transported from the updrift side of the inlet to the downdrift side through a process referred to as sediment bypassing.

The main inlet channel includes the inlet throat, usually the narrowest and most constricted portion of the channel (Figure 1). The throat is where the greatest current velocities occur and where bi-directional tidal currents flow. Seaward of the inlet throat is the main ebb channel, dominated by ebbing currents, it is also influenced to varying degrees by incident waves and littoral processes. Flanking the main ebb channel and seaward most portion of the channel throat is a body of sediment referred to as the channel margin linear bar. Landward of the inlet throat the channel commonly bifurcates forming a series of flood channels which commonly dissect the flood shoal as depicted in Figure 1 by the 3 landward pointing arrows. These channels focus flood tidal currents. Along the west-central Florida coast, backbay flood shoals often include vegetated supratidal regions bound by flood channels.

Flanking the landward most end of the main ebb channel on the ocean side, and hugging the ends of both barrier islands are marginal flood channels. These marginal channels focus flood tide currents around the ends of the barrier islands and can have significant influences on beach processes there. As depicted in Figure 1, flooding and ebbing currents do not always follow the same paths. In other words, when the tide changes flow direction as it transitions from ebbing to flood or the reverse, the water does not simply reverse direction and follow the same path. This
spatial segregation of flood and ebb flow paths is a feature common to many tidal inlet systems. During the flood tide cycle, maximum velocities tend to occur late in the cycle, between mid- and high-tide when the water is deepest. This causes flooding currents to move in a more sheet-like flow across the ebb shoal through the system of marginal flood channels (Figure 1). Conversely, during the ebbing stage, maximum flow velocities tend to occur between mid- and low-tide when water is shallower, forcing the ebb currents to become more channelized and concentrated within the main ebb channel. Oertel (1988) further described asymmetries between ebbing and flooding currents (Figure 2), with ebbing currents forming free jets confined to the main ebb channel, and flooding flow tending to be more uniformly distributed yielding a convergent flow pattern distributed about the inlet throat or entrance channel. He characterized flood flow as more similar to sheet flow. Since the flooding flow is distributed over a broad arc in contrast to the confined ebb jet, flow velocities through the main ebb channel (Figure 1) are considerably less. As a consequence, within the main ebb channel seaward of the channel throat, flood currents tend to transport less sediment than ebbing currents.

Inlets are often characterized as being flood or ebb dominated (Walton, 2002). Inlets with flooding current velocities greater than ebbing velocities are considered flood dominated and tend to build larger flood shoals than ebb shoals, while the reverse yields an ebb dominated inlet with larger ebb shoals than flood shoals. A consequence of the former is reduced amounts of sediment being delivered to the ebb shoal and adjacent beaches, potentially leading to chronic shoreline erosion patterns. Pingree and Griffiths (1979) discussed the correlation between sediment transport directions and temporal asymmetries caused by harmonic tidal constituent interactions, or more simply stated, tide related sea level variations and the resulting currents.
Walton (2002) discussed tidal asymmetry in the context of flood asymmetric (flood dominate) and ebb asymmetric (ebb dominated) inlet systems. He defined the earlier as those whose falling tide duration exceeds that of the rising tide leading to larger peak flood current velocities, and the former as those whose falling tide duration is shorter than that of the rising tide yielding stronger peak ebb current velocities. His definition assumed total flow \( F_t \) equals zero after integrating over a tidal cycle in order to fulfill the continuity requirement (no volume losses), with

\[
F_t = u(t) A_c
\]  

where \( u = \) current velocity, and \( A_c = \) channel gorge cross sectional area. He further described other factors influencing temporal asymmetries including offshore directed winds which act to push water out of a bay increasing ebbing current velocities while retarding flooding currents, and vertical asymmetries associated with stratified estuaries where the less dense upper freshwater

---

Figure 2. Asymmetry between ebbing and flooding currents exiting and entering an inlet. Panel A illustrates the ebb flow field; panel B the flood flow field, and panel C the composite flow field (from Oertel, 1988). Reproduced with permission from Springer Publishing.
layer during ebbing stage would carry less sediment than the denser saline lower layer during flooding stage. Escoffier and Walton (1979) also examined asymmetries associated with fluid stratification in the context of riverine input to a bay system. Costa and Isaacs (1977) examined the influence of tide gates on temporal asymmetries. Asymmetries as a function of bed friction were examined by Mota-Oliveira (1970), who suggested that head losses associated with higher friction in an inlet channel would yield decreases in bay tidal prism and thus would favor flood dominance over ebb. The relationship between friction and flow asymmetry was explored through numerical modeling simulations by Seelig and Sorenson (1978). They found that higher Manning’s coefficients (a common parameter used to calibrate numerical models) lead to an increased likelihood that an inlet will exhibit flood dominant characteristics. Similarly, through numerical modeling simulation Seelig and Sorenson (1978), and Speer and Aubrey (1985) found that shallow channels (higher friction) tend to be more flood dominant than deeper channels, consistent with Komar (1996) and Oertel (1988) as previously discussed.

As previously described, the morphology of a tidal inlet varies as a function of tidal processes, wave climate, sediment supply, and antecedent geology (FitzGerald, 1996). Tidal forcing tends to push sediment in and out of an inlet, while waves act to drive sediment landward and into the channel. The interaction of tides and waves is greatest over the ebb shoal where wave energy is focused (Hayes, 1980). The spatial distribution of forces generate energy and sediment transport gradients. This is especially pronounced during ebbing stage, when seaward directed tidal currents interact with incident waves, resulting in complex depositional patterns largely confined to the ebb shoal complex. Large scale depositional features (10’s to 100’s of meters in length) of the ebb shoal complex include channel margin linear bars, swash bars, and ebb shoal terminal lobes (Figure 1). Superimposed on these features are a range of smaller scale
bedforms including ripple (<60 cm spacing), megaripples (60-6 cm spacing) and sand waves (>6 m spacing) (Hayes 1980). Depositional features within the flood shoal region include sand waves (Figure 1) and ripples which are dominantly current related since most incident wave energy is attenuated over the ebb shoal seaward of the inlet throat.

Incident waves refract as they approach and interact with bathymetry of the ebb shoal complex. This wave refraction and associated wave driven current can cause local reversals in the prevailing longshore sediment transport direction (Hayes et al., 1970; Hayes and Kana, 1976; FitzGerald et al., 1976). In a study of the Merrimack River Inlet, Massachusetts where net longshore transport (LST) is north to south, Hayes et al (1970) observed a local reversal in LST along the south side of the inlet which they attributed to wave refraction over the inlet’s ebb shoal, to the extent that the downdrift beach accreted becoming offset seaward relative to the shoreline immediately north (updrift) of the inlet. Similar patterns of updrift beach erosion and downdrift beach accretion were observed by FitzGerald et al (1976) at the Prince Inlet, South Carolina, by Lynch-Blosse and Kumar (1976) at Brigantine Inlet, New Jersey, and Goldsmith et al (1975) along the Delmarva Peninsula, Delaware. Goldsmith et al (1975) also noted that the more erosional short period waves (4-6 seconds) tended to refract less, concentrating along the shoreline immediately north of the inlet, while long period accretionary waves (12 seconds) were more strongly refracted and concentrated along the shoreline south of the inlet. Hayes and Kana (1976) considered the wave refraction phenomena as the primary mechanism responsible for the formation of drumstick-shaped barrier islands.

Sediment transport gradients tend to be greater over the shallower portions of the ebb shoal where waves begin to shoal and interact with the seabed and/or where waves break. The result is more active suspension of sediment over those regions, leading to development of
complex depositional features (Komar, 1996). Examining ebb shoal morphologic patterns at tide dominated inlets along the Georgia Bight, Oertel (1972) noted that wave refraction contributed to complex patterns of crossing wave crests. In areas where waves were breaking coincident with crossing wave crests, he observed an increase in sediment suspension with the bores subsequently transporting sediment landward. Oertel (1972) further observed that during tide flood stage, wave bores and tidal currents transported sediment over the shallowest portions of the ebb shoal, while only tidal currents transported sediment shoreward around the shoals and through marginal channels, and during ebbing stage, currents flowed seaward across the shoal, through tidal channels, and around shoal margins. Using fluorescent sand tracers, he also observed, wave-current interaction over the shoals locally yield gyres in sediment transport direction. FitzGerald et al (1976) and FitzGerald and Numendal (1983) correlated sediment transport patterns using inlet hydraulic data, wave refraction diagrams, measured flow velocities, and measured bedform orientations to infer sediment transport directions at Price Inlet, South Carolina. Their results suggested that bedform orientations over the ebb shoal were the product of landward transport (wave and flooding current interactions), while orientations of sand waves and mega-ripples in the main ebb channel indicated deposition resulting from seaward directed current flow (ebbing current). Interestingly, based on current measurements made at Price Inlet by FitzGerald et al. (1976), ebbing flow through the main ebb channel was estimated to have ca 3x the transport capacity of longshore transport, suggesting that sediment carried into the main channel during flood stage would be largely flushed out during ebbing stage.

The interaction of tides and waves and the resulting currents act to distribute sediment contained within an inlet system as well as sediment actively being delivered to the inlet system.
Sediment can come from several sources including: (1) upland material delivered to the backbay or estuary through downstream transport, (2) material being eroded from the underlying paralic substrate, and (3) sediment eroded from updrift and downdrift beaches and delivered through littoral or longshore transport processes. Along the west-central Florida coast, sediment input through river sources is nominal (Davis, 1994). As a consequence, west-central Florida inlet systems largely rely on littoral processes for sediment delivery, in addition to reworking of sediment on the inner continental shelf. In a shorter engineering time scale, provenance for this sediment is from updrift and to a lesser extent downdrift beach stretches. Excluding riverine input, Walton and Adams (1976) suggested sediment stored within inlet shoals largely consists of material eroded from updrift barrier island shorelines. However, contributions from adjacent downdrift shorelines that have been sites of large beach-fill or nourishment projects cannot be excluded from consideration based on the processes discussed above.

As waves approach the shoreline, they shoal to conserve energy, and the once circular deep water particle trajectories begin to compress and become elliptical and ultimately linear after the wave breaks. As the wave shoals and begins to interact with the seabed, sediment becomes entrained or suspended. Turbulence generated as a wave breaks also acts to entrain sediment. Similarly, as the wave breaks, the wave energy transforms, and the longshore component of momentum or radiation stress drives the longshore current (Longuet-Higgins 1970). This shore parallel current, commonly referred to as longshore current transports sediment downdrift. Longshore transport delivers sediment to the downdrift inlet, where some of the sediment is captured by the inlet through current and wave processes discussed earlier and is deposited within the inlet system, while the balance bypasses the inlet continuing on to the downdrift shoreline.
How an inlet redistributes delivered as well as contained sediment varies as a function of current-wave interactions, and more importantly, which of the two processes - wave or tide - dominate. The dominant forcing mechanism can be revealed, to a certain degree, by an inlets morphologic expression.

Davies (1964) recognized the relationship between coastal morphology and tidal range \( (R') \), and classified coastal morphologies based on tidal range. His classification included three categories, microtidal \( (R' = 0-2 \text{ m}) \), mesotidal \( (R' = 2-4 \text{ m}) \), and macrotidal \( (R' > 4 \text{ m}) \). In the case of barrier island-inlet systems, microtidal and mesotidal regimes are only pertinent since strong shore normal tide driven flow within macrotidal environments inhibits barrier island development (Price 1955; Gierloff-Emden 1961; Glaeser 1978; Davis and Hayes, 1984). In addition, a large percentage of barrier island systems around the world are restricted to medium-wave energy environments (Hayes 1979). Hayes (1979) examined barrier shoreline and inlet morphologies along the Texas and Florida Gulf coasts, the New England, North and South Carolina Atlantic coasts, the Alaska Pacific coast, and the Iceland coast. His study in conjunction with Davies’ (1964) tidal range classification, considered inlet morphology to be a function of wave energy, considering low wave energy regions as those with mean wave heights \( (H) < 60 \text{ cm} \), and high energy as those with \( H > 150 \text{ cm} \). He found that wave-dominated coastal systems typically developed in microtidal regions and morphologically tended to yield long thin barriers with widely spaced inlets that exhibited well-developed flood deltas, and small to nonexistent ebb deltas, while tide dominated systems favored mesotidal coasts and were characterized by short, wide drumstick shaped barriers with numerous inlets with well-developed ebb deltas.

Hubbard et al. (1979) examined inlet morphologies within and adjacent to the Georgia bight, identifying 3 types of inlets based on the degree to which tide or wave energies dominated
inlet geometry and morphology. The regional shoreline geometry of the Georgia bight is concave facing the Atlantic which acts to focus tidal flow resulting in mesotidal conditions, while to the north, the relatively straight Atlantic shoreline along South and North Carolina lacks that tidal focusing, yielding microtidal conditions and allowing wave processes to dominate over tidal. The Hubbard et al. (1979) study found that: (1) tide-dominated inlets are characterized by deep ebb-dominated channels flanked by long linear channel margin bars, and poorly developed to non-existent flood deltas, (2) wave-dominated inlets are characterized by large lobate flood-tidal deltas with small ebb tidal deltas that extend a short distance seaward, with channels that are generally shallow (< 6 m), and (3) transitional inlets (mixed tide and wave energies) are characterized by sand bodies concentrated in the inlet throat, and in general host a wide variety of sand body morphologies. The findings of Hubbard et al. (1979) are consistent with the spatial distribution of tidal ranges in that tide dominated inlets were found within the central Georgia bight region and wave dominated inlets were identified to the north of the bight region. Observing that it was possible to have wave dominated characteristics within virtually any tidal regime, and tide dominated characteristics even with small tidal ranges, Davis and Hayes (1984) recognized the importance of wave climate and tidal prism over tidal range. Tidal prism refers to the product of local tidal range and backbay area serviced by an inlet. The volume of water passing through an inlet is directly proportional to the tidal prism, and therefore has more influence on sediment transport processes than tidal range. Tidal inlets along the low wave energy, microtidal west-central Florida barrier island chain exhibit tide, wave, and transitional morphologies with tidal prism being the common variable (Gibeaut 1991). Based on those morphological variations which are manifested primarily in channel orientation relative to the updrift and downdrift barriers and asymmetry of the ebb delta and updrift and downdrift barrier island ends, Davis and Gibeaut
(1990) devised a classification scheme for inlets along the Florida west-central barrier chain (Figure 3). Their classification scheme assumes that morphologic variation will vary as a function of the inlet systems dominant forcing mechanism, with two end members tide or wave, and transitional intermediate forms. As shown in the upper left panel of Figure 3, in an inlet dominated by tidal forcing, the channel is straight and oriented perpendicular to the updrift and downdrift shorelines, the updrift and downdrift shorelines extend out into the open ocean equal distances (they are not offset from one another), and the ebb shoal is relatively large. In addition, the ebb shoal and barrier islands are mostly symmetrical about the channel. The straight channel and symmetry of the barrier ends and ebb delta indicate that obliquely incident waves have less influence on sediment transport and thus morphology within the inlet system than ebbing and flooding tidal currents. This type of inlet exhibits the greatest stability. The lower right panel of Figure 3 illustrates the other end member, a wave dominated inlet. In this type of inlet there is little symmetry due to sediment transport being dominated by obliquely incident waves and the associated wave driven current. In the example shown longshore transport (driven by breaking obliquely incident waves) is from the bottom to the top of the image. The updrift barrier grows in a spit-like manner downdrift and the channel adjusts its position accordingly. The ebb shoal is poorly developed owing to the strong longshore current generated by the incident waves. This type of inlet is migratory by nature and represents the least stable inlet form. Of the two intermediate forms, the mixed energy offset form (Figure 3, lower left panel) is characterized by a moderately developed ebb shoal which tends to be skewed in the downdrift direction, a larger and typically drumstick shaped (Hayes and Kana, 1976) downdrift barrier island, who’s shoreline is offset seaward relative to the updrift barrier shoreline, and a channel that is slightly bent in the downdrift direction. Although transitional, when combined, the consistent bias in morphology to
the downdrift direction indicates wave energy dominates to some degree over tidal forcing. In contrast, the mixed energy straight form (Figure 3, upper right panel), characterized by a largely straight channel although not oriented perpendicular to the updrift and downdrift shorelines, well developed mostly symmetrical ebb shoal, and roughly equal positions of the updrift and downdrift shorelines suggests tidal forcing dominates to some degree over wave energy.

Carr-Betts et al. (2012) used an empirical approach considering tidal range, wave energy, and tidal prism variables to classify tidal inlet morphology. They examined eighty-nine inlets along U.S. coastal waters that had measured or calculated tidal prism data, quantitatively

![Figure 3. Classification of inlet types found along the microtidal west-central Florida barrier island chain based on dominant forcing mechanism. Hatching indicates areas along the shoreline that are most affected by tidal inlet dynamics. The ocean is to the left and the bays are to the right (from Davis and Gibeaut, 1990). Reproduced with permission from Florida Sea Grant.](image)
characterizing wave exposure using Walton and Adams (1976) parameter $H^2T^2$ (where $H$ is mean wave height and $T$ is wave period) to define, mildly wave-exposed (0-2.8 m$^2$s$^{-2}$), moderately exposed (2.8 – 27.9 m$^2$s$^{-2}$), and highly wave-exposed (> 27.9 m$^2$s$^{-2}$) coastlines. They found the best correlations with inlet morphology were gained when considering tidal prism and wave exposure variables, and poorer correlation with tidal range and wave climate, supporting the assertion put forth by Gibeaut (1991) regarding the influence tidal prism has on inlet morphology. While most of the studies so far discussed have provided qualitative insights into inlet morphologic evolution, on engineering time scales, understanding the physical processes involved in maintaining a stable inlet channel are principal concerns of coastal managers and engineers.

From a coastal management perspective, inlet stability is commonly measured by the level and frequency of human intervention required to maintain an open and passable inlet channel. The concept of inlet stability and morphology in the context of physical processes has been the focus of coastal scientists dating back nearly a century. Early efforts yielded three widely applied quantitative approaches to characterize inlet channel stability or equilibrium including: (1) tidal prism – channel cross-sectional area relationship (A-P relationship) (LeConte, 1905; O’Brien, 1931, 1969), (2) Escoffier closure diagram (Escoffier, 1940), and (3) the Bruun stability rule.

Examining the relationship between tides and inlet morphology at four harbor entrances on the U.S. Pacific coast, Le Conte (1905) recognized that the minimum cross-sectional area of an inlet throat ($A_c$) was related to the spring tidal prism ($P$) as a power function

$$A_c = C_1 P^n$$

(2)
where \( C_1 \) and \( n \) are empirical coefficients determined from regression analysis, with \( n \) approaching unity. It is worth noting that the empirical coefficients are dependent on the units of measure. O’Brien (1931), subsequently found that for Pacific coast inlets

\[
A_c = 4.69 \times 10^{-4} P^{0.85} 
\]

(3)

O’Brien (1969) further validated Equation 2 using a larger inlet database that included 28 inlets with 9 from the Atlantic coast, 18 from the Pacific, and 1 from the Gulf coast, finding that Equation 3 agreed well for inlets with two jetties. However, for unstructured inlets (no jetties or terminal structures) the linear relationship

\[
A_c = 2 \times 10^{-5} P 
\]

(4)
yielded more satisfactory results. For Pacific coast inlets Jarrett (1976) suggested \( C_1 = 3.3 \times 10^{-5} \) and \( 4.3 \times 10^{-5} \) for unprotected and inner harbor entrances, respectively. Nayak (1971) and Johnson (1972) provide additional validation of Equations 3 and 4.

While the A-P relationship continues to be widely applied owing to its simplicity and engineering value, it fails to consider the effects of wave forcing and littoral sediment transport seaward of the channel throat. Stive et al. (2009) argued that in terms of inlet stability, the A-P relationship was valid only for inlets that showed phenomenological similarity (i.e. similar magnitudes of wave driven littoral transport, similar tidal amplitudes and periods, similar sediment characteristics and channel cross-section geometries).

In order to account for contributions tide and wave energy have on influencing inlet stability, O’Brien (1980) extended the A-P relationship to by applying a closure coefficient (I) which describes the proportionality of tidal prism power over wave power, and provides a means to predict whether or not an inlet will remain open or close.

\[
I = \frac{(P)(R_t)}{((g_w)(b)(T_w)(T)(H^2)}
\]

(5)
where \( g_w \) = weight per unit mass of water, \( P \) = tidal prism, \( R_t \) = the tidal range, \( b \) = inlet throat width, \( T_w \) = wave period, \( T \) = tidal period, and \( H \) = deep water wave height. O’Brien (1976) determined closure coefficients for 18 inlets along the U.S. Atlantic coast between Pamlico Sound, North Carolina and Ponce Inlet, Florida, and found for \( I < 0.016 \) inlets tended to be less stable and wave dominated, \( 0.016 < I < 0.018 \) characterized transitional inlets (between unstable wave dominated and more stable tide dominated), and for \( I > 0.018 \) inlets were stable and tide dominated.

Hubbard et-al. (1979), examining the morphologic variability of tidal inlets along the same stretch of Atlantic coast, viewed wave and tide energy as the primary factors determining inlet morphology, and provided a qualitative description of the morphologic variability of tide, transitional, and wave dominated inlets. Hubbard et-al. (1979) considered tidal prism, inlet cross-sectional area and shape, and nature and size of back bay as second order controls on inlet morphology, and degree of ebb or flood dominance and wind circulation as third order controls.

In conjunction with O’Brien’s (1966) equilibrium velocity \( (u_e = \sim 1 \text{ m/s}) \), Escoffier (1940, 1972) addressed the issue of inlet channel stability and equilibrium by examining the relationship between mean channel flow velocity \( (V_m) \) and channel cross-sectional area \( (a_c) \). He hypothesized that an inlet’s cross-sectional area can be reduced as currents (wave and tide generated) move sediment into an inlet channel; however, given a fixed mean channel flow velocity (assuming constant tidal prism), currents will scour away any deposition that reduces channel cross-sectional area \( (a_c) \) below its equilibrium value (Figure 3). In other words, referencing Figure 3, considering point P1 as a stable inlet position, any reduction in \( a_c \) will increase velocity resulting in increased scouring and a return to P1 mean velocity. Similarly, an increase in \( a_c \) results in decreased velocity. As velocity declines, sedimentation increases, reducing \( a_c \), ultimately increasing
velocity, resulting in an eventual return to equilibrium position P1. Conversely, from point P2, an unstable position, if $a_c$ declines, velocity declines and the inlet eventually closes. If $a_c$ increases, velocity increases until point P1 is reached and the inlet becomes stable. Considering episodic storms, if the inlet lies within the “equilibrium range” and a large enough volume of sediment is introduced into the inlet channel through storm forcing, $a_c$ could be reduced and the inlet could become unstable or close. While Escoffier’s curve does not consider wave forcing it does indirectly consider the consequences of sedimentation.

Escoffier (1940, 1972) provided a general approach to quantitatively characterize inlet stability given a single inlet channel or gorge connecting a bay to the open ocean (Figure 4).

![Escoffier diagram showing relationship between mean velocity and channel cross-sectional area. Region between points P2 and P1 and to the right of P1 indicate stable channel conditions. Region to the left of P2 represents unstable channel conditions (from Escoffier, 1940).](image)

Figure 4. Escoffier diagram showing relationship between mean velocity and channel cross-sectional area. Region between points P2 and P1 and to the right of P1 indicate stable channel conditions. Region to the left of P2 represents unstable channel conditions (from Escoffier, 1940).
inlet channel systems are however, not always the case, especially along barrier island coasts where dual (two) or multiple (N) inlets often drain a common bay, the earlier being the case for the JPBPIS. Van de Kreeke (1984, 1990) recognized that within multi-inlet systems, morphologic change in one inlet can influence the stability of the other inlets within the system. Expanding on Escoffier’s (1940) stability analysis to include multiple inlet channels draining a common bay, Van de Kreeke (1984, 1990) considered gorge cross-sectional area \( (a_c \text{ in Figure 4}) \), and both maximum bottom shear stress \( (\tau) \) and equilibrium shear stress \( (\tau_{eq}) \) as the principal factors determining inlet gorge stability within multiple inlet systems. He defined equilibrium shear stress as bottom stress induced by tidal currents necessary to flush sediment carried into the inlet gorge by longshore processes, and considered an inlet to be; (1) in equilibrium with its hydraulic environment when maximum bottom shear stress equals equilibrium shear stress, (2) scouring when maximum bottom shear stress was greater than equilibrium shear stress, and (3) shoaling when maximum bottom shear stress was less than equilibrium shear stress. Accordingly, Van de Kreeke (1984, 1990) created equilibrium flow curves for theoretical dual and multi (N) -inlet systems and similarly applied the analysis to the Pass Cavallo and Matagorda inlet system, a dual-inlet system located along the Texas Gulf barrier island coast draining Matagorda Bay. An equilibrium flow curve for a given inlet represents the set of values for gorge cross-sectional area \( (a_c) \) which \( \tau = \tau_{eq} \). Plotting multiple equilibrium flow curves for each inlet within a multi-inlet system reveals the extent, and if they exist, intersecting stability fields, or regions where stable conditions exist simultaneously within each inlet channel. Van de Kreeke (1990) ultimately concluded that no stable equilibrium flow areas exist for two-inlet systems, and at best two sets of stable equilibrium flow regions for N inlet systems may exist. While his analysis couldn’t have included the infinite number of possible multiple inlet system configurations, it serves to illustrate
how sensitive inlet channel stability can be to morphologic change within a multiple channel inlet system. Jetties, terminal groins, seawalls, and periodic inlet channel dredging are common approaches used to mitigate the instabilities Van de Kreeke (1984, 1990) suggested. In the case of the Pass Cavallo and Matagorda dual inlet system, currently Pass Cavallo remains unstructured and open, while Matagorda inlet has been stabilized with a 1000 m long jetty extending into the Gulf of Mexico on the north side and a 1600 m jetty on the south side of the channel. As will be discussed in subsequent sections of this manuscript, construction of terminal groins, seawalls, and periodic dredging has been the engineering approaches used to mitigate channel instabilities within the JPBpis.

While Escoffier’s (1940, 1972) approach to quantitatively characterizing inlet stability did indirectly account for sediment captured by an inlet from longshore sediment transport processes, it failed to consider inlet instabilities associated with sedimentation outside of the channel gorge but still within the main ebb channel and ebb shoal. Consequently, Bruun (1968) considered the A-P relationship too generalized to provide a suitable empirical characterization of inlet stability. His primary argument was that it was too generalized and failed to address the combined hydraulic and sediment transport processes active within inlet systems. In reference to the A-P relationship, Bruun (1986) stated:

“Innumerable papers have been written on the subject, considered by committees that deal with hydraulics, and published in proceedings of conferences on coastal engineering. One is thus tempted to ask whether these researchers that deal with hydraulics have ever seen a tidal inlet on a littoral drift shore.”

While Escoffier’s (1940) approach did indirectly address the issue of sedimentation, Bruun (1986) considered navigability in and out of inlet and thus sedimentation as the fundamental
underlying premise to evaluating inlet stability. While an inlet throat may remain passable under a range of hydraulic conditions as suggested by LeConte, (1905); O’Brien, (1931, 1969), and Escoffier (1940, 1972), sediment delivered to an inlet entrance through littoral processes is of fundamental importance since sedimentation may occur in the channel seaward of the throat. Brunn (1986) thus added an additional dimension to the concept of inlet stability. While an inlet with an adequate tidal prism may be able to maintain a scoured channel throat, the seaward extension of the channel, the stretch passing through the ebb delta is equally as important since vessels must pass over that portion of the inlet system as they enter and exit the bay. Furthermore, it can be argued that the most complex portion of an inlet, in terms of stability and navigability is the portion of the inlet channel extending seaward from the adjacent beach shoreline position, where combined tidal and wave processes are most active. As a matter of fact, it is that portion of the inlet system where most channel markers are installed. So while one component of inlet stability includes maintenance of a passable inlet throat, the portion of the channel passing through the ebb delta cannot simply be assessed solely based on the tidal prism. Such an assessment must consider the mechanisms balancing sedimentation, with tidal flow and littoral processes.

Brunn and Gerritson (1960), while working on coastal erosion problems in Holland, Denmark, and Florida, recognized that an inlet’s influence on a downdrift beach was variable. They observed that some inlets had large bars at their entrances that “bar-bypassed” material, while others with smaller entrance bars appeared to bypass sediment through more complicated current and wave interactions, referring to those inlets at “flow-bypassers”. They suggested that these different bypassing behaviors could be described by considering the maximum inlet discharge volume ($Q_{\text{max}}$) (which considers the tidal prism), and the volume of sediment crossing the inlet.
entrance through littoral processes (M)

\[ \frac{M}{Q_{\text{max}}} = r \]  \( (6) \)

According to Brunn and Gerritson (1960), when \( r \) is large (>200-300) bar bypassing occurred, and when \( r \) is small (< 10-20), tidal flow bypassing dominated. Later Brunn (1968, 1974, 1978, 1986) revised this ratio to

\[ \frac{\Omega}{M_{\text{tot}}} = r \]  \( (7) \)

where \( \Omega = \) tidal prism, and \( M_{\text{tot}} = \) total amount of material carried to the inlet entrance through littoral processes. Bruun (1968, 1974, 1978) argued that this ratio more adequately describe the overall stability of a tidal inlet accounting for tidal prism and littoral processes as they relate to morphologic change and sediment transport processes. Bruun (1968, 1974, 1978), related this ratio to navigational suitability, describing “bar-bypassers” as problematic in terms of navigational concerns, and “flow-bypassers” as more favorable since their navigation channels tended to be less obstructed by bars and shoals at their entrances. He considered this ratio more representative of inlet stability than the A-P relationship since it viewed an inlet in a broader perspective, incorporating aspects of sediment transport and morphology change as well as tidal prism. Furthermore, this approach was also relevant to downdrift coastal erosion issues.

The proceeding discussion provides a brief review of commonly applied empirically based approaches to characterizing inlet stability. Bruun and Gaerritson (1960) and Bruun’s (1968, 1978, 1986) approaches provided an important step forward in predicting inlet stability by integrating littoral contributions (relate to sediment transport and morphology change) with hydraulic conditions (related to tidal prism). With those tools, coastal managers and engineers have a practical method through which overall inlet stability can be characterized. In addition, related to
and of equal importance to coastal practitioners is management of inlet sedimentation and concomitant morphology change.

Tidal inlet systems store variable volumes of sediment. Moslow and Heron (1978) and Hayes (1979) have suggested that inlet shoals may contain 30%-60% of the sediment deposited within a barrier island system. Most of this material is stored within inlet ebb and flood shoals (Figure 2), with subordinate volumes in the inlet channel. Excluding riverine input, sediment stored within inlet shoals largely consists of material eroded from updrift barrier island shorelines (Walton and Adams, 1976), and delivered to the inlet through littoral processes. Accordingly, coastal managers and engineers are most interested in the volumes stored within these shoals, particularly the ebb shoals, as a source of sediment for beach nourishment (Marino and Mehta, 1988). In an engineering time scale, most of the sediment stored within inlet shoals is material captured from the littoral system. Therefore, when assessing the viability of exploiting that sediment resource, management considerations must include: (1) assessing inlet sediment accumulations to account for sediment budgets along stretches of shoreline interrupted by inlets, and (2) determining the role of the inlet in influencing adjacent shoreline erosion/deposition rates (Bruun et al. 1978; Marino and Mehta, 1988).

While the morphology of an ebb delta is primarily a function of wave versus tidal energy (Fitzgerald, 1996), Oertel (1975) suggested that the distribution of shoals (i.e. channel margin linear bars and swash/bypass bars) within an ebb delta complex (Figure 2) is a reflection of the volume of sediment delivered to the inlet through littoral processes versus the volume transported seaward by ebbing currents. Walton and Adams (1976), in a study of 44 U.S. inlets, suggested ebb shoal sediment volumes were a function of inlet tidal prism. In their study, correlations were made between ebb shoal volumes and their associated tidal prisms. Shoal volumes were determined
using the method described by Dean and Walton (1973), while tidal prism measurements were determined from current velocity data taken from the throat of the inlets or using the “cubature method” described by Jarrett (1976). The individual inlets were further classified into 3 energy groups: (1) mildly exposed, (2) moderately exposed, and (3) highly exposed, based on the product of wave height squared and wave period squared ($H^2T^2$). Quantitatively, Walton and Adams characterized the volume of sediment stored in the ebb shoal ($\mathcal{V}$) by

$$\mathcal{V} = aP^b$$

(8)

where $P =$ tidal prism, with $a$ and $b$ representing correlation coefficients determined through regression analysis. It should be noted that $a$ and $b$ are dependent upon units of measure. Through regression and using cubic yards for $\mathcal{V}$ and cubic feet for $P$, Walton and Adams (1976) determined $b = 1.23$ yielding the following $a$ values for the corresponding wave energy classifications; highly exposed coasts (7 inlets) = $8.7 \times 10^{-5}$, moderately exposed coasts (18 inlets) = $10.5 \times 10^{-5}$, mildly exposed coasts (16 inlets) = $13.8 \times 10^{-5}$, and value for all coasts = $10.7 \times 10^{-5}$. Considering O’Brien’s A-P relationship, Walton and Adams (1976) subsequently revised equation (8) replacing tidal prism ($P$) with inlet channel cross-sectional area since that value was somewhat simpler to determine for most inlet systems, yielding

$$\mathcal{V} = aA^b$$

(9)

where $\mathcal{V} =$ volume of sand stored in ebb shoal (in cubic yards), $A =$ minimum channel cross-sectional area (in square feet), determining $b = 1.28$ through regression. This revision yielded $a$ values of: (1) highly exposed coasts (7 inlets) = 33.1, moderately exposed coasts (18 inlets) = 40.7, and mildly exposed coasts (16 inlets) = 45.7. Results using tidal prism ($P$) showed scatter but did illustrate consistent increases in ebb shoal volumes with increasing tidal prism over two orders of magnitude (Gibeaut, 1991). The increased scatter when applying tidal prism may be in-part due
to prism measurement inaccuracies as well as unaccounted influence littoral flux may have on
delivered sediment volumes. While knowledge of the gross volumes of sediment stored within an
inlet’s shoals, as discussed above, provides coastal managers and engineers with useful
information, understanding variability of stored sediment is critical to managing those resources.
This suggests a detailed and balanced sediment budget is essential to inlet management.

A sediment budget is a balance of volumes (or volume rate of change) for sediments
entering and leaving a selected region of coast (Figure 5), and the resulting erosion or accretion in
the coastal area under consideration (Rosati, 2005). A sediment budget for inlets and adjacent
beaches provides a conceptual and quantitative model of sediment transport magnitudes and
pathways for a given time period. It provides a framework for understanding a complex inlet and
coastal system under its natural or engineered conditions (Rosati and Kraus, 1999). Modern inlet
management practices must carefully consider their influences on sediment budget and sediment
transport pathways, not only for inlet management purposed, but also to predict how inlet
management activities may effect adjacent beaches.

A sediment budget is a tallying of sediment gains and losses, or sources and sinks, within
a specified control volume (or cell) or series of connecting cells, over a given time (Rosati and
Kraus, 1999; Rosati, 2005). The general equation for formulating a sediment budget can be
expressed as (Rosati, 2005),

$$\Sigma Q_{source} - \Sigma Q_{sink} - \Delta V + P - R = \text{Residual}$$

(10)

where $Q_{source}$ and $Q_{sink}$ represent sources and sinks of sediment to the control volume,
respectively; $\Delta V =$ the net change in volume within the cell; $P$ and $R =$ the amount of material
placed in and removed from the cell respectively. The Residual volume represents the degree to
which the cell is balanced. A schematic of the distribution of terms in equation (10) is illustrated
in Figure 4 (Rosati and Kraus, 1999). In the case of most west-central Florida inlets, $Q_{source}$ and $Q_{sink}$ should dominantly come from longshore sediment transport. The $P$ (beach fill and dredge placement) and $R$ (dredging and mining), and $\Delta V$ (beach erosion/accretion) terms also play significant roles in formulating sediment budgets for barriers and inlets along the west-central Florida due to the frequency of channel dredging and beach fill projects.

![Figure 5. Sediment budget parameters in Equation 10 (modified from Rosati and Kraus, 1999). Note, for the case of west-central Florida inlets, bluffs, river influx, wind-blown transport, and submarine canyon terms are not significant.](image-url)

Sediment management at tidal inlets is a complicated and difficult task. In the Coastal Engineering Manual (USACE, 2002), Bodge and Rosati (2002) provided a comprehensive review, along with various engineering tools and case studies, of regional sediment management in the vicinity of tidal inlets. They refer to the use of littoral, estuarine, and riverine sediment resources in an environmentally beneficial and economical manner. Bodge and Rosati (2002) emphasize that regional sediment management must strive to maintain or enhance the natural exchange of sediment within the boundaries of the physical system. Therefore, an accurate understanding of
natural sediment exchange is crucial to regional sediment management. Specially, for a tidal inlet system, natural sediment exchange generally involves longshore sediment transport to and away from an inlet, trapping of longshore transported sand by the inlet channel and ebb and flood shoals, and bypassing of longshore transported sediment from one side of the inlet to the other. Exact sediment transport magnitudes and pathways are site-specific and controlled by numerous factors including regional geology, morphological characteristics, wave and tide conditions, sedimentological characteristics, and sediment supply. Bodge and Rosati (2002) reviewed various mechanisms of sediment trapping in the inlet channels, which bears on navigational safety, and processes and pathways of sediment bypassing, which play a major role in the accretion and erosion of adjacent beaches. Bodge and Rosati (2002) also provided guidance and examples for sediment budget formulation and various engineering methods and experiences on sediment management at tidal inlets. The concepts of regional sediment management and balanced sediment budget are recent advancement on inlet management practices over the gross empirical approaches discussed earlier.

Understanding how sediment moves from one side of the inlet to the other, referred to as sediment bypassing, plays a crucial role on sustained inlet stability and the state of adjacent beaches and is a central issue to modern inlet management practices. Mehta (1993) discussed beach/inlet processes and management associated with sediment bypassing, with an emphasis on inlets along southeast Florida coast. Stauble (1993) provided an overview of the tidal inlet morphodynamics along the southeast Florida coast. He suggested that the morphology of southeast Florida inlets is controlled by: (1) bay or lagoon configuration; (2) structures along the throat-adjacent shoreline; (3) updrift and downdrift jetty configuration and length; (4) seaward length of the dredged channel; and (5) proximity to shore-normal rock and reef bottoms. For much
of the northern west-central Florida coast, rock and reef bottoms are not significant as few significant exposure of hard bottom have been identified (CPE, 1992; CTC, 1993). Bodge (1993) discussed the crucial influences of gross longshore sediment transport, as oppose to net longshore transport on sediment management and bypassing at inlets, emphasizing that channel or dredge pit infilling can be closely related to gross transport rate, which can be substantially greater than net longshore transport rate. Dean and Work (1993) discussed the application of even/odd analysis to shoreline changes along the beaches located updrift and downdrift of an inlet. Existing shoreline or volume change data can be decomposed into even and odd components. The even component of shoreline or volume change can be interpreted as being due to sediment losses to the flood and/or ebb shoals, removal of sediment from the system by dredging and/or background changes unrelated to the presence of the inlet. Conversely, under idealized conditions, the odd component can be interpreted as sediment impoundment on the updrift side and corresponding erosion on the downdrift side of an inlet (Dean and Work, 1993). The odd component should be closely related to net longshore sediment transport. Dean (1993) examined the influences of terminal structures (jetties and groins) on sediment transport pathways in the vicinity of inlets, and discussed John’s Pass, Florida as an example of terminal structure applications. Dean (1993) concluded that under proper conditions, terminal structures can be effective in alleviating erosion along the adjacent shorelines and preventing accelerated deposition in the deep channel. Walther and Douglas (1993) developed a simple model to evaluate transport and trapping rates over an ebb shoal borrow area in order to predict impacts to bypassing and borrow area infilling rates. The model assumes that the transport rate ratio before and after ebb shoal dredging is a power function of the pre- and post-dredging depth ratio. The recovery of an ebb shoal dredge pit can have significant influence on the sand bypassing across an ebb shoal. Based on modeling results, Walther and Douglas (1993)
found that for the same dredged volume, a shallow cut will initially reduce the natural bypassing rate less than a deeper cut. However, over a comparatively long period of time the influence of a deeper cut will be nearly the same. They also found that their approach consistently overestimated the rate at which a borrow area recovered. Two examples from their study included estimating ebb shoal borrow pit recovery rates at Boca Raton Inlet located along the Florida Atlantic coast and at John’s Pass, the subject of this current study. In both cases predicted infilling rates were overestimated by ca 45% as will be discussed in Chapter 6 of this manuscript.

Sand management at inlets need also consider various ecological factors. Nelson (1993) provided a review of ecological research needs and management issues for southeast Florida beach-inlet systems. He emphasized the crucial need for managing the integrated inlet ecosystem and not simply individual pieces selected on an ad-hoc basis, with the goal of maintaining the biotic integrity of the entire beach-inlet system to the greatest degree possible. Sea turtle nesting constitutes a crucial issue to inlet-beach management especially in tropical to sub-tropical regions. Montague (1993) recommended a series of design criteria for sea-turtle nesting beaches.

A primary objective of this study was to develop a local and regional sediment budget for the JPBPIS, and identify sediment pathways within the dual inlet system. Accordingly, this study adopted the concept of regional sediment management and developed a detailed sediment budget for JPBPIS based on field data collected over a 5-year period. In the following chapter, the study area and research methodologies used in this study are described.
CHAPTER 3

STUDY AREA

3.5 Location and Background Information

John’s Pass and Blind Pass are tidal inlets situated along the northern portion of the west-central Florida barrier island chain (Figure 6). John’s Pass the northernmost of the two inlets separates Sand Key on the north from Treasure Island, while Blind Pass, located 5.5 kilometers to the south separates Treasure Island from Long Key the southernmost barrier in this study. The inlets connect the Gulf of Mexico (GOM) to the northern portion of Boca Ciega Bay in Pinellas County, Florida.

The west-Florida barrier island chain consists of ca 29 barrier islands and 30 tidal inlets. The barrier islands are dominantly composed of Pleistocene siliciclastic sediment with lesser Holocene to recent biogenic carbonate sediment (Davis, 1994; Davis et al., 2003). Currently, the barrier islands are receiving no new terrigenous sediment and the source of the material through which they are maintained is reworked older siliciclastic material and Holocene to modern biogenic carbonate sediment (Davis, 2003). The barrier islands directly overly a broad Miocene-age and older carbonate platform (Scott, 1982); however, in places a variably thick layer of Pleistocene-age siliciclastic sediments overlie the Miocene strata separating the Holocene from the Miocene lithologies (Davis, 1994). The barrier islands rest on a gently sloping continental shelf with gradients ranging from 1:700 off headland areas such as Sand Key to 1:5000 near the northern reaches of the island chain (Davis, 1994). There are localized clusters of shoreface detached sand
Figure 6. Aerial image (2000) showing Sand Key, Treasure Island, and Long Key and the locations of John’s Pass and Blind Pass inlets. Note, purple circles represent R-monument locations and numbers, and the red outline represents the boundary of the numerical modeling domain used in this study (discussed in subsequent chapters). The inset in the lower right corner of the image shows the location of study area and the numerical modeling domain (in red).
ridges of Holocene-age scattered throughout the inner shelf region estimated to contain on the order of 1.4 billion cubic meters of potentially beach quality sand (Finkle et al. 2007). The thickness of the Holocene section making up the barrier island system rarely exceeds 10 m (Davis and Kuhn, 1985; Davis et al. 1989), a factor that can act to limit the depth of tidal inlet channel incision.

The west-central Florida barrier island chain is transgressive in nature, and developed between ca. 3000 ybp and 1800 ybp as the rate of sea level rise declined during the Holocene transgression (Davis and Kuhn, 1985; Stapor et al. 1988; Davis et al. 1989; Davis, 1994). The ages of the barrier islands increase from north to south (Davis, 1994). While there is some debate regarding mid-Holocene transgression rates with estimates as high as 30 cm yr\(^{-1}\) for the eastern Gulf of Mexico (Evans et al., 1985), most agree rates approached the current rate of ca. 0.1 - 0.2 cm yr\(^{-1}\) (Kraft, 1976). In reference to the broader Gulf of Mexico (GOM), Otvos (1970) suggested that most of modern barrier islands around the GOM began forming between 5000 and 3500 years before present (ybp) in conjunction with a mid-Holocene deceleration in sea level rise. The rate of transgression prior to mid-Holocene appears to have been too rapid to promote barrier development. Rapid rates of transgression don’t allow enough time for sediment to accumulate as the shoreface marches too rapidly landward. During rapid rates of sea level rise, if nearshore bars and spits develop, it is likely that high frequency overwash associated with the rapid rise in water level would inhibited dune and beach ridge growth, suppressing emergence. A slowdown in rate of sea level rise initiated in the mid-Holocene would have yielded conditions more favorable for west-central Florida barrier island formation.
The shoreline orientation extending south from the headlands on Sand Key to Long Key (Figure 5) is NW-SE (ca 320 degrees). While both John’s Pass and Blind Pass inlets and their associated backbay region initially formed by natural processes, for a variety of reasons ranging from inlet instability issues to land reclamation and development, the inlet-backbay system has been extensively modified.

Owing to its use as a primary navigation channel, John’s Pass became a federally authorized inlet in 1964 under the Section 107 of the 1960 River and Harbors Act. This designation provides a legal basis through which the U.S. Army Corps of Engineers (USACE) is given exclusive authority to manage engineering activities within the inlet. Blind Pass is not federally authorized; however, due to inlet channel shoaling problems in conjunction with chronic erosion issues at Upham Beach located immediately south (downdrift) of the inlet (north end of Long Key), it is managed collaboratively by Pinellas County and the USACE using a sand sharing model. The sand sharing management model includes periodic dredging of the Blind Pass channel and portions of its developing ebb shoal along with other nearby offshore sediment sources, and placement of the dredged material on the chronically eroding Upham Beach (Elko and Wang, 2007; Roberts and Wang, 2012). John’s Pass is managed in a similar manner; however, borrow material is typically placed on eroding stretches of Treasure Island and Sand Key. John’s Pass has been dredged nine times since 1960 with dredging events occurring at an average frequency of 6 years (see Appendix A). Blind Pass has been dredged 11 times since 1960, at an average frequency of 5 years. Interestingly, although Blind Pass is the smaller of the two inlets in terms of contained sediment, ca 500,000 m³ more sediment has been excavated from Blind Pass than John’s Pass since 1960. Excessive dredging at Blind Pass may have exacerbated inlet stability and sediment bypassing issues, and is discussed in greater detail in subsequent chapters.
The entire coastal region surrounding the two inlets, including the upland portion of the barrier islands and backbay shorelines has been intensely reengineered mostly for residential and commercial development purposes, as well as ancillary infrastructure development. Bridge construction across John’s Pass connecting Sand Key to Treasure Island has influenced currents passing through the inlet. Both inlet channels have been hardened with seawalls and revetments in order to stabilize the channels, and terminal groins have been constructed on both sides of the inlets to prevent sediment from entering the inlet channels and help retain sand along adjacent stretches of beach. Most of the backbay shoreline has been hardened with seawalls. Beaches along the southern ends of Sand Key and Treasure Island, as well as the northern end of Long Key have been re-engineered through the construction of groins in an effort to mitigate shoreline erosion issues. In addition, numerous stretches of all three barrier islands are periodically re-nourished with sediment borrowed from John’s Pass and Blind Pass inlet channel maintenance dredging and other nearby offshore sources in order to mitigate beach erosion issues (Roberts and Wang, 2012). The beach re-nourishments alter the volume of sediment being transported within the littoral system, and consequently alter local and regional sediment budgets. Generally speaking, the JPBPIS has a rich history of engineering modifications. A tabulation of historical engineering modification is provided in Appendix A.

A byproduct of land development and coastal re-engineering along Florida’s shorelines was the establishment of a series of survey benchmarks referred to as Range Monuments (R-monuments) located at ca 1000 foot (305 m) intervals along most of the Florida coastline. The survey benchmarks were located and installed by the Florida Department of Environmental Protection in order to establish and maintain accurate and consistent spatial control along the states coastal regions. Along the studied stretch of Pinellas County coast, R-monuments are permanently
imbedded in concrete, typically within a seawall that borders the upland/backbeach region (Figure 5).

3.2 Previous Studies

Owing to the importance of the JPBPIIS to coastal west-central Florida commercial, recreational, and ecological concerns, a number of studies have been conducted on the dual-inlet system as well as individual components of the system over the last several decades.

Comprehensive studies focused at providing regulatory support for the development of inlet management plans were conducted at John’s Pass in 1993 by Coastal Technology Corporation (CTC, 1993), and at Blind Pass in 1992 by Coastal Planning and Engineering, Inc. (CP&E, 1992). Those studies largely relied on publically available data with the aim of providing long-term comprehensive management plans designed to maintain and improve the inlets. In addition to providing inlet management strategies, those studies also examined the influence inlet processes may have on beach erosion along adjacent stretches of beach, and provided recommendations if warranted to mitigate erosive impacts. Both studies found process-response relationships between inlet processes and beach erosion along the adjacent downdrift (south) stretches of beach. At Blind Pass, inlet related erosion along Upham Beach (Figure 8) was recognized and the proposed plan to mitigate that erosion largely followed the sand sharing model; dredging and placement of dredged material on the beach to mitigate the erosion; however, an additional mitigation measure was proposed involving the construction of 2 groins on the beach to increase retention of the placed sediment. The recommended engineering approaches were implemented and while Upham Beach continues to erode despite the engineering modifications, the groin construction appears to have reduced the rate of erosion and decreased the nourishment frequency (Wang and Roberts, 2009).
This study further examined the relationship between inlet processes and erosion at Upham Beach, the results of which are discussed in subsequent chapters.

At John’s Pass, the approach proposed to mitigate inlet related beach erosion along Sunshine Beach, the stretch of beach immediately south of the inlet on Treasure island (Figure 10), included ongoing scheduled channel maintenance dredging, with placement of dredged material on the eroding stretch of beach, and construction of a terminal groin on the south side of the inlet designed to trap and retain more of the placed sediment (CTC, 1993). Those recommendations were subsequently implemented.

While the 1992 and 1993 inlet management studies discussed above provided technically comprehensive evaluations of the inlet systems, numerous other studies have been conducted on the inlets. In general, prior to the 1990’s most of the studies surrounding the JPBPIS involved direct and indirect measurements of various inlet hydrodynamic and morphologic/geometric parameters. Those data were in turn applied to empirically derived characterizations of inlet stability. Mehta et al (1976a) and Mehta et al (1976b) examined various factors controlling hydrodynamic and sediment transport processes within the JPBPIS. In those studies they provided various inlet parameters including John’s Pass ebb shoal volume (4.6-5.4 x 10^6 m^3), northern Boca Ciega Bay tidal prism (17,000,000 m^3 using 2.7 foot tidal range), as well as examining A-P relationships associated with the dual inlet system and sediment transport rates. Jerrett (1976), examined the A-P relationship at 108 U.S. structured and unstructured inlets including John’s Pass, Florida and provided estimates of the John’s Pass tidal prism (14,000,000 m^3). His assessment of John’s Pass and was based on backbay area estimates made prior to the dredge and fill practices implemented in 1950’s, and prior to the construction of terminal structures at John’s Pass, and therefor don’t necessarily apply to modern conditions. Dean and O’Brien (1987) compiled historic
inlet dredging data (1960-1983), ebb shoal volumes, reported apparent erosional inlet-beach interactions, and provided inlet management recommendations for Florida west coast inlets.

A number of studies have been focused on characterizing historical morphodynamics of Florida west coast inlets. Since little measured hydrodynamic or bathymetric data existed prior to the late 20th century, most of these studies rely on historical aerial photos to qualitatively assess changes in inlet morphology. Krock (2005), who’s study focused on the historical morphodynamics of John’s Pass, provided updated geometric or morphologic data on the inlet as well as a local sediment budget for John’s Pass. Davis and Gibeaut (1990) and Gibeaut and Davis (1993) examined the morphologic evolution of Florida west coast inlets providing an empirical morphologic classification of the inlets studied. Those studies, largely based on ebb delta planform extracted from aerial images, classified the inlets based on the degree to which wave energy or tidal energy dominated inlet processes yielding either wave dominated, tide dominated or mixed-energy inlet forms (see Chapter 2). Accordingly, they suggested that John’s Pass, while historically exhibiting mixed-energy characteristics later developed tide dominated morphology while Blind Pass, originally exhibiting a mixed-energy morphology, over time began illustrating wave dominated morphologic characteristics. They attributed the evolution of the two inlets to primarily gains or losses in the share of the tidal prism the respective inlets captured, with John’s Pass gaining increasing volumes of the tidal prism at the expense of Blind Pass. In other words, as John’s Pass gained and increasing share of the tidal prism, it evolved from a mixed-energy inlet to one dominated by tidal flow. And as John’s Pass gained an increasingly larger share of the tidal prism, the volume of tidally driven flow through Blind Pass was reduced allowing wave forcing to become the mechanism dominating sediment transport within the inlet system. The process-response mechanisms responsible for these changes were in part attributed to engineering
modification to the backbay (Davis and Barnard, 2000, 2003; Wand and Beck, 2012) and are discussed in greater detail in subsequent chapters.

In addition to discussing historical morphodynamics of Florida west coast inlets, Hine et al., (1986), Barnard (1998), and Davis and Barnard (2000, 2003) also examined anthropogenic influences on the morphologic evolution of the inlets. While any substantial engineering modification to an inlet system can yield a cascading range of changes as the system equilibrates to its new form, as will be discussed in subsequent chapters, mining ebb shoals for beach nourishment sand can have profound consequences on sediment bypassing processes.

Walther and Douglas (1993) both of whom contributed to the 1993 CTC study examined several ebb shoal borrow area recovery rates including a dredge pit excavated in the John’s Pass ebb shoal in 1988 (see Figure 48). Although it is unclear as to the precise volume of sediment excavated from the ebb shoal, it was reported by Dean and Lin (1990) that 405,000 m$^3$ of sediment dredged from John’s Pass was placed on the beach at Redington Shores on Sand Key in June, 1988 (Dean and Lin, 1990). However, CTC (1993) reported that the 1988 dredging yielded 380,000 m$^3$ from both channel maintenance and ebb shoal dredging citing a personal communication with Tom Martin of the USACE Jacksonville, Florida district in 1992 as the source of that information. The discrepancy in volumes is further exacerbated by the fact that from this experience, dredged volumes commonly exceed the volume of sand ultimately placed on the beach since some losses occur during transport from the dredge site to the beach. Never the less, since the dredging created new accommodation space within the ebb delta, it was further suggested that while the dredge pit filled, the rate of channel infilling at John’s Pass would be reduced (CTC, 1993; Walther and Douglas, 1993). In other words, sediment that would normally be deposited in the inlet channel, would be diverted to and deposit in the dredge pit. Furthermore, they suggested
this should act to reduce the frequency of channel maintenance dredging. Based on a 1992 bathymetry survey of the John’s Pass ebb shoal (4 years post dredging), Walther and Douglas (1993) indicated that 24,020 m$^3$ per year (96,080 m$^3$ total) had been deposited in the excavation during the 4 years post-dredging, and that complete infilling would take ca 42 years (Figure 7). They further reported that the pre-dredging depth of the borrow area was -4 m and that the average post-dredging depth of the borrow area was -6.5 m; however, no datum was provided. Cialone and Stauble (1998) compared the Walther and Douglas (1993) findings from John’s Pass with 7 other ebb shoal mining projects completed in the U.S. between 1981 and 1988 in order to gain insights into the rates at which ebb deltas recover following ebb shoal mining. Shoaling rates in the Blind Pass entrance channel subsequent to a 2000 dredging project were examined by Tidwell (2005) and Wang et al (2007). As will be discussed in subsequent chapters, dredge pit infilling rates at John’s Pass and Blind Pass were quantified during this study using multiple time-series bathymetric surveys.

In the 1990’s as powerful personal computers became readily available, numerical modeling of inlet and inlet-beach systems became a common tool used in such studies. Becker and Ross (1999, 2001) using published as well as measured hydrodynamic and morphologic data conducted a numerical modeling study of the JPBPIS. They constructed and calibrated a 2-D numerical model of the dual-inlet system in order to simulate existing hydraulic conditions and conduct predictive simulations to evaluate the consequences various hypothetical modifications including inlet shoaling, dredging, and deepening may have on inlet stability (i.e. A-P relationship). They concluded that “traditional stability analyses alone may be inadequate for characterizing the behavior of multi-inlet systems because the morphologic development of an inlet is influenced by factors that affect the tidal-prism distribution of the bay”. In other words, traditional stability
Analysis provides few provisions for segregating the share of tidal prism captured by an inlet belonging to a multi-inlet system that shares the water contained within a bay.

The Coastal Modeling System (CMS) (Buttolph et al., 2006; Reed et al., 2011; Wu et al., 2011; Lin et al., 2011; Larson et al., 2011; Sanchez and Wu, 2011; Sanchez et al., 2014) developed by the Arm Corp of Engineers has been used in several studies to numerically simulate tidal and wave driven currents, waves, sediment transport, and morphologic change within the JPBPIS. Beck and Wang (2009), in addition to using historical aerial photos to gain insights into the morphologic evolution of the JPBPIS, used the CMS to simulate 2 years of inlet hydrodynamics, sediment transport directions and magnitudes, and morphology changes using measured hydrodynamic and bathymetric data to parametrize and calibrate the model. They found that the simulated inlet hydrodynamics, sediment transport directions and magnitudes, along with some
key morphology changes compared well with observed trends. In addition, 24 month simulations of Blind Pass using bathymetry measured immediately following a dredging project in 2000 as well as synthetic bathymetry simulating future proposed dredging projects at Blind Pass and John’s Pass were used to gain insights into inlet response to the actual and proposed dredging projects. That study concluded that the simulations yielded “physically plausible results”. In similar studies, Wang and Beck (2011) and Wang et al (2011) used the CMS in conjunction with measured hydrodynamics and bathymetry to model regional scale hydrodynamic and morphologic patterns within the JBPBIS and along adjacent stretches of beach. Those studies found good correlation between measured and numerically simulated hydrodynamic and morphologic patterns. Collectively the three studies discussed above validated the efficacy of the CMS for simulating complex multi-inlet systems and associated inlet-beach interactions.

In addition to the numerous studies focused at characterizing inlet morphodynamics discussed above, the beaches along the Pinellas County, Florida coast have been the subject of numerous studies. Elko and Davis (2004) described inlet-beach interactions along the north end of Long Key (Figure 5), immediately down drift from Blind Pass. That study examined the active morphodynamics and inlet-beach processes responsible for Long Key evolving from a drumstick type barrier island (Hayes and Kana, 1976) to a wave dominated barrier island (Davis and Hayes, 1984). Saint John (2004) quantified erosion rates and mechanisms at Upham Beach located on Long Key immediately downdrift of Blind pass. Elko (2005, 2006) discussed construction of beach nourishment projects during the active 2004 hurricane season on Treasure Island and Long Key, and storm influenced sediment transport gradients at Upham Beach. Beach nourishment performance, inlet-beach interactions, and natural and anthropogenic influences on the
morphodynamics at Sand Key, Treasure Island and Long Key were examined by Roberts (2012) and Roberts and Wang (2012).

3.3 Blind Pass Engineering History Summary

Blind Pass lies between R-monument 143 on the north and 144 to the south (Figure 6). Over the course of the last 90 years, the inlet’s morphology has varied substantially (Figure 8). It is the older of the two inlets. Prior to the opening of John’s Pass in 1848 by hurricane breach, Blind Pass exhibited mixed-energy and stable morphologic characteristics (Davis and Gibeaut, 1990; Barnard, 1998). Following the opening of John’s Pass, as the new inlet began to capture more of the northern Boca Ciega Bay tidal prism, Blind Pass began to exhibit wave dominated morphologic characteristics, and a number of instabilities including updrift barrier island spit growth, and associated north to south channel migration and infilling. To stabilize the southward migrating channel, terminal groins were constructed on both sides of the entrance channel and a combination of revetment and seawalls were built to anchor the south end of Treasure Island and the inlet channel (Figure 9) (see Appendix A). Blind pass represents one of the most intensely structured (hardened) inlets in Florida. As previously discussed, channel dredging and dredging of the flood shoal (inner shoal) is conducted periodically and the dredged material is typically placed on the north end of Long Key at Upham Beach (Figure 9). Similarly, due to chronic shoreline/beach erosion issues, Upham Beach has been re-engineered through the construction of T-groins (conventional shore perpendicular groin structures with shore parallel T-heads attached to seaward end) designed to attenuate incident wave energy and trap sediment entrained within the littoral system and increase retention of placed (nourishment) sediment.
Figure 8. Time-series aerial photos of Blind Pass from 1926 to 2006. Note the diminishment of the ebb shoal over the years and the severe downdrift beach erosion.

Figure 9. 2010 aerial image of Blind Pass showing the numerous engineering modifications. Also shown are T-groins installed along Upham Beach immediately south of the inlet, and the location of R-monument 143 for spatial reference.
In summary, within the Blind Pass inlet system, three phases of engineering activities have taken place, and are summarized below:

1) Prior to 1937 few engineering modifications were made to the inlet, and the inlet illustrated continuous southward migration over a distance of 2 km. The morphologic response to, in this case, essentially no anthropogenic modifications was maintenance of a well-developed ebb shoal supporting active sand bypassing.

2) Between 1937 and the 1969, substantial engineering activities were implemented primarily directed at mitigating channel migration and infilling. These modifications were dominated by hard engineering measures including construction of concrete and stone terminal groins, seawalls, and revetments. In addition, during this period, extensive engineering modifications were made to the back bay in the form of seawall construction and more importantly, dredge and fill projects designed to create made land for residential development inside northern Boca Ciega Bay. The engineering activities and subsequent morphologic responses are summarized below:

   a. Construction of seawalls and jetties stabilized inlet channel arresting the rapid southward migration;
   b. Substantial dredge-and-fill projects in the back-barrier bay resulted in a reduction of the bay area by ca 20% yielding a corresponding reduction in the tidal prism;
   c. As the inlets share of the tidal prism was reduced, the inlet developed wave dominated characteristics, the ebb shoal collapsed, and shoaling inside the channel becomes a chronic issue;
   d. A temporary increase in accretion along the immediate downdrift beach (Upham Beach) occurred due to the collapsing and subsequent welding of the ebb shoal to the downdrift beach (Upham Beach). The collapse of the ebb shoal altered sediment bypassing characteristics of the inlet-beach system;
   e. A groin field was constructed along the south end of Treasure Island to mitigate chronic beach erosion issues; and,
f. Terminal groins were constructed on both sides of the inlet channel. The groin on the north side of the channel trapped sediment in a fillet immediately north of the inlet, while at the same time mitigated some of the channel infilling.

3) From 1969 to 2015, extensive engineering measures with a focus towards soft engineering solutions (dredging and beach nourishment) were implemented to mitigate inlet channel infilling and chronic beach erosion along Upham Beach immediately south of the inlet. Spoil material dredged from the inlet channel in 1969 placed on Treasure Island to mitigate shoreline erosion issues marked the beginning of a beneficial use of dredge spoils model that remains the dominant method of inlet and beach management to this day. A summary of engineering solutions and associated morphologic responses includes:

a. The inlet developed chronic channel infilling requiring frequent dredging of the entrance channel. On several of the channel dredging events, a portion of the small ebb shoal that did exist was dredged. Dredging spoils are regularly used to nourish adjacent stretches of eroding beach;

b. Both terminal groins were extended in an attempt to mitigate channel infilling on the north side of the channel, and shoreline erosion along Upham Beach to the south;

c. Changes in the regional sediment budget resulting from over 30 years of nearby beach nourishment projects and a cessation of ebb shoal dredging is promoting regrowth of the inlets ebb shoal which will influence and promote sand bypassing; and,

d. A series of T-groins were installed at Upham Beach to mitigate shoreline chronic shoreline erosion problems.

3.4 John’s Pass Engineering History Summary

John’s Pass was opened in 1848 by storm breach. Since its opening, the inlet has exhibited largely tide-dominated characteristics (Barnard, 1998), and consequently exhibits more stability than Blind Pass. The inlet was federally authorized in 1964; however, the earliest engineering modification to the inlet system consisted of construction of a bridge connecting Sand Key to
Treasure Island in 1926 (Figure 10). Subsequently, to reduce the frequency of maintenance dredging primarily associated with entrance channel infilling, the inlet was re-engineered through the construction of terminal groins on the north and south sides of the entrance channel, and the channel margins were hardened with seawalls and revetments (Figure 11). To the north on Sand Key, in an effort to mitigate shoreline/beach erosion 39 groins were constructed along Madeira Beach, as can be seen on the 1957 aerial photo (Figure 10).

Additional engineering modifications included extensive dredge and fill construction in Boca Ciega Bay (Figure 8 aerial photos since 1957) implemented in the 1940’s and 1950’s in order to create additional waterfront real estate for residential development. Some of these backbay modifications simply reconfigured preexisting portions of the inlet’s flood deltas; however, extensive areas of new land (“made-land”) were created through dredging and filling. Between 1940 and the early 1960’s, dredge and fill projects were commonplace throughout much of the backbay regions of Pinellas County. Dredging and filling of northern Boca Ciega Bay yielded an overall reduction in that backbay area of \( \text{ca} \ 20\% \). Unfortunately, at the time, little was understood regarding the consequences of these types of modifications, practices which we now know can have profound effects on the tidal prism and overall stability of the inlets serving those water bodies. In the case of the JPBVIS, reductions in tidal prism exacerbated preexisting inlet stability issues.

In the early 1960s a nearshore berm nourishment was conducted using sand from one of the channel maintenance dredging projects. The berm accreted upward and migrated onshore eventually attaching to the shoreline forming what is referred to as O’Brian’s lagoon (Figure 10). Water stagnation issues developed within the lagoon prompting the Florida DEP to fill-in the lagoon.
The engineering history of John’s Pass illustrates three general phases of engineering activities. Those activities and corresponding morphology responses are summarized below:

1) Prior to 1926, the inlet remained in largely a natural state with a well developed ebb shoal and active sediment bypassing around the inlet:
   a. A bridge was constructed across the inlet channel connecting Sand Key to Treasure Island. Bridge footings in the main channel would influence currents and sediment transport patterns within the inlet channel; and,
   b. The inlet remained largely stable, exhibiting tide dominated characteristics, with well-developed ebb and flood shoals, and active sand bypassing.

2) During the period 1926 through the early 1970’s substantial engineering activities largely in the form of hard engineering measures were implemented. The inlet was federally authorized in 1964 sanctioning any subsequent maintenance to the U.S. Arm Corp of Engineers. Engineering measures and associated morphologic responses include:
   a. The construction of causeways, bridges and backbay dredge and fill projects resulting in increased dissection of the back-barrier bay and reduction of the tidal prism;
   b. John’s Pass channel was dredged three times during this period, with the dredge spoils used as beach fill on adjacent stretches of eroding shoreline. Material from one of the dredging events was used as a nearshore berm nourishment along the north end of Treasure Island. The berm aggraded and formed a small lagoon (referred to as O’Brian’s Lagoon). Subsequent water quality issues within the lagoon prompted the Florida DEP to fill-in the lagoon;
   c. Terminal groins were constructed and subsequently extended on both sides of the inlet channel to mitigate channel in-filling;
   d. A groin field was constructed to the north of the inlet at Madeira beach on Sand Key to mitigate erosion issues; and,
e. The inlet remained largely stable, exhibiting tide dominated characteristics, with well-developed ebb and flood shoals, and active sand bypassing.

3) From the 1970’s to 2015, mostly soft engineering solutions were implemented with a few modifications to existing hard structures. were implemented, including:
   a. John’s Pass channel was dredged 5 times during this period. During one of those dredging events, the ebb shoal was also dredged. Spoil material from the dredging events was used to nourish adjacent stretches of eroding shoreline;
   b. A terminal groin was constructed on the south side of the inlet channel, and the north terminal groin was extended; and,
   c. Overall, the inlet remained largely stable, exhibiting tide dominated characteristics, with well-developed ebb and flood shoals, and active sand bypassing.

Figure 10. Time-series aerial photos of John’s Pass from 1926 to 2010. Note the relatively stable flood tidal shoal, the shoreline variation near the inlet, and the nearshore berm nourishment shown on the 1970 photo.
3.5 Oceanographic Characteristics

3.5.1 Wind Patterns

The region lies within the “horse latitudes” which marks the boundary between prevailing westerly winds to the north and the northeast trade winds to the south. Summer season (from beginning of April to beginning of October) wind patterns are dominated by easterly trade winds driven by high pressure over the Atlantic around the 30 degree north latitude (Pinet, 2014). These summer patterns are periodically interrupted by low pressure systems spilling off the African continent, which when combined with high sea surface temperatures can create tropical depressions and/or hurricanes. Conversely, winter wind patterns are more strongly influenced by
high pressure systems moving south from the polar regions driving strong northerly to northwesterly flows.

Statistical wind conditions recorded at the NOAA Clearwater Beach station CWBF1 (8726724), located *ca* 22 kilometers north of John’s Pass for the period 2010 through 2014 (5 years) are shown in Figure 12. The statistically dominant wind directions are northeast, east, and southeast. These winds are generally less than 10 m/s (19.4 knots) and occur during the summer months. While these winds are directed offshore and have little influence on the beach processes in the study area, the easterly component may influence backbay water surface elevations as strong easterly winds may act to “push” water out of the bay, generating meteorological tides. In addition, summer season convective wind often referred to as “sea breeze” occurs diurnally and flows westerly, counter to the dominant summer season prevailing wind direction. Although these convective winds rarely exceed 7 m/s (14 knots) they do generate onshore directed waves in the afternoon yielding a minor influence on beach processes. The strongest winds of up to 15 m/s (29 knots) in the region excluding the rare tropical storms, occur relatively regularly during late fall, winter, and early spring associated with the passage of cold fronts. These winds are northerly (northwest, north, and north-northeast) and generates highly oblique incident waves. It is these waves that are largely responsible for the net southward longshore sediment transport in the study area.
Figure 12. Wind rose based on measurements made at the NOAA Clearwater Beach station CWBF1 (#8726724) from 2010 to 2014 (5 years). Wind direction is reported using the meteorological convention (i.e., north winds are northerly originating out of the north and blowing south). Wind speed is in meters per second. Refer to Figure 2.1 for the station location.

3.5.2 Wave Patterns

Within the general context of wave energy along world coasts, the west-central Florida coast is considered a low energy coast (Davis, 1994). This is due to a combination of factors including fetch, prevailing wind patterns, and size and bathymetry of the eastern Gulf of Mexico (GOM) shelf. Wind patterns during the late spring, summer and early fall (ca 50% of the year) are dominantly easterly and therefore yield easterly waves which have little influence on coastal processes along the eastern GOM. Similarly the seasonal convective diurnal westerly winds are too weak and fetch limited to generate large waves. In addition, large waves that do form as a consequence of strong westerly winds associated with winter storms lose much of their energy as
they pass over the wide and gently sloping eastern GOM shelf. Statistical wave conditions for the
study area were obtained from WAVEWATCH III (http://polar.ncep.noaa.gov/waves/index2.shtml) for the period 2000 to 2014 (15 years), and are shown in Figure 13. WAVEWATCH III wave conditions are modeled wave statistics based on measured input data of water surface elevation, currents, and wind conditions obtained from offshore buoied sensors. Using those input data, the WAVEWATCH III model solves the random phase spectral action density balance equation for wavenumber-direction spectra for a GOM basin-wide model domain. Governing equations of the WAVEWATCH III model include refraction and straining of the wave field due to temporal and spatial variations of the mean water depth and of the mean current (http://polar.ncep.noaa.gov/waves/wavewatch/wavewatch.shtml). The statistical wave conditions shown in Figure 13 were obtained for a numerically simulated wave station located near the seaward boundary of the study area, approximately 7 km offshore of John’s Pass. As illustrated in Figure 13, most of the waves approach from westerly directions, and are less than 0.5 m. Higher waves (> 0.5 m) tend to approach from west and northwest directions, and are associated with the passage of winter cold fronts.

Nearshore wave conditions from a non-directional wave gauge deployed 300 meters offshore of Blind Pass by the University of South Florida Coastal Research Laboratory during the period spanning November 25, 2003 to February 26, 2005 are show in Figure 14. Wave sampling was conducted at an interval of 90 minutes yielding a total of 4,181 measurements or ca 261 days of wave data; however, due to periods of equipment servicing, the wave record is not continuous. The average measured significant wave height (mean wave height of the highest third of the waves) was 0.26 m with an average peak wave period of 5.8 s, which are similar to estimates for the region made by Tanner (1960). In the 2003-2005 data-set the influence of winter cold fronts on wave
height is apparent as shown by the frequent high wave events (> 0.8 m) recorded during the October to March winter season. It should be noted that the summer of 2004 was exceptional in that three hurricanes, Frances, Ivan and Jeanne made passage through the Gulf in August and September, resulting in three anomalously high wave events as shown in Figure 14. The distal passage of Hurricane Ivan generated long-period (12-16 s) swells which are generally rare for this coast. Both directional and non-directional wave conditions were also measured during this study and are discussed in the following chapters.

Figure 13. Statistical wave conditions for the period 2000 through 2014 computed from WAVEWATCHIII (http://polar.ncep.noaa.gov/waves/index2.shtml) for a numerically simulated wave station located ca 7 km offshore from John’s Pass. Wave velocities are reported in meters per second.
Figure 14. Wave conditions measured *ca* 400 m offshore Blind Pass in 4 m water depth. The measurements were conducted from November 25, 2003 to February 26, 2005 with some gaps due to equipment maintenance. Upper panel shows significant wave height, and lower panel shows corresponding peak wave period. The 2004 hurricanes are labeled as: 1-Francis, 2-Jeanne, and 3-Ivan.

### 3.5.3 Tides

Tides along the west-central Florida coast exhibit both mixed and semi-diurnal tidal patterns. The spring tide illustrates a mixed tidal pattern with a maximum tidal range of *ca* 1.2 m, while the neap phase tends to approach a semi-diurnal pattern with a maximum range of *ca* 0.4 m (Figure 15). During spring tide flood stage, a low amplitude water-level decline occurs yielding the mixed pattern, while the sign of the slope of the ebbing phase curve is continuous from high- to low-water slack stages. The magnitude of the water-level decline during the spring flooding phase increases as the spring cycle approaches the neap cycle, eventually translating into a semi-diurnal pattern with two highs and two lows of near equal magnitude occurring during a 24 hour
period. Figure 2.8 illustrates water levels measured over a 2 week tidal cycle between July 23, 2008 and August 5, 2008 at a location ca 3 km offshore of John’s Pass and are representative of the study area. However, meteorological influences can modify these patterns on short-term temporal scales. Longer term detailed water surface elevations (tide) were measured at offshore and numerous inshore locations during this study in order to identify spatially variable tide stage phase lag. Tidal stage phase lag, especially between offshore and inshore regions and the corresponding difference in water surface elevations are what drive current through inlets, and is discussed further in Chapter 5.

Figure 15. Tide measurements collected from a site located ca 3 kilometers offshore from John’s Pass during the period July 23, 2008 to August 5, 2008.
CHAPTER 4
METHODOLOGY

4.1 Field Methods Introduction

This study utilizes a broad temporal and spatial hydrodynamic, morphologic, and sedimentological data-set in conjunction with numerical modeling in order to: (1) gain insights into the morphologic evolution of the inlet ebb deltas, (2) develop a sediment budget and identify sediment pathways for the dual inlet system, and (3) examine the morphodynamic behavior of the John’s Pass-Blind Pass dual inlet system under a variety of inlet management alternatives. To this end, in 2014 and 2015, measurements of hydrodynamic conditions, morphological states and sedimentological characteristics were made and used to quantify rates of sedimentation and morphologic change within the inlet systems, and to parameterize, calibrate and verify numerical model simulations of the dual-inlet system. To complement this data-set, time series bathymetric surveys of the inlets and topographic beach profile survey data collected by the University of South Florida Coastal Research Laboratory between 2006 and 2015 were used to quantify inlet, beach and nearshore morphologic changes. In the following sections the field measurement and numerical modeling methods employed in this study are described. First discussed are methods used in the collection of hydrodynamic data, followed by morphologic and sedimentological measurements, and finally the approach employed to numerically simulate the dual-inlet system.
4.1.1 Wave Measurements

Incident waves are generated in the GOM and propagate into the study area. In order to quantitatively characterize these wave conditions, two directional wave gauges were deployed within the study area domain (Figure 16). A Teledyne RDI Workhorse Sentinel capable of measuring directional wave, current, and water surface elevation was deployed near the offshore boundary of the numerical modeling domain (Figure 16) at a depth of 8-m from 6/6/2014 to 6/16/2015 (11 months 10 days) with one gap in the data set between 8/8/2014 and 8/20/2014 during which time the gauge was deployed in the John’s Pass channel. Wave sampling was conducted every 90 minutes for a duration of 900 seconds (15 minutes), sampling at a frequency of 2 hertz. Water surface elevation for constraining tide stage, and current sampling was conducted every 20 minutes sampling every 24 seconds (ca 0.04 hz) for a duration of 20 minutes. The Teledyne RDI Workhorse Sentinel is a fully autonomous sensor with self-contained memory and battery power. Battery capacity and memory storage limitations dictate deployment durations and sampling rates. Owing to the depth at which the Teledyne RDI gauge was deployed, little bio-fouling occurred and the equipment yielded continuous measurements throughout the duration of the deployment.

The second offshore gauge, a SonTek Triton PUV (pressure and velocity) directional wave gauge was deployed ca 300 meters offshore Treasure Island (R-133) at a depth of ca 2.5-m from 5/7/2014 to 10/7/2014 (6 months). Wave sampling was conducted every 90 minutes for a duration of 512 seconds sampling at 2 hertz. Owing to the shallow water at this deployment site in conjunction with high seasonal water temperatures, the Triton acoustic transducer and receivers were rapidly bio-fouled limiting the velocity measurements needed for the computation.
Figure 16. Image of study area showing the locations of hydrodynamic sensors deployed during this study, and the boundary of the numerical modeling domain (red border). Panel A shows greater study area; B shows gauge locations within the John’s Pass inlet channel, and C shows gauge locations within the Blind Pass inlet channel. Green triangles represent upward looking acoustic Doppler wave and current gauge locations; blue diamonds are side looking acoustic Doppler current gauges, and red pentagons are water surface elevation (tide) gauges. Range monuments (R-Monuments) are shown in purple for spatial reference.
of wave direction which became unreliable after *ca* 7 days. As a consequence, nearshore wave measurements are largely non-directional.

In addition to measured wave conditions, longer duration wave records were required to drive long-term (2 year) numerical simulations of the dual-inlet system. As previously discussed in Section 3.5.2, these wave data were obtained from NOAA’s WAVEWATCH III modeled wave data for a station located coincident with the Teledyne RDI gauge location. To validate the WAVEWATCH III computations, those data were compared to the measured data returned from the Teledyne RDI gauge (Figures 18, 19, and 20). While the temporal distribution of WAVEWATCH III wave heights and wave direction correlated well with measured data, the WAVEWATCH III data under-predicted wave heights for waves higher than 0.6 m by *ca* 9%. In addition, while measured wave conditions for low waves at times yielded periods on the order of 10 seconds, a characteristic of approaching distal swells, WAVEWATCH III failed to

![Figure 17](image_url)

Figure 17. Measured significant wave heights at the seaward boundary of the numerical modeling domain compared to WAVEWATCH III modeled significant wave heights for the period 6/7/2014 – 12/31/2014.
Figure 18. Measured wave peak periods at the seaward boundary of the numerical modeling domain compared to WAVEWATCH III modeled wave peak periods for the period 6/7/2014 – 12/31/2014.

Figure 19. Measured wave principal directions at the seaward boundary of the numerical modeling domain compared to WAVEWATCH III modeled wave principal directions for the period 6/7/2014 – 12/31/2014.

capture those long period waves, and may in-part explain the under-prediction of the modeled wave heights. Since high wave conditions are more important to sediment transport and morphology change than small waves, given the correlation between the measured and modeled
WAVEWATCH III wave conditions, for long-term numerical model simulations, WAVEWATCH III statistical wave heights were increased by 9% for modeling purposes.

4.1.2 Current Measurements

Currents passing in and out of an inlet play a crucial role in sediment transport and morphology change of the inlet system. Therefore, insights into inlet related sediment transport can be gained by examining the bi-directional current magnitudes and their spatio-temporal distribution. In addition, measured current velocity data is critical to calibrating and validating numerical model simulations of an inlet system. Several approaches were used to quantify ebbing and flooding currents during this study. Current magnitudes and directions were measured vertically throughout the water column and horizontally across the inlet channels from discrete fixed positions using upward and horizontal looking acoustic Doppler current meters, respectively. In addition, to provide broader spatial coverage of current velocity magnitudes within the inlet systems, a ship mounted downward looking acoustic Doppler current meter was employed to map the inlet flow fields during ebbing and flooding stages.

Within the inlet channels, current velocities through the water column (in the vertical dimension), were measured using a Teledyne RDI Workhorse Sentinel. Figures 17B and 17C show the locations of the upward looking Workhorse Sentinel acoustic Doppler gauges (ADCP) deployed in John’s Pass and Blind Pass, respectively. In the case of John’s Pass, the ADCP was deployed in the channel thalweg (Figure 17B) at a depth of 9.25 m (depth at peak spring tide level) on 7/22/2014 and retrieved on 8/13/2014 yielding a continuous 23 day record ensuring that full spring and neap cycles were captured. Water surface elevation for constraining tidal stage, and current sampling was conducted every 6 minutes, sampling at a frequency of 1 hertz for a duration
of 50 seconds. Due to equipment and mounting platform dimensions, and blanking distance, samples were collected in 0.25-m bins extending from 1.88 m above the top of the ADCP, precluding current velocity measurements along the bottom boundary layer. In Blind Pass, the same ADCP equipment was deployed from 8/14/2014 to 9/13/2014 (31 days) in the channel thalweg (Figure 17C) at a depth of ca 10 m (depth at peak spring tide level). Measurements were made, using the same sampling scheme as that used in John’s Pass; water surface level and current sampling was conducted every 6 minutes, sampling at a frequency of 1 hertz for a duration of 50 seconds. Samples were collected in 0.25 m bins extending from 1.38 m above the top of the ADCP. In both cases, the ADCP’s yielded current velocity for 3 directions \( u \), \( v \), and \( w \), as well as water surface level variations (tide) relative to the top of the ADCP. It should be noted, as described in section 3.1.1, the ADCP deployed at the offshore boundary of the numerical modeling domain (Figure 16) also measured water level and current velocities in three directions, \( u \), \( v \), and \( w \) independent of the wave data; however, at reduced frequencies relative to the ADCPs deployed in the inlet channel thalwegs.

Cross-channel current velocities were measured in both John’s Pass and Blind Pass utilizing acoustic Doppler current gauges. The equipment used was a 600 kHz Teledyne RDI Channel Master horizontal ADCP (H-ADCP). The H-ADCPs were deployed simultaneously in John’s Pass and Blind Pass from 8/21/2014 to 9/13/2014 (23 days) ensuring that full spring and neap cycles were captured. In John’s Pass the H-ADCP was fixed to a dock piling along the south side of the inlet channel (Figure 17B) at ca 2 m below the water surface (at low tide) with the beams oriented perpendicular to the channel orientation. At this depth, given a signal beam width of 1.5 degrees, the signal beam remained well below the water surface and minimized any influence vessel traffic may have had on the measurements. In Blind Pass, the H-ADCP was
similarly mounted to a dock piling, at a depth of \textit{ca} 1 m below the water surface (at low tide), which equated to \textit{ca} 50\% of the water depth at that location. In each case the signal beams were oriented perpendicular to the channel orientation. Sampling of current velocity ($u$, $v$, and $w$) and water surface elevation in 1 m bins was conducted every fifteen minute at a frequency of 0.05 Hz for a duration of fifteen minutes. H-ADCP’s were also deployed at the northern (“The Narrows”) and southern (Corey causeway) backbay boundaries (Figure 16) of the apparent hydrodynamic domain from 12/8/2014 to 1/16/2015 (40 days). At the northern “Narrows” boundary, the H-ADCP was fixed to a piling below the Park Boulevard bridge at a depth of 1.6 m below the water surface (at low tide). At the southern Corey causeway site, the H-ADCP was fixed to a dock piling, at a depth of \textit{ca} 1.5 m below the water surface (at low tide). Sampling was conducted using the same sampling scheme as described above for the John’s Pass H-ADCP deployment.

Figure 20. Survey vessel showing downward looking ADCP (left image) and RTK GPS equipment (right image) used to map current flow fields within John’s Pass and Blind Pass.
In order to characterize the flow fields in the vicinity of the inlets, a ship mounted downward looking acoustic Doppler current profiler was fixed to a survey vessel allowing real-time measurement of current velocities \((u, v, \text{ and } w)\) during spring ebb and flood tide stages. The surveys were conducted on July 22, July 31, August 7, and August 13, 2014 in John’s Pass (capturing spring ebb and flood tide stages), and on August 20 and 24, 2014 in Blind Pass (capturing spring ebb tide stage) using a Teledyne RDI Monitor synchronized with a Trimble RTK GPS system to maintain spatial control (Figure 20). A PC mounted onboard the survey vessel recorded all current and position data. Sampling was conducted through the water column using 0.25 bins, extending from below the equipment’s blanking distance of 1.5 m.

4.1.3 Water Level – Tide Measurements

Water level variations were measured at six locations in the back-bay using In-Situ water level sensors. The water level sensors were installed in stilling wells. Ambient barometric pressure and its variations were measured simultaneously with water-level measurements. Barometric pressure and water level were measured every six minutes. Water-level variations were also measured in the open Gulf at the offshore boundary of the numerical modeling domain as previously discussed in Section 3.1.2. Water level measurements in the backbay were conducted from August 6, 2014 through September 13, 2014, and also from December 5, 2014 through January 16, 2015. These data were used to characterize tidal behavior within the dual-inlet system, and to calibrate and verify numerical simulations of the dual-inlet system. For long-term (2 year) numerical simulations of the dual-inlet system, tide data was obtained from the NOAA Clearwater tide gauge station discussed in Section 2.2.1.
4.1.4 Bathymetric Surveys

Bathymetric surveys were conducted in and adjacent to John’s Pass and Blind Pass to provide bathymetric control for numerical modeling purposes, as well as morphologic data necessary for quantifying rates of morphologic change, volumetric analysis, formulation of a sediment budget, and identifying sediment pathways. Both single beam and multi-beam echo sounders were used in this study.

Detailed bathymetric surveys of both inlet systems were conducted in July 2014 using a Teledyne Odom MB1 multibeam echosounder equipped with an internal motion sensor for heave-pitch-roll correction, and a sound velocity sensor to maintain accurate on-the-fly acoustic signal velocity control. Heading control, which is particularly important in maintaining proper spatial orientation of the multibeam swath was accomplished using an integrated Hemisphere Vector VS131 GPS heading compass. The MB1 was synchronized with a Trimble R4 RTK GPS system to maintain precise lateral and vertical (tide correction) spatial control. Reson PDS 2000 software was used for multibeam data acquisition, survey planning and guidance, and post-processing. The 2014 multibeam surveys of the John’s Pass and Blind Pass ebb shoals and channels were completed using a 10 meter longitudinal (shore parallel) survey-line spacing to ensure that detailed bathymetry was captured (Figure 21).

The MB1 system is limited to water depths greater than 1.5 m, and therefore multibeam coverage of the flood shoal region was limited due to shallow water conditions. To fill-in the gaps over those portions the John’s Pass flood shoal that could not be surveyed with the multibeam system, in June and July, 2014, a single beam survey of those regions was conducted using equipment capable of collecting accurate data in water depths as shallow as 0.5-m. In addition, single beam surveys of the offshore extensions of the R-monument based beach profiles were also
Figure 21. Image showing extent (red lines) of 2014 multibeam bathymetric survey coverage of the JPBPIIS.
Figure 22. Image showing extent of 2014 single beam bathymetric survey coverage of the northern portion of Boca Ciega Bay in red, and single beam surveys extending R-monument beach profile surveys in black.

surveyed in June and July 2014 (Figure 22). The single beam surveys employed a Teledyne Odom Echotrac CV100 single beam echo sounder equipped with a SMSW200-4a narrow beam (4°) transducer. The narrow-beam equipped CV100 performs especially well in shallow water. The CV100 system was synchronized with a Trimble R4 RTK GPS for spatial control and tide level correction. HYPACK software was used for single beam survey data acquisition, planning and guidance, and post processing.
In addition to the 2014 bathymetric surveys, single beam bathymetric surveys of the inlet ebb shoals and channels completed by the author in June 2010, October 2010, January 2011, September 2011, and July 2012, as well as offshore bathymetric extensions of the R-monument based beach profiles conducted annually since 2009 (blacklines Figure 22) were used in this study. The single beam surveys employed the same Teledyne Odom Echotrac CV100 equipment and procedures as described above. The inlet bathymetric surveys were completed on a grid of transverse and longitudinal lines spaced 50-m apart.

4.1.5 Sediment Sampling

In order to gain insights into the relationship between inlet morphological features and corresponding sedimentological characteristics, and to parameterize numerical modeling simulations of the dual-inlet system, ninety-two sediment samples were collected within the John’s Pass and Blind Pass system (Figure 23). Sediment sample locations were pre-selected based on morphological features imaged in the 2014 multibeam bathymetric surveys. Sample position coordinates were in-turn entered into HYPACK navigation software which was integrated with a Trimble R4 RTK GPS system to ensure that accurate sample positions were achieved in the field. A clam-shell grab sampler was used to collect bottom sediment samples at the predefined sites. Samples were returned to the laboratory where they were split into 2 halves. One half was analyzed for grain-size distribution using standard sieves at 0.25 phi intervals, and the remaining split was digested in HCL to determine carbonate content. The moment method was used to calculate mean grain size, and percent distribution (e.g., D10, D50, or D90).
4.2 Sediment Budget Formulation

A detailed and balanced sediment budget is essential to inlet management. A sediment budget is a balance of volumes (or volume rate of change) for sediments entering and leaving a selected region of coast, and the resulting erosion or accretion in the coastal area under consideration (Rosati, 2005). A sediment budget for inlets and adjacent beaches provides a conceptual and quantitative model of sediment transport magnitudes and pathways for a given time period. It provides a framework for understanding a complex inlet and coastal system under its natural or engineered conditions (Rosati and Kraus, 1999). Modern inlet management practices must carefully consider their influences on sediment budgets and sediment transport pathways.

Figure 23. Distribution of sediment samples (red triangles).
In the case of this study, a sediment budget was developed for the stretch of coast extending from the north end of Sand Key to the south end of Long Key.

The formulation of tidal inlet sediment budgets discussed by Rosati and Kraus (1999 and 1999b), Rosati and Kraus (2003), and Rosati (2005) was used in this study. The Rosati and Kraus (1999) method is also recommended in the Coastal Engineering Manual (Bodge and Rosati, 2002). Volumetric changes in the ebb shoals subsequent to the 2010 dredging events were determined based on time series bathymetric surveys conducted by the USF-CRL. The rate of longshore sediment transport plays a central role in sediment budgets (CERC, 1984; Wang et al., 1998; Wang, 1998; and Wang and Kraus, 1999). The rate of longshore sand transport ($Q_{\text{source}}$, $Q_{\text{sink}}$) was calculated based on time-series monthly to bi-monthly beach profile surveys conducted by the USF-CRL between 2006 and 2014. The beach profiles are spaced every 300 m (1000 ft) down the beach at every FDEP R-monument along Sand Key, Treasure Island, and Long Key. Since the profiles extend to the short-term depth of closure (Wang and Davis, 1999), it is reasonable to assume that the net beach-profile volume changes ($\Delta V$) are related to longshore sand transport.

Beach nourishment volumes ($P$) and dredged volumes ($R$) were measured based on the previously discussed time-series beach and bathymetric surveys, and where available, those measured volumes were compared to published figures. Contributions and losses from upland and offshore sources and sinks are considered nominal and ignored in the sediment budget calculations. Volumetric changes of the ebb shoals and channels between the last dredging event in 2010 to July 2014 are determined based on time series surveys conducted by USF-CRL.

The regional scale John’s Pass sediment budget formulation is bounded on the north by R-monument 60. Based on Sand Key beach-profile survey data (Roberts and Wang, 2012), profile R60 has the peak profile volume loss along North Sand Key (Figure 24). This volume change
pattern is interpreted as being caused by a divergence in longshore transport caused by wave refraction over the Clearwater Pass ebb shoal. North of R60 the net longshore transport is to the north toward Clearwater Pass while south R60, net longshore transport is to the south toward

![Sand Key Volume Change: 2006-2010](image)

Figure 24. Volume change (2006-2010) above four contours representative of the dry-beach, shoreline, nearshore, and entire profile for Sand Key beach profiles.

John’s Pass (Figure 24). Therefore, profile R60 is determined to be the north boundary for the John’s Pass and Blind Pass regional sediment budget. The south tip of Long Key (north side of Pass-A-Grille inlet) was considered the southern limit of the sediment budget.

In addition to natural sediment volume changes along Sand Key, Treasure Island, and Long Key beaches, stretches of shoreline on each island have been renourished. These added sand volumes ($P$ in equation 10) are accounted for in formulation of the JPBPI S sediment budget.

### 4.3 Numerical Modeling

#### 4.3.1 Overview of the Coastal Modeling System (CMS)

The Coastal Modeling System (CMS), developed by the Coastal Inlets Research Program (CIRP) at the United States Army Corps of Engineers (USACE) was used in this study to simulate
both short-term and long-term behavior of the John’s Pass-Blind Pass dual inlet system under several hypothetical engineering modification scenarios. The CMS is an integrated suite of numerical models for simulating current flow, waves, sediment transport, and morphology change in coastal settings (Buttolph et al., 2006; Reed et al., 2011; Wu et al., 2011; Lin et al., 2011; Larson et al., 2011; Sanchez and Wu, 2011; Sanchez et al., 2014). CMS has been broadly used by the USACE and many other researchers in quantifying tidal inlet processes (e.g., Demirbilek et al., 2015a, 2015b; Li et al., 2012; Wang and Beck, 2012; Beck and Legault, 2012; Wang et al. 2011; Beck et al., 2008).

There are four main components to CMS, current flow, wave, sediment transport, and morphology change (Figure 25). The model couples these physical processes and responses to ensure that interactions between them are properly reflected in simulation output. The model addresses these numerical process-response components through two computation modules, CMS-Flow and CMS-Wave. CMS-Flow is a coupled hydrodynamic and sediment transport model designed to compute depth-averaged circulation and sediment transport due to tides, wind and waves. CMS-flow solves the conservative form of the shallow water equations and includes terms for Coriolis force, wind stress, wave stress (obtained from CMS-Wave), bottom stress, vegetation flow drag, bottom friction, and turbulent diffusion. Sediment transport and morphology changes are computed in CMS-Flow. All equations are solved using the Finite Volume Method on a non-uniform Cartesian grid.

CMS-Wave is a spectral wave transformation model and solves the steady-state wave-action balance equation on a non-uniform Cartesian grid. It considers wind wave generation and growth, diffraction, reflection, dissipation due to bottom friction, whitecapping and breaking, wave-wave and wave-current interactions, wave runup, wave setup, and wave transmission.
through engineered structures. Relevant information is “steered” or passed between CMS-Flow and CMS-Wave as shown in Figure 26.

The CMS model construction, execution, and output analyses are facilitated through the Surfacewater Modeling System (SMS) which serves as the graphical interface (http://cirp.usace.army.mil/products/sms.php). While both CMS – Flow and Wave can be run through a command prompt, the SMS graphical interface provides a number advantages. The interface allows for the construction of telescoping grids or grids designed to provide spatially variable resolution. This allows for higher grid resolution at critical locations such as inlet

Figure 25. The four major coupled components of CMS. From the CMS Wiki page (http://cirpwiki.info/wiki/CMS).
channels and ebb shoals. The SMS interface also allows manipulation of very large datasets (e.g., 10s of GB) generated by long-term (one year or longer) model runs. An additional benefit of the interface is that it allows the user to generating images of the modeling results, such as vector plots of the current field, wave field, and sediment transport field, as well as contour plots which are important in morphologic analyses. Contour plots can also be illustrated as 3-D surface maps. SMS allows for the calculation of temporal and spatial variations which are also important when examining morphology changes.

Figure 26. Steering between CMS-Flow and CMS-Wave. From the CMS Wiki page (http://cirpwiki.info/wiki/CMS).
Grid construction in this study incorporated detailed bathymetry measured during the 2014 bathymetric surveys, and temporally equivalent beach and nearshore topography measured by the USF Coastal Research Lab (USF-CRL). Bathymetry for regions of the model domain not surveyed was based on publicly available data, specifically the U.S. Coastal Relief Model (NOAA - https://www.ngdc.noaa.gov/mgg/coastal/crm.html).

4.3.2 Model Construction, Calibration, and Validation

Model construction, calibration and validation were achieved using measured bathymetry, wave, tide and sedimentological data described earlier in this chapter. And while model construction, calibration and validation can be considered components to this projects methodology, since those procedures are in large part based on results of direct measurements made during this study, a detailed discussion of such is presented in Chapter 5.
CHAPTER 5

RESULTS

5.1 Field Measurements

5.1.1 Wave Conditions

Significant wave height, and period for waves measured at the offshore domain boundary wave gauge (Figure 16) between June 2014 and June 2015 in order to temporally overlap with inshore hydrodynamic measurements and are shown in Figures 28 and 29. Mean significant wave height ($H_s$) and peak period ($T$) for the 12 month sampling period was 0.38 m and 4.5 seconds respectively. The highest and longest period waves approach the shoreline from SW-NW directions (Figures 30 and 31). These longer period and higher waves are mostly associated with the passages of October thru April cold fronts that occur with a frequency of ca 7 to 14 days. Wave heights between 1-1.5 meters are commonly associated with winter cold fronts. Higher waves originating out of the southwest are associated with pre-frontal troughs or low pressure that immediately precedes a cold front generating waves approaching 1-m with wave periods of 7-9 seconds. These pre-frontal conditions are generally of short duration (<24 hours). During the summer season, wave heights were mostly less than 1 m. However, two high wave events associated with slow moving low pressure systems over the eastern GOM on July 17 and July 29 (Figure 32) drove persistent 10-20 knot westerly winds (Figure 31) for approximately 72 hours.
Figure 27. Significant wave height recorded at the numerical modeling domain boundary (see Figure 6) between June 2014 and June 2015.

Figure 28. Peak wave period recorded at the numerical modeling domain boundary (see Figure 6) between June 2014 and June 2015.
Figure 29. Rose diagram of significant wave height and direction recorded at the numerical modeling domain boundary between June 2014 and June 2015. Note that waves with heights exceeding 1 m tend to originate out of the W-WSW-WNW.

Figure 30. Rose diagram of peak wave period and direction recorded at the numerical modeling domain boundary between June 2014 and June 2015.
Figure 31. July 2014 wind record recorded near Clearwater Beach, Florida. Blue lines represent sustained winds, red lines represent wind gusts, and black arrows represent wind direction. Note strong wind events peaking on July 17 and 29.

Figure 32. July 2014 air pressure record at the NOAA Clearwater Beach station. Note moderate duration low pressure events on July 17 and 29 which correspond with high wind and high wave events which peak on July 17 and 29.
Figure 33. Significant wave heights measured at the nearshore Triton PUV gauge (blue line) compared to the offshore ADCP significant wave heights (red line) for the period 6/8/2014 - 10/7/2014. Note the gap in ADCP data shown by the inclined straight red line segment in mid-to late August.

Figure 34. Dominant wave period measured at the nearshore Triton PUV gauge (blue line) compared to the offshore ADCP (red line) dominant wave period for the period 6/8/2014 - 10/7/2014. Note the gap in ADCP data shown by the inclined straight red line segment in mid-to late August.
generating wave heights of ca 1–m (Figure 27). The July high wave events were not associated with unusually long wave periods (Figure 28) reflecting the relatively nearshore position of the low pressure system and limited fetch. With those exceptions, the summer of 2014 was generally calm with no tropical storms influencing the study area.

Nearshore wave height and wave period measurements made with the Triton PUV gauge (Figures 34 and 35) correlate well with the offshore gauge (Figures 28 and 29). However, due to rapid biofouling of the PUV gauge sensors, calculation of directional data was not possible. Mean wave heights measured at the nearshore and offshore gauge for the sampling period were 0.22 m and 0.35 m, respectively. Mean dominant periods for the nearshore and offshore gauges for the same sampling period were 4.7 and 4.5 seconds respectively.

5.1.2 Current Through and in the Vicinity of the Inlets

As discussed in Section 4.1.2, current measurements were made; (1) throughout the water column from upward looking ADCPs (U-ADCP) deployed within the John’s Pass and Blind Pass channel thalwegs, (2) horizontally across both inlet channels using a horizontal looking ADCP (H-ADCP), and (3) of the flow fields of each inlet during ebbing and flooding stages using a Teledyne Monitor downward looking ship mounted ADCP.

Stationary ADCP current meter deployment locations are shown in Figure 16. At John’s Pass, the U-ADCP was deployed in the deepest portion of the channel thalweg and should therefore yield the greatest velocity magnitudes. Depth averaged velocities measured between 7/22/2014 to 8/13/2014 are shown in Figure 35. Measured peak flood velocity was 1.6 m/s, with a peak ebb velocity of 1.3 m/s. Figure 36 shows the vertical distribution of current velocities during peak ebb and flood stage. The current profiles are largely uniform throughout most of the water column.
Similar uniform current profiles were documented in an earlier study at John’s Pass and Blind Pass by Wang et al. (2011) and Wang and Beck (2012). As previously discussed,

Figure 35. Depth averaged current velocities measured using a U-ADCP deployed in the John’s Pass channel thalweg. Ebbing stage velocities are represented as negative values and flood stage as positive values.

sampling was conducted using 0.25 m bins extending from 1.38 m above the top of the ADCP at 0.5 m from the seabed. Due to the 1.88 m blanking distance, depth averaged velocity measurements may overestimate current velocities since measurements along the bottom boundary layer cannot be achieved.

At Blind Pass, the U-ADCP was also deployed in the deepest portion of the channel thalweg and should therefore yield the greatest velocity magnitudes. Depth averaged velocities measured between 8/14/2014 to 9/13/2014 are shown in Figure 37. Measured peak flood velocity
was 0.6 m/s, with a peak ebb velocity of 1.05 m/s. Figure 38 shows the vertical distribution of current velocities during peak ebb and flood stage. The current profiles are largely uniform throughout most of the water column.

Figure 36. Vertical current velocity profiles measured using a U-ADCP deployed in the John’s Pass channel thalweg. Velocities were measured in 0.25 m bins extending from 1.88 meters above the top of the gauge. Positive values represent maximum flood velocities, and negative values represent maximum ebbing velocities recorded during spring tide conditions.
Figure 37. Depth averaged current velocities measured using a U-ADCP deployed in the Blind Pass channel thalweg. Ebbing stage velocities are represented as negative values and flood stage as positive values.

Current measurements across the John’s Pass and Blind Pass channels were conducted using an H-ADCP. The deployment locations were as close as was practical to the U-ADCP deployment locations (see Figure 16). The H-ADCPs require an external 12 volt DC power source and fixed vertical platform to attach the ADCP to limiting to some extent deployment locations. The manufacturers reported range of the H-ADCPs was 90 m; however, in practice, accurate cross-channel current velocity measurements extended 50-m and 36-m in John’s Pass and Blind Pass respectively. At John’s Pass, the H-ADCP was deployed from 8/21/2014 to 9/13/2014 in order to capture a full tidal cycle. Cross-channel flow velocities in John's Pass measured in 1 meter bins during spring tide conditions are shown in Figure 39. Maximum measured ebb and flood flow
velocities were 1.20 m/s and 1.25 m/s respectively. Mean cross-channel flood velocities exceeded ebb current velocities.

Figure 38. Vertical current velocity profiles measured using a U-ADCP deployed in the Blind Pass channel thalweg. Velocities were measured in 0.25 m bins extending from 1.88 meters above the top of the gauge. Positive values represent maximum flood velocities, and negative values represent maximum ebbing velocities recorded during spring tide conditions.
Figure 39. Cross-channel distribution of tidal flow velocities measured at John’s Pass. Upper panel shows H-ADCP location and range (black line) of the measurement. Lower panel shows peak flood (blue) and ebb (orange) velocities measured during spring tide. The channel thalweg is centered ca 40-m from the sensor.
Figure 40. Cross-channel distribution of tidal flow velocities measured at Blind Pass. Upper panel shows location of H-ADCP and range (black line) of the measurement. The U-ADCP location is also shown. Lower panel shows peak flood (blue) and ebb (orange) velocities measured during spring tide.
In Blind Pass, H-ADCP measurements were collected from 8/21/2014 to 9/13/2014 and temporally overlap the U-ADCP measurements made in that inlet channel; however, unlike the H-ADCP and U-ADCP locations in John’s Pass which are in close proximity to one another, due to field conditions, in Blind Pass the H-ADCP was located ca 350 m northeast of the U-ADCP in a narrower segment of the channel and further from the channel entrance (Figures 17 and 41). Cross-channel flow velocities measured in 1 meter bins during spring tide conditions are shown in Figure 40. Maximum measured ebb and flood flow velocities were 0.90 m/s and 1.1 m/s respectively. Mean flood velocities exceed ebb current velocities, unlike the higher mean ebbing velocities and lower flood current velocities measured at the U-ADCP.

Flooding and ebbing current velocities and the spatial extent of those velocities play important roles in inlet morphodynamics. This is especially important in the case of the ebb jet since it strongly controls morphodynamics of the ebb shoal and sand bypassing across the ebb shoal. In order to characterize the John’s Pass and Blind Pass tidal current flow fields, a downward looking ship mounted ADCP was used to map current velocities at numerous positions over the inlet’s shoals and channels during flooding and ebbing tide stages. In order to minimize uncertainty, the surveys were conducted during calm sea-state conditions. Measurements were taken over the course of several hours during each tidal stage, and therefore do not represent simultaneous velocity measurements, but do provide a spatial characterization of the flow field, and depth averaged current velocities associated with the corresponding tidal stage.

Measurements made during the ebbing stage at John’s Pass (Figure 41) indicate the ebb jet extends over 1.2 km into the Gulf of Mexico. Depth averaged velocities in excess of 0.3 m/s extend ca 1.2 km seaward from the channel entrance. Ebb jet velocity vectors exiting the main channel are largely parallel extending ca 1 km seaward from the channel entrance. Beyond that
distance, velocity vectors illustrate greater divergence. A maximum depth averaged current velocity of 1.2 m/s was measured over the deepest portion of the channel thalweg consistent with the U-ADCP and H-ADCP current measurements made in the same location. Flood stage flow field mapping results for John’s Pass are shown in Figure 42. In contrast to ebbing stage velocity vectors, flood stage vectors at the channel entrance illustrate convergence. Within the channel

Figure 41. Ebb stage flow field depth averaged velocities at John’s Pass. Velocities are shown in meters per second next to velocity proportional vector symbols. Inset shows vertical velocity profiles measured at the same time in the channel thalweg with a U-ADCP (see Figure 14 for U-ADCP location). Note, inset velocities are reported as negative values reflecting the ebbing flow direction.
throat, velocity vectors are parallel and begin to diverge as flow approaches the flood shoal. A maximum depth averaged current velocity of 1.2 m/s was recorded over the channel thalweg near the U-ADCP and H-ADCP locations.

Measurements made during the ebbing stage at Blind Pass (Figure 43) indicate the ebb jet extends ca 0.5 km into the Gulf of Mexico. Depth averaged velocities in excess of 0.3 m/s extend ca 0.53 km seaward from the channel entrance. Ebb jet velocity vectors directly outside of the main channel are slightly deflected to the south relative to the entrance channel orientation, and become strongly deflected to the south 450 m seaward from the channel entrance. A maximum depth averaged current velocity of 0.88 m/s was measured over the deepest portion of the channel.
thalweg. This velocity, although less than the 1.05 m/s maximum velocity measured with the Blind Pass channel thalweg U-ADCP, is consistent with the maximum ebbing velocity measured by the U-ADCP at the time of the survey (Figure 37). No flood stage survey of Blind Pass was conducted.

Figure 43. Ebb stage flow field depth averaged velocities at Blind Pass. Velocities are shown in meters per second next to velocity proportional vector symbols. Inset shows tide stage leading up to and following the survey period shown in red.
5.1.3 Offshore and Backbay Tides

Tidal water level fluctuations were measured at 7 locations within the study area, including the offshore domain boundary with a U-ADCP, and in the inlet channels, back-bay, and lateral boundaries connecting to other water bodies using In-Situ Aqua TROLL water level gauges (Figure 44). Water level measurements at the offshore U-ADCP were made between June 2014 and June 2015. Water level measurements at inshore locations using the Aqua TROLL gauges were made from 8/6/2014 to 9/13/2014. The Aqua TROLL gage at the north boundary of Boca Ciega Bay (Figure 44, gauge location 2) malfunctioned during the initial and subsequent deployments failing to provide any data.

While the tidal range at all locations is similar (Figure 45), a phase lag is evident between the offshore and inshore tide, with offshore tides leading inshore tides. The phase lag is greater during flood stage than ebbing stage. To more clearly illustrate tidal relationships throughout the study area, a 2-day spring tide record is shown in Figure 46. During the flooding phase, the offshore (ca 7 km from shoreline) tide leads the tide in the Blind Pass channel by ca 40 minutes, and John’s Pass channel and back-bay tides by ca 70 minutes (Figure 44). On the ebbing phase, the offshore tide leads both John’s Pass and Blind Pass channels by ca 20 minutes, and the back-bay tide by ca 60-70 minutes. This tidal phase lag plays a significant role in driving flow through the inlet system.
Figure 44. Location of water level measurement gauges. Red pentagons are In-Situ Aqua TROLL gauges showing gauge numbers referenced in text, and the green triangle is the location of the offshore U-ADCP.
Figure 45. Tide water-level variations measured within the greater study area. The measurement locations are shown in Figure 44. Note, a gap exists in the offshore gauge data between 8/13/14 and 8/20/14 due to equipment servicing.

Figure 46. Two day tide from 8/10/2014 – 8/12/2014 during spring tide conditions, showing phase lag between offshore and inshore tide. Refer to Figure 44 for gauge locations.
5.1.4 Bathymetric Characteristics

The overall bathymetry of the study area is shown in Figure 47. The bathymetry shown in Figure 47 is that used to construct the numerical modeling grid. It should be noted that water depth in Figure 47 is referenced to mean sea level with water depths depicted as positive values (i.e. 6 meters equals 6 meters below mean sea level). Mean sea level in the study area is 0.087 m below 0.0 m NAVD 88 (based on the Clearwater Beach NOAA station 8726724 located \(ca\) 20 km north of the study area). The slope of the inner continental shelf through the central portion of the study area is 1:750 consistent with Davis (1994), with water depths of \(ca\) 8-m at the seaward edge of Figure 47. Linear bathymetric features visible in the northwest portion of the offshore area are large NW-SE oriented sand ridges. The relatively shallow water offshore the southern portion of Treasure Island is likely an older abandoned segment of the Blind Pass ebb shoal left behind as the inlet migrated south subsequent to the opening of John’s Pass. A relic dredge pit from nearshore dredging conducted in 1968 off the southern shore of Treasure Island (Sunset Beach area) is visible in the 2014 bathymetry (Figure 47).

In general, water depths in the offshore area are greater south of John’s Pass than north of John’s Pass. Water depths in the backbay are strongly influenced by engineering modifications, which include filled areas (made land) and associated finger channels, and the Intracoastal Waterway (\(ca\) 3-m deep). In unmodified regions and away from inlet channels, backbay water depths are generally shallow, typically less than 2 m.

The 2014 multi-beam bathymetric surveys of the inlet channels and ebb shoals revealed new morphologic details poorly resolved by earlier single beam bathymetric surveys of the inlet.
Figure 47. Bathymetry of the study area. Water depth is referenced to mean sea level and water depths are depicted as positive values (i.e. 6 meters equals 6 meters below mean sea level).
Figure 48. Detailed bathymetry of the John’s Pass ebb shoal based on July 2014 multi-beam bathymetric survey data showing 1988 and 2010 dredge pits, the channel margin linear bar (CMLB), swash bar attachment point, and locations of cross-sections shown in Figure 49. Note, elevations are in meters relative to NAVD88, and there is some distortion of the underlying aerial base due to parallax associated with the 3D bathymetry rendering.

Figure 48 illustrates the complex bathymetry revealed in the July 2014 survey of the John’s Pass ebb shoal. Bathymetry is more complex on the southern downdrift side of the ebb shoal than along the updrift north side. North of the main channel, morphology is dominated by the channel margin linear bar (CMLB) (Figures 49, 50b and 50c) and a relic dredge pit. The CMLB is oriented 230 degrees (SW-NE), parallel to the main channel and has a maximum
Figure 49. Bathymetric cross-sections of the John’s Pass ebb shoal (refer to Figure 48 for cross-section locations).
relief of *ca* 3 meters from crest to channel bottom (Figure 50b). The dredge pit was originally excavated in 1988. On the south downdrift side of the channel, a complex series of swash/bypass bars dominate the bathymetry. These large-scale bedforms take the form of at least six discrete and roughly parallel curvilinear transverse bars, with amplitudes of *ca* 1-m. The distance between adjacent crests ranges from 50 m to 150m (Figure 50c). Bar orientations vary as a function of position. Along the landward most portion of the swash/bypass bar complex bar orientations are *ca* 60 degrees (NE-SW). Further seaward, bar orientations are 90 degrees (E-W). Several NW-SE bars with orientations ranging from 303 to 321 degrees are present at the seaward or terminal end of the ebb shoal. The swash/bypass bars coalesce into an arcuate shaped bar that attaches to the beach at the shoreline attachment point around R129-130.

John’s Pass main channel is oriented 230 degrees (SW-NE), roughly perpendicular to the shoreline. The deepest part of the channel throat is *ca* 12 m deep and coincides with the position
of John’s Pass Bridge which spans across the narrowest and deepest stretch of the channel. Channel throat depths range from 8-12 m, shallowing both landward and seaward. The main channel splits into three branches over the flood shoal (Figure 47), and in the seaward direction the channel becomes less distinctive near the terminal lobe of the ebb shoal. Also visible in the 2014 bathymetry is a dredge pit excavated in 2010 along the western flank of the ebb shoal terminal lobe (Figure 48).

Similar in morphology to the John’s Pass ebb shoal, but smaller in size and in complexity of bedforms, the Blind Pass ebb shoal has a CMLB oriented 230 degrees parallel to and on the updrift (north) side of the main channel. The CMLB has a maximum relief of \( ca \ 2.5 \text{-m} \) from bar crest to channel bottom. An arcuate mostly continuous bypass bar extends from the seaward end of the CMLB to the shoreface (Figure 50). Similar to the spatially variable orientation of the bypass bars in the John’s Pass ebb shoal, at Blind Pass, the bypass bar orientation ranges from \( ca \ 250 \text{ degrees} \) near the shoreline to \( ca \ 305 \text{ degrees} \) near the terminal edge of the ebb shoal. At least 2 additional poorly developed swash/bypass bars are also present near the shoreline with similar 205 degree orientations. The maximum relief on the bypass bars \( ca \ 0.5 \text{ m} \) (Figure 51b). Blind Pass does not have a flood shoal in the classic sense. The main channel, at the entrance is oriented 240 degrees and extends inward from the entrance \( ca \ 250 \text{ m} \) where it bends \( ca \ 90 \text{ degrees} \) and continues in a northerly direction along the Treasure Island barrier spit at \( ca \ 335 \text{ degrees} \). Flood tide related deposition does occur along the northern half of the entrance channel stretch (Figure 51a). This deposition extends around the 90 degree bend and a small volume of sediment is deposited along the east shoreline of the Treasure Island barrier spit. Arguably it is these deposits along the north and west sides of the channel that represent the Blind Pass flood shoal. In this study, those flood stage related deposits within the inlet channel are referred to as the inner shoal.
Figure 50. Detailed bathymetry of the Blind Pass ebb shoal and channel based on July 2014 multi-beam bathymetric survey data, showing locations of cross-sections shown in Figure 51. Scale bar shows elevations relative to NAVD88. Note that there is some distortion of the underlying aerial base due to parallax associated with the 3D bathymetry rendering.
Figure 51. Bathymetric cross-sections of the Blind Pass ebb shoal (refer to Figure 50 for cross-section locations).
Deposition along the northern portion of the main entrance channel has effectively forced the channel thalweg south where it hugs the southern channel margin before entering the GOM. The deepest part of the channel _ca_ 8 m deep. Currently, there is no clear attachment of the bypass bars to the shoreline (attachment point) along Long Key; however, this morphologic feature is developing as will be shown in time series bathymetric changes discussed in Section 5.3.3.
5.1.5 Sediment Characteristics

In general, the west-central Florida coast is composed of bi-modal sediment, with the two modes consisting of fine quartz sand and distinctly coarser shell debris. The mean grain size is mainly controlled by the percent content of shell debris. High percentages of shell debris results in coarser mean grain sizes (Figure 54). When shell debris is absent or of a very low percentage, the mean grain size of the quartz sand is ca 0.16 mm.

Ninety-two sediment samples were collected from various morphological features of the inlets (Figures 24, 52, and 53) and analyzed during this study. The coarsest sediment is located in the main channels, and often coincides with the deepest part of the channel where current velocities are the highest. The fast flowing current removes the finer sediment, leaving coarse lag deposits on the seabed. Lag deposits are composed almost entirely of shell fragments. The grain size of lag deposits in the John’s Pass and Blind Pass channel thalwegs can be up to 10 mm, with large shell fragments of several centimeters common. The coarse channel lag deposits act to armor the substrate surface preventing excessive scour of the main channel. Coarse sediment is also concentrated near or along the crests of swash/bypass bars on the south side of the John’s Pass ebb shoal, and is likely the product of selective erosion and transport of the finer grain-size fractions by waves and wave driven currents.

The finest sediment is found along the seaward margins of both inlets ebb shoals and on the John’s Pass flood shoal, with grain sizes of 0.125 – 0.15 mm. In the flood shoal region, near mangrove and dense seagrass, a small percentage of mud-sized organic sediment exists. However, the sediment in the study area is dominantly non-cohesive. Cohesive sediments play a negligible role and are not considered in the numerical modeling schematization. Excluding the coarse lag material found in the channels and swash bar crests, and the fine sediment associated with the
flood shoal, sediment in the study area is fairly uniform, with a mean grain size of approximately 0.17 mm (2.56 phi).

Figure 52. John’s Pass sediment sample locations showing mean grain-size in phi units, overlain on 2014 bathymetry.
Figure 53. Blind Pass Sediment sample locations showing mean grain-size in phi units, overlain on 2014 bathymetry.
Figure 54. Relationship between mean grain-size and carbonate content. Upper panel represents John’s Pass samples, and lower panel, Blind Pass samples.
5.2 CMS Model Construction, Calibration and Verification

5.2.1 Model Grid Construction

The modeling grid is constructed based on detailed inlet and nearshore bathymetry surveyed during this study, combined with existing NOAA Coastal Relief Model data for the offshore area. The modeling grid is composed of a wave grid and a flow (current) grid. The model couples wave and current and “steers” between the wave grid and current grid. The wave grid is illustrated in Figure 55. The CMS-Wave grid construction used a refined grid which allows for high grid resolution in areas of interest (i.e. in the nearshore area and over the shallow portions of the ebb shoal where wave breaking occurs). The finest wave grid resolution is 10 x 10 meters covering the inlet channels, most of the shoreline, and the ebb shoals. The grid sizes increase offshore to a maximum of 320 x 320 m. For the modeling of sediment transport and morphology change, it is essential that the wave breaking patterns in the nearshore and over the ebb shoal be computed accurately. Radiation stresses associated with wave breaking are calculated by CMS-Wave and are passed (“steered”) to CMS-Flow for the computation of breaking induced flow such as the longshore current and wave driven current over the ebb shoal. These currents play important roles in beach processes, beach-inlet interaction, and sediment bypassing across the inlet. The refined grid in the nearshore and over the ebb shoals ensures that detailed wave breaking patterns are captured.

The CMS-Flow grid construction used a telescoping grid system. The telescoping grid provides more flexibility in spatial coverage than the refined grid system, and allows for more flexibility and improved grid resolution over key morphology features, such as the inlet channels and ebb shoals. The telescoping grid is not yet available for CMS-Wave. Figure 56 shows the overall CMS-Flow grid, illustrating the increased grid resolution in the inlets, and telescoping
toward the offshore. The finest grid over the inlet channels is 10 x 10 m, allowing each inlet to be covered by 16 grid cells (Figure 57).

Figure 55. The CMS “refined” wave grid for the entire numerical modeling domain.
This provides adequate grid coverage to examine the modeled cross-channel distribution of flow patterns, which is crucial to identify areas of scour and deposition. The grid size increases to 20 x 20 m over the ebb shoal, back-bay, and in the nearshore. The grid size increases further offshore to 40 x 40 m, ultimately reaching 320 x 320 m cell sizes furthest offshore. Although Figure 57 appears to show a closed system, the two lateral boundaries in the back-bay, one near the Narrows (Park Boulevard) on the north end, and one near the Corey Causeway on the south end are open.
Figure 57. Detail view of the “telescoping” CMS-Flow grid at John’s Pass illustrating increased resolution over the inlet, in the nearshore and ebb shoal.

boundaries with measured water surface elevation data serving as the boundary condition input. The grid system configuration used balances optimal spatial resolution with computational efficiency.

5.2.2 Model Calibration

The main calibration parameter for both CMS-Wave and CMS-Flow is the friction coefficient. The Manning’s friction coefficient (n) is used as the primary calibration parameter. The duration of the model calibration runs was 35 days, and used measured data as boundary condition input. The measured field data used for model calibration and verification (discussed in
Section 5.2.3) included: (1) water level variations and wave conditions measured at the seaward boundary as the offshore boundary condition forces; (2) water level variations in the back-bay as the driving force; (3) peak current flow through the channel thalwegs to compare with modeled results; (4) spatial extent and velocities of the ebb jets to compare with modeled results; and (5) measured wave conditions in the nearshore just seaward of the closure depth to compare with modeled results. Various lengths of computational time steps were first tested. An implicit time step of 300 seconds yielded the best computational efficiency and was used in all subsequent model runs.

Measured wave conditions at the seaward boundary were used to drive CMS-Wave. Wave calibration tested various friction coefficients, and the modeled wave solutions were compared to waves measured at the Triton ADV site (see Figure 16). It was found that computed waves in the vicinity of the Triton ADV site were not measurably sensitive to the friction coefficient parameter, likely due to the low wave heights and relatively deep water. Figure 58 shows a comparison of measured and modeled waves in the vicinity of the Triton ADV site (see Figure 16) using the CMS default friction coefficient (Manning’s $n = 0.02$). The Willmott (1981) skill ($S_w$) is used to provide a quantitative comparison of modeled and measured wave heights.

$$S_w = 1 - \frac{\sum (V_{model} - V_{measure})^2}{\sum (|V_{model} - V_{measure}| + |V_{model} - V_{model}|)}$$  \hspace{1cm} (11)

A comparison of measured versus modeled wave heights yielded a Willmott skill of 0.970, indicating an overall accurate prediction of wave height. In summary, the wave model calibration confirmed that the default friction coefficient ($n=0.02$) provides accurate results compared to measured data.
Figure 58. Measured and modeled wave height just seaward of the closure depth (~4 m) using default friction coefficient provided by CMS-Wave.

Measured water level fluctuations at the seaward boundary and at the north and south boundaries within the back-bay, and measured offshore wave conditions were used as the driving forces for steered CMS-Flow and CMS-Wave runs. While the CMS default friction coefficient was used for the wave model, various friction coefficients were applied to calibrate the flow model. The input water level and wave boundary conditions are illustrated in Figure 59. Only half of the 35-day record is shown so that the lag between the offshore and inshore tides can be distinguished. Sensitivity tests indicated that time lag between the ocean boundary and the landward boundaries have considerable influence on the modeled flow velocities. For calibration runs, this is not relevant since measured water levels were used; however, for longer-term runs (2 year), this time lag is an important factor.
Various Manning’s friction coefficients ($n$), ranging from 0.01 to 0.035, were tested during the CMS Flow model calibration. The flow model is sensitive to the friction coefficient parameter. An excessively low (less than 0.0175) friction coefficient yielded computational errors, and as a consequence, the model became unstable and self-terminated (crashed) prior to completing the 35-day simulation. An excessively high (greater than 0.04) friction coefficient yielded computed velocities that were significantly lower than measured current velocities. Figure 60 compares the calculated velocities using different Manning’s friction coefficients with measured values. A Manning’s coefficient of 0.02 was the smallest value that produced stable model runs while yielding current velocities approaching those measured. A Manning’s coefficient of 0.02 was determined to be the optimal friction coefficient for the John’s Pass and Blind Pass study, and was used in subsequent CMS production runs. It should be noted that while the measured velocities are greater than the predicted values, as discussed earlier, the measured depth-averaged velocity does not include the velocity within 1.8 m from the bed. Therefore, the decreasing velocity within the bottom boundary layer was not accounted for in the averaging. This may result in depth-
averaged velocities faster than those measured since the near-bed slower velocities were not included in the averaging.

Figure 60. Comparison between CMS simulated current velocities using different Manning’s $n$ values and measured velocity at John’s Pass. Positive values represent flood flow and negative values represent ebb flow.

5.2.3 Model Verification

The following discussion on model verification focuses on comparing the measured hydrodynamic conditions with the modeled values. Rates of sediment transport are very difficult to measure directly in the field. Therefore, the calculated sediment transport rate cannot be directly verified. Modeled morphology change and comparison with measured values are discussed separately. This section discusses the modeled flow field in comparison with the measured flow.

Flow velocities through the main channels at both inlets were measured using upward-looking ADCPs and compared with calculated values by CMS. A Manning’s coefficient of 0.02 was used to calibrate the model. The model simulated the measured velocities well (Figures 62
and 63). It is worth noting again that the measured depth-averaged velocities are likely faster than actual values because the slower near-bed velocity was not accounted for in the averaging. Therefore, some under-prediction by the model would be expected. At John’s Pass, CMS closely predicted the ebb velocity but under-predicted the flood velocity. Overall, for John’s Pass, modeled versus measured current velocities returned a Willmott skill (Equation 11) of 0.957, indicating good correlation. Being the secondary inlet, both the ebb and flood velocities through the Blind Pass main channel are smaller than those at John’s Pass. The CMS reproduced the measured flow well at Blind Pass (Figure 62), yielding a Willmott skill of 0.989.

Tidal flow patterns in the vicinity of inlets, such as the ebb jet, alongshore flood flow, and interactions between tidal flow and wave-driven longshore current play crucial roles in inlet dynamics and nearby beach processes. In the following, modeled spatial patterns of flow are discussed and compared qualitatively with field data. Since flow patterns are difficult to measure, only limited field data are available.

While John’s Pass services most of the back-bay, the Blind Pass tidal prism is limited to the south end of the domain (Figure 63). Relatively high current velocities in the channel that connects north Boca Ciega Bay to south Boca Ciega Bay, immediately east of Blind Pass (Figure 63) were modeled. These high velocity tidally driven currents were also observed in the field.

The ebb jet plays an essential role in the formation of ebb shoals and in sand bypassing around the inlet. As previously discussed, the ebb jets at both John’s Pass and Blind Pass were mapped using a ship-mounted downward looking ADCP. Those measured data were qualitatively compared to the CMS simulation output.
Figure 61. Measured and modeled current velocity in John’s Pass main channel.

Figure 62. Measured and modeled current velocity in the Blind Pass main channel.
Figure 63. Modeled flow field during a peak spring ebbing event at both John’s Pass and Blind Pass.

At John’s Pass, the ebb jet extends seaward from the channel entrance *ca* 1.2 km (Figure 64). Ebb jet current velocities decrease seaward as the jet spreads. In contrast, flood tide driven currents converge about the seaward side of the John’s Pass channel entrance (Figure 65). These converging currents include a shore parallel component that flows along the immediately adjacent beaches. This shore parallel flow has significant implications on adjacent beach processes and sedimentation within the inlet channel. Specifically, at John’s Pass, it contributes to chronic erosion at Sunshine Beach located at the north tip of Treasure Island, immediately south of John’s Pass. The CMS reproduced the distribution and magnitudes of both ebbing and flooding currents at John’s Pass well.
The ebb jet at Blind Pass does not extend as far seaward as the John’s Pass ebb jet (Figure 66). This is due to overall lower current velocities, and channel geometry. The 90-degree bend in the Blind Pass channel acts to retard current flow, and is a feature common to migratory inlets associated with spit migration. In addition, since Blind Pass captures a substantially smaller percentage of the available tidal prism than John’s Pass, overall current velocities are less than...
those at John’s Pass. Due to the 90-degree channel bend, flooding and ebbing currents flowing through the channel follow significantly different trajectories. Ebbing flow tends to focus along the south side of the channel where the channel is the deepest, while flood flow tends to converge at the channel entrance and distributes uniformly across the entire channel (Figure 67). As a consequence, sediment input from the net annual southward longshore transport, in conjunction with flood tide currents results in sedimentation along the north side of the channel forming the inner shoal, or what might be considered the Blind Pass flood shoal. Overall, the CMS simulated the different ebb and flood flow patterns and current velocity magnitudes at Blind Pass well.

Longshore current driven by obliquely incident waves and its interaction with tidal flow plays a significant role in the morphodynamics of ebb shoals and their adjacent beaches. Along the studied stretch of coast, the frequent passage of winter cold fronts (roughly every 10-14 days) contributes significantly to driving energetic conditions and is the dominant mechanism
responsible for the southward net longshore sand transport (Wang and Beck, 2012). Unfortunately, energetic conditions often prevent the collection of field data. As a consequence, largely all the inshore and nearshore field measurements made during this study were made during summer months. Therefore, in order to more closely examine longshore current and inlet and beach response to the passage of a typical energetic winter front, a model run was conducted simulating

Figure 66. Measured and modeled flow field during a peak spring ebbing event at Blind Pass.
Figure 67. Modeled flow field during a peak spring flooding event at Blind Pass.

a northerly incident wave with a significant wave height of 1.5 m, peak period of 5.7 s, and incident angle of 300 degrees, during a spring-neap tidal cycle. The CMS yielded longshore current velocities of 0.2 to 0.4 m/s within the breaker zone (Figure 68).

At John’s Pass, convergence of the longshore current with the ebb jet results in an offshore directed flow on the updrift side and a eddy on the downdrift side (Figure 68). The convergence of the longshore current and ebb jet provides the mechanism in-part responsible for the development of the ebb shoal and channel margin linear bar. The eddy and the diverging flow on the downdrift side of the ebb shoal is responsible for chronic erosion along Sunshine Beach, and sedimentation on the south side of the ebb shoal (Figure 68).
Figure 68. Interaction of a southward longshore current and ebb jet at John’s Pass. Note eddy on the south side of the ebb shoal immediately offshore of Sunshine Beach.

At Blind Pass, wave-driven longshore current flows into the inlet along the north side of the channel and becomes entrained within the ebbing flow exiting the inlet along the south side of the channel (Figure 69). This process is responsible for deposition along the updrift side of the inlet channel as documented by Wang et al. (2007). Downdrift of the inlet, an eddy begins to form and the longshore current resumes along the chronically eroding stretch of Upham Beach. The model correctly reproduced the processes responsible for the beach erosion there. Overall, the CMS captured key dynamic processes of inlet-beach interactions in terms of the interaction of wave-driven longshore current and tidal flow.

Numerical modeling of sediment transport and morphology change at complicated tidal inlet systems is currently not as advanced as simulating hydrodynamic conditions. The morphology changes measured between October 2011 and July 2012 were used to verify the
Figure 69. Interaction of a southward longshore current and ebb jet at Blind Pass. Red squares are ADCP deployment locations.

modeled morphology results. The adjustment of empirical as well as scaling parameters were required to yield satisfactory results. While it is beyond the scope of this dissertation to discuss the numerous morphology verification modeling runs, empirical parameters and scaling factors that yielded the most realistic results are summarized.

As discussed earlier, WAVEWATCHIII data tended to under-predicted the measured wave height by ca 9%. Therefore, a 9% increase of wave height was applied in the longer-term (1 year) morphology modeling runs. A recent advancement of the CMS allows the input of multiple sediment layers with multiple sediment grain sizes to simulate more realistic grain-size distributions. Simulations completed using a single grain-size yielded unrealistic erosion patterns in the form of excessive scouring in and adjacent to the inlet channels. Accordingly, a number of
Figure 70. Computed morphology change over a 10 month simulation period, at John’s Pass (upper panel) and Blind pass (lower panel). Input wave forcing used WAVEWATCHIII wave heights increased by 9%. The simulation also employed a $D_{50}$ sediment grain size of 0.17 mm, an adaptation length of 10 m, and applied a suspended and bedload sediment transport scale factor of 1.3.

modeling runs were completed testing various sediment layer and grain-size parameters and scaling factors which led to an optimum sediment parameterization characterized by ten 1-m thick sediment layers with grain size distributions of $D_{90} = 0.08$ mm, $D_{50} = 0.17$ mm and $D_{10} = 10$ mm.
This parameterization yielded the most realistic morphology simulation output, and most closely agrees with actual sediment characteristics discussed earlier. Another recent advancement of the CMS is application of an adaptation length parameter in the morphology computation. Adaptation length can be adjusted either spatially or temporally to smooth sediment transport gradients in order to avoid unrealistic abrupt morphology changes between adjacent cells. Various spatial and temporal adaptation lengths were test and it was determined that an adaptation length of 10 m yielded the most reasonable morphology change. Finally, a scale parameter of 1.3 was applied to both the suspended and bedload sediment transport computations. Output from one of the CMS morphology change verification simulations is shown in Figure 70.

Based on a series of systematic calibration and verification model runs, the following model set-up parameters were quantitatively (Wilmott skill) and qualitatively determined to provide the most accurate wave, current, and morphology change simulation output for the inlets and adjacent beaches based on a comparison with measured field data and a current understanding of the inlet morphodynamics.

1) For CMS-Wave, the default friction coefficient of 0.025 (Manning’s $n$) was used throughout the entire modeling domain.
2) Wave breaking was computed based on Goda criteria (Goda, 1970).
3) For CMS-Flow, the implicit version of the model was used with a time step of 300 s.
4) A spatially constant Manning’s $n$ of 0.02 was used for CMS-Flow.
5) For sediment transport computation, the non-equilibrium total load formulation (Sanchez and Wu, 2011) was used.
6) The Lund-CIRP sediment transport formulas with exponential sediment concentration profiles was used (Larson et al., 2011).
7) An adaptation length of 10 m was used in the non-equilibrium sediment transport computation.
8) A sediment transport scaling factor of 1.3 was used for both bedload and suspended load transport calculations.

9) Layered multiple sediment-grain sizes were used:
   a. Sediment layer thickness = 1 m, with up to 10 layers.
   b. $D_{90}$ is 0.08 mm.
   c. $D_{50}$ is 0.17 mm.
   d. $D_{10}$ is 10 mm.

10) The model results output was set as:
   a. Water level and current: every 30 minutes
   b. Wave: every 3 hours.
   c. Sediment transport rate: every 3 hours.
   d. Morphology change: every 3 hours.

The finest spatial resolution used during construction of the JPBPIS numerical modeling grid was 10 x 10 m, which was used for the inlet channels, areas in the vicinity of the inlets, and most of the nearshore region. The ebb shoals were resolved using 20 x 20 m cells. The offshore model domain boundary was located approximately 7 km from the shoreline (see Figure 16). The northern back-bay boundary is located at the Narrows (Park Boulevard), and the south back-bay boundary is located at the Corey Causeway. Both the north and south boundaries are driven by measured water level data, or water level data obtained from the NOAA Clearwater tide station (Station No. 8726724). The CMS-Flow model grid included 95,893 cells, while the CMS-Wave model was composed of 41,870 cells. Computation time is largely controlled by the CMS-Flow model. Using the model set-up parameters described above, the numerical model computed output at a rate of 1:30. In other words, morphologic change occurring over the course of 30 days, could be computed in 24 hours. The final objective was to have the capability of completing long-term (2 years) simulations in approximately 30 days.
5.3  Volumetric and Morphologic Change

In the following, time-series bathymetric and land-based survey data (see Section 4.1.4) is used to quantify, (1) sediment resources stored within the inlet ebb shoals, (2) inlet dredge-pit infilling rates, and (3) morphologic and volumetric changes occurring to the inlet systems as a function of time. Dredge pit infilling rates and spatio-temporal volume changes are of particular interest to coastal managers since the earlier provides some basis to assess the sustainability of ebb shoal mining activities, while the latter provides data critical to formulating a local and regional sediment budget and identifying sediment transport pathways within the inlet systems (discussed in Sections 5.3.2 - 5.3.4). The volumetric analysis was conducted using 2010 thru 2014 bathymetric and land-based survey data.

5.3.1  John’s Pass and Blind Pass Ebb Shoal Volumes

Inlet ebb shoals store large volumes of sediment, and include pathways for sediment bypassing across the inlet to the downdrift shoreline. In order to calculate the volume of sediment stored within the JPBPIS ebb shoals, a synthetic base bathymetry was constructed removing all bathymetric expression of the inlet channels and ebb shoals. The synthetic bathymetry was constructed using 2014 surveyed beach and offshore profiles located adjacent to the respective inlet. At John’s Pass, the synthetic bathymetry was constructed using profile R120, located approximately 1500 m (5000 ft) north of the inlet, and profile R134 which is located approximately 2700 m (9000 ft) south of the inlet. Due to the southward skew of the ebb shoal, the base profile south of the inlet is much farther from the inlet channel than the profile to the north. The synthetic base bathymetry for John’s Pass is shown in Figure 71, while Figure 72 illustrates the 2014 bathymetry of the John’s Pass ebb shoal overlain on the synthetic bathymetry. Based on the 2014
bathymetry, the area of the John’s Pass ebb shoal is 2,043,000 m$^2$, and the volume above the synthetic bathymetry (Figure 72) is 3,286,000 m$^3$ (4,298,000 yd$^3$). This approaches Davis and Gibeau (1990) estimate of 3,838,000 m$^3$ based on 1984 bathymetry, and is considerably less than the 7,000,000 yd$^3$ obtained by CTC (1993). It is worth noting that the landward limit of both the ebb-shoal area and volume calculation is the shoreline, defined by NAVD88 zero.

At Blind Pass, the synthetic bathymetry north of the inlet was constructed using profile R142 which is approximately 400 m (1300 ft) from the inlet. The bathymetry south of the inlet was constructed using profile R148 which is approximately 1200 m (4000 ft) from the inlet. As with John’s Pass, due to the southward skew of the ebb shoal, the base profile south of the inlet

Figure 71. Synthetic bathymetry of the John’s Pass inlet region, constructed using 2014 R-monument beach and offshore profiles. The inlet ebb shoal and channel have been removed. Note, elevation is relative to NAVD88 and vertical exaggeration of the image is 20x.
Figure 72. John’s Pass ebb shoal based on July 2014 survey data, overlain on the synthetic bathymetry shown in Figure 71. The scale in the upper right represents the synthetic bathymetry, and the lower right represents ebb shoal bathymetry, with both scales relative to NAVD88. Note, vertical exaggeration of the image is 20x.

Figure 73. Synthetic bathymetry of the Blind Pass inlet region, constructed using 2014 R-monument beach and offshore profiles. The inlet ebb shoal and channel have been removed. Note, vertical exaggeration of the image is 20x. Elevation is relative to NAVD88.
Figure 74. Blind Pass ebb shoal as surveyed in July 2014, overlaying the synthetic bathymetry shown in Figure 73, with 20X vertical exaggeration. The elevation scale in the upper right represents the synthetic bathymetry, and the lower right represents ebb shoal bathymetry. All elevations are relative to NAVD88.

is much farther than the profile to the north. The synthetic base bathymetry illustrated in Figure 73 has had all bathymetric expression of the Blind Pass inlet channel and ebb shoal removed. Figure 74 illustrates the 2014 surveyed bathymetry of the Blind Pass ebb shoal overlaying the synthetic base bathymetry. Based on 2014 survey data, the area of the ebb shoal is 899,000 m$^2$, and the volume of the ebb shoal above the synthetic base bathymetry is 515,000 m$^3$ (673,000 yd$^3$). Based on conditions present in 1992, CP&E (1992) reported that “there is presently no appreciable ebb shoal at Blind Pass”. The lack of an ebb shoal at that time is due to the collapse of the Blind Pass ebb shoal in the 1960’s following reductions in the inlets share of tidal prism discussed earlier. Prior to the collapse of the ebb shoal, Mehta et al., (1976) estimated its volume based on 1952 data to be 1,024,000 m$^3$. It should be noted that for this study, sedimentation on the north side of the main inlet channel (the “inner shoal”) was not included in this volume calculation because it is deposited by flood currents and is not considered to be part of the ebb shoal. Similar to the case
at John’s Pass, the landward limit of both ebb-shoal area and volume calculation is also the shoreline, defined by NAVD88 zero.

5.3.2 Rates of Dredge Pit Infilling

Time series volume changes constrained to dredging footprints are discussed here. Both John’s Pass and Blind Pass channels and ebb shoals have been dredged in the past for channel maintenance purposes and to mine sediment for renourishment of nearby beaches (see Appendix A). To gain insights into dredge pit infilling rates, volume changes in dredge pits excavated into the John’s Pass ebb shoal in 1988 and 2010, and Blind Pass in 2010 were examined.

In 1988 channel maintenance dredging and mining of sediment from the northern flank of the John’s Pass ebb shoal was conducted (CTC, 1993; Walther and Douglas, 1993) (see Figures 49 and 50c). The sediment was used to renourish Redington Shores beach on Sand Key (CTC, 1993). While no verifiable dredging volumes are available, ca 407,000 m$^3$ of sand from that dredging was placed on the Redington Shores beaches (Dean and Lin, 1990). Additionally, Walther and Douglas (1993) reported that: (1) the pre-dredging elevation of the borrow area was -4 m (no datum reported), (2) the post dredging average elevation of the ebb shoal borrow site was -6.5 m (no datum reported), and (3) during the 4 years following the dredging ca 96,000 m$^3$ infilled the dredge pit equating to ca 24,000 m$^3$ year$^{-1}$. While the precise position and dimensions of the 1988 dredge pit are unknown, the general location is based on CTC (1993) and Walther and Douglas (1993), and the obvious bathymetric depression that currently remains (Figure 48). As of July 2014, the latest bathymetric survey collected during this study, the minimum elevation in the excavation is -5.4 m (NAVD). Between June 2010 and July 2014 which represents post dredging years 22-26, the dredge pit received ca 1300 m$^3$. Walther and Douglas (1993), using the transport ratio methodology described in Chapter 2 (Figure 7) predicted infilling rates for the 22-
26 year post dredging period ranging from \(ca\) 5000 m\(^3\)/year during year 22 to \(ca\) 3000 m\(^3\)/year during year 26 with an average rate over the 4 year period of \(ca\) 4000 m\(^3\)/year, \(ca\) 80\% higher than those estimated by this study. Similarly, as described in Chapter 2, the approach used by Walther and Douglas (1993) at Boca Raton Inlet overestimated the infilling rates there by \(ca\) 47\%.

John’s Pass and Blind Pass ebb shoals and channels were dredged in June 2010 (Figure 75). The excavated sediment was used to renourish Sunshine, Sunset, and Upham beaches on Treasure Island and Long Key. Bathymetric surveys of both inlets ebb shoals and channels were conducted by the USFCRL in June 2010 prior to the dredging and again in October 2010 immediately post dredging. Subsequent bathymetric surveys of the inlet shoals and channels were completed in January 2011, September 2011, July 2012, and July 2014. The 2010 dredging program at John’s Pass included channel maintenance dredging and ebb shoal mining. Two dredge pits were excavated, one along the seaward most portion of the ebb shoal (referred to as the terminal lobe) and a second within the main channel which including portions of the channel margin linear bar (Figure 75 left panel). Based on pre- and post-dredging bathymetric surveys of the John’s Pass ebb shoal and channel, \(ca\) 126,000 m\(^3\) of material was dredged from the inlet channel and channel margin linear bar, and \(ca\) 158,000 m\(^3\) was removed from the terminal lobe yielding a total of 284,000 m\(^3\). During the first year post dredging (10/2010 – 9/2011) 39,000 m\(^3\) of sediment was deposited into the main channel dredge pit. During the subsequent 10 months (9/2011 – 7/2012) 11,000 m\(^3\) was deposited in the channel dredge pit, and from 7/2012 to 7/2014
(24 months) 30,000 m$^3$ or 15,000 m$^3$ year$^{-1}$ was deposited in the channel dredge pit. Overall, during the 4 years post dredging, the channel dredge received \emph{ca} 22,000 m$^3$/yr of sand equating to \emph{ca} 65\% of the material removed. At that annualized rate, it would take 5.3 years to recover to pre-dredging conditions. However, as shown in Figure 76, while the first year infilling rate was \emph{ca} 39,000 m$^3$ it declined to \emph{ca} 15,000 m$^3$ in subsequent years. Assuming those infilling rates, it would take \emph{ca} 7 years to recover to pre-dredging conditions. Figures 79 and 80 illustrate infilling patterns within the channel pit during the first and second year, respectively.

The rate of infilling at the terminal lobe dredge pit was substantially less than the channel pit, likely influenced by its distal position relative to the ebb jet in conjunction with a limited supply of sediment. The floor of the dredge pit lies at -4.2 m NAVD88. During the first year, the dredge pit received \emph{ca} 5,100 m$^3$ of sediment (Figure 77), which equates to 13\% of the volume deposited in the John’s Pass channel dredge pit during the same time period. During the second year (10 months to be exact), the pit received \emph{ca} 1000 m$^3$ of sedimentation (annualized rate = 1200 m$^3$) or \emph{ca} 10\% of the volume of sediment deposited in the channel dredge pit during the same time period. Infilling rates increased to 2500 m$^3$ during years 3 and 4. Based on the current rate of infilling, it would take \emph{ca} 63 years to recover to pre-dredging conditions. Figures 79 and 80
illustrate the patterns of infilling during the first and second year, respectively. In the two years post dredging, most of the sedimentation occurred at the northwest corner and along the eastern and western pit margins.

In 2010, ca 121,000 m$^3$ of sediment was dredged from the Blind Pass ebb shoal and inner shoal (Figure 75 right panel). At its deepest point, the dredge pit extended to a depth of -4.75 m NAVD88. Sediment infilling during the first year post-dredging was ca 20,000 m$^3$ (Figure 78). This is lower than the 35,000 m$^3$ (46,000 yd$^3$) infilling obtained by Wang et al., (2007) following dredging in 2000, and is likely due to the fact that in 2000 the dredge pit extended much further seaward and deeper than the 2010 dredge pit. During the second year (10 months to be exact), sedimentation of 21,000 m$^3$ (28,000 yd$^3$) was measured. This equates to an annualized volume of 25,200 m$^3$, ca 25% greater than the amount deposited during the first year (Figure 80). During the 3rd and 4th years, the infilling rate declined to 14,000 m$^3$/yr for each year. At the current infilling rate, it would take ca 7.53 years to recover to pre-dredging conditions. While that infilling rate appears to be lower than the generally accepted net longshore sand transport rate, it does not account for the additional volume associated with the continued growth of the Blind Pass ebb shoal, which when included yields a volume consistent with reported gross transport rates (CP&E, 1992).

Figures 82 and 83 illustrate infilling patterns in the dredge pit during the first and second year, respectively. In general, sedimentation in the dredge pit spreads both landward and seaward over time and illustrates the temporal variability of depositional patterns. Deposition in the north central portion of the pit during the first year post dredging experienced erosion during the second year. The eroded sediment along with additional sediment delivered to the inlet from southward longshore transport moved landward and seaward during year two. A similar pattern of landward-seaward spreading was observed following dredging in 2000 (Wang et al., 2007).
spreading is important to the continued development of the Blind Pass ebb shoal and illustrates how sediment bypassing is initiated. It is important to note that the 2000 dredging of Blind Pass effectively removed most of the ebb shoal that existed at the time, in addition to much of the inner shoal. Therefore, the current Blind Pass ebb shoal effectively represents sedimentation that has occurred subsequent to the 2000 dredging, equating to a growth rate of ca 37,000 m$^3$/year during the 14 years between 2000 and 2014.

![JP 2010 Channel Dredge Pit Infilling Rate](image)

Figure 76. Annualized infilling rates of the John’s Pass inlet channel dredge pit during the 4 years following the 2010 dredging.
Figure 77. Annualized infilling rates of the John’s Pass inlet terminal lobe dredge pit during the 4 years following the 2010 dredging.

Figure 78. Infilling patterns in the John’s Pass dredge pits during the first year post dredging from October 2010 to September 2011.
Figure 79. Infilling patterns in the John’s Pass dredge pits during the second year (10 months) post dredging from September 2011 to July 2012.

Figure 80. Annualized infilling rates of the Blind Pass dredge pit during the 4 years following the 2010 dredging.
Figure 81. Infilling of the Blind Pass dredge pit during the first year post dredging from October 2010 to September 2011.

Figure 82. Infilling of Blind Pass dredge pit during the second year (10 months) post dredging from September 2011 to July 2012. Note the landward and seaward spreading of the infilling sediment in contrast to the first year’s infilling pattern.
5.3.3 Time-Series Ebb Shoal Volume Changes

In order to gain insights into sediment pathways, an examination of time-series volume changes within the JPBPIS channels and ebb shoals was conducted. At John’s Pass, a volume gain of 64,000 m$^3$ (84,000 yd$^3$) over the entire ebb shoal was measured during the 11 months between October 2010 and September 2011. This suggests an annualized rate of 70,000 m$^3$/year and generally agrees with existing estimates of gross longshore sediment transport rates (CTC, 1993). Sedimentation in the channel margin dredge pit continued from the previous 3 months, supplied by southward longshore sand transport. In addition, sedimentation was also measured at the numerous swash bars also referred to as bypassing bars (Kraus, 2000), which as described earlier coalesce at the shoreline attachment point (Figure 84). Deposition at the attachment point continued, fed by sand from the bypassing bars. Deposition as opposed to the erosion measured during the initial 3 months, was measured directly south of the south terminal groin. The spatial pattern of sedimentation at the bypassing bars connecting to the attachment point illustrates a primary sediment pathway from the updrift (north) side to the downdrift (south) side of the inlet. Both the updrift (north) and downdrift (south) flanks of the ebb shoal experienced erosion.

A volume gain of 104,000 m$^3$ (136,000 yd$^3$) over the entire John’s Pass ebb shoal was measured during the 21-month period between October 2010 and July 2012. This suggests an annualize rate of 59,000 m$^3$/year (77,000 yd$^3$/year) over the 2-year period. The sedimentation rate during the second year following the 2010 dredging was 48,000 m$^3$, or about 31% less than during the first year. Sedimentation in the channel margin dredge pit continued from the previous year but at a slower rate (Figure 91). Sedimentation at the bypassing bars continued during the second year indicating a rather persistent sediment pathway. It is worth noting that a significant summer storm, Tropical Storm (TS) Debby, impacted the study area just before the July 2012 survey. TS
Debby approached the study area from a southerly direction yielding forcing focused largely in a northerly direction as opposed to the southerly direction of net annual longshore sand transport. Based on the overall volume and spatial pattern of sedimentation over the John’s Pass ebb shoal, TS Debby did not significantly alter sand bypassing around John’s Pass in 2012. TS Debby did however induced substantial beach erosion along the Pinellas County beaches. Sedimentation at the attachment point and just south of the south terminal groin continued. Increased levels of erosion along the southern flank of the ebb shoal were measured during this period as compared to the previous periods. This may be due to the dominantly northerly forcing and resulting erosion associated with the passage of TS Debby.

A volume gain of 270,000 m$^3$ (353,000 yd$^3$) over the entire John’s Pass ebb shoal was measured during the 45-month period between October 2010 and July 2014. This suggests an annualize rate of 72,000 m$^3$/year (94,000 yd$^3$/year) over the 4-year period. The 270,000 m$^3$ volume gain equates to slightly over 8% of the total John’s Pass ebb shoal volume of 3,280,000 m$^3$. Sedimentation in the channel margin dredge pit continued with sand supplied from the southward longshore transport (Figure 92). Sedimentation at the bypassing bars continued during the subsequent two years further illustrating a persistent sediment pathway. Deposition at the attachment point continued, paired with erosion just seaward. This suggests onshore migration of the swash/bypass bars. It is worth noting that the July 2014 survey was conducted immediately after the Sunshine Beach nourishment project. Some of the placed sand was accounted for in the volume calculation of the ebb shoal although most of the sand was place landward of the 2014 shoreline (defined as NAVD88 0 m). As described above, the landward limit of the ebb-shoal volume calculation was the 2014 shoreline. The beach nourishment contributed to the greater
volume change measured in the July 2014 survey. Erosion along the north and south flanks of the ebb shoal measured during the previous surveys was replaced by deposition.

The July 2014 survey was conducted using the multi-beam system as described earlier. The multi-beam survey lines were spaced at 10-m intervals, rather than the 50-m spacing employed during the earlier single beam surveys. The higher resolution captured during the multi-beam survey resolved complicated morphological features over the ebb shoal in much greater detail than the single beam surveys. Therefore, in order to more accurately compare the 2014 survey data with previous surveys, the multi-beam survey data was re-sampled based on a 50-m line spacing. The volume change discussed above was based on the re-sampled multibeam data. When the high-resolution multi-beam data were used directly, a greater volume change of 283,000 m$^3$ (370,000 yd$^3$), versus 270,000 m$^3$ (353,000 yd$^3$) was obtained indicating that the higher resolution 2014 survey data yielded 5% greater volume than the lower resolution single-beam bathymetric survey data.

Figure 83. Sedimentation and erosion patterns over John’s Pass ebb shoal between October 2010 and January 2011. Red color scale represents deposition in meters. Blue color scale represents erosion in meters. Note the deposition in the channel margin dredge pit and erosion just updrift.
Figure 84. Sedimentation and erosion patterns over John’s Pass ebb shoal between October 2010 and September 2011. Red color scale represents deposition in meters. Blue color scale represents erosion in meters. Note the deposition in the channel margin dredge pit and erosion just updrift, and deposition along the bypassing bars.

Figure 85. Sedimentation and erosion patterns over John’s Pass ebb shoal between October 2010 and July 2012. Red color scale represents deposition in meters. Blue color scale represents erosion in meters. Note the deposition in the channel margin dredge pit and erosion just updrift, and deposition at bypassing bars.
Figure 86. Sedimentation and erosion patterns over John’s Pass ebb shoal between October 2010 and July 2014. Red color scale represents deposition in meters. Blue color scale represents erosion in meters. Note the deposition in the channel margin dredge pit and erosion just updrift, and deposition at bypassing bars.

At Blind Pass, during the 11 months between October 2010 and September 2011, a volume gain of 68,000 m$^3$ (89,000 yd$^3$) was measured over the entire Blind Pass ebb shoal. This suggests an annualized rate of 74,000 m$^3$/year (97,000 yd$^3$/year), which is slightly greater than existing estimates of gross longshore sand transport rate and substantially greater than the net longshore transport rate (CPE, 1992). This volume gain is also greater than the 64,000 m$^3$ measured at John’s Pass, and can be attributed to sediment artificially added to the system during renourishment projects at Sunset Beach and Upham Beach located immediately adjacent to Blind Pass (Figure 87). Substantial sedimentation was measured in the 2010 dredge pit. It should be noted that the ebb shoal volume change calculated here did not include the sedimentation occurring within the entrance channel (inner shoal), as is apparent in Figure 87. The sedimentation within the entrance channel is largely related to longshore transport and flood tidal currents and therefore should not be considered as part of ebb shoal. Growth along the southern flank of the ebb shoal is apparent.
The erosion northwest of that deposition is likely reflecting migration of the developing bypassing bars, while sedimentation occurring directly seaward of Upham Beach can be attributed in part to profile adjustment of the beach nourishment there.

During the 21-month period between October 2010 and July 2012, a volume gain of 73,000 m$^3$ (95,000 yd$^3$) occurred over the entire Blind Pass ebb shoal (Figure 88). This suggests an annualize rate of 42,000 m$^3$/year (55,000 yd$^3$/year) over the 2-year period. The sedimentation rate during the second year following the 2010 dredging was 10,000 m$^3$/year, much less than the 74,000 m$^3$/year that occurred during the first year. Further seaward and southward growth of the ebb shoal is evident in the 2012 survey data (Figure 88). The north to south longshore sand transport likely transported some of the sediment from the ebb shoal downdrift, and illustrates part of the process responsible for chronic erosion at Upham Beach. As described earlier, TS Debby (June 2012) approached the study area from a southerly direction, yielding a dominant northerly forcing direction, opposite to that of the net southward annual longshore sand transport. Based on the overall volume and spatial pattern of sedimentation over the Blind Pass ebb shoal, TS Debby did not have significant influence on the sedimentation patterns there.

During the 45-month period between October 2010 and July 2014, a volume gain of 194,000 m$^3$ (254,000 yd$^3$) was measured over the entire Blind Pass ebb shoal (Figure 89). This suggests an annualize rate of 52,000 m$^3$/year (68,000 yd$^3$/year) over the 4-year period. The continued growth of the ebb shoal over time is clearly evident (Figure 89). In addition, the sediment accumulation adopted a crescent shape morphology, a common morphological characteristic of bypassing bars (Kraus, 2000), which is well illustrated at the more mature John’s Pass ebb shoal. Sedimentation within the 2010 dredge pit continued during this period. The volume gain of 194,000 from October 2010 to July 2014 constitutes 38% of the entire Blind Pass
ebb shoal volume of 515,000 as measured in 2014. This indicates that at the time of this study, the Blind Pass ebb shoal is continuing to grow at a rapid rate. In other words, the annual growth rate of 52,000 m$^3$/year (68,000 yd$^3$/year) represents slightly over 10% of the entire ebb shoal volume. It is worth noting that the July 2014 survey was conducted immediately following beach renourishment at Sunset Beach and Upham Beach. While some of the placed sand was accounted for in the volume calculation of the ebb shoal, most of the nourishment sand was placed landward of the 2014 shoreline (defined as NAVD88 0 m), and therefore landward of the region included in the ebb-shoal volume calculation. Beach nourishment sand volumes were included in beach volume changes captured in the July 2014 land survey. The two beach nourishment projects during the 4-year study period also contributed to an apparent lack of significant erosion measured directly seaward of the chronically eroding Upham Beach. The 52,000 m$^3$/year (68,000 yd$^3$/year) growth rate of the Blind Pass ebb shoal equals the gross rate of longshore transport (CPE, 1992).

As described earlier, the July 2014 bathymetric survey was conducted using a multi-beam system yielding higher spatial resolution than the single beam surveys used in previous surveys. This improved spatial resolution revealed more detailed swash bar/bypass bar patterns and resulted in slightly (~5%) greater volume changes.
Figure 87. Sedimentation and erosion patterns over Blind Pass ebb shoal comparing bathymetry survey of September 2011 with that of October 2010. Red color scale represents deposition in meters. Blue color scale represents erosion in meters. Note the deposition in the channel margin dredge pit and erosion just updrift, and deposition at bypassing bars.

Figure 88. Sedimentation and erosion patterns occurring between October 2010 and July 2012 over the Blind Pass ebb shoal. Red colors represent deposition in meters, and blue colors represent erosion. Note the deposition in the channel dredge pit and updrift erosion, and deposition at bypassing bars.
Regional Sediment Budget and Sediment Pathways

The quantification of a regional sediment budget is complicated by the introduction or removal of sediment artificially through inlet dredging (removal of sediment) and beach nourishment (addition of sediment). In order to minimize these influences, the regional sediment budget for John’s Pass and Blind Pass is based on survey data spanning the period from October 2010 to June 2014. This time period begins immediately following the last dredging events and associated beach nourishment projects on Treasure Island and Long Key in 2010, and ends immediately prior to 2014 beach renourishment projects on Treasure Island and Long Key. Accordingly, sediment volumes placed on Treasure Island and Long Key during the 2010 nourishments, as well as sediment volumes placed on Sand Key in 2012 during beach nourishment projects north of and updrift from John’s Pass and Blind Pass were accounted for when developing
the regional sediment budget. Given that the beaches within the study area are nourished regularly and the budget period incorporates a large portion of a beach nourishment cycle, the sediment budget arrived at in this study should represent a typical situation incorporating artificial sand supplies from beach nourishment projects.

The total budget period was 44 months, or 3.7 years and in addition to the temporal constraints justified above, was in-part temporally constrained by the availability of field data. The USF-CRL conducted bathymetry surveys over John’s Pass and Blind Pass channels and ebb shoals in June 2010 (before the 2010 dredging), October 2010 (post dredging), January 2011, October 2011, July 2012, and July 2014. In addition, these data were supplemented with bi-monthly beach profile surveys conducted by the USF-CRL between 2010 to 2014 along Sand Key, Treasure Island, and Long Key, extending from FDEP R-monument R55 (north end of Sand Key) to R165 (south end of Long Key).

The regional sediment budget formulation was bounded on the north at Profile R60 based on 2006 to 2010 Sand Key beach-profile survey data (Roberts and Wang, 2012) which illustrates a peak profile-volume loss along North Sand Key at profile R60 (see Figure 24). This volume change pattern is interpreted to represent a divergent zone, north of which the net longshore transport is to the north towards Clearwater Pass, and south of which the net longshore transport is to the south towards John’s Pass. Accordingly, profile R60 was determined to be the north boundary for the formulation of John’s Pass and Blind Pass regional sediment budget.

The USF-CRL bi-monthly beach surveys extended to the short-term depth of closure in the study area (ca -3.5-m NAVD88). Profile-volume changes illustrated in Figure 24 represent those above the closure depth. Therefore, zero profile-volume change represents no net longshore sand transport. The sum of all the beach-profile volume change along Sand Key south of R60, which
is a negative number representing a net loss, is treated as sediment input to the John’s Pass inlet system.

A balanced regional sediment budget for the JPBPI is shown in Figures 92 and 93. Figure 90 illustrates the entire sand budget over the 44-month (or 3.7-year) period. Figure 91 illustrates the annualized budget. Over the 44-month period, a total of 453,000 m$^3$ (or 122,000 m$^3$/yr) of sand from Sand Key entered John’s Pass inlet system, including the ebb shoal, channel and adjacent beaches. The John’s Pass inlet system gained 251,000 m$^3$ of sand over the 44-month period, or 68,000 m$^3$/yr, and was substantially influenced by contributions from the 2012 Sand Key nourishment. A total of 202,000 m$^3$ of sand bypassed John’s Pass to Treasure Island beaches over the 44-month period, equating to an annualized rate of 54,000 m$^3$/yr. Treasure Island beaches lost 50,000 m$^3$ of sand over the 44 months, or at an annualized rate of 14,000 m$^3$/yr. Most of the sand loss can be attributed to erosion at Sunset Beach, which is discussed in the following Treasure Island budget.

Over the 44 months, a total of 252,000 m$^3$ (or 68,000 m$^3$/yr) of sand entered the Blind Pass inlet system, which includes the channel, ebb shoal, and immediately adjacent beaches. The Blind Pass inlet system gained 157,000 m$^3$ of sand over the 44 months, equating to an annualized rate of 43,000 m$^3$/yr. A total of 95,000 m$^3$ of sand bypassed the Blind Pass inlet system onto Long Key, equating to 25,000 m$^3$/yr. The beach along Long Key gained 15,000 m$^3$ of sand or 4,000 m$^3$/yr over the 44-month period. Most of the sand gain occurred in the middle of the island, as is discussed in detail in the following on Long Key sediment budget. Over the 44 month period, 80,000 m$^3$ of sand or 21,000 m$^3$/yr exited Long Key and entered the Pass-a-Grille inlet system. Artificial sand supplies from 2010 Treasure Island and Long Key beach nourishments contributed significantly to the sand gains on the ebb shoals.
Figure 90. Regional sediment budget of John’s Pass and Blind Pass system determined based on field data collected from October 2010 to June 2014.
Figure 91. Regional annualized sediment budget of John’s Pass and Blind Pass system determined based on field data collected from October 2010 to June 2014.
Figures 94 and 95 illustrate the detailed sediment budget within the John’s Pass inlet system. Here the John’s Pass inlet system is composed of the main channel and all the branches, the ebb shoal, the flood shoal, and the immediate adjacent beaches which include the south end of Sand Key (R121-R124) and Sunshine Beach (R127-R129) at the north end of Treasure Island. The adjacent beaches were determined based on the extent of the ebb shoal. The south end of Sand Key gained a total of 37,000 m$^3$ of sand over the 44-month period (Figure 92), equating to an annualized rate of 10,000 m$^3$/yr (Figure 93). This sand gain can be largely attributed to the 2012 beach nourishment on Sand Key in conjunction with the net annual southward longshore transport.

The John’s Pass ebb shoal gained 270,000 m$^3$ of sand over the 44 months at an annualized rate of 73,000 m$^3$/yr. The channel throat in the vicinity of the bridge received approximately 4,000 m$^3$ sand deposition during the 44 months. Most of the deposition occurred along the north side of the channel, illustrated by a small sub-aerial beach below and adjacent to the bridge piers. Sunshine Beach located immediately south of the inlet lost 60,000 m$^3$ of sand over the 44 months. Most of that sediment was sediment that had been placed on Sunshine Beach during the 2010 nourishment in addition to the background erosion rate. Those sand losses contributed to gains in the ebb-shoal as well as sand bypassing to Treasure Island. The John’s Pass system received 453,000 m$^3$ of sand from Sand Key beaches, equating to an annualized rate of 122,000 m$^3$/yr. Of that volume, 37,000 m$^3$ was deposited at the south end of Sand Key, 270,000 m$^3$ was deposited on the John’s Pass ebb shoal, and 4,000 m$^3$ was deposited in the main channel. Combined with the sand volume loss of 60,000 m$^3$ from Sunshine Beach, a total of 202,000 m$^3$ of sand bypassed the John’s Pass system contributing to the downdrift Treasure Island, Blind Pass, and Long Key sediment budgets. The annualized volume rate of change is illustrated in Figure 93. In order to
Figure 92. Sediment budget at John’s Pass determined based on field data collected from October 2010 to June 2014.
Figure 93. Annualized sediment budget at John’s Pass determined based on field data collected from October 2010 to June 2014.
gain insights into sediment pathways within the John’s Pass inlet system, volume changes within discrete morphological regions of the inlet system were examined and are discussed below.

Figures 96 and 97 illustrate sedimentation patterns over the John’s Pass inlet and ebb shoal specifically within dredged regions and the various morphological components which combined make up the dynamic components of the inlet system. Over the 44-month period, the navigation channel (black dashed line) as outlined on the most recent published NOAA marine navigational chart received 35,000 m$^3$ of sand (Figure 94), equating to an annualized rate of 9,000 m$^3$/yr (Figure 95). The inlet channel (beige box) received 4,000 m$^3$ of sand over the 44 months. Most of that sediment was deposited along the north side of the channel along the bridge pilings and further east where a number of commercial boat docks exist.

The shallowest water depths over the ebb delta complex are found over the CMLB (yellow box). Over the 44 months, 1,000 m$^3$ of sand was lost over the CMLB. This small volume change suggests that the CMLB is likely at or near an equilibrium state, which can be attributed to the shallow water and frequent wave breaking which would act to limit additional deposition. The 2010 inlet channel dredge pit (pink box) received 80,000 m$^3$ of sand during the 44 month period (Figure 94), equating to an annualized rate of 22,000 m$^3$/yr (Figure 95) and illustrating the sustainability of sediment supply. The 2010 west dredge pit (teal box) received 10,000 m$^3$ of sand over the 44 months or 3,000 m$^3$/yr. The low sedimentation rate can be attributed to the relatively deep water and limited sediment supply over that portion of the ebb shoal complex.

The greatest volume of sedimentation occurred on the ebb shoal terminal lobe, mostly over the swash/bypassing bars (light blue box). A total of 212,000 m$^3$ of sand was deposited in this region over the 44-month period, equating to an annualized rate of 57,000 m$^3$/yr. This region represents ca 37% of the ebb shoal area, and accounts for ca 79% of the 270,000 m$^3$ volume gain
of over the entire John’s Pass ebb shoal. It should be noted that the terminal lobe, or bypassing bar complex, overlaps with other morphological features discussed above. The region where the bypassing bars coalesce and attach to the shoreline (green box) received 44,000 m$^3$ of sand over the 44 months. This equates to an annualized rate of 12,000 m$^3$/yr. The active sedimentation along the terminal lobe, which is largely composed of numerous shallow swash/bypass bars, represents a primary pathway for sand to move from the updrift (north) side to the downdrift (south) side of the ebb shoal complex.

Figure 96 and 99 illustrate the detailed sediment budget along Treasure Island. Over the 44-month period, Sunshine Beach at the north end lost 60,000 m$^3$ of sand (Figure 96), or 16,000 m$^3$/yr (Figure 97). It should be noted that the substantial volume loss along Sunshine Beach during this period does not reflect typical background erosion rates but rather post-construction adjustment of the beach fill (nourishment) project completed in 2010. Combined with the sand bypassed around John’s Pass, 202,000 m$^3$ of sand entered Treasure Island beach region over the 44-month period, equating to 54,000 m$^3$/yr. Of that 202,000 m$^3$, 38,000 m$^3$ (10,000 m$^3$/yr) was deposited along the central Treasure Island beach between R-monuments 129 and 135. Over the 44 months, the Sunset Beach stretch of the island, located between profiles R135 and R140, lost 88,000 m$^3$ of sand, at an annualized rate of 24,000 m$^3$/yr. As with the Sunshine beach stretch of the island, this substantial beach volume loss does not reflect typical background erosion rates but rather post construction adjustment of the 2010 Sunset Beach nourishment. Combined with 34,000 m$^3$ sand loss at the very south end of Treasure Island, a total of 286,000 m$^3$ of sand entered the Blind Pass system, equating to an annualized rate of 77,000 m$^3$/yr. This rate is much greater than the 30,000 m$^3$/yr net annual southward longshore sand transport rate (CPE, 1992; CTC, 1993), and can be attributed in large part to sand input from the 2010 nourishments on Treasure Island.
Figure 94. Sedimentation patterns over John’s Pass ebb shoal determined based on field data collected from October 2010 June 2014.
Figure 95. Annualized sedimentation pattern over John’s Pass ebb shoal determined based on field data collected from October 2010 to June 2014.
In summary, along Treasure Island, based on the time-series beach-profile data, most of the sediment bypassing John’s Pass is transported south along the Treasure Island beach ultimately entering the Blind Pass system. A relatively small volume of sediment, 38,000 m$^3$ was deposited along the middle accretionary portion of the island, where the beach is very wide and largely maintained by deposition associated with the John’s Pass ebb shoal shoreline attachment. North and south of the attachment point, at Sunshine and Sunset beaches respectively, as well as the stretch of beach south of Sunset Beach, erosional processes dominate despite the large volume of sediment being transported along the island.

The Blind Pass sediment budget is shown in Figures 100 and 101, and includes the southern end of Treasure Island (profiles R140-R143), the 90-degree entrance channel, the ebb shoal, and Upham Beach at the northern end of Long Key (profiles LK1-LK4). A total of 252,000 m$^3$ of sediment (Figure 98), or 68,000 m$^3$/yr (Figure 99) entered the Blind Pass system from the north during the 44-month period. A total of 192,000 m$^3$ or 52,000 m$^3$/yr of sediment was gained over the Blind Pass ebb shoal during the 44 months. The inlet channel, defined here as the channel landward of the tip of the north terminal groin (Figure 98), which includes the inner shoal or flood shoal, gained 89,000 m$^3$ of sand during the 44 months, or 24,000 m$^3$/yr. A portion of this sand was deposited on the north side of the Gulf facing entrance channel/channel throat (inner shoal/flood shoal), while a substantial amount of sediment is transported around the 90 degree bend and is deposited along the east shore of Treasure Island, forming a narrow subaerial beach.

The chronically eroding stretch of Upham Beach lost 90,000 m$^3$ of sand during the 44 months, or 24,000 m$^3$/yr. This substantial loss can be attributed in large part to sediment placed
Figure 96. Sediment budget at Treasure Island determined based on field data collected from October 2010 to June 2014.
Figure 97. Annualized sediment budget at Treasure Island determined based on field data collected from October 2010 to June 2014.
on the beach during the 2010 renourishment of Upham Beach. A portion of the sand lost from Upham Beach appears to be transported and deposited on the Blind Pass ebb shoal in a similar morphodynamic manner as Sunshine Beach transfers sediment to the John’s Pass ebb shoal, with the balance being transported downdrift. A total of 95,000 m$^3$ of sand entered the Long Key beach equating to 25,000 m$^3$/yr. This 95,000 m$^3$ includes sediment bypassing across the Blind Pass ebb shoal, and sediment eroded from Upham Beach.

Figures 102 and 103 illustrate the spatial distribution patterns of sediment deposition over the Blind Pass inlet system. The navigation channel outlined by the black dashed line received essentially no sedimentation over the 44 months. It should be noted that unlike John’s Pass which has a federally authorized and therefor defined channel, Blind Pass, not being federally authorized has no defined navigation channel. The navigation channel outlined in Figures 102 and 103 represents the deepest portions of the main ebb channel based on the 2014 bathymetric data. The 2010 dredge pit, outlined by the teal (green) box, received 100,000 m$^3$ of sand during the 44-month period, or 27,000 m$^3$/yr.

The developing CMLB along the north side of the channel, outline by the yellow box in Figures 102 and 103, received 37,000 m$^3$ of sedimentation over the 44 months, or 10,000 m$^3$/yr. Unlike the John’s Pass CMLB, which appears to be at or near an equilibrium state receiving negligible sedimentation, the Blind Pass CMLB is still developing and received a considerable volume of sediment. The developing terminal lobe, or bypassing bars, as outline by the light blue box received 73,000 m$^3$ of sand during the 44 months at an annualized rate 20,000 m$^3$/yr. The terminal lobe received 38% of the sedimentation over the entire Blind Pass ebb shoal, while representing only 18% of the surface area. The active sedimentation over the developing
Figure 98. Sediment budget at Blind Pass determined based on field data collected from October 2010 to June 2014.
Figure 99. Annualized sediment budget at Blind Pass determined based on field data collected from October 2010 to June 2014.
terminal lobe represents a primary pathway for sand to move from the updrift (north) side to the
downdrift (south) side. As described earlier in the engineering history of Blind Pass, the ebb shoal
was dredged or in this case more appropriately described as mined in 2000 and again in 2010.
While the 2000 dredging removed a substantial portion of the ebb shoal impacting
sediment bypassing around the inlet, the 2010 dredging was largely confined to the inner shoal or
flood shoal. Subsequent to both dredging events, the ebb shoal has begun to recover. Currently
the morphologic features characteristic of an ebb shoal including the terminal lobe and
swash/bypass bars are clearly evident (Figures 102 and 103); however, a shoreline attachment
cannot yet be identified on Long Key.

Figure 102 and 105 illustrate the detailed sediment budget for Long Key. Over the 44-
month period, the northern end of Long Key from LK1 to LK4 lost 90,000 m$^3$ of sediment or
24,000 m$^3$/yr. A portion of that lost sediment was transported and deposited onto the developing
Blind Pass ebb shoal, with the balance being transported to the south. Combined with the sediment
bypassing around Blind Pass, 95,000 m$^3$ of sediment or 25,000 m$^3$/yr was transported to the
southern portion of Long Key. The stretch of Long Key from LK4 to R148 lost 22,000 m$^3$ or
6,000 m$^3$/yr of sediment over the 44 month period, despite the 90,000 m$^3$ of sediment supplied
from the north. This sand loss combined the input from Blind Pass and the stretch from LK1 to
LK4, providing 117,000 m$^3$ or 31,000 m$^3$/yr of sediment to the middle section of Long Key. A
considerable portion of this sediment, ca 78,000 m$^3$ or 21,000 m$^3$/yr was deposited along the mid-
section of Long Key (between R148 to R161).

A relatively small portion of the sediment supply from the north, 39,000 m$^3$ or 11,000 m$^3$/yr,
entered the southern end of Long Key, i.e., the Pass-a-Grille Beach. Over the 44 months, Pass-a-
Grille Beach lost 41,000 m$^3$ of sand at an annualized rate of 11,000 m$^3$/yr, despite the
Figure 100. Detailed sediment budget at Blind Pass determined based on field data collected from October 2010 to June 2014.
Figure 101. Detailed annualized sediment budget at Blind Pass determined based on field data collected from October 2010 to June 2014.
Figure 102. Sediment budget at Long Key determined based on field data collected from October 2010 to June 2014.
Figure 103. Annualized sediment budget at Long Ley determined based on field data collected from October 2010 to June 2014.
sand supply from the north. In other words, the sediment that bypassed Blind Pass combined with that lost from the northern portion of Long Key did not contribute to deposition along the south end of the island. The sand lost from the southern-most stretch, in addition to a portion of the sand that was transported from the north entered the Pass-a-Grille inlet system. Overall, 80,000 m$^3$ of sand or 21,000 m$^3$/yr entered the Pass-a-Grille inlet system.

5.5 Modeled Hydrodynamic and Morphology Changes

The calibrated and verified CMS model discussed in the preceding sections was used to investigate various hypothetical management alternatives at John’s Pass and Blind Pass. The results from these modeling efforts combined with the sediment budget developed by this study are discussed here with the aim of evaluating how the various management alternatives influence morphodynamics of the JPBPIS. The following numerical model simulations were conducted:

1) **Existing Conditions**: *Baseline simulation over July 2014 bathymetry*: This case uses existing “baseline” conditions to forecast inlet evolution for a case in which no modifications are made to the system, and for comparison with the various management alternatives.

2) **Alternative 1**: *Dredging 280,000 m$^3$ of sediment from the northern portion of John’s Pass ebb shoal in the nearshore area down to -5.0 m mean sea level (msl) and placing the sediment in a relic dredge pit offshore Sunset Beach*: The nearshore area of the northern half of John’s Pass ebb shoal has a large amount of beach quality sand. This alternative hypothesized that filling the old dredge pit offshore Sunset Beach might mitigate the chronic erosion problem at Sunset Beach.

3) **Alternative 2**: *Dredging 121,000 m$^3$ of sand from the John’s Pass south swash/bypassing bars to -4.25 m msl in a pit immediately landward of the 2010 west/terminal lobe dredge pit, and placing the sand as nearshore berms directly offshore Sunshine Beach and Upham Beach*: This case examines: (1) the consequences of additional mining of the John’s Pass ebb shoal and (2) using the mined sediment for nearshore berm nourishments of nearby chronically eroding stretches of beach.
4) Alternative 3: Re-dredging 151,000 m$^3$ of sand from the 2010 John’s Pass 2010 channel dredge pit down to -5 m msl, and re-dredging 137,000 m$^3$ of sand from the 2010 Blind Pass west dredge pit to -5 m msl: No placement was included in this alternative since the current (2014) beach condition already included recent beach fill from the 2014 nourishment projects. This is essentially the same inlet management options applied in 2010 with the exception of the sediment placement.

5) Alternative 4: Extend both north and south terminal groins at John’s Pass and Blind Pass: This alternative investigates a structural option designed to more aggressively influence the interaction between the inlet systems and the prevailing longshore sediment transport mechanisms.

The baseline and alternative numerical model simulations extend over a 2-year period. Incident wave conditions were obtained from the WAVEWATCHIII model. The two-year wave data included records from April 1, 2009 to March 31, 2010 for year 1 and April 1, 2012 to March 31, 2013 for year 2. Year 1 wave conditions represent a typical year based on statistical analyses of WAVEWATCHIII data from 2000 to 2014. Year 2 data included more energetic conditions, specifically forcing conditions associated with Tropical Storm Debby, a weak but slow moving tropical storm that impacted the study area in 2012. Figure 104 illustrates the input wave conditions for the 2-year production model run. High waves on day 450 were associated with the passage of Tropical Storm Debby. The starting date of April 1, the beginning of summer season, is used to aid in examining possible seasonal changes. The WAVEWATCHIII wave heights were multiplied by 1.09 based on comparison with field measurements as previously discussed.

Tides measured at the Clearwater Beach NOAA tide station during corresponding time periods were used as the input water-level conditions. Based on field measurements discussed earlier, a 48-minute lag between the ocean boundary and the land boundary was artificially added to the tide records. Measured water level data were used in the modeling instead of computed tidal
constituents so that meteorological tides associated with weather events would be incorporated into the simulations.

![Figure 104](image)

Figure 104. Input significant wave height at the seaward boundary for the 2-year production CMS model run.

### 5.5.1 Baseline Conditions Simulation

The baseline simulation was based on the bathymetry acquired in 2014 (Figure 105). Important features contained in the 2014 bathymetry include the partially filled 2010 dredge pits at John’s Pass and Blind Pass, as well as beach fill placed on Treasure Island at Sunshine Beach and Sunset Beach, and on Long Key at Upham Beach and Pass-A-Grille beach. Sediment for the 2014 beach nourishments was obtained from borrow areas located near the mouth of Tampa Bay, outside of the study area. The purpose of the baseline run was to provide insights into the evolution of the JPBPIS based on existing conditions, and for comparison with the other alternatives, specifically to examine the consequences hypothetical engineering modifications may have on the JPBPIS.
Modeled morphology changes for John’s Pass under baseline conditions after 12 and 24 months are shown in Figure 106 (upper and lower panels respectively). The simulation yielded: (1) erosion of the CMLB, (2) deposition in the 2010 channel dredge pit, (3) deposition along the swash/bypassing bar complex, and (4) deposition at the shoreline attachment point. These patterns of erosion and deposition persisted over the 24 month simulation, and are consistent with the time-series survey results discussed previously (Figures 96 and 97). The baseline simulation results suggest that the CMS model is capable of capturing spatial patterns of sedimentation and erosion over the John’s Pass ebb shoal. One exception to the efficacy of the model is unrealistic levels of scouring simulated in the vicinity of the John’s Pass bridge pilings. While some scouring around the bridge pilings does occur and would be expected, the magnitude of erosion output by the model is excessive and unrealistic, and may be attributed to the 2-D nature of the model.

Modeled morphology changes for Blind Pass under baseline conditions after 12 and 24 months are shown in Figure 107 (upper and lower panels respectively). The simulation yielded: (1) erosion of the CMLB seaward of the north terminal groin, (2) deposition within in the 2010 inner shoal/channel dredge pit, (3) bar and trough type erosional and depositional patterns along the swash/bypassing bar complex, (4) erosion along Upham Beach, and deposition at the southeast corner of the channel at the 90-degree bend. These patterns of erosion and deposition persisted over the 24 month simulation, and are consistent with the time-series survey results discussed previously (Figures 102 and 103).
Figure 105. Bathymetry for the Alternative 1 baseline run. This bathymetry was surveyed in 2014 by this study. Upper: John’s Pass and its ebb shoal; Lower: Blind Pass and its ebb shoal. Note, scale is reporting water depth (elevation = water depth multiplied by -1).
Figure 106. Modeled bathymetry change under baseline conditions at John’s Pass after 12 months (upper panel) and 24 months (lower panel).
Figure 107. Modeled bathymetry change at Blind Pass under baseline conditions after 12 months (upper panel) and 24 months (lower panel).
5.5.2 Alternative 1

A significant volume of beach quality sand accumulates at the northeast portion of the John’s Pass ebb shoal forming a relatively extensive shallow area in the nearshore. This shallow area also includes the channel margin linear bar, which serves in-part as the sediment supply for infilling of the main navigational channel. Examining the impact dredging this sediment may have on the overall morphodynamics of the inlet system, as well as the rate of channel infilling are the primary goals of this simulation. The simulation also includes placement of the dredged material in a 1969 dredge pit ca 300 meters offshore of a nearby chronically eroding stretch of beach. The efficacy of this placement strategy in mitigating the beach erosion is also examined in this simulation.

In 1969 a dredge pit was excavated ca 300-600 meters offshore of Sunset Beach on Treasure Island (Figure 47). Sunset Beach is a chronically eroding stretch of shoreline. Based on wave modeling, Roberts and Wang (2012) suggested that the erosion along Sunset Beach is due to a high sediment transport gradient along the southern end of Treasure Island. They further suggested that the 1969 dredge pit acts to induced modifications to the nearshore wave field contributing to the increased sediment transport gradient there, explaining, at least in-part, the cause of the chronic erosion there. In the Alternative 1 simulation, the dredged material is used to fill a portion of the 1969 dredge pit (Figure 108). This is based on the hypothesis that by reducing the depth of the 1969 dredge pit, some incident wave energy will be attenuated by the shallower bathymetry influencing the nearshore wave field and in–turn the sediment transport gradient to the extent that the rate of erosion along Sunset Beach will be measurably reduced.

Bathymetric profiles of the simulated dredge pit, placement berm and modeled time-series bathymetric changes are shown in Figure 109. The placement berm in the 1969 dredge pit resulted
in a bar-shaped feature with a maximum elevation of ca -3.2 m mean sea level (Figure 109). Figure 110 illustrates in plan-view the computed morphology change after one and two

Figure 108. Bathymetry for the Alternative 1 simulation, which includes a dredge pit excavated in the northeast portion of the John’s Pass ebb shoal. The dredged sediment is placed as a berm in a dredge pit excavated in 1969 seaward of Sunset Beach. Also shown in the image are the locations of bathymetric profiles shown in Figure 109. Note, scale is reporting water depth (elevation = water depth multiplied by -1).
years. The modeled solutions predicted infilling of the simulated dredge pit, with the highest rates of deposition occurring at the north and south corners of the excavation. These two corners are adjacent to relatively shallow water, where breaking wave induced sediment transport would be the most active. Similarly, areas of erosion adjacent to the north and south corners appear to provide the sediment infilling the pit. Some erosion in the main channel was predicted by the model, along with erosion of the beach immediately landward of the excavation (Figure 110).

Deposition at the attachment point was predicted by the model, indicating that the dredge pit did not reverse the trend of sand bypassing over the ebb shoal. However, compared to the baseline simulation (Figure 106), more erosion was predicted along the southern part of the ebb shoal (swash/bypass bars) and along the beach immediately north of the inlet on Sand Key, with

Figure 109. Initial and subsequent bathymetric profiles of the Alternative 1 dredge pit and placement berm. Profile locations are shown in Figure 108.
Figure 110. Modeled morphology change for Alternative 1 after 1 year (upper panel), and 2 years (lower panel). Note the infilling of the simulated dredge pit.
a reduction in deposition at the shoreline attachment indicating some influence on sediment bypassing. The increased erosion of the southern portion of the ebb shoal may be in response to a local deficit in the volume of sediment bypassing around the ebb shoal due to increased sedimentation in the dredge pit. Since the sediment supply was reduced while the competency of the bypassing mechanism remained largely unchanged, the system managed the sediment deficit by eroding and transporting sediment from the swash/bypassing bars.

Over the 24 month simulation nominal changes occurred to the placement berm (see Figure 109, section B-B’). This is likely due to the water depth at the placement site and at the berm crest. The top of the berm lies at ca 3.25 m below mean sea level (Figure 114), which is slightly below the -3 m (NAVD88) local depth of closure (Roberts, 2012). The depth of closure represents the depth below which, under normal wave conditions, little to no sediment transport occurs. As shown in profile B-B’ (Figure 109), over the simulation period, a minor amount of erosion occurred along Sunset Beach. Erosional and depositional patterns in the Blind Pass channel were essentially the same as the baseline case, suggesting that the berm placement had little influence on the sediment transport patterns in and around Blind Pass. Erosion along Upham Beach as with Sunset Beach was largely unchanged from that of the Baseline simulation, suggesting that the berm placement had little influence on beach processes immediately north and south of Blind Pass.

It was anticipated that the nearshore dredge pit may influence incident wave conditions directly landward. In order to examine and attempt to quantify any influence the dredge pit may have on those wave conditions, the difference between Baseline simulation wave-heights and Alternative 1 wave-heights was calculated by subtracting the Baseline simulation wave-heights
Figure 111. Modeled morphology change for Alternative 2, emphasizing the evolution of the nearshore berm.
from those of Alternative 1. Therefore, positive values indicate an increase in wave-height relative to the baseline case, and negative values indicate a wave-height decrease. In addition, in order to examine wave-height variability as a function of incident wave direction, relatively energetic wave conditions approaching from SW, W, and NW were applied to Baseline and Alternative 1 simulations, as well as other Alternatives as will be discussed later in this chapter. Figure 112 illustrates the modeled wave-height differences for the three simulated wave directions in the vicinity of the dredge pit. Based on the simulation output, the dredge pit appears to have considerable influence on incident wave conditions in the vicinity of the dredge pit, with its influence varying as a function of incident wave angle.

For SW and W approaching waves, the model predicted wave-height increases along the NE and SE margins of the dredge pit, in the entrance channel, and along the beach immediately north of the inlet and landward of the dredge pit (Figure 112 upper and middle panels). The increased wave heights landward and SE of the dredge pit is likely due to a combination of reduced wave sheltering that occurred following dredging (removal) of the shallow shoal, in conjunction with rapid wave shoaling along the landward and SE margins of the excavation. The SE margin of the excavation is the CMLB. For NW incident waves, the simulation yielded a small magnitude wave-height decrease over the dredge pit and immediately landward (Figure 112 lower panel), and a small wave-height increase along the SE margin of the excavation. The reduced wave heights can be attributed to reduced wave shoaling over the excavated shallow shoal. It is likely that the wave height increases, although nominal, may be reflecting rapid shoaling over the CMLB. Overall, the influence of the dredge pit on the northwest incident waves is less severe than for the southerly approaching waves.
The placement berm constructed in the dredge pit offshore Sunset Beach had little influence on the fair weather wave field because of the ca 3.25 m water depth over the crest of

Figure 112. Difference between Baseline simulation and Alternative 1 wave heights for three different incident wave directions. Upper panel shows a SW incident wave (220 degree) with 1.1 m significant wave height and 6.26 s peak wave period. Middle panel shows a W incident wave (270 degree) with 1.5 m significant wave height and 8.20 s peak wave period. Note, Figure 117 is continued on the following page.
the berm (below the local depth of closure). The incident wave angle makes negligible difference in the interaction of the relatively deep berm and the wave field. A slight increase in wave height due to shoaling of the incident waves was calculated by the model (Figure 113). Wave conditions at the entrance to Blind Pass were not significantly influenced by the berm placement.

In terms of tidal flow patterns, relative to the Baseline simulation, the Alternative 1 dredge pit influences tidal flow patterns through and adjacent to John’s Pass main channel. Figure 114 shows vector plots of Baseline and Alternative 1 peak ebb velocities and the difference between the two simulations. Model results illustrate a decrease in peak ebb velocities in the region of the dredged pit relative to the Baseline simulation. Reduced ebb velocities in the region of the dredge pit can be attributed to the increased cross-sectional area of the entrance channel immediately seaward of the John’s Pass bridge created by the dredge pit. Portions of the ebb jet near the channel thalweg and in the distal portion of the ebb shoal experienced velocity increases.
Figure 113. Difference between Baseline simulation and Alternative 1 wave-heights over the berm placed in the 1969 dredge pit for three different incident wave directions. Upper: SW incident wave (220 degree) with 1.1 m significant wave height and 6.26 s peak wave period. Middle: W incident wave (270 degree) with 1.5 m significant wave height and 8.20 s peak wave period. Lower: NW incident wave (310 degree) with 1.1 m significant wave height and 7.70 s peak wave period.
Flow velocities through the southern half of the main channel between the two barrier islands also increased. The ebb jet velocity over the southern half of the ebb shoal decreased relative to the baseline case. Overall, during peak ebbing stage flow, the Alternative 1 dredge pit resulted in a northward swing of the ebb jet, likely due to the increased water depth and reduced friction. Ebbing current flow patterns along the adjacent beaches were not significantly influenced by the dredging.

Examining flood stage tidal current flow relative to the Baseline simulation, it’s clear that the Alternative 1 dredge pit influences current flow directions and velocities, primarily through the inlet channel and to a lesser degree along the beach immediately north of the inlet (Figure 115). A conspicuous feature of the Alternative 1 flood tide is a large eddy that develops along the northern side of the channel between the end of the terminal groin and the seaward side of the John’s Pass bridge (Figure 115, middle panel). This eddy results in a substantial decrease in current velocity in this region relative to the Baseline simulation, while flood velocities in the southern half of the channel increased. Alongshore flowing flood current immediately north of the inlet increased substantially, likely in response to increased water depths in the dredge pit. Increased alongshore flow may induce beach erosion immediately north of the inlet. The increased flow along the beach to the north and reduced velocity along the northern portion of the inlet channel may lead to increased sedimentation in the northern portion of the inlet throat. Currently there are several commercial boat docks along the northern side of the inlet throat. Additional sedimentation and shoaling in that region would adversely affect minimum draft requirements for docking vessels as well as navigation safety through the inlet. The CMS model predicted that the
Figure 114. Modeled peak ebb flow velocities for the Baseline simulation (upper panel), and Alternative 1 (middle panel). The lower panel shows difference between Alternative 1 and Baseline simulation peak ebb velocities.
flood flow over the northern portion of the ebb shoal would decrease, likely responding to the increased flow along the beach. Flood flow along the beach directly south of the inlet remained largely unchanged, suggesting that the Alternative 1 dredge pit would not have significant impact on beach processes along the north end of Treasure Island at Sunshine Beach. Both ebb and flood tidal current patterns at Blind Pass were unchanged relative to the Baseline, and do not warrant discussion.

Overall, the CMS predicts that the Alternative 1 dredge pit would result in considerable change to wave conditions along the stretch of beach immediately north of John’s Pass, especially the stretch directly landward of the excavation, and in the entrance channel. Similarly, the simulation also predicted significant changes in both flood and ebb current patterns in and around John’s Pass. The northward swing of the ebb jet may influence sand bypassing around the inlet, while the decreased flood flow along the northern portion of the inlet may lead to additional sedimentation which would adversely impact commercial boat dock facilities located along the north side of the channel throat. In addition, increased flood flow along the southern portion of the channel may lead to scouring of the numerous waterfront structures located there.
Figure 115. Modeled peak flood flow velocities for the Baseline simulation (upper panel), and Alternative 1 (middle panel). The lower panel shows the difference between Alternative 1 and the Baseline case.
5.5.3 Alternative 2

Alternative 2 was designed to examine the morphodynamic response of dredging sediment contained in the bypass bars on the south side of the John’s Pass ebb shoal, and using that sediment for berm nourishments at Sunshine Beach on the north end of Treasure Island, and Upham Beach on the north end of Long Key (Figure 116). The dredge pit for this simulation is located immediately landward (east) of the 2010 west dredge pit. The terminal portion of both John’s Pass and Blind Pass ebb shoals tends to contain finer sediment than the more landward portions of the ebb shoals (Figures 53 and 54). Accordingly, it would be more appropriate to place finer sediment as nearshore berms rather than directly on the beach. Bathymetric cross sections of the dredge pit and berm placement are shown in Figure 117. Pre-dredging water depths at the dredge pit ranged from ca 2 to 3 m, suggesting that sediment transport would likely be active during energetic conditions. Post-dredging water depths in the excavation are ca 4.25 m and lie below the local depth of closure (Roberts, 2012) suggesting that sediment transport processes necessary to infill the dredge pit may not be active at those depths, limiting the rate of infilling. This slow rate of infilling is an issue that has become apparent at the 2010 John’s Pass west dredge pit and presents an issue of sustainability with regard to mining sediment resources contained in inlet ebb shoals.

The two nearshore berms were placed close to the shoreline with berm crest elevations of less than -1 m msl. The nearshore berms were designed to simulate natural nearshore bars. However, it should be noted that owing to their positions relative to the inlet systems, Sunset Beach and Upham Beach are not normally barred beaches. Beach morphodynamics immediately south of John’s Pass and Blind Pass do not support persistent offshore bars. Along those stretches of beach, ephemeral bars often form following energetic events such as strong winter storms, tropical storms or hurricanes. In addition, nearshore bars may form shortly after beach nourishments as the
placement equilibrates and spreads (Roberts and Wang, 2012). However, since the prevailing morphodynamic processes do not typically support formation and maintenance of an offshore bar, as erosion persists and the beach becomes depleted of sand, the nearshore bars tend to erode rapidly. Alternative 2 acts to restore a nearshore bar along these two erosive beaches. The goal of the numerical simulation is to examine rates of infilling in the dredge pit and the behavior of the artificial nearshore berms.

Figures 119 and 120 illustrate modeled morphology changes at John’s Pass for the Alternative 2 dredge pit and Sunshine Beach berm nourishment. Model results suggest limited infilling of the dredge pit would occur during the 2-year simulation period, with the majority of sedimentation occurring along the northern portion of the excavation where water depths are relatively shallow (Figure 117, upper left panel). The computed low infilling rate appears to be controlled by limited wave breaking and sediment supply. Over the 24 month simulation period, the Sunshine Beach nearshore berm migrated onshore and some deposition occurred along Sunshine Beach (Figure 117, middle left panel). The simulated Sunshine Beach berm behavior is consistent with the findings of Brutsche et al. (2014) who examined the evolution of a nearshore berm placement at Ft. Myers Beach. The model also predicted nominal infilling of the 2010 dredge pit, and bar crest and trough erosional and depositional patterns over the bypass bar complex of the ebb shoal consistent with that observed in the baseline simulation. Deposition at the shoreline attachment point was predicted suggesting that the Alternative 2 dredge pit does not significantly influence the overall sediment bypassing mechanism.
Figure 116. Input bathymetry for Alternative 2 showing the dredge pit and the berm nourishment offshore Sunshine Beach (upper panel) and the berm nourishment along Upham Beach (lower panel). Also shown are the locations of bathymetric profiles shown in Figure 117. Note, scale is reporting water depth (elevation = water depth multiplied by -1).
Unlike the Sunshine Beach berm, over the 24 month simulation, the Upham Beach berm largely eroded (Figure 117 profiles C, D, E and F). The final profile returned to a monotonic profile lacking any distinct bar feature. During the first year, the originally rectangular shaped berm assumed a curved morphology mimicking the shape of the adjacent shoreline (Figure 119, upper panel). While little morphologic evidence of the berm remained after 24 months, some of
the sediment placed was retained along the southernmost portion of the placement, the region farthest from the inlets influence (Figure 117, profile C-C’). As would be expected given the placement berms downdrift position, patterns of erosion and deposition at Blind Pass were essentially the same as the Baseline simulation. However, erosion along Upham Beach was reduced (Figure 119), suggesting that the berm nourishment may provide some sediment to the beach, and/or may provide some protection to the beach prior to erosion of the berm.

Overall, the CMS simulation suggested a slow rate of infilling in the dredge pit. The Sunshine Beach nearshore berm migrated onshore during the simulation period and promoted accretion on the beach. The nearshore berm at Upham Beach mostly eroded over the 2-year period, while apparently mitigating some of the erosion there.

Relative to the Baseline simulation, wave model solutions for Alternative 2 suggest the dredge pit and Sunshine Beach berm nourishment have some influence on the wave field in and adjacent to John’s Pass. The influence varies as a function of incident wave angle. For SW and NW approaching waves, wave heights declined over the Sunshine Beach placement berm and were largely unchanged over the dredge pit (Figure 120, upper and lower panels). For westerly approaching waves, an increase in wave height was indicated over the dredge pit, with similar wave height reductions over the Sunshine Beach berm as seen for SW and NW approaching waves (Figure 120, middle panel). The increased wave heights over the dredge pit may be the result of rapid wave shoaling along the eastern margins of the excavation. Conversely, the nearshore berm placement functioned similar to a submerged breakwater, significantly reducing wave heights landward. Owing to the berms NNW-SSE orientation, SW approaching wave heights were influenced the most (Figure 120 upper panel), with smaller wave height reductions associated with W and NW approaching waves.
Figure 118. Alternative 2 modeled morphology change at John’s Pass and at the Sunshine Beach berm nourishment after one year (upper panel) and two years (lower panel).
Figure 119. Alternative 2 modeled morphology change at the Upham Beach berm nourishment after one year (upper panel) and two years (lower panel).

At Upham Beach, the nearshore berm also functioned as a submerged breakwater significantly reducing wave heights landward of the berm (Figure 121). Similar to the Sunshine Beach berm, the wave height reduction for SW approaching waves was the greatest (Figure 121 upper panel), and least for NW approaching waves (Figure 121 lower panel). As previously
discussed, levels of erosion at Upham Beach were reduced likely as a consequence of the wave-height reductions. The submerged berm had negligible influence on the wave field at Blind Pass and over the inlet’s ebb shoal.

The influence Alternative 2 had on ebbing tidal current velocities and spatial flow patterns relative to the Baseline simulation in and adjacent to John’s Pass is shown in Figure 122. As would be expected given the offshore location of the dredge pit, Alternative 2 yielded negligible influence on the ebb jet, ebbing current velocities, and spatial flow patterns (Figure 122) in and adjacent to John’s Pass.

During peak flood tide at John’s Pass, relative to the Baseline simulation, Alternative 2’s influence on current velocities and flow patterns was mostly confined to the inlet channel, with negligible influence along adjacent beaches (Figure 123). Overall, the dredge pit and berm placement caused flooding flow to be more focused to the southern portion of the main channel with a corresponding increase in flow velocity there. Elsewhere in the John’s Pass inlet system and adjacent beaches, little variation in flood stage tidal flow was seen relative to the Baseline simulation.

In the region in and adjacent to Blind Pass, the nearshore berm at Upham Beach had nominal influence on both flood and ebb tidal current velocities and flow patterns (Figures 126 and 127). Relative to the Baseline simulation, Alternative 2 flow patterns through the inlet and over the ebb shoal during both flood and ebb stages were essentially unchanged.
Figure 120. Alternative 2 wave-heights relative to Baseline wave heights in the region in and adjacent to John’s Pass. Upper panel shows SW incident wave (220 degree) with 1.1 m significant wave height and 6.26 s peak wave period. The middle panel shows W incident wave (270 degree) with 1.5 m significant wave height and 8.20 s peak wave period, and the lower panel shows NW incident wave (310 degree) with 1.1 m significant wave height and 7.70 s peak wave period.
Figure 121. Alternative 2 wave-heights relative to Baseline wave heights in the region in and adjacent to Blind Pass. Upper panel shows SW incident wave (220 degree) with 1.1 m significant wave height and 6.26 s peak wave period. The middle panel shows W incident wave (270 degree) with 1.5 m significant wave height and 8.20 s peak wave period (middle panel), and the lower panel shows NW incident wave (310 degree) with 1.1 m significant wave height and 7.70 s peak wave period.
Figure 122. Modeled peak ebb flow velocities at John’s Pass for the Baseline simulation (upper panel), Alternative 2 (middle panel), and the difference between Alternative 2 ebbing current velocities and those from the Baseline simulation (lower panel).
Figure 123. Modeled peak flood flow velocities at John’s Pass for the Baseline simulation (upper panel), Alternative 2 (middle panel), and the difference relative to the Baseline simulation.
Figure 124. Modeled peak ebb flow velocities at Blind Pass for the Baseline simulation (upper panel), Alternative 2 (middle panel), and the difference relative to the Baseline simulation.
Figure 125. Modeled peak flood flow velocities at Blind Pass for the Baseline simulation (upper panel), Alternative 2 (middle panel), and the difference relative to the Baseline simulation.
5.5.4 Alternative 3

Alternative 3 examines the morphodynamic response of the JPBPIIS to dredging of the John’s Pass and Blind Pass channels, using the 2010 dredging template. In this case however, at John’s Pass, only the channel dredge pit is included since the 2010 west dredge pit had not substantially in-filled by July 2014 when the bathymetry was surveyed. In addition, the dredged sediment is removed from the model domain since the models initial elevation grid already included the 2014 beach nourishments at Sunshine Beach, Sunset Beach, Upham Beach, and Pass-A-Grille Beach.

Figure 126 shows the initial bathymetry used for Alternative 3, including the dredge pits at John’s Pass and Blind Pass, and the locations of bathymetric profiles A-A’ and B-B’. Pre- and post-dredging bathymetric profiles A-A’ and B-B’ are shown in Figure 127. It is worth noting that since Alternative 3 employed the 2010 dredging template, the pre-dredging profiles shown in Figure 127 (black line) represent sediment deposited in the channel since the 2010 dredging, as of July 2014 when the bathymetry shown was surveyed.

The simulation predicted infilling of the dredge pits (Figures 130 and 131) in a pattern similar to measured infilling patterns previously discussed. At John’s Pass, infilling sediment appears to come from erosion of the CMLB just north of the dredge pit. Elsewhere within the inlet system, depositional and erosional patterns were similar to those observed and described for the Baseline simulation.

At Blind Pass, deposition in the dredge pit is initiated in the vicinity of the updrift shoreline, a pattern consistent with southward longshore sediment transport serving as the primary infilling mechanism (Figure 129). This pattern of sedimentation also agrees with field measurements. As with John’s Pass, excluding the region in and immediately adjacent to the dredge pit, depositional
and erosional patterns elsewhere were similar to those observed and described for the Baseline simulation.

Figure 126. Input bathymetry for the Alternative 3 simulation. Bathymetric profiles A and B are shown in Figure 127. Note, scale is reporting water depth; elevation relative to mean sea level equals water depth multiplied by -1).
Relative to Baseline simulation wave conditions, the Alternative 3 dredge pit at John’s Pass had localized influence on the wave field. The influence varied as a function of incident wave angle. Westerly waves had the greatest influence yielding modest wave-height increases along the seaward end of the dredge pit and over the adjacent portions of the ebb shoal, and slight wave-height decreases landward (Figure 130, middle panel). For SW and NW approaching waves (Figure 130, upper and lower panels respectively), minor wave-height decreases over the dredge pit were predicted. Overall, the dredge pit had little influence on the wave field at the John’s Pass.
Figure 128. Infilling of the John’s Pass dredge pit for Alternative 3 case after 1 year (upper panel) and 2 year (lower panel).
Relative to the Baseline simulation wave conditions, the Alternative 3 dredge pit at Blind Pass had localized influence on the wave field. The influence varied as a function of incident wave angle. Westerly and SW incident waves had the greatest influence yielding moderate wave height increases at the channel bend and adjacent to the north terminal groin (Figure 131, upper panel).
Figure 130. Modeled wave-height change at John’s Pass for Alternative 3, as compared to the existing condition (Alternative 1 baseline run). Upper: SW incident wave (220 degree) with 1.1 m significant wave height and 6.26 s peak wave period. Middle: W incident wave (270 degree) with 1.5 m significant wave height and 8.20 s peak wave period. Lower: NW incident wave (310 degree) with 1.1 m significant wave height and 7.70 s peak wave period.
Figure 131. Modeled wave-height change at Blind Pass for Alternative 3, as compared to the existing condition (Alternative 1 baseline run). Upper: SW incident wave (220 degree) with 1.1 m significant wave height and 6.26 s peak wave period. Middle: W incident wave (270 degree) with 1.5 m significant wave height and 8.20 s peak wave period. Lower: NW incident wave (310 degree) with 1.1 m significant wave height and 7.70 s peak wave period.
and middle panels). In addition, westerly waves also yield a slight wave height increase along Upham Beach, immediately south of the inlet. Northwesterly waves generated minor wave height decreases over the dredge pit (Figure 131, lower panel). Relative to the Baseline simulation, Alternative 3’s influence on the wave field over the ebb shoal was minor.

The Alternative 3 dredging of the John’s Pass channel would effectively widen, deepen, and in places shift the main channel to the north. Relative to the Baseline simulation, the model predicted some influence on the tidal flow patterns through the main channel (Figures 134 and 135). Ebbing current velocities increase near the seaward terminus of the ebb shoal suggesting that the dredging resulted in a seaward extension and strengthening of the ebb jet. Increased current velocities extend seaward from the bridge along the north side of the CMLB suggesting some widening of the ebb jet as well. Decreased relative velocities occurred over the ebb shoal immediately south of the channel and over the shallowest portion of the CMLB. Little change in ebbing current velocities along the adjacent beaches was indicated in the simulation.

The influence Alternative 3 has on flood stage currents at John’s Pass’s relative to the Baseline simulation is minor (Figure 133). Scattered patches of low magnitude increases and decreases in velocity occur over the excavation seaward of the bridge. Slight increases in velocities occur at the entrance to the channel throat and extend east along the north and south sides of the channel throat. A slight decrease in velocity occurs in the central portion of the channel throat east of the bridge. Current velocities along the beach north of the inlet increased slightly, while little change was observed along Sunshine Beach south of the inlet.
Figure 132. Modeled peak ebb flow velocities at John’s Pass for Alternative 3. Upper panel shows Baseline simulation velocities, middle panel shows Alternative 3 velocities, and the lower panel shows the difference between Alternative 3 and the Baseline case.
Figure 133. Modeled peak flood flow velocities at John’s Pass for Alternative 3. Upper panel shows Baseline simulation velocities, middle panel shows Alternative 3 velocities, and the lower panel shows the difference between Alternative 3 and the Baseline case.
As with John’s Pass, Alternative 3 dredging at Blind Pass effectively widens, deepens, and shifts the main channel to the north. The influence the dredging has on peak ebbing currents at Blind Pass relative to the Baseline simulation is shown in Figure 134 (lower panel). As shown, increased current velocities were indicated over the seaward most portion of the excavation, resulting in a seaward extension of the ebb jet. In addition, the path of the ebb jet was shifted slightly to the north, and a low magnitude current velocity increases was indicated along the north side of the channel throat. Low to moderate magnitude current velocity decreases were indicated over the eastern portion of the excavation, along the central portion of the inlet channel throat, and extending from the south terminal groin in a SW direction seaward (Figure 134, lower panel). The model predicted modest relative changes in flood flow patterns.

Increasing the depth and width of the channel yielded a decrease in flood current velocities through the channel throat (Figure 135). Conversely, low magnitude increases in flood current velocities were indicated along the beach to the north of the inlet and to the south along Upham Beach. Influences of the dredge pit to flood flow over the greater ebb shoal were nominal. Overall, Alternative 3’s influence at Blind Pass resulted in changes to both ebb and flood flow patterns through the entrance channel. As previously discussed, the dredging also had some influence on wave conditions within the inlet.
Figure 134. Modeled peak ebb flow velocities at Blind Pass for Alternative 3. Upper panel shows Baseline simulation velocities, middle panel shows Alternative 3 velocities, and the lower panel shows the difference between Alternative 3 and the Baseline case.
Figure 135. Modeled peak flood flow velocities at Blind Pass for Alternative 3. Upper panel shows Baseline simulation velocities; middle panel shows Alternative 3 velocities, and the lower panel shows the difference between Alternative 3 and the Baseline case.
5.5.5 Alternative 4

Alternative 4 examines the influence structural modifications have on inlet-beach morphodynamics. The Alternative simulates extending the north and south terminal groins at both inlets by 70 meters. With the exception of the groin extensions, the initial bathymetry used in this simulation is the same as that used in the Baseline simulation (Figure 136).

Relative to the Baseline simulation, the groin extensions at John’s Pass yielded a range of morphology changes (Figure 137). Additional deposition occurred along the north side of channel throat landward of the John’s Pass Bridge. This increase in deposition extended seaward along the channel-side slope of the CMLB, effectively increasing the width of the bar. Deposition also occurred along the south channel margin, translating seaward into bar and trough erosion and deposition patterns characteristic of the swash/bypass bar complex. Sediment was eroded from the east updrift side of the CMLB and from the main channel likely supplying the sediment for the bar growth. Deposition also increased at the shoreline attachment and along the seaward side of the attachment region where the swash/bypass bars coalesce. Impoundment of sediment occurred along the extended groins, leading to modest increases in deposition along the adjacent north and south (Sunshine Beach) beaches. Erosion also occurred along the terminal portion of the ebb shoal, with increased deposition further seaward suggesting an overall seaward growth of the ebb shoal. This seaward growth is further supported by the increased deposition occurring in the 1988 dredge pit (Figure 137).

As with John’s Pass, relative to the Baseline simulation, the Alternative 4 groin extensions had significant influence on Blind Pass morphology (Figure 138). Increased levels of erosion were projected along the terminal flanks of the ebb shoal, and in the channel throat along
Figure 136. Input bathymetry for Alternative 4. Note the groin extensions in grey at John’s Pass (upper panel) and Blind Pass (lower panel).
Figure 137. Predicted morphology change at John’s Pass, as compared to the baseline case, for Alternative 4 case with extensions of both north and south jetties after 1 year (upper panel) and 2 years (lower panel).
the channel-side flank of the inner shoal effectively widening the channel to the north. Similarly, increased deposition along the southeast corner (90 degree bend in channel) and along the south side of the channel throat further illustrate a north-northwest shift in the channel position. Increased levels of deposition were indicated along and extending from both updrift and downdrift sides of the groin extensions. The increased deposition along the downdrift side of the south groin extends to the southern portion of the ebb shoal, and appears to be mitigating some erosion along Upham Beach immediately adjacent to the south terminal groin. This is likely the result of sediment impoundment along the groin extension. Away from the groins, low levels of increased erosion were indicated along Sunset Beach to the north and Upham Beach to the south.

Alternative 4’s influences on the wave field at John’s Pass for multiple wave angles relative to the Baseline simulation are shown in Figure 139. The structural modifications yielded localized influence proximal to the groins for SW, W, and NW incident waves. In addition, for NW waves, the groin extensions provide some wave sheltering to the main channel (Figure 139, lower panel).

The influences the extended groins have on the wave field at Blind Pass relative to the Baseline simulation are shown in Figure 140. The extended groins provide some wave protection to the entrance channel, illustrated by the slight decrease in wave heights for SW, W, and NW incident wave angles (Figure 140). The CMS-WAVE model also indicated local wave height increases along Upham Beach south of the inlet.

In terms of tidal current flow patterns, the groin extensions influence is evident at both inlets. The groin extensions act to more strongly confine tidal flow through the inlet channels. As would be expected this is particularly evident during ebbing flow at both inlets.
Figure 138. Predicted morphology change at Blind Pass, as compared to the baseline case, for Alternative 4 case with extensions of both north and south jetties after 1 year (upper panel) and 2 years (lower panel).
Figure 139. Alternative 4 wave-heights relative to Baseline wave heights in the region in and adjacent to John’s Pass. Upper panel shows SW incident wave (220 degree) with 1.1 m significant wave height and 6.26 s peak wave period. The middle panel shows W incident wave (270 degree) with 1.5 m significant wave height and 8.20 s peak wave period (middle panel), and the lower panel shows NW incident wave (310 degree) with 1.1 m significant wave height and 7.70 s peak wave period.
Figure 140. Alternative 4 wave-heights relative to Baseline wave heights in the region in and adjacent to Blind Pass. Upper panel shows SW incident wave (220 degree) with 1.1 m significant wave height and 6.26 s peak wave period. The middle panel shows W incident wave (270 degree) with 1.5 m significant wave height and 8.20 s peak wave period (middle panel), and the lower panel shows NW incident wave (310 degree) with 1.1 m significant wave height and 7.70 s peak wave period.
Relative to the Baseline simulation, during peak ebb flow at John’s Pass, the groin extensions move seaward, the region where the ebb jet begins to diverge. While the ebb jet is more confined along its landward (east) extents, the seaward portion is shifted seaward and the width along its seaward extension is increased (Figure 141, lower panel). This also yields a straightening and slight shifting of the ebb jet to the north, accounting for the increased rate of sedimentation in the 1988 dredge pit. In addition to the velocity declines extending from the groin extensions, a nominal velocity decline occurs over the shallowest portion of the CMLB. The extended groins appear to have little influence on ebbing flow patterns landward of the structures.

Relative to the Baseline simulation, during peak flood stage at John’s Pass, the groin extensions yielded a seaward shift of the region where flow strongly converges near the channel mouth. This yields a large magnitude current velocity reduction at the corners of the entrance channel where the groin extensions obstruct converging flow entering the channel, and a low magnitude reduction in tidal driven flow along the adjacent beaches (Figure 142). The reduced current velocities along the groin extensions promotes impoundment of sediment along and adjacent to the structural extensions as discussed earlier. As the groin extensions act to better confine flow entering the channel throat, velocity increases are indicated along the central portion of the channel and along the north side of the channel throat east of the John’s Pass bridge (Figure 142, lower panel).

Relative to the Baseline simulation, during peak ebb flow at Blind Pass, the groin extensions act to confine flow more strongly, extending the influence of the ebb jet and shifting flow divergence further seaward (Figure 143, lower panel). While the greatest increased ebb
Figure 141. Alternative 4 modeled peak ebb flow velocities at John’s Pass. Upper panel shows peak ebb flow for the Baseline simulation. The middle panel shows peak ebb flow for Alternative 4, and the lower panel shows the difference between Alternative 4 and the Baseline simulation.
Figure 142. Alternative 4 modeled peak flood flow velocities at John’s Pass. Upper panel shows peak flood flow for the Baseline simulation. The middle panel shows peak flood flow for Alternative 4, and the lower panel shows the difference between Alternative 4 and the Baseline simulation.
current velocities occur at the mouth of the channel and extend seaward, lower magnitude velocity increases occur in the central portion of the channel extending to the inside corner of the channel bend (NW corner). Corresponding reductions in current velocity occur along the north and south banks of the channel. The regions of increased and reduced current velocities inside the channel correlate well with the simulated morphology changes discussed previously (see Figure 138). The groin extensions have little influence on ebbing current flow patterns along the adjacent beaches.

Relative to the Baseline simulation, at Blind Pass during peak flood stage, the groin extensions yielded a seaward shift of the region where flow strongly converges near the channel mouth (Figure 144). This yields current velocity reductions at the corners of the entrance channel where the groin extensions obstruct converging flow entering the channel, and along the adjacent beaches. Reduced current velocities were also predicted along the south margin of the channel extending to the outside corner of the channel bend (SE corner) where increased rates of deposition were predicted. Similarly, reduced current velocities along the groin extensions promotes impoundment of sediment along and adjacent to the structural extensions consistent with depositional patterns described earlier. A region of slightly increased current velocities is predicted in the central portion of the channel and can be attributed to structurally enhanced flow confinement near the channel mouth extending east to the channel bend.
Figure 143. Alternative 4 modeled peak ebb flow velocities at Blind Pass. Upper panel shows peak ebb flow for the Baseline simulation. The middle panel shows peak ebb flow for Alternative 4, and the lower panel shows the difference between Alternative 4 and the Baseline simulation.
Figure 144. Alternative 4 modeled peak flood flow velocities at Blind Pass. Upper panel shows peak flood flow for the Baseline simulation. The middle panel shows peak flood flow for Alternative 4, and the lower panel shows the difference between Alternative 4 and the Baseline simulation.
5.6 Quantification and Distribution of North Boca Ciega Bay Tidal Prism

An examination and quantification of the northern Boca Ciega Bay tidal prism was conducted in order to determine the share of tidal prism each of the studied inlets is capturing. Previous estimates of the tidal prism contained within north Boca Ciega Bay include 16,896,663 m$^3$ based on a tidal range of 0.82 m (Mehta, 1981), and 19,800,000 m$^3$ using a 1.05 m tidal range (Becker and Ross, 2001). This study quantified the tidal prism by taking the product of the bay area based on 2006 aerial photos and the spring tidal range of 1.05 meters yielding 21,661,524 m$^3$. In addition, to gain insight into how anthropogenic modifications, including causeway and finger channel construction implemented in the 1950’s and 1960’s altered the tidal prism, the bay area prior to those dredge and fill projects was calculated, aided by pre-1960 aerial photos of the region. The results are shown in Table 1. Dredge and fill projects completed in the backbay during the 1950’s and 1960’s reduced the bay area by 20%, yielding a corresponding reduction in tidal prism (Figure 146).

To quantify the portion of the tidal prism captured by each of the two competing inlets, the discharge passing through each inlet throat during spring tide ebbing stage was calculated (Table 1). As previously discussed, depth-averaged flow velocities through the inlet channels computed by the CMS-FLOW model compared well with the measured velocities. Therefore, to determine discharge through the inlet channels, observation cells were established in the channel throat within the CMS-FLOW model grid. The observation cells were spaced every 10 meters across the channel. Depth averaged velocities for each cell were calculated every 30 minutes during spring tide ebbing stage and saved in an output file. The product of the depth averaged velocity and the
Table 1. North Boca Ciega Bay tidal prism

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical area of Boca Ciega Bay - prior to 1950’s and 1960’s dredge and fill projects (m²)</td>
<td>25,659,819</td>
</tr>
<tr>
<td>Current (2006) area of Boca Ciega Bay (m²)</td>
<td>20,630,023</td>
</tr>
<tr>
<td>Change (m²)</td>
<td>-5,029,796</td>
</tr>
<tr>
<td>Change (%)</td>
<td>-20%</td>
</tr>
<tr>
<td>Tidal Prism based on the bay area and a 1.05m spring tidal range (m³)</td>
<td>21,661,524</td>
</tr>
<tr>
<td>Tidal prism based on modeled discharge during spring tide (m³)</td>
<td>16,674,622</td>
</tr>
<tr>
<td>Blind Pass Tidal prism based on modeled discharge during spring tide (m³)</td>
<td>3,142,925</td>
</tr>
<tr>
<td>John’s Pass Tidal prism based on modeled discharge during spring tide (m³)</td>
<td>13,530,697</td>
</tr>
</tbody>
</table>
Figure 146. Area of north Boca Ciega Bay pre- and post-dredge and fill projects. Left panel shows pre-dredging land area, and right panel shows 2006 land area. The red line represents shoreline.

cross-sectional area of the respective cell yields the discharge in that cell. Since velocities were reported every 30 minutes, the discharge reported for each cell was multiplied by 30 minutes to yield total discharge for the respective cell for each 0.5-hour increment. Summing all the discharges for each cell over the duration of the spring ebbing cycle yields an estimate of the portion of the tidal prism passing through the inlet channel. The tidal prism based on modeled discharge through the inlet channels is 23% less than the tidal prism calculated based on bay area and spring tidal range. This suggests that a portion of the water contained in North Boca Ciega Bay discharges through the domain boundaries at the Narrows to the north and Corey Causeway on the south rather than passing through John’s Pass or Blind Pass. The calculations further suggest John’s Pass captures 81% of the available tidal prism, with the remaining 19% passing through Blind Pass, consistent with previous estimates by Mehta et al (1976).
CHAPTER 6

DISCUSSION AND CONCLUSIONS

6.1 Discussion of Inlet Morphodynamics

6.1.1 Historical Morphodynamics of the John’s Pass-Blind Pass Dual-Inlet System

Estuaries and bays along barrier island coasts such as those bordering the Gulf of Mexico and the US Atlantic Ocean are often served by multiple inlets. In such cases, barring any dramatic changes in shoreline orientation or bathymetry between inlets, those inlets are subjected to largely identical wave and tide conditions, and thus should develop similar morphologies. This however is not the case, since other common variables such as tidal prism and sediment availability can vary substantially over the relatively short distances that separate the inlets. John’s Pass and Blind Pass share the tidal prism of northern Boca Ceiga Bay, and provide an excellent example of a microtidal, dual-inlet system in which one inlet clearly dominates over the other in terms of tidal prism. John’s Pass captures ca 81% of the available tidal prism and is the dominant of the two inlets. It exhibits largely stable mixed-energy morphologic characteristics while Blind Pass exhibits less stable wave dominated characteristics. Given that both inlets have been stabilized through the construction of terminal groins, channel bank revetments and seawalls, any inherent instabilities have been muted. However, in the absence of such engineering modifications, those instabilities would be substantially magnified.
In the following, the morphodynamics of the JPBPIS is discussed. Discussion of 19th and 20th century morphodynamics are mostly qualitative and based on what can be interpreted from aerial photos, while discussion of modern morphodynamics is quantitative to semi-quantitative and based on measured data and numerical modeling simulations. It should be noted that interpretations made from aerial images include uncertainties associated with unknown conditions such as tide stage and sun angle at the time the image was captured. Similarly, the 2-D nature of the numerical model introduces some uncertainty particularly for morphology change, however, as discussed in Chapter 5, modeled wave and current conditions correlated well with measured data yielding Willmott skill assessments ranging from \(ca\ 0.96-0.99\).

Engineering modifications including terminal groin construction, ebb shoal dredging, and channel armoring, in conjunction with dredge and fill projects (land reclamation) in the backbay have had substantial influence on the modern morphodynamics of the JPBPIS. Prior to the opening of John’s Pass in 1848, Blind Pass was a natural, persistent and relatively stable inlet, sharing the tidal prism of Boca Ceiga Bay with ephemeral inlets that opened from time-to-time through storm induced breaching and subsequently closed. Blind Pass was likely the dominant inlet at the time, capturing a majority of the Boca Ciega Bay tidal prism. The next persistent inlets to the north at that time were Indian Pass, a wave dominated inlet (Davis and Gibeaut, 1990) located south of Indian Rocks Beach on south Sand Key, and Little Pass later renamed Clearwater Pass, a mixed energy inlet (Davis and Gibeaut, 1990) located at the north end of Sand Key. Given the location Indian Pass near the Narrows, it would have captured a portion of the Boca Ciega tidal prism; however, given its wave dominated morphology and location, its share was likely a minority one. The tidal prism supplying Little Pass (a.k.a. Clearwater Pass) is hydraulically separated from that of northern Boca Ciega Bay by the Narrows, and thus, Little Pass would likely have had nominal
influence on the morphodynamics of Blind Pass during the late 19th century. The next inlet to the south of Blind Pass was Pass-A-Grille inlet which at the time exhibited wave dominated characteristics (Davis and Gibeaut, 1990). And since Boca Ciega Bay had not yet been hydraulically segregated by causeway construction, it’s likely that Pass-A-Grille inlet also shared a portion of the Boca Ciega Bay tidal prism with Blind Pass; however, as with Indian Pass, given its wave dominated characteristics and greater distance, it was also likely a minority share. During this period of time the morphology of Blind Pass reportedly exhibited mixed-energy offset characteristics (Davis and Gibeaut, 1990). And while this may have been the case between 1848 and 1873, given that the inlet migrated downdrift (south) at a rate of 26 m/yr between 1873 and 1937 (Barnard, 1998) when its migration was halted by the construction of a groin along its south side, its behavior is more suggestive of wave dominated morphodynamics.

The 1926 image of Blind Pass (Figure 8) illustrates a rather narrow but discernable ebb shoal, and very wide subaerial beaches on both updrift and downdrift sides. The small size of the ebb shoal in conjunction with the extremely wide adjacent beaches suggests that the ebb shoal may have been in the process of collapsing and thus providing the sediment for the wide beaches evident in the image. Although there is a paucity of morphologic data on John’s Pass prior to the early 20th century, it is reasonable to assume that subsequent to it’s opening in 1848, John’s Pass gradually captured an increasing share of the available tidal prism at the expense of Blind Pass. Between 1926 and 1937 the Madeira Beach, Treasure Island, and Corey causeways were constructed (Barnard, 1998) further reducing the tidal prism available to the JPBPIS.

The morphology of John’s Pass as depicted in the 1926 image (Figure 10) shows a straight channel, with a poorly developed ebb shoal, and relatively wide beaches north and south of the inlet with the downdrift shoreline (south of the inlet) offset seaward relative to the north shoreline.
The morphology most closely resembles that of a mixed-energy offset inlet (Davis and Gibeaut, 1990). Rather profound morphology changes appear to have occurred between the 1920’s and the 1940’s at both inlets.

In the 1942 image of Blind Pass (Figure 8), the wide beaches evident in the 1926 image have been eroded, there is little in the form of an ebb shoal extending seaward from the channel, and based on Bernard (1998) the south end of Treasure island had migrated \textit{ca} 600 m further south. As previously mentioned, a terminal groin was constructed on the south side of the inlet channel in 1937 halting its southerly migration. Additionally, in the 1942 image, the inlet channel wraps conspicuously around the groin structure. It appears that without the 1937 terminal structure, the channel would have little if any SW-NE oriented component to it and would have followed a NW-SE path \textit{ca} parallel to the shoreline. It is during this period of time that a pattern of deposition along the inner shoal, and erosion along the immediately downdrift Upham Beach region began. Substantial changes were also occurring at John’s Pass during this period of time.

The only engineering modifications to John’s Pass between the 1920’s and the 1945 image (Figure 10) was the construction of a bridge across the inlet in 1926, which would have had some influence on currents passing through the inlet channel. The only other changing conditions occurred in the early 1930’s when Indian Pass, located to the north of John’s Pass and an unnamed ephemeral inlet located to the south between John’s Pass and Blind Pass closed (CP&E, 1992) increasing the tidal prism available to the JPBPIS. This appears to have largely been to the benefit of John’s Pass as its ebb shoal grew substantially, while Blind Pass continued to exhibit increasingly unstable wave dominated morphological characteristics. As shown in the 1945 image (Figure 10), relative to 1926 morphologic conditions, John’s Pass ebb shoal grew substantially seaward, developed swash/bypass bars and a channel margin linear bar, and a downdrift shoreline
attachment point developed indicating an active sediment bypassing mechanism. The inlet channel while mostly straight, curved to the south at its seaward most extension, and similarly the ebb shoal was skewed to the south, both of which illustrate some component of wave energy contributing to its morphodynamics. However, the inlet at this time exhibits mixed-energy straight to slightly offset morphodynamic characteristics.

During the early 1940’s to the late 1950’s dredge and fill actives in the backbay peaked, resulting in a 20% decrease in the tidal prism available to the JPBPIS. The only other engineering modifications to the system during this time period included extending the Blind Pass 1937 terminal groin further east (CP&E, 1992). While it is unclear how far east the groin was extended, the 1957 image of Blind Pass (Figure 8) suggests that some additional hardening of the channels south bank was conducted. This is suggested by the conspicuous 90 degree bend in the channel’s south bank and by how the channel thalweg appears to hug that bank. The engineering modifications implemented at Blind Pass between the 1930’s and the 1950’s effectively arrested the inlet’s southerly migration. As shown in the 1957 of Blind Pass, a small ebb shoal is apparent, with a well-developed channel margin linear bar on the north side of the channel that curves to the south. The beach immediately downdrift (south) of the inlet (Upham Beach) appears to have accreted and is wider than in the 1942 image. It is unclear what prompted this increase in beach width. During the same period of time at John’s Pass, the beach along the north end of Treasure Island (Sunshine Beach) became wider, extending that shoreline further seaward relative to the shoreline north of the inlet. And aside from the inlet channel appearing to have straightened out slightly along its seaward extension, the morphology of the ebb shoal appears to be largely consistent with its form shown in the 1945 image. Given that the downdrift beaches at both inlets grew in width during this period of time suggests the system received additional sediment possibly
associated with a hurricane that destroyed many of the structures on Treasure Island in June of 1945 (CTC, 1993). During the subsequent 12 years, a number of engineering modification were made to the JPBPIS, and significant morphologic changes occurred at both inlets.

Between 1957 and 1969, engineering modifications that would have influenced the morphodynamic of Blind Pass included, (1) construction of a groin field (56 groins) on Treasure Island (in 1960) which would have acted to reduce the sediment available to the inlet, (2) construction of a 130 m long terminal groin on the north side of the inlet which would further act to reduce the sediment available to the inlet, dredging 7,600 m$^3$ from the inlet channel with the dredge spoils placed on Sunset Beach located immediately north of the inlet (updrift) increasing the sediment available to the inlet, and (3) the first large scale nourishment (604,000 m$^3$ of sand) of Treasure Island in 1969, similarly increasing the sediment available to the inlet. As shown in the 1969 image of the inlet, there is little evidence of an ebb shoal, the beach immediately north of the inlet has increased in width likely due to the 7,600 m$^3$ of sand placed on Sunset Beach forming a fillet on the updrift side of the newly constructed terminal groin, a decrease in the width of the downdrift Upham Beach, and sedimentation at the channel bend which nearly closed the inlet. The absence of the ebb shoal in conjunction with infilling of the inlet channel suggests a reduction in tidal prism and an increase in the volume of sediment delivered to the inlet through littoral processes. Without ebbing current velocities capable of flushing out sediment brought into the channel during flooding stage, the channel would infill, and the ebb shoal would erode since little sediment would be delivered to it through inlet or longshore transport processes. This may be a delayed morphodynamic response to the 20% reduction in tidal prism resulting from the earlier dredge and fill projects in the backbay.
John’s Pass was federally authorized in 1964, initiating a new paradigm in management of the JPBPIIS and the adjacent beaches. Generally speaking, engineering modifications to the dual-inlet system, especially in the form of adding sediment to the system began to accelerate following the federal authorization. Between 1957 and 1970 (13 years), engineering modifications implemented at John’s Pass included, (1) dredging of 72,000 m$^3$ of sand from the inlet channel which was placed just offshore of Sunshine Beach as a quasi-berm nourishment, (2) construction of a terminal groin on the north side of the inlet channel, (3) channel dredging yielding 23,000 m$^3$ of sediment that was placed on the beach immediately north (updrift) of the inlet, and (4) hardening of the south channel bank through construction of revetment. The sediment dredged from the channel and placed just offshore Sunshine Beach subsequently migrated landward and formed a lagoon which is clearly evident in the 1970 image (Figure 10). The lagoon was referred to as O’Brien’s Lagoon. Other significant morphologic changes that occurred to the inlet system during this period of time included substantial erosion of the inlet channels south bank (north end of Treasure Island) likely prompting the revetment construction described above, and accretion along the beach immediately north of the inlet which can be attributed to a fillet forming behind the newly constructed terminal groin in conjunction with the 23,000 m$^3$ of sediment placed there. It is unclear what if any changes occurred to the greater ebb shoal since the 1970 image lacks adequate resolution and spatial coverage to asses such changes. However, O’Brien’s Lagoon provides some insight into the morphodynamics around that region of the inlet during that period of time. The 72,000 m$^3$ of sediment placed just offshore Sunshine Beach migrated landward forming the lagoon shown in the 1970 image (Figure 10). The northern most portion of the berm formed a recurved spit-like feature that attached to the shoreline, likely due to sediment transport associated with flood tidal flow through a marginal flood channel. The south end of the berm
appears to have multiple fingers extending to the shoreline similar to the behavior of the simulated berm in the Alternative 2 modeled simulation, and consistent with the bypassing related shoreline attachment seen in the modern bathymetry. In general, the onshore migration is consistent with a weak landward directed sediment transport gradient simulated in the Baseline and Alternative 2 (see Chapter 5) numerical simulations. The landward migration of the berm is consistent with the behavior of a nearshore berm placement at Ft. Meyers Beach (Brutsche et al., 2014). In 1971, ca 57,000 m³ of the sediment forming O’Brien’s Lagoon was excavated and used for beach fill during the first periodic renourishment of Treasure Island. Subsequent to this period of time, both inlets were further engineered to mitigate instabilities, and as can be seen in the time-series aerial images (Figures 9 and 11). In the images more recent than 1970, little obvious morphologic change that can be attributed to those engineering modifications is evident (Figures 9 and 11). Accordingly, the following discussion focuses on modern morphodynamics and is based on insights provided by measured data (hydrodynamic, bathymetric and volumetric) and numerical simulations.

6.1.2 Modern Morphodynamics of the John’s Pass-Blind Pass Dual-Inlet System

John’s Pass and Blind Pass are both heavily structured inlets. Both inlet channels have been hardened and their positions anchored with rock revetments and seawalls. In order to minimize channel sedimentation, terminal groins have been constructed on the north and south sides of each inlets’ main channel. To mitigate what sedimentation does occur in the inlet channels, periodic channel maintenance dredging is conducted under a sand sharing model that uses the dredged material to fill adjacent eroding stretches of beach. In other words, the inlets have been forced to behave with engineering measures designed to maintain stability based on existing climate conditions and current sea levels. Therefore, hydrodynamic, bathymetric, and volumetric
data collected over the course of this study along with numerical model simulations of the dual-inlet system can be considered representative of both inlets current morphodynamics.

The forces driving morphodynamics of the dual-inlet systems are tide and wave. Tides along the west-central Florida Gulf coast are semi-diurnal to mixed with a spring tidal range of 1.1 m (Figures 46 and 47). As discussed in section 5.1.3, a phase lag exists between offshore and inshore tidal water levels. The gradient between offshore and inshore water surface elevations created by the phase lag is what drives flow through the inlet channels. During flood phase, the offshore (ca 7 km from shoreline) tide leads the tide at Blind Pass by ca 40 minutes, and at John’s Pass by ca 70 minutes (Figure 46). The greater phase lag associated with flood stage tide at John’s Pass may explain in-part why flood current velocities there exceed those at Blind Pass (Figure 146). On the ebbing phase, the offshore tide leads both John’s Pass and Blind Pass by ca 20 minutes. Given the magnitude of flood and ebb tidal current velocities (Figure 146), John’s Pass would be considered flood dominated while Blind Pass would be considered ebb dominated.
(Walton, 2002). However, while the morphology of Blind Pass is consistent with an ebb dominated inlet system (i.e. larger ebb shoal than flood shoal), the morphology of John’s Pass is not clearly consistent with a flood dominated inlet system (i.e. larger flood shoal than ebb shoal) since it’s flood shoal is largely static (CTC, 1993; Barnard, 1998) and volumetrically smaller than its ebb shoal (Mehta, 1976).

Another aspect of tidal current flow patterns within the JPBPIS is how they relate to sediment transport and depositional patterns. Both inlets exhibit shoaling along the north margins of their channels, and erosion along their immediate downdrift (south) beaches. In the case of John’s Pass 122,000 m$^3$/yr is delivered to the inlet from the north annually through littoral processes. Of that volume, ca 1000 m$^3$/yr is deposited in and along the north side of the channel, while Sunshine Beach, the stretch of beach immediately downdrift (south) of the inlet loses 16,000 m$^3$/yr. In the case of Blind Pass 68,000 m$^3$/yr is delivered to the inlet from the north through littoral processes. Of that volume, ca 24,000 m$^3$/yr is deposited in and along the north side of the channel (the inner shoal), while Upham Beach, the stretch of beach immediately downdrift (south) loses 24,000 m$^3$/yr. Although the delivery of sediment through littoral processes is wave related (breaking waves drive the longshore current), deposition along the north margins of each inlets main channel can be attributed to the combined effects of tidal flow and longshore current, the earlier serving as the landward and seaward directed transport mechanism and the latter serving as the delivery mechanism. Insights into these specific processes were gained through numerical modeling of the inlets as follows. At both inlets, during flood phase sediment delivered to the inlet through littoral processes is entrained by flood currents and transported landward through marginal flood channels into the inlet throat as the flooding currents converge on the channel. This results in deposition and shoaling along the north sides of each of the inlet channels. The two inlets
however behave very differently during ebbing stage. At John’s Pass, during ebbing phase, sediment transported south through littoral processes converges with the ebb jet and is in turn transported seaward, providing the mechanism for development of the ebb shoal and the channel margin linear bar. However, at Blind Pass, the wave-driven longshore current flows into the inlet, merges with ebbing flow and exits the inlet along the south side through the main channel (Figure 147). This process is responsible for the deposition along the north side of the inlet channel (inner shoal). Tidal current flow patterns at Blind Pass do not result in seaward flushing of the sediment carried into the inlet by flood currents and longshore transport.

![Figure 147](image_url)  
**Figure 147.** Interaction of the southward longshore current and the ebb jet at Blind Pass.

While sediment at John’s Pass is only carried into the inlet during flood stage, at Blind Pass sediment is carried dominantly by longshore transport processes during both flooding and ebbing tide stages as discussed above, and may explain why deposition along the inner shoal at Blind Pass is so much greater than at John’s Pass. Similarly, during ebbing phase at John’s Pass,
along the downdrift (south) margin of the channel, flow begins to diverge as it exits the channel and an eddy is formed. The eddying current appears to provide a mechanism in-part responsible for the 16,000 m$^3$/yr eroded from Sunshine Beach (Figure 95). That in conjunction with converging flood stage flow along the south margin of the channel provides a compelling set of mechanisms responsible for the erosion along Sunshine Beach. Similar flow patterns during ebbing stage flow are apparent at Blind Pass. There, during ebbing flow, a small eddy is formed offshore the north end of Upham, Beach. As with John’s Pass, the eddying current appears to provide a mechanism in-part responsible for the 24,000 m$^3$/yr eroded from Upham Beach (Figure 104). A portion of that sediment appears to be transported onto the ebb shoal, and eventually becomes entrained by the longshore current and transported downdrift, bypassing Upham Beach. Through this process, Upham Beach indirectly - via the Blind Pass ebb shoal - supplies sediment to the downdrift beaches. Upham Beach has long been considered a chronically eroding feeder beach (U.S. Army Corps of Engineers (USACE), 1999); however, the precise pathway that sediment takes to get from the beach into the longshore transport system has been less clear.

As eluded to above, based on numerical modeling results, the inlets ebb jets in conjunction with sediment delivered to the inlet through littoral processes are important mechanisms contributing to the morphodynamics of inlet systems. At John’s Pass, ebbing current velocities greater than 0.2 m/s extend ca 1 km from the shoreline, and about half that distance at Blind Pass. Beyond those distances little morphologic change is observed based on the bathymetry surveys conducted during this study (between 6/2010 and 7/2014). At John’s Pass that equates to a short-term inlet specific depth of closure of ca -5 m (NAVD88) and at Blind Pass ca -4 m (NAVD88). Depth of closure represents the depth seaward of which minimal morphologic change occurs (Kraus et al., 1999). It is a morphodynamic boundary rather than a sediment transport boundary.
(Nicholls et al., 1998), is temporally variable, and is typically reserved for discussions related to offshore beach environments identified through convergence of time series beach profiles. Along the Pinellas County beaches the short-term depth of closure is ca -3 m (NAVD88) (Roberts, 2012). Therefore, where substantive morphology changes occur along the Pinellas County coast at depths in excess of -3 m (NAVD88) adjacent to an inlet, there must be mechanisms other than littoral currents exclusively controlling morphology change. In the case of inlets, the ebb jet is the most reasonable other mechanism. The correlation between the spatial extents of the ebb jets at John’s Pass and Blind Pass and the inlet specific depth of closure as described above further support the ebb jet as a contributing mechanism responsible for morphologic change beyond the local beach related depth of closure.

Alternative 4 (Section 5.5.5) simulated the influence extending the jetties at both John’s Pass and Blind Pass would have on morphology change, wave conditions and current conditions. Since the primary response of extending those structures was increased confinement of the ebb jet resulting in extending its influence further seaward, the simulation provides insights into the morphodynamic contribution the ebb jet has at each respective inlet. Based on this inference, the ebb jet is responsible for transporting sediment delivered to the inlet through littoral processes seaward, and for scouring the main ebb channel. As the jet transports sediment seaward, deposition occurs along the margins of the jet where current velocities are reduced forming channel margin linear bars. Sediment that the jet transports out to the distal margins of the ebb shoal is deposited there as the jet spreads and velocities decrease. It is also worth noting that at both inlets, while channel margin linear bars are clearly evident along the north sides of the channels, they are much less apparent along the south downdrift side, suggesting that sediment supplied through littoral processes, which is initially delivered to the north sides of the channels plays an important role in
Figure 148. 2014 bathymetry of the John’s Pass ebb shoal showing regions where 1-m (black contour), 1.5-m (blue contour) and 2-m (red contour) high waves would break.

Figure 149. Modeled sediment concentration at Johns Pass. Note the high sediment concentration in areas with wave breaking (modified from Beck and Wang, 2009).
the development of the channel margin linear bars. While the above discussion has focused on tide driven currents and associated morphodynamic patterns, the combined effects of tide and wave are equally as important to inlet morphodynamics. The influence of waves on an inlet system is largely confined to the ebb shoal since extensive wave breaking occurs there resulting in active sediment transport, and most of the wave energy is attenuated over the ebb shoal.

As described in Section 5.1.1 mean significant wave height and peak periods in the study area are on the order of 0.4-m and 4.5 seconds, respectively (Figures 28 and 29). However, winter storms, summer tropical storms and hurricanes in the GOM, and pre-frontal winds can yield waves of substantially greater heights (> 1m) than mean wave heights. The highest and longest period waves entering the study area domain are W-WSW-WNW (Figure 29) with the highest waves mostly associated with winter storms.

Waves breaking over shallow portions of an inlets ebb shoal agitate the sediment, placing some of it in suspension, and transporting it through wave driven currents. Similarly, sediment placed into suspension by breaking waves is susceptible to transport by tidal currents. As an example, using the criteria established by McCowan (1894), Figure 148 shows the 2014 bathymetry of John’s Pass ebb shoal with contours outlining regions where waves with wave heights ranging from 1-2 meters would break. Figure 149 illustrates tide and wave interactions and the resulting sediment concentrations within the water column over the John’s Pass ebb shoal. Comparing Figures 149 and 150, regions with the highest sediment concentrations correlate well with those regions where waves would be breaking. The interaction of tidal currents and incident waves appears to be especially active along the channel margin linear bar where the influence of the ebb jet is especially pronounced. This wave-tide interaction is likely also an important morphodynamic process along adjacent beaches where converging flood tidal currents can interact.
with sediment suspended by waves breaking along the shoreline. Elsewhere over the ebb shoal, the tidal influence is less and wave processes dominate sediment transport.

Fair weather waves would have nominal influence driving sediment transport processes in and around the JPBPI, while higher longer period waves would. Regions with breaking waves and the associated wave driven currents appear to be the dominant mechanisms responsible for sediment transport and the morphology along the portions of the John’s Pass and Blind Pass ebb shoals south of the main ebb channel (Figure 1). The varying angles of the bypass/swash bars crests are likely a reflection of varying incident wave angles and the magnitude and spatial distribution of wave refraction occurring over the ebb shoals; however, additional wave modeling would be required to confirm the latter. In order to get a broader perspective of the sediment transport processes leading to the ebb shoal morphologies we currently see within the JPBPI, in the following, volumetric sediment data is examined within the context of wave and tide processes discussed above.

### 6.1.3 Sediment Pathways and Bypassing

Inlets act as sediment sinks, storing sediment delivered to the inlets through longshore transport processes. The sediment stored is temporally and spatially variable, controlled by prevailing hydrodynamic conditions, bathymetry and sea level. Understanding pathways the sediment follows after delivery from longshore transport processes and where deposition and erosion occur within the inlet system is important to coastal managers, particularly when considering exploiting inlet sediment resources for beach nourishment projects. Changes in bathymetry can in turn influence hydrodynamic and sediment transport processes, and thus sediment bypassing mechanisms. For example, if downdrift beaches rely on a certain volume of
sediment to be delivered through longshore transport processes in order to maintain a certain beach width, and updrift ebb shoal mining interrupts prevailing bypassing rates or processes, those downdrift beaches may subsequently encounter excessive levels of erosion.

Between June 2010 and July 2014, John’s Pass received 453,000 m$^3$ of sediment through littoral processes from updrift sources. Of the volume delivered to John’s Pass, the inlet system retained 251,000 m$^3$ or 55% and bypassed 202,000 m$^3$. Figure 99 illustrate where those volumes were spatially distributed. As discussed earlier, at John’s Pass converging flood tide currents passing through the northern marginal flood channel transport *ca* 4000 m$^3$ (1.6% of total ebb shoal gain) of sediment landward into the inlet, yielding sedimentation along the north side of the channel throat. Shoaling in this region is cumulative and ongoing, and does not appear to be feeding any bypassing mechanisms. In fact, that shoaling is creating navigational issues for the Hubbard’s Marina and other commercial vessel docking facilities located in that area along the north side of the channel throat. As shown in Figure 100, the channel margin linear bar (CMLB) lost 1000 m$^3$. The minor morphologic and volumetric change occurring there suggests the CMLB is in or near equilibrium. Given that the CMLB is the shallowest region of the ebb shoal, slightly elevated wave conditions would easily erode sediment from the bar. That sediment is in-turn entrained in the ebb jet during ebbing conditions and transported seaward, or conversely pushed into the inlet channel throat during flooding conditions, potentially contributing to accretion along the north side of the channel as described above. In the earlier case, that sediment would contribute to bypassing while the latter would not. The navigational channel and 2010 dredge pit had a combined gain of 115,000 m$^3$ (46% of total ebb shoal gain). Figures 78 and 79 and Figures 83-86 illustrate the time-series volume changes in the channel dredge pit and over the navigational channel. As shown, deposition is initiated shoreward and translates seaward over time and is
persistent, indicating a primary sediment pathway dominantly controlled by the ebb jet, and to a lesser degree by wave breaking over the CMLB. As described in Section 5.3.2, based on the measured volumes infilling the 2010 channel dredge pit over the 4 year survey period and the 2014 infilling rate (Figure 75) it would take ca 7 years for the pit to recover to pre-dredging conditions, a length of time that should be considered renewable and sustainable on engineering time scales. As discussed in Section 5.3.2, sedimentation in the 1988 dredge pit, which lies marginally within the region influenced by the ebb jet, equated to ca 1300 m$^3$ between June 2010 and July 2014 or ca 325 m$^3$/yr which is ca 80% less than predicted (Walther and Douglas, 1993). This suggests that the 1988 dredge pit actually lies beyond the influence of active sedimentation pathways within the John’s Pass inlet system, and will take well in excess of the 40 years previously estimated (Walther and Douglas, 1993) to recover to pre-dredging conditions. This excavation lies below the 5-m inlet depth of closure estimated earlier further explaining the lack of sedimentation there.

The majority of the sediment delivered to the John’s Pass ebb shoal during the 4 year survey period was along the arcuate shaped bypass/swash bar region (Figure 94). There, 212,000 m$^3$ was deposited representing 84% of the total volume gained over the ebb shoal during the 4 year period. Sediment entrained by the ebb jet is transported seaward along the flank of the CMLB and ebb channel (Figure 1) to the central and distal portions of the ebb shoal where it encounters incident and refracted waves. There waves and wave driven currents act to redistribute that sediment landward along the downdrift side of the ebb shoal. The southern skew to the ebb shoal and southern bend of the channel reflect the dominant N-S wave induced forcing mechanism associated with winter storms. Along the distal margin of the ebb shoal a small volume of sediment, ca 10,000 m$^3$ or 2,500 m$^3$/yr is currently trapped in the 2010 west dredge pit (Figures 76 and 78). At that infilling rate, it will take ca 63 years for the dredge pit to recover to pre-dredging conditions,
suggesting that the sand resources contained along the distal most margins of the ebb shoal are effectively non-renewable on engineering time scales. In addition, sediment grain-sizes along the distal margins of the ebb shoal and just seaward of the ebb shoal beyond the inlet depth of closure are consistently fine-grained approaching 3 phi (Figures 53 and 54), and generally considered too fine-grained for beach nourishment applications. As shown in Figures 79 and 80, infilling of the west dredge pit occurs dominantly along the NW and SE portions of the excavation. Low rates of sedimentation in conjunction with waning ebb jet current velocities (Figure 41) indicate a limited sediment supply is available along the distal margins of the ebb shoal. As previously mentioned, in 2010 the floor of the dredge pit was at an elevation of -4.75 m (NAVD88), slightly above the inlet depth of closure discussed earlier. It is likely that any significant sediment transport along the distal portion of the ebb shoal occurs only during extreme wave events.

Landward of the 2010 dredge pit, ebb shoal morphology is dominated by bypass/swash bars. Bar orientations range from nearly shore parallel along the western distal margin of the ebb shoal just landward of the 2010 dredge pit, to near shore perpendicular as they approach the shoreline. Since it is unlikely that tide driven current velocities are adequate to generate the bedforms observed it’s reasonable to assume they are wave-built, and their orientations are a function of incident and refracted wave angles. Figures 84-87 illustrate the persistent sedimentation and erosion patterns over that region of the John’s Pass ebb shoal suggesting a persistent sediment pathway. Fitzgerald et al (1976) considered the landward migration of swash bars as the primary bypassing mechanism at stable tidal inlets. In the case of John’s Pass, the bathymetry clearly shows the swash/bypass bars coalescing near the shoreline and as shown in Figure 84, merging with the shoreline at the shoreline attachment point. Over the 4 year survey period, this translated to 44,000 m$^3$ delivered to the beach downdrift of Sunshine Beach near range
is included within the volume captured by the John’s Pass ebb shoal over the 4 year survey period. Through the same bypassing pathways discussed above, over the 4 year survey period, 202,000 m$^3$ or 54,000 m$^3$/yr bypassed around John’s Pass and was transported downdrift through littoral processes along Treasure Island.

Blind Pass is located 5.5 km south of John’s Pass. Shoreline orientations at both inlets are similar, as is the offshore bathymetry suggesting incident wave energy at both inlets should be comparable. On the other hand, as discussed earlier, tidal forcing, at least during flooding stage exhibits significant current velocity asymmetries. In addition, there is a substantial variation in the tidal prism captured by each inlet. Blind Pass captures ca 75% less of the available tidal prism than John’s Pass, so the volume of discharge exiting Blind Pass is substantially less than John’s Pass. While the magnitude of current velocities passing through the channel thalwegs are comparable at both inlets during peak spring ebbing stage as shown in Figure 146, the distribution of cross-channel velocities vary considerably (see Figures 40 and 41). As a consequence, Blind Pass cannot flush sediment out of its channel efficiently, and flushing is largely limited to the channel thalweg while substantial sedimentation occurs along the north side of the channel (inner shoal) away from the thalweg. Another consequence of the limited volume of tidal prism the inlet captures is the limited seaward extend of its ebb jet which extends ca half as far offshore as the John’s Pass ebb jet. This is reflected in the size of the inlets ebb shoal. As previously mentioned, the 2000 dredging of Blind Pass effectively removed most of the ebb and inner shoal that existed at the time. Therefore, the current Blind Pass ebb and inner shoals effectively represent sedimentation that has occurred subsequent to the 2000 dredging, equating to a growth rate of ca 37,000 m$^3$/year during the 14 years between 2000 and 2014. During the 4 year survey period, the Blind Pas ebb shoal gained 194,000 m$^3$ which constitutes 38% of the 2014 ebb shoal volume.
indicating the ebb shoal is continuing to grow at a rapid rate. As previously described, the ebb shoals annual growth rate equates to ca 10% of the total ebb shoal volume. As the ebb shoal grows, sediment transport pathways and bypassing mechanisms evolve accordingly.

Between June 2010 and July 2014, Blind Pass received 252,000 m$^3$ through littoral processes from updrift sources. An additional 34,000 m$^3$ eroded from the south end of Treasure Island was delivered to the inlets ebb and inner shoal, along with some fraction of the 90,000 m$^3$ eroded from Upham Beach (Figure 100). Of the volume delivered to Blind Pass, the inlet system gained 281,000 m$^3$ between its ebb shoal and inner shoal and bypassed 95,000 m$^3$. Figure 101 illustrate how that sediment is spatially distributed within the Blind Pass inlet system. While the migratory nature of Blind Pass as described earlier has been arrested through structural mitigation measures, the legacy of that morphodynamic behavior remains in the form of the channel configuration. More precisely, the 90 degree bend in the channel reflects the previous southward barrier spit growth of Treasure Island. This 90 degree bend and the associated increased friction yields reduced current velocities, and influences current distribution patterns across the channel throat which are especially critical during ebbing stage.

As discussed earlier, sediment delivered to the inlet through littoral processes from updrift sources including Sunset Beach enters the inlet throat. During flooding tide sediment is
Figure 150. Time series morphology of the Blind Pass inlet.
transported into the inlet by a combination of wave-driven current and flood tidal currents. That sediment is in turn deposited over the inner shoal along the north side of the channel. During ebbing flow, wave driven currents similarly push sediment into the inlet throat, and while in both cases the result is sedimentation along the north side of the inlet throat, during the ebbing phase, some of that sediment becomes entrained in the ebbing flow and is transported seaward by the ebb jet. The deposition inside the inlet throat is persistent and ongoing and represents in part a sediment sink as well as a sediment pathway (during ebbing flow). Unlike John’s Pass ebb shoal which has well established pathways and bypassing mechanism (i.e. swash/bypassing bars and shoreline attachment), Blind Pass exhibits greater spatio-temporal variability in morphology and sediment pathways, and a less distinct bypassing mechanism. This is due to the rapid rate at which the ebb shoal is growing (Figure 150).

Prior to the 2010 dredging, the morphology of Blind Pass included a distinct channel margin linear bar and swash/bypass bars; however, no distinct shoreline attachment was evident. At the time, Blind Pass was still recovering from the 2000 ebb shoal and inner shoal mining; however, it appears that sediment pathways had been partially established. Based on the morphology and hydrodynamic patterns revealed in numerical model simulations of the system, sediment delivered to the inlet through updrift littoral processes enters into the channel throat during both ebb and flood tide phases. During the flooding tide, that sediment is deposited along the north side of the channel (inner shoal), and during the ebbing phase while a portion of that sediment is deposited over the inner shoal the balance is carried seaward by ebbing currents and the ebb jet. These processes combined with northerly and westerly incident waves act to build the channel margin linear bar and bypass/swash bars. Although no shoreline attachment had been established, it is likely that its formation was imminent. However, in July 2010 the ebb shoal and
inner shoal was re-dredged. During that event, ca 122,000 m³ of sand was removed and placed on Upham Beach (see Appendix A). The dredging effectively removed most of the inner shoal, and a significant portion of the channel margin linear bar (Figure 157, 10/2010 panel), the latter being most critical since it likely represented an important pathway critical to the inlets bypassing system.

The Blind Pass 2010 dredging created a significant volume of accommodation space along the north side of the channel where the inner shoal had previously developed, and along the portion of the ebb shoal previously occupied by the channel margin linear bar. Figures 82 and 83 illustrate sedimentation patterns in the dredge pit as it infilled during the 1st and 2nd years post dredging. As described earlier, as the dredge pit infilled sedimentation spread both landward and seaward over time. While the landward spreading contributes sediment to the inner shoal which acts largely as a sink and contributes little to bypassing, the seaward spreading is fundamentally important since it relates to growth of the ebb shoal which is required in order to reestablish the inlets bypassing system. Figures 88-90 show cumulative sedimentation and erosion patterns over the ebb shoal between 10/2010 and 7/2014. As shown during the 1st and 2nd years post dredging, seaward infilling of the dredge pit is persistent and represents rebuilding of the channel margin linear bar. This is important for developing a pathway for sediment delivered to the inlet from updrift sources to be transported seaward for further growth of the ebb shoal, ultimately forming the pathway that allows sediment to get from the updrift to the downdrift (south) side of the ebb shoal. Cumulative depositional patterns between 2010 and 2014 (Figure 89) suggest substantial rebuilding of the channel margin linear bar and bypass/swash bars. Similarly, the greater ebb shoal has adopted the characteristic crescent shape morphology suggesting that a pathway from the updrift sediment delivery source to the downdrift bypassing bars has been established. Although the 2014 data indicate that a shoreline attachment hasn’t yet formed, it is likely that with a cessation of dredging
that shoreline connection will develop and provided a more robust pathway for sediment to bypass around the inlet to the downdrift beaches.

Also evident in Figures 88-90 is sedimentation extending from Upham Beach seaward along the downdrift side of the ebb shoal. This is particularly interesting in that it illustrates an important secondary sediment pathway between the ebb shoal, Upham Beach, and the downdrift longshore sediment transport system. As mentioned above, _ca_ 122,000 m$^3$ of sand was placed on Upham Beach from the 2010 dredging. As the beach fill spreads and equilibrates, it appears to become entrained in the eddying current that forms during ebb tidal flow along the south side of the inlet channel near the north tip of Long Key. This pathway is persistent throughout the entire time-series shown in Figures 86-88. This indicates that the pathway is active after the beach placement has largely equilibrated and spread. Similarly, it further supports the notion that the eddying currents provide a significant mechanism responsible for erosion along Upham Beach. Furthermore, in conjunction with sediment bypassing from the ebb shoal to the downdrift longshore current, it further helps to explain the mechanism leading to the notion that Upham Beach serves as a feeder beach to downdrift stretches of Long Key.

Overall, John’s Pass provides an example of sediment bypassing mechanisms associated with a heavily structured mix-energy tidal inlet. The main pathway for sediment bypassing is the shallow outer lobe of the ebb shoal. The morphology the bypassing sediment adopts is in the form of swash bars (a.k.a. bypassing bars) with variable orientations ranging from shore parallel to shore perpendicular reflecting. The bar orientations and morphologies are a direct reflection of the primary transport mechanism, waves and wave driven currents. Blind Pass provides an example of a heavily structured and artificially stabilized migratory inlet. While repeated mining of the Blind Pass ebb shoal has inhibited the development of an active bypassing mechanism, a cessation
of ebb shoal mining will allow the continued development of an ebb shoal which is crucial to establishing an active bypassing mechanism. However, continued growth of the ebb shoal may influence the navigability of the inlet channel because wave-induced sediment transport, which is crucial to sediment bypassing, requires shallow water for wave breaking. Allowing extensive shallow water in the vicinity of the inlet entrance channel may pose hazards to navigation. Balancing the above two issues constitute the most challenging task for inlet management. The findings discussed here from John’s Pass and Blind Pass should be applicable to other microtidal inlets not only along Florida’s coast but worldwide.

6.2 Conclusions

John’s Pass and Blind Pass are heavily structured tidal inlets sharing the tidal prism of northern Boca Ciega Bay. John’s Pass captures ca 81% of the tidal prism and Blind Pass captures the remaining 19%. The tidal prism captured by each inlet in conjunction with channel geometry determines the magnitude of ebbing current velocities flowing through each inlet’s channel. The influence of the latter was numerically modeled in Alternative 4 where jetty extensions at both inlets were simulated. Ebbing current velocities in-turn dictate how efficiently the inlet can transport sediment seaward that accumulates in the channel during flood and ebb stage flow, and the spatial extent and velocity distribution of the inlet’s ebb jet. The seaward extent of the ebb jet in-turn plays a major role in the morphodynamics of the inlet by transporting sediment delivered to the inlet through longshore transport seaward where incident waves and wave driven currents can further act upon that sediment. Similarly, the ebb jet plays a crucial role in sediment bypassing across the ebb shoal. The ebb jet at John’s Pass extends ca 1200 m from the shoreline, while the ebb jet at Blind Pass extends ca half that distance. The seaward extent of the ebb shoals and active
sediment transport at each inlet approximates those distances. Therefore any changes to the tidal prism induced by events such as the opening of another inlet through storm breaching and/or changes in channel geometry can yield dramatic changes in the stability, morphodynamics, sediment bypassing mechanisms, and sediment pathways of an inlet. Major findings of this study are as follows:

John’s Pass
1) John’s Pass exhibits mixed-energy straight morphologic characteristics.
2) The John’s Pass ebb shoal contains ca 3,286,000 m$^3$ of sediment, and gained 270,000 m$^3$ between October 2010 and July 2014 (45 months), which equates to ca 8% of its total volume.
3) The relatively small volume gain occurring over 45 months suggests that the ebb shoal is approaching equilibrium conditions.
4) Approximately 122,000 m$^3$ of sediment is delivered annually to John’s Pass through longshore transport processes, and ca 54,000 m$^3$ is bypassed around the inlet to Treasure Island.
5) Of the volume of sediment delivered to the inlet annually through littoral processes, <2% is deposited along the north side of the channel throat, ca 45% is deposited within the navigation channel and 2010 channel dredge pit, ca 4% is deposited in the 2010 west/terminal lobe dredge pit, and ca 50% is deposited over the bypass/swash bars and at the shoreline attachment.
6) A portion of the sediment eroded annually from the downdrift Sunshine Beach is transferred to the ebb shoal swash platform by eddy currents that form during ebbing flow.

7) The majority of sediment that is delivered to the inlet through longshore transport processes along with sediment put into suspension by waves breaking over the channel margin linear bar is transported seaward by the ebb jet. Near the seaward margins of the ebb shoal, waves and wave induced currents transport sediment downdrift over the swash platform (swash/bypass bars). Continued wave driven downdrift transport results in swash bar migration to the extent that the bars become stacked and/or coalesce at the shoreline attachment.

8) Sediment delivered to the shoreline attachment reenters the Treasure Island littoral system and continues on a downdrift path along the Treasure Island beaches toward Blind Pass.

9) Along the margins of the John’s Pass ebb shoal (distal edges of the terminal lobe) nominal sediment transport occurs below -5 m (NAVD88). It is likely that sediment transport in this region occurs only during storm-driven high wave events.

Blind Pass

10) Although heavily structured and hardened, Blind Pass currently exhibits mixed-energy characteristics. However, owing to its intense structural hardening, conventional morphodynamic characterization such as “mixed-energy” or “wave dominated” may no longer be appropriate.
11) The Blind Pass ebb shoal contains *ca* 515,000 m$^3$ of sediment and gained 194,000 m$^3$ between October 2010 and July 2014, equating to *ca* 38% of the entire ebb shoal volume.

12) The relatively large volume gain over the 45 month period indicates the ebb shoal is growing at a rapid rate, equating to an annual growth rate of *ca* 10%.

13) Approximately 101,000 m$^3$ of sediment is delivered annually to Blind Pass through longshore transport processes combined with sediment eroded from Sunset Beach (updrift) and Upham Beach (downdrift), and *ca* 25,000 m$^3$ is bypassed around the inlet to Long Key.

14) Of the volume of sediment delivered to the inlet annually, *ca* 32% is deposited at the inner shoal along the north side of the channel throat, and *ca* 68% is deposited over the ebb shoal (including the channel margin linear bar and swash platform).

15) A portion of the sediment eroded annually from the downdrift Upham Beach is transferred to the ebb shoal swash platform by eddy currents that form during ebbing flow.

16) Unlike John’s Pass where sediment is carried into the inlet only during flood tidal flow, at Blind Pass, sediment is carried into the inlet during both ebb and flood flow, accounting for the large volume of sedimentation along the inner shoal.

17) Due to repeated mining of the Blind Pass ebb shoal, currently the inlet is not bypassing sediment to the downdrift beaches. Instead sediment delivered to the inlet is serving to build an ebb shoal, and the associated bypassing pathways. In 2014, a channel margin linear bar and swash/bypassing bars were evident; however no shoreline attachment had yet developed. If the ebb shoal is allowed to fully develop and establish a bypassing mechanism, the frequency of nourishments at downdrift Upham Beach may be reduced.
18) Along the margins of the developing Blind Pass ebb shoal (distal edges of the terminal lobe) nominal sediment transport occurs below -4 m (NAVD88). It is likely that sediment transport in this region occurs only during storm-driven high wave events.

Since managing inlet sediment resources has become a primary concern of coastal managers, future work should be directed at quantifying rates of sediment transport in and around the inlet ebb shoals. This should include quantifying rates of swash/bypass bar migration, as well as infilling rates within burrow areas. Field measurements can in-turn be used to parameterize and validate numerical modeling simulations of morphology change as well as infilling of borrow pits. These efforts would allow coastal practitioners to effectively design more sustainable approaches to sand sharing projects.
REFERENCES


LeConte, L.J., 1905. Discussions of "Notes on the improvement of rivers and harbor outlets in the United States" by Watts, P.A. Transactions of American Soc. of Civil Engineers, 55, 306-308.


APPENDIX A

TABLE OF ENGINEERING HISTORY
<table>
<thead>
<tr>
<th>Year</th>
<th>Project Description</th>
<th>Volume (yd^3)</th>
<th>Comments</th>
<th>Start Location</th>
<th>End Location</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1848</td>
<td>JP opened through BI breach associated with hurricane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mehta et al, 1976</td>
</tr>
<tr>
<td>1926</td>
<td>BP bridge constructed and road on TI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CTC, 1993</td>
</tr>
<tr>
<td>1926</td>
<td>JP bridge constructed and road on TI</td>
<td></td>
<td>Two 150 foot groins constructed on VA beach at Madiera Beach</td>
<td></td>
<td></td>
<td>CTC, 1993</td>
</tr>
<tr>
<td>1934</td>
<td>Madiera Beach groin construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CTC, 1993</td>
</tr>
<tr>
<td>1937</td>
<td>Blind Pass groin constructed on south side</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dean and Obrien, 1987</td>
</tr>
<tr>
<td>1937</td>
<td>BP dredged concurrent with groin construction</td>
<td>N.A.</td>
<td></td>
<td></td>
<td></td>
<td>CPE, 1992</td>
</tr>
<tr>
<td>1945</td>
<td>Hurricane (June 19-27) destroys TI seawall and upland homes</td>
<td></td>
<td>much of the backbay bulkheaded during this period</td>
<td></td>
<td></td>
<td>CTC, 1993</td>
</tr>
<tr>
<td>1950</td>
<td>Dredge and fill BB 1940-1950's</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CTC, 1993</td>
</tr>
<tr>
<td>1950's</td>
<td>BP south groin extended east</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CPE, 1992</td>
</tr>
<tr>
<td>1957</td>
<td>Madera Beach groins constructed</td>
<td></td>
<td>37 timber concrete groins constructed</td>
<td></td>
<td></td>
<td>PinCo comp plan_ch-2</td>
</tr>
<tr>
<td>1960</td>
<td>JP dredged</td>
<td>94,000</td>
<td>dredge material placed on outer bar- later formed Obrien's lagoon (1968)</td>
<td></td>
<td></td>
<td>Dean and Obrien, 1987; Loeb, 1994</td>
</tr>
<tr>
<td>Year</td>
<td>Project Description</td>
<td>Volume (yd^3)</td>
<td>Comments</td>
<td>Start Location</td>
<td>End Location</td>
<td>Reference</td>
</tr>
<tr>
<td>------</td>
<td>---------------------</td>
<td>--------------</td>
<td>----------</td>
<td>----------------</td>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>1960</td>
<td>56 groins constructed on TI</td>
<td></td>
<td>460 ft curved jetty constructed on N side of JP/terminal structure/filled with 30,000 cy from JP</td>
<td></td>
<td></td>
<td>PinCo comp plan_ch-2</td>
</tr>
<tr>
<td>1961</td>
<td>North terminal structure constructed at JP</td>
<td></td>
<td>placed on beach directly north of inlet</td>
<td></td>
<td></td>
<td>PinCo comp plan_ch-2; CTC, 1993</td>
</tr>
<tr>
<td>1961</td>
<td>JP dredged</td>
<td>30,000</td>
<td></td>
<td></td>
<td></td>
<td>Dean and Obrien, 1987</td>
</tr>
<tr>
<td>1962</td>
<td>BP terminal structure constructed on N side of BP</td>
<td></td>
<td>425ft long stone/rubble mound groin/jetty</td>
<td></td>
<td></td>
<td>PinCo comp plan_ch-2; Loeb, 1994</td>
</tr>
<tr>
<td>1964</td>
<td>BP dredged</td>
<td>10,000</td>
<td>placed on sunset beach</td>
<td></td>
<td></td>
<td>Dean and Obrien, 1987; PinCo comp plan_ch-2; CPE 1992; Loeb, 1994</td>
</tr>
<tr>
<td>1964</td>
<td>sunset beach nourished</td>
<td>10,000</td>
<td>dredged from BP R141</td>
<td>R143</td>
<td></td>
<td>Dean and Obrien, 1987; CPE, 1992</td>
</tr>
<tr>
<td>1964</td>
<td>federal authorization of dredging JP</td>
<td></td>
<td>authorized under Section 107 of the 1960 River and Harbors Act</td>
<td></td>
<td></td>
<td>Elko, 2005; CTC, 1993</td>
</tr>
<tr>
<td>1966</td>
<td>revetment construction S bank of JP</td>
<td></td>
<td>920 ft along S bank of JP (cost $ 106,000.00)</td>
<td></td>
<td></td>
<td>CTC, 1993</td>
</tr>
<tr>
<td>Year</td>
<td>Project Description</td>
<td>Volume (yd^3)</td>
<td>Comments</td>
<td>Start Location</td>
<td>End Location</td>
<td>Reference</td>
</tr>
<tr>
<td>------</td>
<td>---------------------</td>
<td>--------------</td>
<td>----------</td>
<td>----------------</td>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>1966</td>
<td>JP dredged</td>
<td>78,000</td>
<td>placed offshore</td>
<td></td>
<td></td>
<td>Dean and Obrien, 1987; CTC, 1993</td>
</tr>
<tr>
<td>1966</td>
<td>CEOL conducts surface current study at JP</td>
<td></td>
<td>COEL, 1966</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1968</td>
<td>BP dredged</td>
<td>30,000</td>
<td>Volume uncertain</td>
<td>PinCo comp plan_ch-2; Loeb, 1994</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1968</td>
<td>revetment construction</td>
<td></td>
<td>sunshine beach</td>
<td>R126</td>
<td>R131</td>
<td>ACE 2014</td>
</tr>
<tr>
<td>1968</td>
<td>Obrien's Lagoon forms</td>
<td></td>
<td>CTC, 1993</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1968</td>
<td>State establishes MHW on TI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1969</td>
<td>BP dredged</td>
<td>108,000</td>
<td>contributed to 790000 yd^3 placed on TI (see below)</td>
<td></td>
<td></td>
<td>CPE, 1992</td>
</tr>
<tr>
<td>1969</td>
<td>New Bridge constructed across JP</td>
<td></td>
<td>CTC, 1993</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1969</td>
<td>First nourishment of TI</td>
<td>790,000</td>
<td>material dredged from shore parallel-offshore pit 600 m offshore, and BP</td>
<td>R133</td>
<td>R141</td>
<td>ACE 2014; CTC, 1993; CPE, 1992</td>
</tr>
<tr>
<td>1971</td>
<td>Mid-Beach renourishment- 1st renourishment</td>
<td>75,000</td>
<td>dredged from offshore R127-130;</td>
<td>R131</td>
<td>R133</td>
<td>PinCo comp plan_ch-2; ACE 2014; CPE 1992</td>
</tr>
<tr>
<td>1972</td>
<td>Sunset Beach renourishment - 2nd renourish</td>
<td>155,000</td>
<td>dredged from offshore TI (CPE, 1992)</td>
<td>R141</td>
<td>R142</td>
<td>PinCo comp plan_ch-2; ACE 2014; CPE 1992</td>
</tr>
<tr>
<td>Year</td>
<td>Project Description</td>
<td>Volume (yd^3)</td>
<td>Comments</td>
<td>Start Location</td>
<td>End Location</td>
<td>Reference</td>
</tr>
<tr>
<td>------</td>
<td>---------------------</td>
<td>--------------</td>
<td>----------</td>
<td>----------------</td>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>1974</td>
<td>Attached breakwater on S side of BP extended 261' by city</td>
<td></td>
<td>City extended BP S. breakwater/jetty from 171 ft to 261 ft</td>
<td></td>
<td></td>
<td>PinCo comp plan_ch-2; Loeb, 1994</td>
</tr>
<tr>
<td>1975</td>
<td>BP dredged</td>
<td>75,000</td>
<td>used for beach fill at Upham</td>
<td></td>
<td></td>
<td>Dean and Obrien, 1987; CPE, 1992</td>
</tr>
<tr>
<td>1975</td>
<td>2 &quot;kingpile groins constructed at Upham</td>
<td></td>
<td>filled with 75,000 cy from BP</td>
<td></td>
<td></td>
<td>PinCo comp plan_ch-2</td>
</tr>
<tr>
<td>1975</td>
<td>Upham nourished</td>
<td>75,000</td>
<td>dredged from BP</td>
<td>R144</td>
<td>R148</td>
<td>PinCo comp plan_ch-2; CPE 1992</td>
</tr>
<tr>
<td>1976</td>
<td>Groin built at BP to extend original N jetty</td>
<td></td>
<td>Groin on N. side of BP extended to 360 ft.</td>
<td></td>
<td></td>
<td>CPE, 1992; Loeb, 1994</td>
</tr>
<tr>
<td>1976</td>
<td>BP dredged (&quot;dredged offshore&quot;) between 1972 &amp; 1976</td>
<td>405,000</td>
<td>2500 ft N, and 2500 ft offshore BP</td>
<td></td>
<td></td>
<td>ACE 2014; Mehta et al, 1976</td>
</tr>
<tr>
<td>1976</td>
<td>groin constructed on TI at Sunset Beach</td>
<td></td>
<td>Built 2300 ft N. of BP</td>
<td>R141</td>
<td></td>
<td>PinCo comp plan_ch-2; ACE 2014; Loeb, 1994</td>
</tr>
<tr>
<td>1976</td>
<td>Sunset Beach renourishment - 3rd renourish</td>
<td>405,000</td>
<td></td>
<td>R135</td>
<td>R142</td>
<td>PinCo comp plan_ch-2; ACE 2014; Mehta, 1976</td>
</tr>
<tr>
<td>1978</td>
<td>BP completely closed due to shoaling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Loeb, 1994</td>
</tr>
<tr>
<td>1978</td>
<td>N. jetty at BP raised 2.5 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PinCo comp plan_ch-2</td>
</tr>
<tr>
<td>Year</td>
<td>Project Description</td>
<td>Volume (yd³)</td>
<td>Comments</td>
<td>Start Location</td>
<td>End Location</td>
<td>Reference</td>
</tr>
<tr>
<td>------</td>
<td>---------------------------------------------</td>
<td>--------------</td>
<td>---------------------------------------------------------------------------</td>
<td>----------------</td>
<td>--------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>1978</td>
<td>BP dredged</td>
<td>50,000</td>
<td>placed on S TI</td>
<td></td>
<td></td>
<td>Loeb, 1994</td>
</tr>
<tr>
<td>1978</td>
<td>Sunset Beach renourishment- 4th renourish</td>
<td>50,000</td>
<td>dredged from BP</td>
<td>R135</td>
<td>R142</td>
<td>Loeb, 1994</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>material placed on Upham Beach and offshore to form breakwater</td>
<td></td>
<td></td>
<td>ACE 2014; Loeb, 1994</td>
</tr>
<tr>
<td>1980</td>
<td>BP dredged</td>
<td>253,760</td>
<td></td>
<td></td>
<td></td>
<td>ACE 2014; Loeb, 1994</td>
</tr>
<tr>
<td>1980</td>
<td>Upham nourishment - initial restoration</td>
<td>253,760</td>
<td>material dredged from BP. Some placed as offshore berm placement</td>
<td>R144</td>
<td>R146</td>
<td>ACE 2014</td>
</tr>
<tr>
<td>1981</td>
<td>JP dredged</td>
<td>53,500</td>
<td>placed on sunshine beach</td>
<td></td>
<td></td>
<td>ACE 2014</td>
</tr>
<tr>
<td>1983</td>
<td>BP N jetty extended 520 ft.</td>
<td>53,500</td>
<td></td>
<td></td>
<td></td>
<td>CPE, 1992</td>
</tr>
<tr>
<td>1983</td>
<td>BP dredged</td>
<td>220,000</td>
<td>placed on Sunset Beach</td>
<td></td>
<td></td>
<td>ACE 2014</td>
</tr>
<tr>
<td>1983</td>
<td>Sunset Beach renourishment 5th renourish</td>
<td>220,000</td>
<td>dredged from BP</td>
<td>R138</td>
<td>R142</td>
<td>ACE 2014</td>
</tr>
<tr>
<td>Year</td>
<td>Project Description</td>
<td>Volume (yd^3)</td>
<td>Comments</td>
<td>Start Location</td>
<td>End Location</td>
<td>Reference</td>
</tr>
<tr>
<td>------</td>
<td>---------------------</td>
<td>--------------</td>
<td>----------</td>
<td>----------------</td>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>1985</td>
<td>Redington shores breakwater constructed</td>
<td></td>
<td></td>
<td>R101</td>
<td></td>
<td>ACE compilation, 2014</td>
</tr>
<tr>
<td>1986</td>
<td>attached breakwater constructed on seaward end of S BP groin (terminal groin/jetty)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PinCo comp plan_ch-2; CPE 1992</td>
</tr>
<tr>
<td>1986</td>
<td>BP south jetty extended</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dean and Obrien, 1987</td>
</tr>
<tr>
<td>1986</td>
<td>Upham nourishment - 1st renourishment</td>
<td>96,712</td>
<td>material dredged from Pass-a-Grille ebb shoal</td>
<td>R144</td>
<td>R146</td>
<td>ACE 2014</td>
</tr>
<tr>
<td>1986</td>
<td>Sunset Beach renourishment (emergency after Elena)</td>
<td>550,000</td>
<td>material dredged from Pass-a-Grille shoals</td>
<td>R129</td>
<td>R141</td>
<td>ACE 2014</td>
</tr>
<tr>
<td>1987</td>
<td>N jetty/terminal groin reconstructed at JP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PinCo comp plan_ch-2; ACE 2014</td>
</tr>
<tr>
<td>1988</td>
<td>JP dredged</td>
<td>380,000</td>
<td>from channel and ebb shoal</td>
<td></td>
<td></td>
<td>Barnard, 1998</td>
</tr>
<tr>
<td>1990</td>
<td>BP dredged</td>
<td>325,000</td>
<td>placed on LK</td>
<td></td>
<td></td>
<td>Loeb, 1994</td>
</tr>
<tr>
<td>1990</td>
<td>Upham Beach renourishment</td>
<td>325,000</td>
<td>dredged from BP</td>
<td></td>
<td></td>
<td>Loeb, 1994</td>
</tr>
<tr>
<td>1990</td>
<td>Renourishment of Sand Key</td>
<td>1,300,000</td>
<td>material dredged from offshore Mullet Key and Egmont Channel</td>
<td></td>
<td></td>
<td>Loeb, 1994</td>
</tr>
<tr>
<td>1991</td>
<td>JP dredged</td>
<td>56,000</td>
<td>placed on sunshine beach</td>
<td></td>
<td></td>
<td>ACE 2014; CTC 1993</td>
</tr>
<tr>
<td>Year</td>
<td>Project Description</td>
<td>Volume (yd³)</td>
<td>Comments</td>
<td>Start Location</td>
<td>End Location</td>
<td>Reference</td>
</tr>
<tr>
<td>------</td>
<td>---------------------</td>
<td>-------------</td>
<td>----------</td>
<td>---------------</td>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>1991</td>
<td>Upham nourishment - 2nd renourishment</td>
<td>230,000</td>
<td>material dredged from Pass-a-Grille ebb shoal</td>
<td>R144</td>
<td>R146</td>
<td>PinCo comp plan_ch-2; ACE 2014; Elko, 2009</td>
</tr>
<tr>
<td>1991</td>
<td>Sunshine beach renourishment -6th renourish</td>
<td>56,000</td>
<td>material dredged from JP</td>
<td>R127</td>
<td>R129</td>
<td>PinCo comp plan_ch-2; ACE 2014</td>
</tr>
<tr>
<td>1996</td>
<td>Upham nourishment - 3rd renourishment</td>
<td>252,950</td>
<td>material dredged from W Egmont shoals</td>
<td>R144</td>
<td>R146</td>
<td>PinCo comp plan_ch-2; ACE 2014; Elko, 2009</td>
</tr>
<tr>
<td>1996</td>
<td>Sunset Beach renourishment - 6th renourish</td>
<td>51,300</td>
<td>material dredged from W Egmont shoals</td>
<td>R138</td>
<td>R141</td>
<td>PinCo comp plan_ch-2; ACE 2014</td>
</tr>
<tr>
<td>2000</td>
<td>JP and BP dredged</td>
<td>390,000</td>
<td></td>
<td></td>
<td></td>
<td>ACE 2014</td>
</tr>
<tr>
<td>2000</td>
<td>terminal structure constructed on S side of JP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PinCo comp plan_ch-2</td>
</tr>
<tr>
<td>2000</td>
<td>Sunset Beach renourishment - 7th renourish</td>
<td>348,722</td>
<td>material dredged from JP and BP</td>
<td>R136</td>
<td>R144</td>
<td>ACE 2014</td>
</tr>
<tr>
<td>Year</td>
<td>Project Description</td>
<td>Volume (yd^3)</td>
<td>Comments</td>
<td>Start Location</td>
<td>End Location</td>
<td>Reference</td>
</tr>
<tr>
<td>------</td>
<td>--------------------------------------</td>
<td>--------------</td>
<td>----------------------------------------</td>
<td>----------------</td>
<td>--------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>2000</td>
<td>Sunshine beach reneourishment - 7th renourish</td>
<td>40,000</td>
<td>material dredged from JP and BP</td>
<td>R126</td>
<td>R129</td>
<td>PinCo comp plan_ch-2; ACE 2014</td>
</tr>
<tr>
<td>2004</td>
<td>Upham emergency nourishment</td>
<td>41,670</td>
<td>material dredged from Pas-a-Grille ebb shoal</td>
<td>R144</td>
<td>R146</td>
<td>ACE 2014</td>
</tr>
<tr>
<td>2004</td>
<td>Upham nourishment - 5th renourishment</td>
<td>366,092</td>
<td>material dredged from Pass-a-Grille ebb shoal</td>
<td>R144</td>
<td>R146</td>
<td>ACE 2014; Elko, 2009</td>
</tr>
<tr>
<td>2004</td>
<td>Sunset Beach renourishment - 8th renourish</td>
<td>225,000</td>
<td>dredged from Pass-a-Grille shoals</td>
<td>R136</td>
<td>R141</td>
<td>ACE 2014</td>
</tr>
<tr>
<td>2006</td>
<td>BP S jetty sand tightened</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DEP, 2008 (SBMP)</td>
</tr>
<tr>
<td>2006</td>
<td>Upham nourishment - 6th renourishment</td>
<td>104,636</td>
<td>material dredged from W Egmont shoals</td>
<td>R144</td>
<td>R146</td>
<td>ACE 2014</td>
</tr>
<tr>
<td>2006</td>
<td>Renourisment of Sand Key</td>
<td>2,210,436</td>
<td>Egmont shoals (1,690,000m^3)</td>
<td>R56</td>
<td>R107</td>
<td>Roberts, 2012</td>
</tr>
<tr>
<td>2006</td>
<td>Sunset Beach renourishment - emergency</td>
<td>106,302</td>
<td>emergency renourishment - material from W Egmont Shoals</td>
<td>R136</td>
<td>R141</td>
<td>PinCo comp plan_ch-2; ACE 2014</td>
</tr>
<tr>
<td>2006</td>
<td>Sunshine beach reneourishment - emergency</td>
<td>77,970</td>
<td>emergency renourishment - material from W Egmont Shoals</td>
<td>R126</td>
<td>R128</td>
<td>PinCo comp plan_ch-2; ACE 2014</td>
</tr>
<tr>
<td>Year</td>
<td>Project Description</td>
<td>Volume (yd^3)</td>
<td>Comments</td>
<td>Start Location</td>
<td>End Location</td>
<td>Reference</td>
</tr>
<tr>
<td>------</td>
<td>----------------------------------------</td>
<td>---------------</td>
<td>-----------------------------------------------</td>
<td>----------------</td>
<td>--------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>2010</td>
<td>Blind Pass Dredging</td>
<td>159,572</td>
<td>material placed on Upham Beach</td>
<td>BP channel</td>
<td></td>
<td>PinCo, 2010</td>
</tr>
<tr>
<td>2010</td>
<td>Renourishment Upham Beach - 7th</td>
<td>159,572</td>
<td>material dredged from BP</td>
<td>R144</td>
<td>R146</td>
<td>PinCo, 2010; ACE 2014</td>
</tr>
<tr>
<td>2014</td>
<td>Upham renourished- 8th renourishment</td>
<td>156,748</td>
<td>material dredged from East Egmont Shoal</td>
<td>R144</td>
<td>R146</td>
<td>ACE 2014</td>
</tr>
<tr>
<td>2014</td>
<td>Sunshine Beach renourishment - 10th</td>
<td>66,892</td>
<td>material dredged from East Egmont Shoal</td>
<td>R126</td>
<td>R128</td>
<td>ACE 2014</td>
</tr>
<tr>
<td>2014</td>
<td>Sunset Beach renourishment - 10th</td>
<td>232,407</td>
<td>material dredged from East Egmont Shoal</td>
<td>R136</td>
<td>R141</td>
<td>ACE 2014</td>
</tr>
<tr>
<td>2014</td>
<td>nourishment of Pass-a-Grille</td>
<td>140,053</td>
<td>material dredged from East Egmont Shoal</td>
<td>R160</td>
<td>R166</td>
<td>ACE 2015</td>
</tr>
</tbody>
</table>
APPENDIX B

FIGURE COPYRIGHT RELEASES
Hi Mark,

Thank you for your message regarding permission requests. Please accept this e-mail as an official approval to use the *Journal of Coastal Research* (JCR) figure you've requested. There is no fee associated with this permission. All we ask for is a proper bibliographic citation and reference to the original source of publication (*Journal of Coastal Research*).

We do require the following citation in the text (or figure caption) to read:


We also require this full reference in the Reference section of that particular chapter or the overall paper:


We thank you for your cooperation with these permission requests.

Best regards,
Chris

Chris Makowski, Ph.D.
Sr. Vice President & Assistant Director The Coastal Education & Research Foundation, Inc. (CERF)

**WWW.CERF-JCR.ORG**
Deputy Editor-in-Chief
*Journal of Coastal Research* (JCR)

**WWW.JCRONLINE.ORG**
5130 NW 54th Street
Coconut Creek, FL 33073, USA
FIGURE 2 Springer copyright release:

7/26/2017 RightsLink Printable License
https://s100.copyright.com/AppDispatchServlet 1/4

SPRINGER LICENSE
TERMS AND CONDITIONS
Jul 25, 2017
This Agreement between Mark H. Horwitz ("You") and Springer ("Springer") consists of
your license details and the terms and conditions provided by Springer and Copyright
Clearance Center.
License Number 4156011400454
License date Jul 25, 2017
Licensed Content Publisher Springer
Licensed Content Publication Springer eBook
Licensed Content Title Inlet Flood Tidal Delta Development through Sediment
Transport Processes
Licensed Content Author Donald K. Stauble
Licensed Content Date Jan 1, 1988
Type of Use Thesis/Dissertation
Portion Figures/tables/illustrations
Number of figures/tables/illustrations 1
Author of this Springer article
No
Order reference number
Original figure numbers Figure 3
Title of your thesis / dissertation
Morphodynamics and Sediment Transport Pathways of the John’s Pass-Blind Pass Dual-Inlet System: Pinellas County, Florida
Expected completion date Jul 2017
Estimated size(pages) 289
Requestor Location Mark H. Horwitz
University of South Florida
School of Geosciences
4202 E. Fowler Ave NES 107
TAMPA, FL 33620
United States
Attn: Mark H. Horwitz
Billing Type Invoice
Billing Address Mark H. Horwitz
Introduction
The publisher for this copyrighted material is Springer. By clicking "accept" in connection with completing this licensing transaction, you agree that the following terms and conditions apply to this transaction (along with the Billing and Payment terms and conditions established by Copyright Clearance Center, Inc. ("CCC"), at the time that you opened your Rightslink account and that are available at any time at http://myaccount.copyright.com).

Limited License
With reference to your request to reuse material on which Springer controls the copyright, permission is granted for the use indicated in your enquiry under the following conditions:

- Licenses are for one-time use only with a maximum distribution equal to the number stated in your request.
- Springer material represents original material which does not carry references to other sources. If the material in question appears with a credit to another source, this permission is not valid and authorization has to be obtained from the original copyright holder.
- This permission is non-exclusive
- is only valid if no personal rights, trademarks, or competitive products are infringed.
- explicitly excludes the right for derivatives.
- Springer does not supply original artwork or content.
- According to the format which you have selected, the following conditions apply accordingly:
  - Print and Electronic: This License include use in electronic form provided it is password protected, on intranet, or CD-Rom/DVD or E-book/E-journal. It may not be republished in electronic open access.
  - Print: This License excludes use in electronic form.
  - Electronic: This License only pertains to use in electronic form provided it is password protected, on intranet, or CD-Rom/DVD or E-book/E-journal. It may not be republished in electronic open access.

For any electronic use not mentioned, please contact Springer at permissions.springer@spiglobal.com.

- Although Springer controls the copyright to the material and is entitled to negotiate on rights, this license is only valid subject to courtesy information to the author (address is given in the article/chapter).
- If you are an STM Signatory or your work will be published by an STM Signatory and you are requesting to reuse figures/tables/illustrations or single text extracts, permission is
granted according to STM Permissions Guidelines: http://www.stm-assoc.org/permissionsguidelines/

For any electronic use not mentioned in the Guidelines, please contact Springer at permissions.springer@spi-global.com. If you request to reuse more content than stipulated in the STM Permissions Guidelines, you will be charged a permission fee for the excess content.

Permission is valid upon payment of the fee as indicated in the licensing process. If permission is granted free of charge on this occasion, that does not prejudice any rights we might have to charge for reproduction of our copyrighted material in the future.

- If your request is for reuse in a Thesis, permission is granted free of charge under the following conditions:
  
  This license is valid for one-time use only for the purpose of defending your thesis and with a maximum of 100 extra copies in paper. If the thesis is going to be published, permission needs to be reobtained.
  
  - includes use in an electronic form, provided it is an author-created version of the thesis on his/her own website and his/her university’s repository, including UMI (according to the definition on the Sherpa website: http://www.sherpa.ac.uk/romeo/);
  
  - is subject to courtesy information to the co-author or corresponding author.

Geographic Rights: Scope
Licenses may be exercised anywhere in the world.

7/26/2017 RightsLink Printable License
https://s100.copyright.com/AppDispatchServlet 3/4

Altering/Modifying Material: Not Permitted
Figures, tables, and illustrations may be altered minimally to serve your work. You may not alter or modify text in any manner. Abbreviations, additions, deletions and/or any other alterations shall be made only with prior written authorization of the author(s).

Reservation of Rights
Springer reserves all rights not specifically granted in the combination of (i) the license details provided by you and accepted in the course of this licensing transaction and (ii) these terms and conditions and (iii) CCC’s Billing and Payment terms and conditions.

License Contingent on Payment
While you may exercise the rights licensed immediately upon issuance of the license at the end of the licensing process for the transaction, provided that you have disclosed complete and accurate details of your proposed use, no license is finally effective unless and until full payment is received from you (either by Springer or by CCC) as provided in CCC’s Billing and Payment terms and conditions. If full payment is not received by the date due, then any license preliminarily granted shall be deemed automatically revoked and shall be void as if never granted. Further, in the event that you breach any of these terms and conditions or any of CCC’s Billing and Payment terms and conditions, the license is automatically revoked and shall be void as if never granted. Use of materials as described in a revoked license, as well as any use of the materials beyond the scope of an unrevoked license, may constitute copyright infringement and Springer reserves the right to take any and all action to protect its copyright in the materials.

Copyright Notice: Disclaimer
You must include the following copyright and permission notice in connection with any reproduction of the licensed material:
"Springer book/journal title, chapter/article title, volume, year of publication, page, name(s)
of author(s), (original copyright notice as given in the publication in which the material was
originally published) "With permission of Springer"
In case of use of a graph or illustration, the caption of the graph or illustration must be
included, as it is indicated in the original publication.
Warranties: None
Springer makes no representations or warranties with respect to the licensed material and
adopts on its own behalf the limitations and disclaimers established by CCC on its behalf in
its Billing and Payment terms and conditions for this licensing transaction.
Indemnity
You hereby indemnify and agree to hold harmless Springer and CCC, and their respective
officers, directors, employees and agents, from and against any and all claims arising out of
your use of the licensed material other than as specifically authorized pursuant to this
license.
No Transfer of License
This license is personal to you and may not be sublicensed, assigned, or transferred by you
without Springer's written permission.
No Amendment Except in Writing
This license may not be amended except in a writing signed by both parties (or, in the case
of Springer, by CCC on Springer's behalf).
Objection to Contrary Terms
Springer hereby objects to any terms contained in any purchase order, acknowledgment,
check endorsement or other writing prepared by you, which terms are inconsistent with these
terms and conditions or CCC's Billing and Payment terms and conditions. These terms and
conditions, together with CCC's Billing and Payment terms and conditions (which are
incorporated herein), comprise the entire agreement between you and Springer (and CCC)
concerning this licensing transaction. In the event of any conflict between your obligations
established by these terms and conditions and those established by CCC's Billing and
Payment terms and conditions, these terms and conditions shall control.
7/26/2017 RightsLink Printable License
https://s100.copyright.com/AppDispatchServlet 4/4
Jurisdiction
All disputes that may arise in connection with this present License, or the breach thereof,
shall be settled exclusively by arbitration, to be held in the Federal Republic of Germany, in
accordance with German law.
Other conditions:
V 12AUG2015
Questions? customercare@copyright.com or +1-855-239-3415 (toll free in
the US) or
+1-978-646-2777.
FIGURE 3 Florida Sea Grant copyright release:

On Jul 24, 2017, at 10:31 AM, Zimmerman, Dorothy <dozimmer@ufl.edu> wrote:

I am pleased to grant permission for the use and re-use of the following image(s) to you and your graduate students in their dissertation publications.

Figure 5, “Composite drawings of inlet types for the west-central Florida barrier chain,” from Florida Sea Grant Technical Paper 55, Historical Morphodynamics of Inlets in Florida: Models for Coastal Zone Planning, by Richard A. Davis, Jr. and James C. Gibeaut, 1990.

Thank you,

Dorothy Zimmerman

Communications Director

Florida Sea Grant

(352) 392-2801

http://flseagrant.org

https://www.facebook.com/flseagrant
FIGURE 7 CTC (Coastal Tech Corp) copyright release:

On Jul 21, 2017, at 5:03 PM, Michael Walther <mwalther@coastaltechcorp.com> wrote:

Mark:

Please accept this email as my approval for you to use the figure below in your dissertation with appropriate citation of the source in your references.

I look forward to (a) reading your dissertation, (b) seeing you at the ASBPA Conference, and (c) exploring opportunities on Florida’s west coast.

Michael Walther | Vice President

Coastal Tech – G.E.C., Inc.

Direct Phone: (772) 562-8580 Ext. 17 | Cell Phone: (772) 559-2493 | Fax: (772) 562-8432

Email: mwalther@coastaltechcorp.com
FIGURES 4, 5, 25 and 26 are in the public domain
ABOUT THE AUTHOR

Mark H. Horwitz received his Bachelor of Science degree in geology from the University of South Florida 2007. In 2008 he entered the graduate program there to begin research with Dr. Ping Wang on coastal processes. He received his Master of Science in geology after completing his thesis focused on the sedimentological characteristics of coastal storm deposits. This research was published in Sedimentology in 2010. Other peer-reviewed journal publications are in the Journal of Coastal Research, Geomorphology, and Studia Geologica. He has presented his research at both national and international conferences.