STATE OF SEBASTIAN INLET REPORT: 2019

An Assessment of Inlet Morphologic Processes, Shoreline Changes, Sediment Budget, and Beach Fill Performance

by

Gary A. Zarillo, Irene M. Watts, Kristen L. Hall, Sara Ramos, Peyman Taeb, Ahsan Habib, Jo-Ann Rosario-Llantín

Coastal Processes Research Group

Department of Ocean Engineering
and
Marine Sciences
Florida Institute of Technology
150 University Blvd.
Melbourne, FL 32901

Executive Summary

The annual update of the State of Sebastian Inlet includes five major areas of work; 1) an update of the analysis of volume contained in the sand reservoirs of the inlet system, 2) analysis of morphologic changes within the inlet system, 3) analysis of the sand budget based on the results of the sand volume analysis, 4) an update of the shoreline change analysis, and 5) numerical modeling analysis of hurricane impacts and infilling patterns of the sand trap, and an introduction to a new modeling system being set up for the Sebastian Inlet area. The volumetric analysis includes the major sand reservoirs within the immediate inlet system and sand volumes within the extended sand budget cells to the north and south of Sebastian Inlet. The volume analysis for each inlet sand reservoir extends from 2006 to 2019. Similar to the volumetric analysis described in previous state of the inlet reports, most inlet sand reservoirs are in a long-term dynamic equilibrium characterized by occasional large seasonal changes in volume superimposed on longer term trends of a lower order of magnitude. An examination of coastal sea level changes and sand volume between 2006 and 2019 revealed two important processes. First, the Sebastian Inlet sand reservoirs and the beach and shoreface areas to the north and to the south of the inlet undergo periods of regional sand volume losses and periods of sand volume gains. These gains and losses cover the entire region rather than being inversely linked to gains or losses in adjacent subsections. Examples are sand volume gains that peaked in 2010 and again in 2016. Periods of regional sand volume loss occurred in the years preceding the sand volume gains.

Secondly, from an examination of the sea level record measured at Sebastian Inlet over the 13-year period between 2006 and 2019, it can be demonstrated that periods of sand volume gains and decreasing cumulative sand volume losses, correspond to periods of falling sea level. Likewise, periods of rising sea level correspond to periods of increasing cumulative sand volume losses. Further, the sea level record for late 2018 and the first five months of 2019 indicates that another period of rising sea level may be beginning. This indicates the potential for an upcoming period of increased loss of sand volume.

The dynamic equilibrium and trends of sand volume change within the inlet sand reservoirs associated with Sebastian Inlet are also reflected in sediment budget calculations. In this report, the sand budget for the Sebastian Inlet region is reported at three-time scales, including a longer time scale of 10 years, a time scale of 5 years, and a shorter time scale of 3 years. The most useful time scale is considered to be 10 years since it integrates over seasonal sand volume changes that masks shorter term trends. During the time period of 2006 to 2019, the benefits of sand by-passing from the sand trap and beach fill placement to the south of the inlet, can be shown to directly offset sand volume gains within the inlet. The impacts of rising and falling sea level are more apparent in the 5-year and 3-year sand budgets presented in this report.

Similar to the sand volume analysis, the results of shoreline mapping from survey data and aerial imagery vary considerably by time scale. Over the 10-year time scale from 2008 to 2018, shoreline changes south of the inlet reflect the position of beach fill placement in 2007, 2011, 2012 and 2014. These beach nourishment projects provided sections of advancing or stable shoreline. The influence of sand placement from the sand trap excavation during the spring of 2014, along with the benefits of a recent 2-year period of falling sea level can be seen in the shoreline accretion between 2013 and 2017 and in the comparison of the 2016-2017 shoreline positions. Between the serial survey of summer 2018 and the summer aerial image survey of 2019 the shoreline position as registered by the approximate high-water line has been recessional. Likewise, in the recent 5-year period between 2013 and 2018 and the 2008 to 2018 10-year period the highwater shoreline has receded. Quantitative shoreline details are presented in the body of this report.

A new model application is being developed that will provide a real time predictions of water levels and current around Sebastian Inlet. The real time simulations will be based on the Deltares, Inc. Delft3D modeling system that has been widely applied in the US and Europe. A similar application created at Florida Tech is now running at Port Everglades, FL Eventually this model will include predictions of sand transport, salinity and water temperature

Table of Contents

List of Figures

List of Tables

1.0 Introduction and Previous Work

This report extends the analysis of the State of Sebastian Inlet from the publication of the 2018 report through the winter and spring months of 2019. In the original 2007 report, sand volume changes, sand budget, and morphological changes between 1989 and 2007 were examined (Zarillo et al. 2007). In addition, shoreline changes were documented between 1958 and 2007 using aerial images and between 1990 and 2007 using field survey data. In the 2013 report, much of the long-term analysis presented in the 2007 report was summarized in the main body of the text and re-stated in a series of appendices. This effort was to present a long-term analysis of inlet evolution and associated management strategies that have been applied over the years. The 2018 report emphasizes the sand volume calculation within the sand reservoirs and sand budget cells of the Sebastian inlet area and the influence of sea level changes on sand volumes The major sand budget cells and sand reservoirs were shown to be more or less stable in terms of longer-term trends outside of seasonal fluctuations, but response to temporary shifts in sea levels. Interannual increases in sea level corresponds to regional losses of sand volume from the shoreface and beach, whereas periods of falling sea level corresponds to sand volume gains.

In the present report, the morphological analysis, sand budget analysis and the shoreline analysis are updated to 2019. The movement and exchange of material between the sediment reservoirs during and after the storm are be examined as well as the hydrodynamic conditions during the storm. The analysis of the link between sea level changes and coastal sand volumes is extended to 2019.

The development of a new real time coastal processes model at Sebastian Inlet is documented in this report. It is expected that the model will provide focast of water levels and circulation that that extend out to 72 hours. The model results will be updated daily on a publicly accessible web site

2.0 Sand Volume Analysis and Sediment Budget

This section of the report provides an update of the sand budget around the inlet based on semiannual surveys of topography and changes in the sand volume contained in the various shoals associated with Sebastian Inlet. Much of the information in this report can be found in a series of annual "State of the Inlet" reports issued since 2007. The body and appendices of these reports provides detailed analyses of morphological and physical processes that control the dynamic equilibrium of the Sebastian Inlet system. In this section of the 2019 Inlet report details of sand volume and sediment budget exchanges around the inlet are provided to verify and update the Sebastian Inlet Sand Budget

The sandy shoals and veneers of sand within the Sebastian Inlet system are considered sand volume reservoirs that can gain, retain, and export sand throughout the system. A conceptual model of inlet sand reservoirs is given in a paper by Kraus and Zarillo, (2003). The concepts presented in this paper are the conceptual basis of littoral sand budgets in the vicinity of tidal inlets. Figure 1 shows the concepts of exchanges among tidal inlet sand reservoirs, including bypassing of sand across the inlet entrance to nourish adjoining shoreface and beaches. The visual concepts included in Figure 1 are the basis of terms used in sediment budget calculations (Rosati et al 1999).

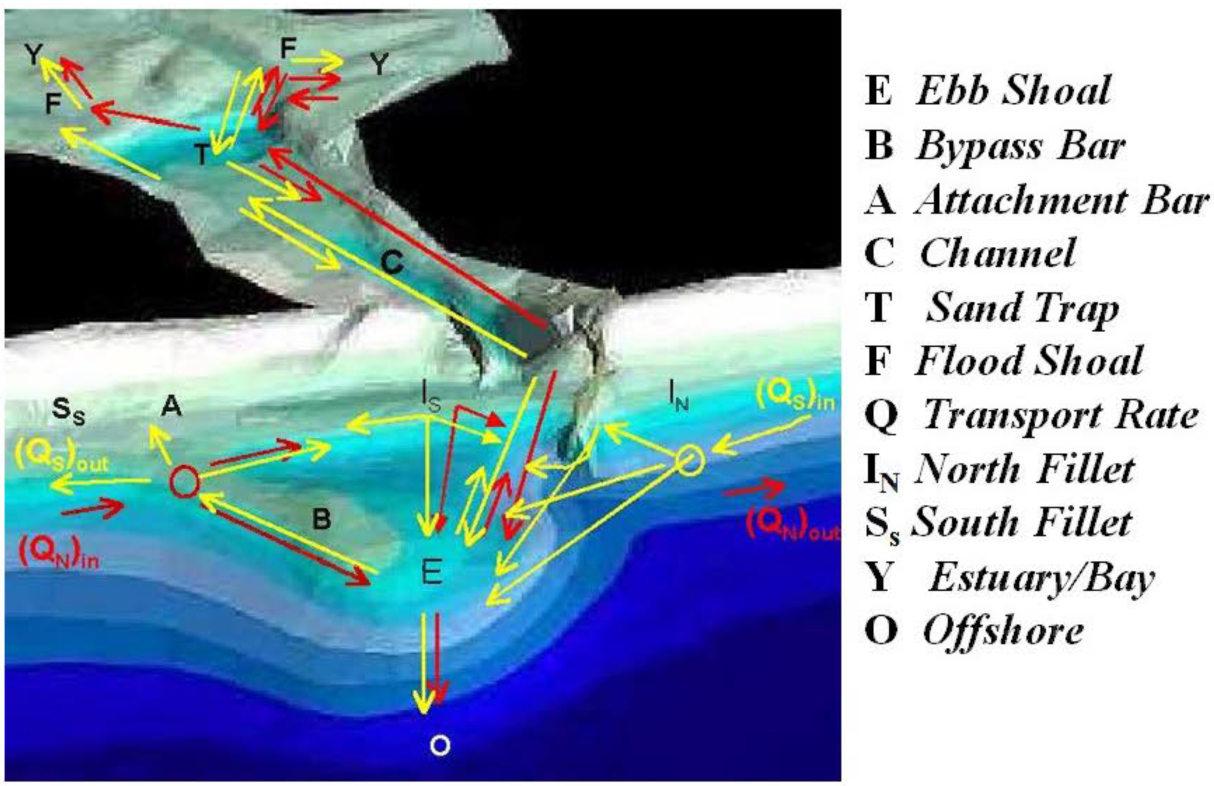


Figure 1. Schematic vector diagram of sediment transport pathways among sand reservoirs at Sebastian Inlet (From Kraus and Zarillo, 2003).

After a review of the sand volume changes within Sebastian Inlet shoals and sand budget cells over a 10-year period, the annualized sand budget in the inlet region is quantified. Sand budgets are presented as annualized terms but calculated over intermediate to longer term time periods. It will be noted in the summary and conclusions that the magnitude of the budget terms, including sand volume retained or exported by the inlet can change according to time scale (Zarillo, 2010). Time scales of 5 years and longer, provide fewer variable terms and more consistency for management.

2.1 Sand Volume Analysis Methods

Certified hydrographic surveys of the inlet system and the surrounding shoreface and beaches have been conducted for the by Sebastian Inlet Tax District (SITD) since the summer of 1989. Table 1 lists the surveys completed in since 2006. Starting in winter 1991, surveys have been performed on a semiannual basis. Offshore elevation data are gathered by a combination of conventional boat/fathometer methods and multibeam acoustic surveying methods from -4 ft. to -40 ft.NAVD88 in accordance with the Engineering Manual for Hydrographic Surveys (USACE, 1994). Multibeam data are collected on the south side of Sebastian Inlet from FDEP Range Maker R1 through R17 in Indian River County, FL.

Figure 2 shows the survey area including the entire inlet system (ebb shoal, throat, sand trap and flood shoal, etc.), and the adjacent barrier island system as well. The survey area extends approximately 30,000 ft. north (Brevard County) and 30,000 ft. south (Indian River County) of the inlet. Beach profiles taken about every 500 ft. Since 2011, survey methods have included multi-beam swath on the south side of the inlet entrance. The multibeam data provides high spatial resolution in areas where reef rock outcrops occur. The dredged channel extension between the inlet and the Intercoastal Waterway (ICW) to the west has been surveyed semi-annually since it was constructed in 2007.

This comprehensive dataset provides excellent support for volumetric calculations of inlet shoal and morphologic features, as well as for the analysis of changes in shoreline position through a "zero contour" extraction technique. Datasets used for this report are complete though the winter of 2019.

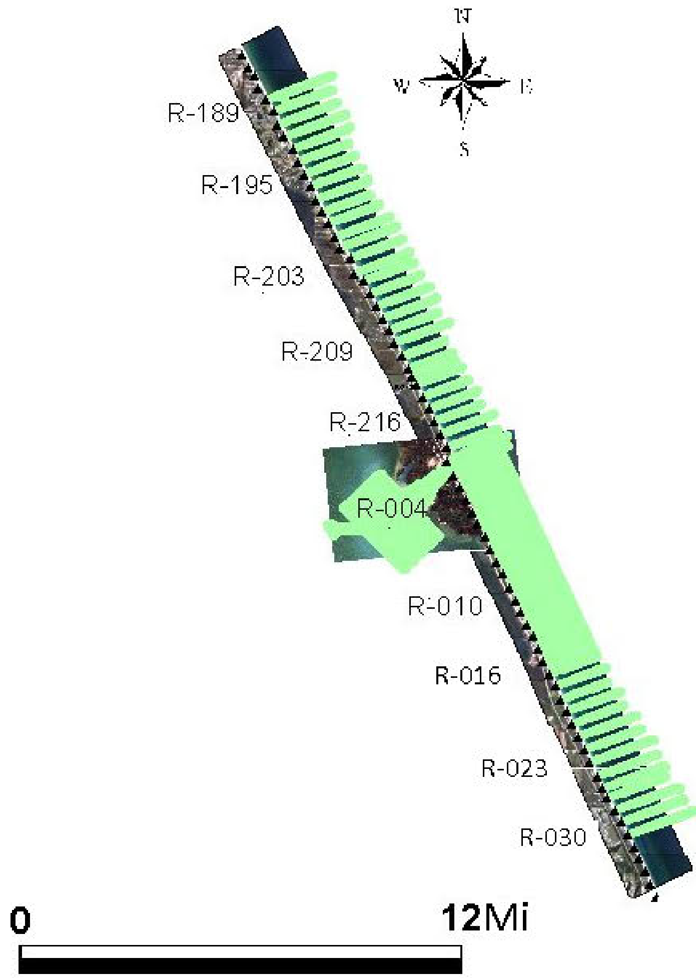


Figure 2. Extent of hydrographic survey (2019 winter).

Table 1. Summary of Hydrographic Surveys completed since 2006

Survey Date	Ebb shoal	Channel	Sand trap	Channel Extension	Flood shoal	North beach (ft)	South beach (ft)
Jan-06	x	x	x		x	30,000	30,000
Jul-06	x	x	x		x	30,000	30,000
Jan-07	x	x	x		x	30,000	30,000
Jul-07	x	x	x		x	30,000	30,000
Jan-08	x	x	x		x	30,000	20,000
Jul-08	x	x	x	x	x	30,000	30,000
Jan-09	x	x	x	x	x	30,000	30,000
Jul-09 *	x	x	x	x	x	30,000	30,000
Jan-10 *	x	x	x	x	x	30,000	30,000
Jul-10 *	x	x	x	x	x	30,000	30,000
Jan-11 *	x	x	x	x	x	30,000	30,000
Jul-11 *	x	x	x	x	x	30,000	30,000
Jan-12 *	x	x	x	x	x	30,000	30,000
Jul-12 *	x	x	x	x	x	30,000	30,000
Jan-13 *	x	x	x	x	x	30,000	30,000
Jul-13 *	x	x	x	x	x	30,000	30,000
Jan-14 *	x	x	x	x	x	30,000	30,000
Jul-14 *	x	x	x	x	x	30,000	30,000
Jan-15 *	x	x	x	x	x	30,000	30,000
Jul-15*	x	x	x	x	x	30,000	30,000
Winter 2016*	x	x	x	x	x	30,000	30,000
Summer 2016*	x	x	x	x	x	30,000	30,000
winter 2017*	x	x	x	x	x	30,000	30,000
Summer 2017*	x	x	x	x	x	30,000	30,000
Winter 2018*	x	x	x	x	x	30,000	30,000
Summer 2018*	x	x	x	x	x	30,000	30,000
Winter 2019*	x	x	x	x	x	30,000	30,000

* Multibeam data

Once each hydrographic survey is complete, volumetric data are added to the series of volume changes and volume changes from one survey to another are calculated. For consistent comparison from survey to survey, the Sebastian Inlet region is divided into subsections representing either a sand budget cell or sand reservoir. Figure 3 shows the sand budget cells used to calculate the changes in sediment volume associated with littoral transport rates over time. The N4 and N3 cells are north of the inlet entrance. N4 is bounded by FDEP R-Markers R189 and R195 in south Brevard County whereas the N3 sand budget cell is bounded between R195 and R203. The N2 and N 3 cells are placed between R203 and R-216. The inlet cell includes all of the sand reservoirs shown in Figure 4 and are bounded to the north by R-216 and to the south in Indian River County by R-4. On the south side of Sebastian Inlet sand budget cells are designated as S1, S2, S3 and S4. The S1 cell begins at R-4 and is bounded to the south by R-10 followed by the S2 cell bounded between R-10 and R16. Sand budget cell S3 extend from R-16 to R-23 followed by cell S4, which terminates at R30. All of the cells extend seaward to an approximate depth of -25 feet, NAVD88, which is considered beyond the depth of closure for changes in topography.

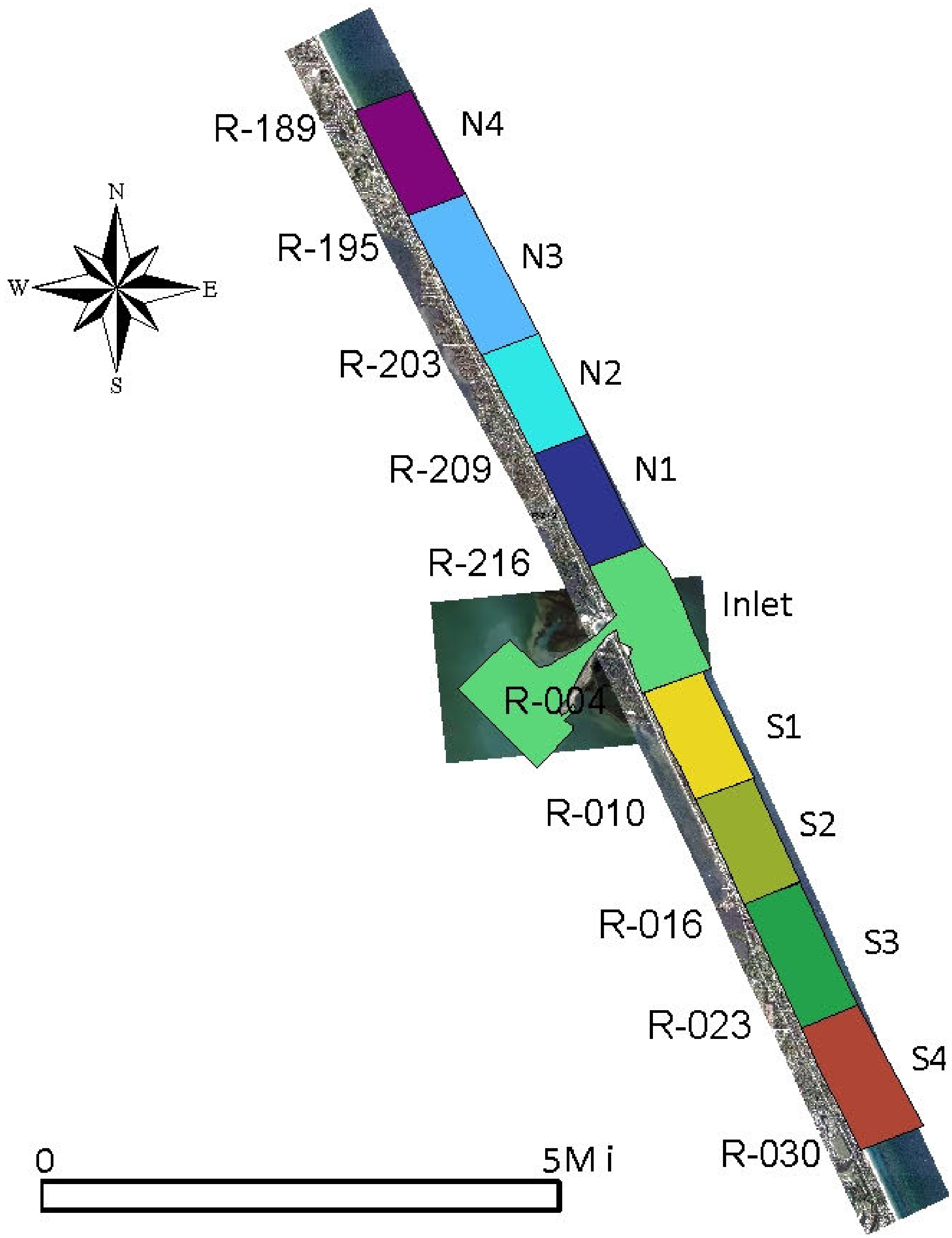


Figure 3. Sand budget cells.

Within the Inlet sand budget cell (Figure 3), further subdivisions are made to characterize sand reservoirs that exchange sand under the influence of strong tidal currents and waves. These subdivisions are shown and identified in Figure 4. Two of the sand reservoirs, the flood shoal and the ebb shoal are volumetrically large and control the magnitude of the topographic changes and sand bypassing within the Sebastian Inlet. The major reservoirs include the ebb shoal, flood shoal, and the sand trap. The sand trap, first excavated in 1962, re-established in 1972, and expanded in 2014 also influences the volume of the sand budget when it is periodically dredged. The most recent excavation of the sand trap was complete in June 2019. Approximately 124,000 ***(123,910 ATM)*** cubic yards of material was dredged from the sand trap of which 113, 500 cubic yards were placed on the beaches to the south of inlet between Indian River County R-Markers R10 and R17. Approximately 52,700 cubic yards of material were placed in the Sebastian Inlet dredge material management area (DMMA).

Other sand reservoirs contain lower sand volume relative to the ebb and flood shoals and the sand trap, but may exert influence over sand transfer as exchange locations as shown in Figure 4. The attachment bar on the south side of the inlet serves this role.

The raw survey data in Easting, Northing, and elevations are imported into the ArcGIS software platform. Using 3D analysis and spatial analysis capabilities of GIS, the total volume of sediment in each cell or reservoir is calculated relative to a base elevation. These volumes are then compared between survey dates.

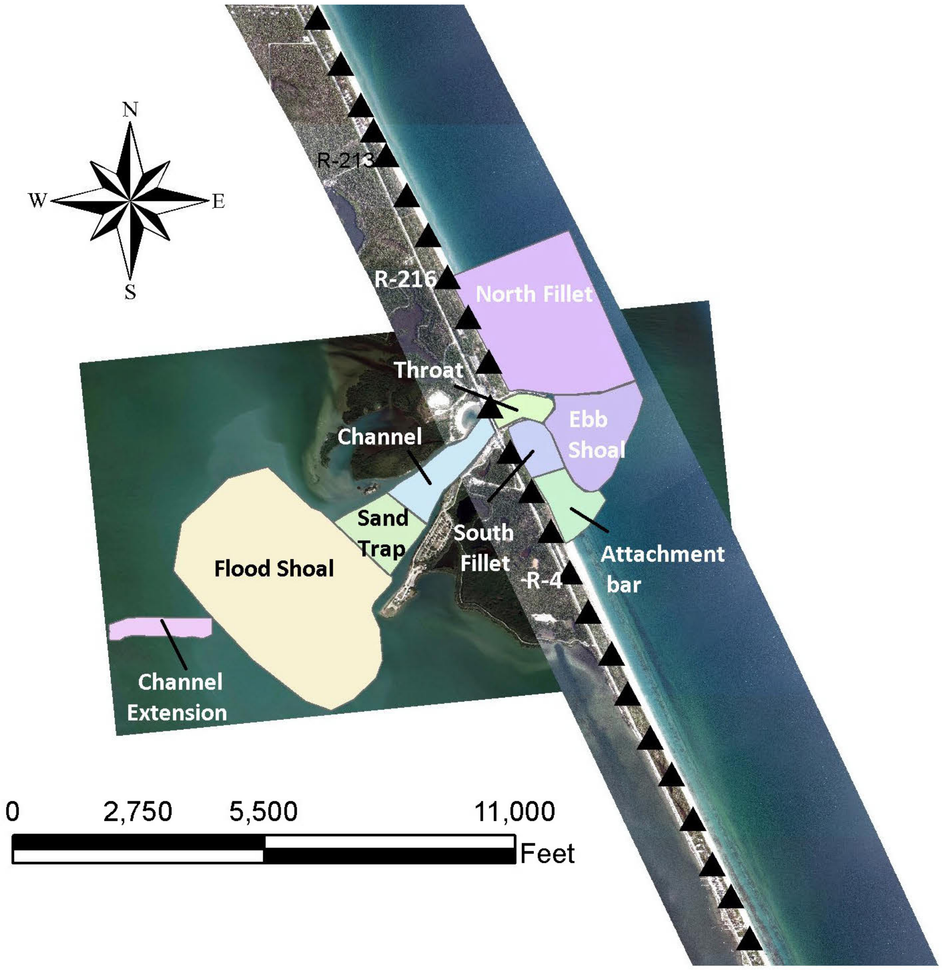


Figure 4. Morphologic features forming the inlet sand reservoirs.

3.0 Sand Reservoir Volume Analysis

The sand reservoirs are contained within the inlet sand budget cell (Figures 3 and 4). In order to fully understand the sand budget process, it is important to examine volume adjustments of each sand reservoir over time and in terms of variability and volume magnitude. Along with the sand reservoirs within the inlet, it is also useful to examine sand volume changes in sand budget cells contained within the barrier island system to the north and south of Sebastian Inlet. By considering the volume and variability of budget terms over shorter and longer time periods, the sand budget analysis can be more effectively applied to managing the regional sand resources. Thus, before presenting the sand budget for the Sebastian Inlet region, the volume evolution is reviewed for the major inlet sand reservoirs and for the cells within the sand budget calculation

Results presented in the volumetric analysis are divided into two subsections. Section 3.1 presents the volumetric evolution of the largest sand reservoirs within the inlet sand budget cell (Figure 4) with plots of net seasonal and cumulative volume change over time. Section 3.2 presents the volumetric evolution of the inlet littoral cells used for the sand budget computation. The calculated net seasonal volume changes (ΔV) serve as inputs to the sand fluxes (ΔQ) for the budget calculations discussed in Section 4. When reviewing the time series plots of volume changes in sand reservoirs and sand budget cells, the range of the vertical scale should be noted for each. Smaller sand bodies having less total volume have a much smaller range in volumetric changes compared to large sand bodies such as the flood shoal.

3.1 Individual Inlet Sand Reservoirs

The volumetric evolution of the ebb shoal from 2005 to 2019 is illustrated in Figure 5. Volume gains and losses that integrate over time to provide net volume change occur on short time scales that are usually on the order of 6 to 12 months. Volume gains or losses are most often followed by counter balancing volume losses or gains. For instance, 12 months of sand volume gains totaling about 89,000 cubic yards on the ebb shoal from July 2013 to July 2014 were followed by about a 50,000 cubic yard sand volume loss from July 2014 to winter 2015. This was followed by approximately 85,000 cubic yards of volume gain though the summer months of 2016 (Figure 5). Little net change occurred from the summer of 2016 to the latest survey completed in March of 2018. Although seasonal and annual changes on the ebb shoal can reach and exceed 50,000 cubic yards it is important to recognize trends of volume change that occur over longer segments of time and can contribute to the overall sand budget of Sebastian Inlet. In Figure 5, a trend of increasing ebb shoal sand volume occurred over an approximate 5-year period between 2005 and 2010 that totaled about 150,000 cubic yards. This was followed by a 3-year period of stability between 2010 and 2013 that bounded a small net loss of 20,000 cubic yards of sand. Between the winter 2013 and summer 2016 survey, the ebb shoal gained approximately 125,000 cubic yards. Between 2016 and 2019 the ebb shoal sand volume varied over a range of only 25,000 cubic yard and showed a net sand volume decrease of about 25,000 cubic yards. The total record for the ebb shoal shown in Figure 5 include about 250,000 cubic yards of volume increase since 2005. This along with volume changes in the flood shoal and sand excavations from the sand trap dominate the sand budget changes limited to the inlet. These interactions are discussed under Section 4 of the report.

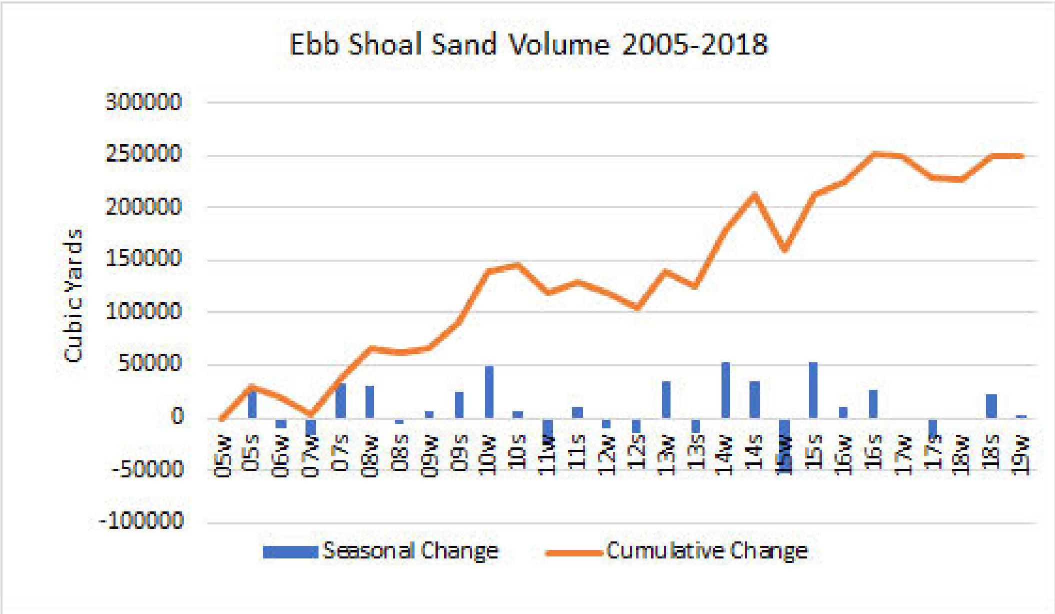


Figure 5. Volumetric evolution of the ebb shoal from summer 2005 to summer 2019.

The sand volume changes of the attachment bar are small due to its role as a sediment redistribution zone rather than an accumulation or storage zone (Zarillo et al., 2007). As seen in Figure 6, volume changes alternate between positive and negative on a seasonal basis. Increases in sand volume usually occur during the winter season of higher wave energy, whereas volume losses from the attachment bar usually occur during the summer season. It is likely that the winter sand volume increases are due to sand bypassing around the inlet entrance by higher energy winter wave conditions. Losses in the summer months are likely due to the movement of sand further south or back to the inlet entrance during the lower energy conditions of the summer season and north directed littoral sand transport by wave energy from the southeast in the summer. Sand volume in the attachment bar has declined by about 35,000 cubic yards since 2017.

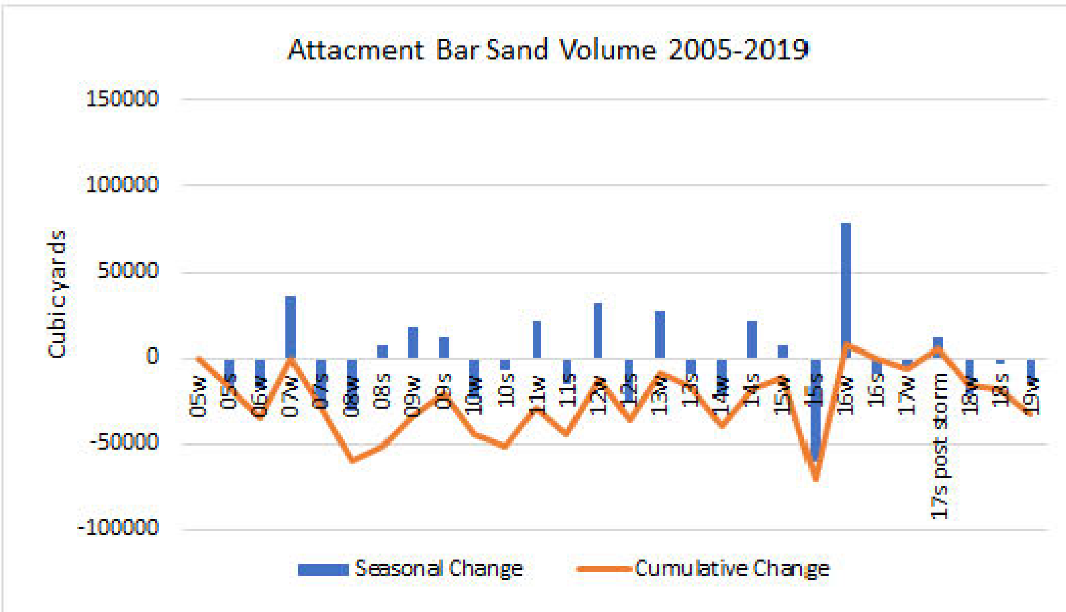


Figure 6. Volumetric evolution of the attachment bar from summer 2005 to winter 2019.

The volumetric evolution of the sand trap is presented in Figure 7. The trends and patterns of volume change are dominated by excavation from the sand trap in 2007, 2012, 2014, and 2019. Post dredge annual sand volume gains are on the order of 30,000 to 40,000 cubic yards averaging 15,000 to 20,000 cubic yards every 6 months. The pattern in Figure 6 shows that the highest rate of sand volume gains occurs in the first 6 months after dredging followed by smaller gains or small loss of volume thereafter until the next dredging cycle. The record from January, 2012 to July, 2014 clearly marks the recent dredging projects to bypass and expand the sand trap in 2014. Figure 7 illustrates the mechanical bypassing of spring 2012 with the removal of approximately 122,000 cubic yards of sand from the sand trap. In the winter to spring of

2014, approximately 160,000 cubic yards of material were removed as the trap was expanded. About 120,000 cubic yards of this material was placed to the south of Sebastian Inlet between R4 and R10. Since the 2014 sand trap expansion sand volume gains totaled about 121,000 cubic yards though the summer of 2018. The gains include about 43,000 cubic yards in the first six months after dredging followed by smaller gains of less than about 6,000 cubic yards per year through the winter of 2016. Analysis of surveys in summer 2016 and winter 2017 indicate a total gain of about 37,000 cubic yards of sand. Sand volume gains in the second half of 2017 were minimal but followed by a gain of about 28,000 cubic yards by the winter survey of 2018. The winter survey of 2019 showed a sand volume loss of about 90,000 cubic yards related to the ongoing dredging of the sand trap. The final as built survey indicates 124,000 cubic yards of sediment was removed from the sand trap.

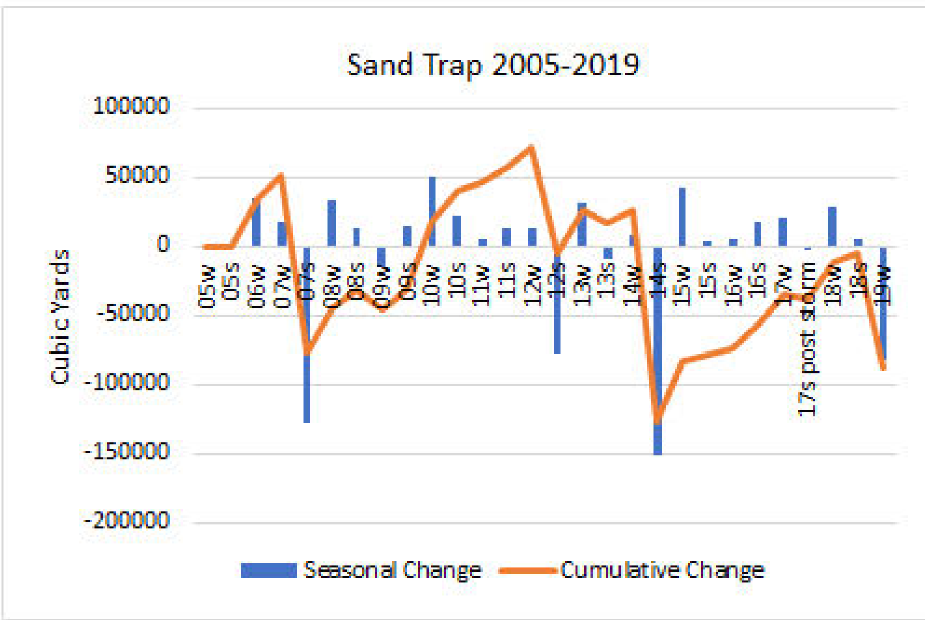


Figure 7. Volumetric evolution of the sand trap from winter 2005 to winter 2019.

Volumetric changes for the flood shoal (Figure 8) can be more than 100,000 cubic yards on a seasonal basis. Temporary loss of sand volume from the flood shoal is associated with sand trap dredging, which temporarily limits the supply of sand reaching the shoal. The pattern of recovery can be seen after the sand trap excavation in 2007 when the flood shoal recovered and increased its volume by summer of 2008. A period of continuing relatively large sand volume loss began in January, 2011 and continuing through 2014 when the sand trap was expanded. Initial losses may have been due to loss of sea grass coverage beginning in 2011, which normally helps to stabilize the flood shoal. After expansion of the sand trap in 2014, the flood shoal entered a period of recovery and expansion, which continued through the summer of 2015 as seen in Figure 8. Seasonal variations in the ebb shoal volume were on the order of 25,000 to 50,000 cubic yards through 2018, followed by a sand volume loss of about 100,000 cubic yards. The sand volume loss recorded by the winter 2019 survey is linked to dredging of the Sebastian Inlet Sand Trap as described in this, and previous State of the Inlet Reports. It is likely that the flood shoal volume will increase over time as the sand trap re-fills and sand is passed to the flood shoal.

Net volume change of the flood shoal in the 16-year period since 2006 is an approximate a loss of only about 25,000 cubic yards, although intra-annual sand volume fluctuations of more than 200,000 cubic yards can occur.

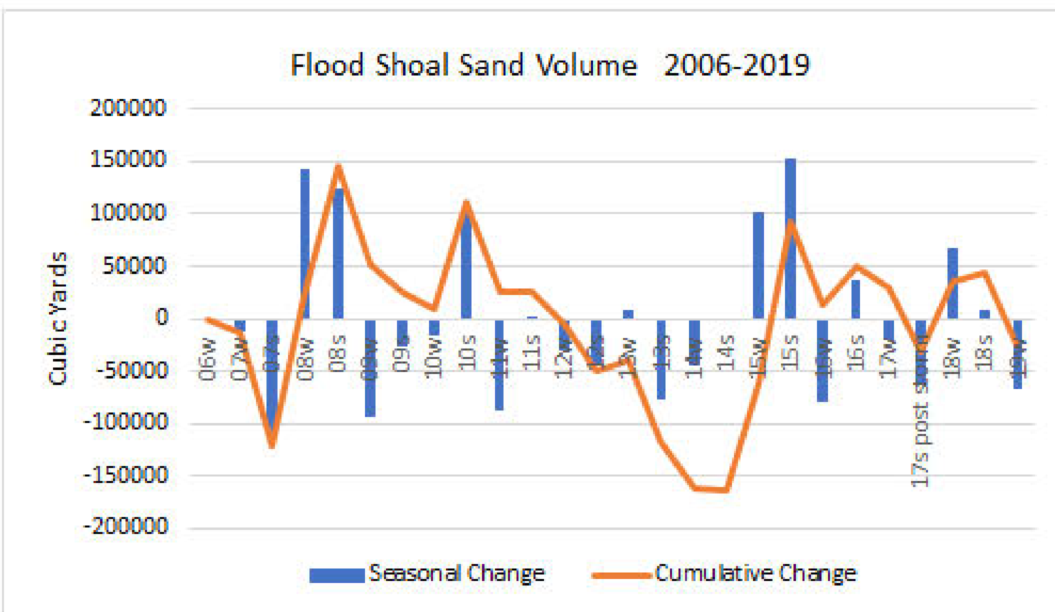


Figure 8. Volumetric evolution of the flood shoal from winter 2006 to winter 2019.

The record of changes in sand volume in the channel extension to the Intracoastal Waterway is shown in Figure 9. This area, first dredged for navigation in 2008 is dynamically linked to the sand trap and flood shoal sand exchanges. Sharp declines in sand volume occurred in 2012 and 2014 as the channel extension areas was dredged along with the sand trap. These declines may have also been influenced by sand volume losses in the adjacent flood shoal area and lined to losses of sea grasses. Similar to the flood shoal, sand volume sharply increased within the channels ins 2015 followed by a loss of about 10,000 cubic yards in the 2016. A sand volume decline of about 13,000 cubic yards between summer 2018 and winter 2014 is to dredging in of the channel extension after the sand trap was dredged

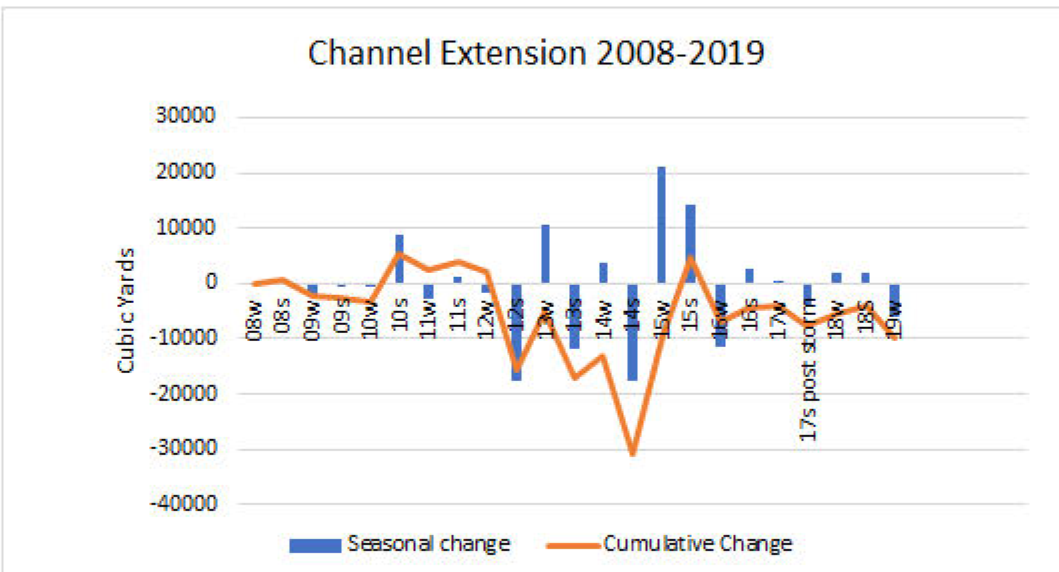


Figure 9. Volumetric evolution of the channel from winter 2008 to winter 2018.

3.2 Sand Budget Cells

The sediment budget calculations discussed in this report depend on the analysis of individual sand budget cells. The sand budget computational cells are shown in Figure 3. The inlet sand budget cell encompassing the nearshore zone from R216 in Brevard County to R4 in Indian River County, includes the ebb shoal, flood shoal, attachment bar and all other reservoirs shown in Figure 4. Annualized volume changes (ΔV) for each cell, calculated over different time periods, were added to the sand budget equation to calculate the annual net littoral sand transport in and out of each cell. Annualized placement and removal volume data are also included to account for dredging/mechanical bypassing and beach fill activities in the cells concerned. Time series of volumetric change since 2006 for the eight littoral sand budget cells shown in Figure 4 are shown in Figure 10 through Figure 18, ranging from the northernmost to the southernmost distal cells.

Volume changes for the N4 cell, the section between R189 and R195, are presented in Figure 10. Results indicate small net change in volume of about -88,000 cubic yards from 2006 to 2019. However, large fluctuations in sand volume have occurred on a seasonal basis and sometimes exceed 200,000 cubic yards of either gains or loses. Particularly large variations occurred 2007 to 2008 and then again in the 2016-2017 period. Recent gains of sand volume from the summer of 2016 to the post storm period of 2017 recovered about 400,000 cubic yards and have offset accumulated losses since the winter of 2016. Since the summer survey of 2017 the N4 cell has declined in sand volume by about 120,000 cubic yards

Volume changes in the N3 cell, (R195 - R203,Figure 3), are presented in Figure 11. Similar to the N4 cell, large volume changes in N3 are usually seasonal; characterized by gains in the winter months and volume losses in the summer months. This cycle is related to the stronger south directed littoral drift under winter conditions sending more sand into the N4 and N3 cells from the beach and shoreface to the north in Brevard County. Over the course of the 13-year record sand volume in this budget cell accumulated by as much as 400,000 cubic yards in a season and then returned to lower volumes over the next6 to 18 months period. Similar to the trends in the N4 cell there was a trend of declining sand volume between 2006 and 2015, followed by a trend of increasing sand volume from 2015 to 2019. These trends may be related to interannual shifts in sea levels as discussed in later sections of this report,

The total volume buildup in this sand budget cell in 2017 may be attributed to increased south directed littoral transport in the winter months and then again due to Hurricane Irma that sent large waves towards the Florida coast as it passed by Florida. Wave heights of up to 17 feet at periods of 12 or more were measured by the Sebastian Inlet wave gage. The net sand volume change of the 2006 to 2019 period is a small loss of about -34,000 cubic yard.

The volume changes found in the N2 sand budget cell (Figure 12) are similar in magnitude and pattern to those recorded in the N3 cell. Large volume changes occurred seasonally during the winter months followed by balancing volume losses over one or more seasons. The 13-year net volume change in N2 was about loss of about 80,000 cubic yards.

Net sand volume change in the N1 Cell (R209-R216) followed the pattern of the N4 and N3 cell with the exception of large sand volume gain of about 250,000 cubic yards recorded in the summer 2016 survey. The N4, N3, and N2 budget cells were characterized by sand volume losses of 100,000 to more than 250,000 cubic yards during this period, which possibly resulted in accumulation in the N1 cell, which is in the south directed net littoral drift pathway. The 2016 sand volume gains in N1 were then largely erased by losses that occurred in the post-Irma period of late 2017 and the winter of 2018. Similar to the other sand budget cells to the north of Sebastian Inlet, net volume change in the N1 cell consisted of a small loss of about -80,000 cubic yards between 2006 to 2019.

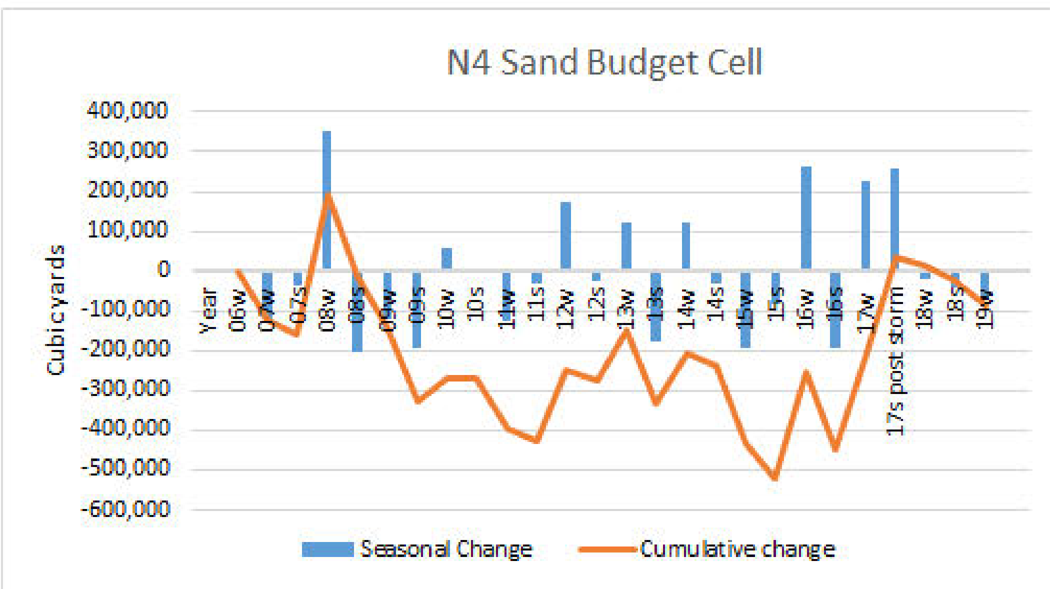


Figure 10. Volumetric evolution of the N4 sand budget cell 2006-2019

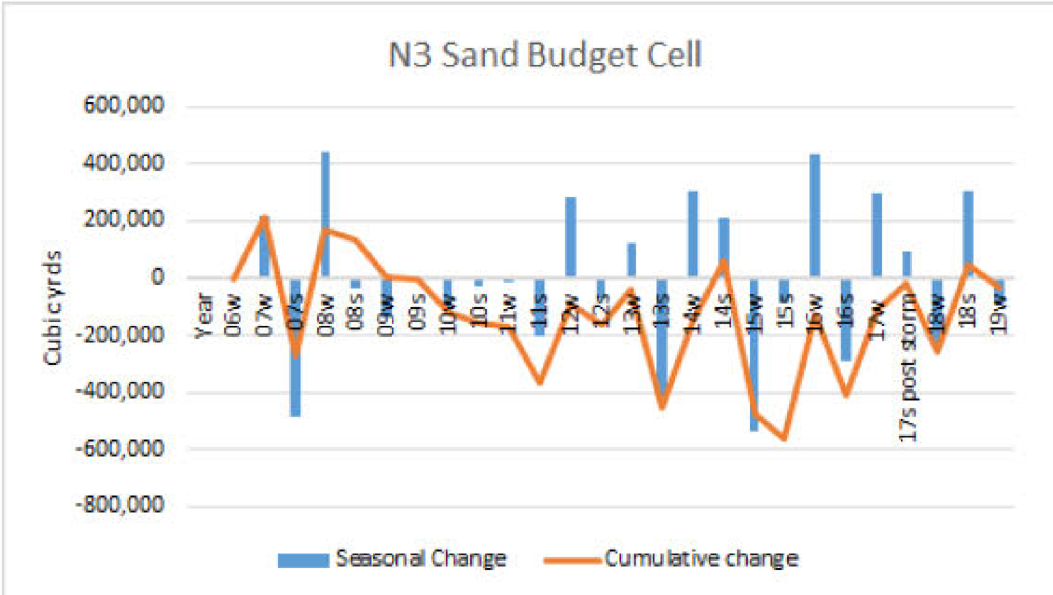


Figure 11.Volumetric evolution of the N3 sand budget cell 2006-2019.

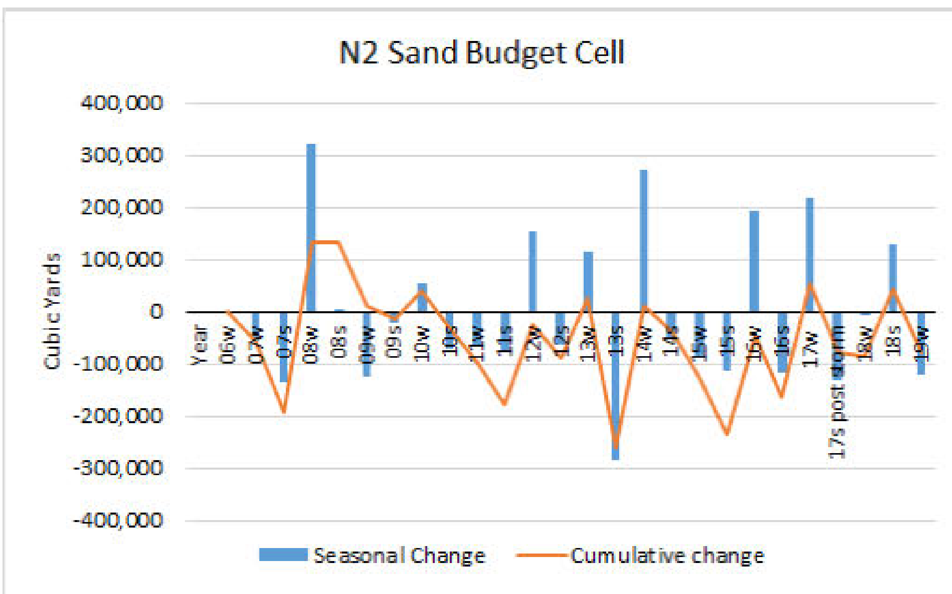


Figure 12. Volumetric evolution of the N2 sand budget cell 2006-2019.

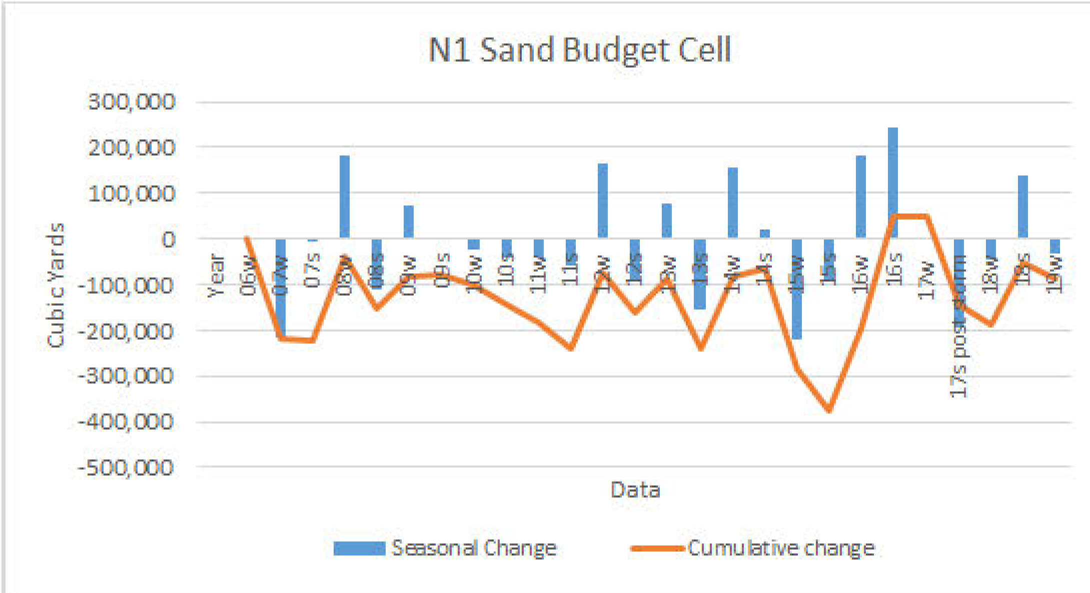


Figure 13. Volumetric evolution of the N1 sand budget cell 2006-2019.

Volume changes for the inlet sand budget cell (Figure 3) are shown in Figure 14. Sand volume in this budget cell is the combination of the ebb and flood shoals, as well as the sand trap and main inlet channel (conveyance channel) Thus, variations and trends of volume change in the ebb and flood shoal are reflected in the sand volume patterns of the inlet budget cell. Sand is also stored in the channel and the fillet areas within about 4,000 feet of beach and shoreface to the north and south of the inlet entrance (Figure 4).

Sand volume seasonally fluctuates showing moderate gains in the higher energy winter months and moderate losses in the lower energy summer months. Divergence from this pattern occurs in association with major storms or in response to bypassing from the sand trap as can be seen in 2007, 2012, 2014 and 2019. This the cycle of abrupt sand loss followed by period of sand volume gain is due to a combination of sand removal by dredging the sand trap and responding losses from the flood shoal followed by recovery of sand volume in the trap and rebound of the flood shoal. The influence of the ebb shoal sand volume within the inlet budget cell is considered to be independent of the sand trap excavation, but linked to accumulations of sand volume from the south directed littoral drift.

Over the past 13 years, net change in sand volume in this cell is a gain of about 400,000 cubic yards. However, this net accumulation has occurred largely within the last 4 years as seen in Figure 14. This volume gain is similar to the trend of increasing volume gain from 2007 to 2010 that occurred after the 2007 sand bypass project. In this period more than 600,000 cubic yards of sand accumulated within the inlet sand budget cell. However, in the next 3 years the inlet cell lost about 400,000 cubic yards of this accumulation. This volume loss was due to volume losses from the flood shoal and the ebb shoal as the inlet system rebounded from the dredging of the sand trap.

Inspecting the volume changes in the sand trap, flood shoal and ebb shoal, as well as volume losses in the N1 cell just to the north of the inlet cell, shows that the post sand bypass volume gains in the inlet are due to a combination of sand trap infilling, flood shoal rebound, and sand releases from the N1 cell to the inlet. The cycle of sand losses and gains within the inlet budget cell beginning with reach sand bypass from the sand trap is likely to be repeated as inlet system again responds to the 2019 sand bypass dredging event. Based on previous experience, the inlet budget cell volume gains since 2014 are likely to decline in rate and reverse to volume losses over the next few years. Sand released from the inlet budget cell is also likely to provide a benefit of increasing sand volume in the S1 to S4 budget cells to the south of the inlet as exemplified by volume gains in the S1 budget cell between 2008 and 2010 as seen in Figure 15.

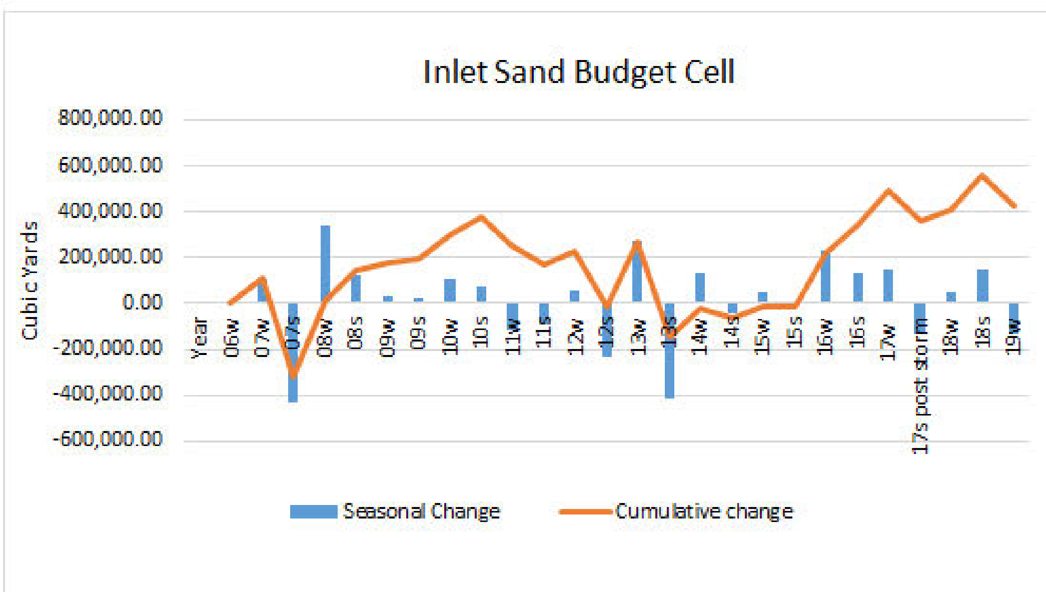


Figure 14. Volumetric evolution of the inlet sand budget cell 2006-2019.

Interannual terns of either sand volume gains or losses in the inlet budget cell can also be linked to interannual shifts in sea level as discussed in the 2018 State of the Inlet Report and discussed later in this report.

The volumetric evolution of the S1 cell, situated immediately south of the inlet cell between R4 and R10, is shown in Figure 15. The normal volume change pattern in this cell is a seasonal variation marked by volume gain in the winter and volume loss in the summer as seen between July, 2007 and winter, 2010. Seasonal losses of about 100,000 cubic yards occurred in this cell though the summer of 2011 followed by a gain of about 150,000 cubic yards recorded in the winter survey of 2012 and another gain of about 50,000 cubic yards by the summer of 2012. These gains are, in part due to 122,000 cubic yards of sand placed within the budget cell from the Sebastian Inlet sand trap. The volume gains of 2013 then dissipated by the summer of 2013 followed by a large volume gain in 2014 in the cell, again in part, due to sand bypass from the inlet sand trap. Large sand volume gains in all sand budget cells observed in the winter survey of 2014 indicate that there was a regional depositional event in this period that may be caused by onshore movement of sand from the lower shoreface. Sand volume gains of 2014 in the S1 cell were then passed to the S4 cell by the summer of 2015 as shown in Figure 18. Losses during this period from S2 and S3 also were passed to the S4 cell (Figure 16 and Figure 17). The S1 cell regained about 380,000 cubic yards of sand by the winter of 2018 due to large volume increases recorded by the winter 2016 survey and the post Irma survey of 2017, which served as the summer survey. Similar to 2014, there was a regional depositional event during this period as seen in the records of all sand budget cells from N4 to S4. Net volume change in the S1 cell from 2006 to 2019 was an increase of about 153,000 cubic yards. The most recent gain recorded in the 2019 winter survey captures some of the fill material bypassed form the sand trap. Although the official placement location for the fill was between R10 and R17, some of this material may have spread into the S1 cell as indicated by sand volume losses recorded in the S2 sand budget cell located between R10 and R17. A sand volume gains of about 81,500 cubic yards was measured between the late summer survey of 2018 and the late winter survey of 2019.

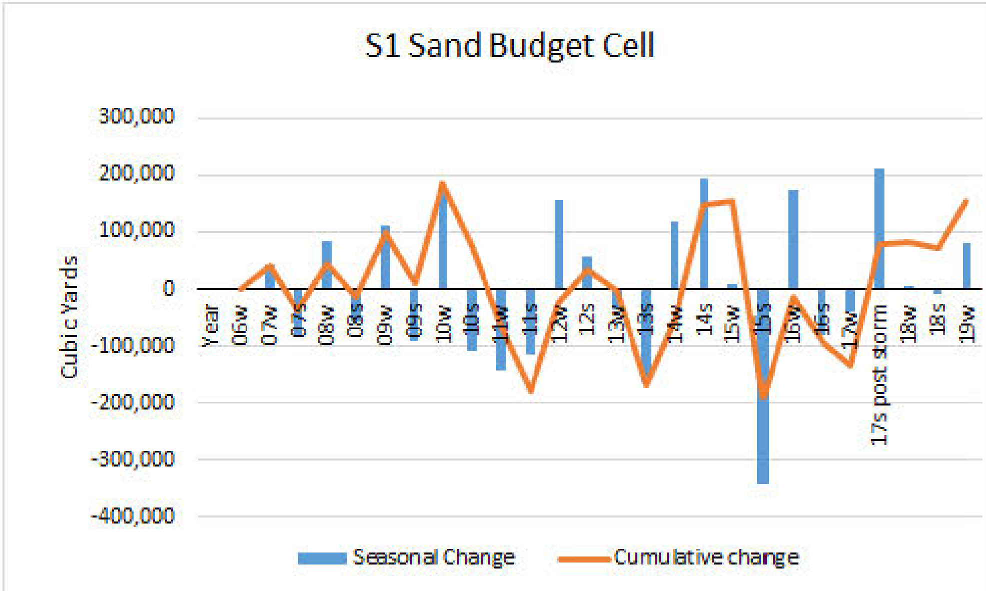


Figure 15. Volumetric evolution of the S1 sand budget cell 2006-2019.

Sand volume changes in the S2 cell (Figure 16, R-10 – R16) were generally similar to those of the S1 cell, being a combination of regional and littoral drift gains followed by sand volume losses that were shifted to the S3 and S4 cells. Gains the in 2010, 2014 and in 2016 are part of regional depositional events followed by sand volume losses over the following year. Over the 13-year period between 2006 and 2019 the net volume change in the S2 cell was a loss of about 284,000 cubic yards, including a loss of about 129,000 yards between the summer 2018 survey and winter 2019 survey. Due to the recently completed 2019 sand bypass project approximately 113,500 cubic yards of sand excavated from the sand trap was placed in this budget cell

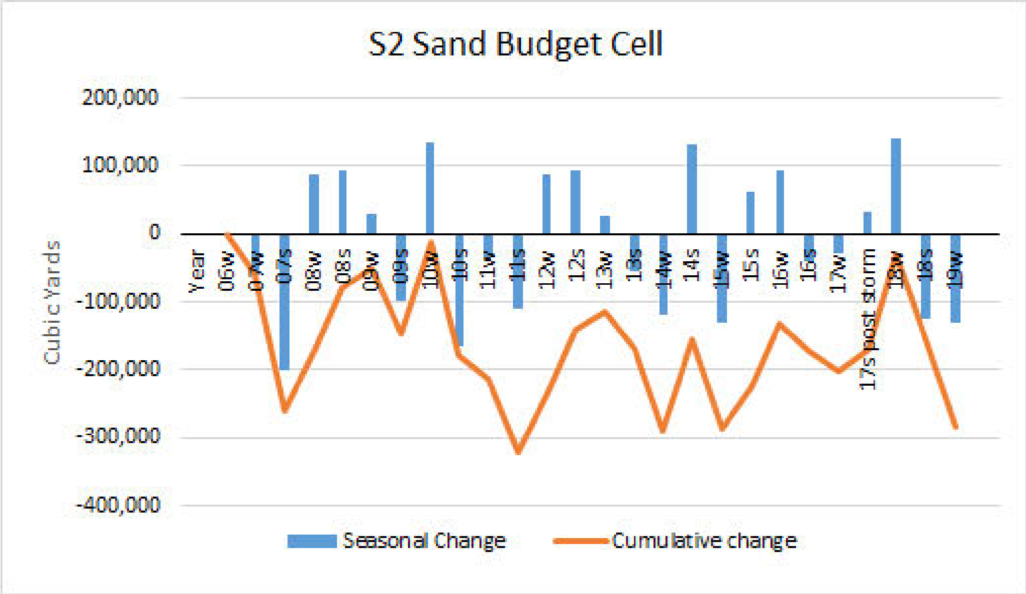


Figure 16. Volumetric evolution of the S2 sand budget cell 2006-2019.

Sand volume changes in the S3 cell (Figure 17) located between R16 and R23 have a more consistent seasonal pattern of gains followed by losses compared to other sand budget cells. However, gains are not always in the winter and losses in the summer. The regional sand volume gains of 2010, 2014, and 2016 are noted in the S3 record. Some of the gains in the S3 cell are offset by one season from a sand gain-loss cycle in cells father to the north indicating transfer of sand to the south by littoral drift. A net sand volume loss of about 318,000 cubic yards between 2006 and 2018 is attributed to a series of seasonal losses not completely balanced by sand volume gains in the following season. This was partially offset by a large seasonal gain of about 194,00 cubic yards between the winter and summer surveys of 2018. However, this was followed by a sand volume loss of about 168,000 cubic yards as recorded in the winter 2019 topographic survey data One of the larger seasonal losses of sand volume occurred in the winter of 2015 of about 350,000 cubic yards. This event was also seen in most of the other sand budget cells.

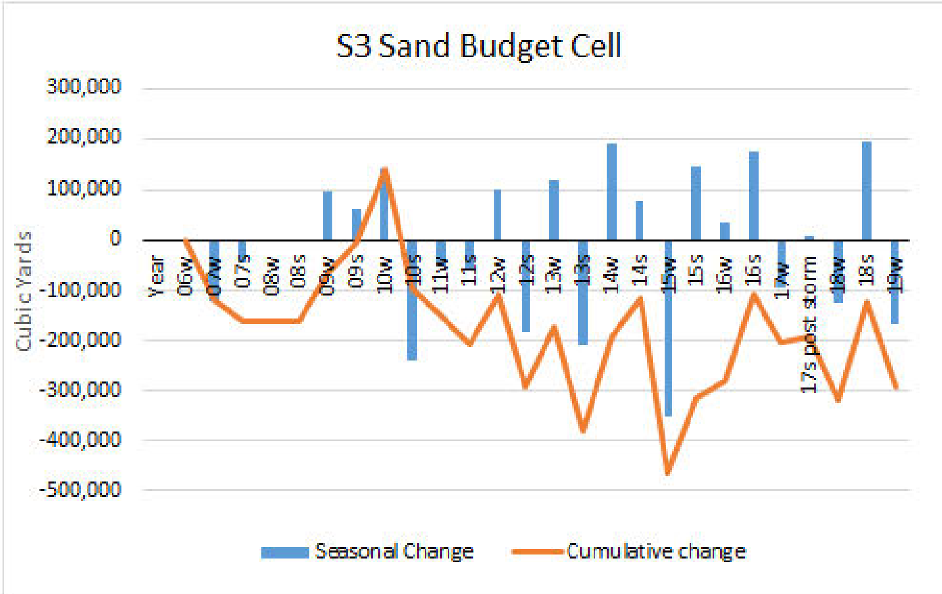


Figure 17. Volumetric evolution of the S3 sand budget cell 2006-2019.

The S4 sand budget cell (Figure 16, located between R23 and R30 (Figure 3) like S3 has an imbalance between seasonal gains and losses that add up to a net volume loss of about 506,000cubic yards between 2006 and 2019. The seasonal pattern of sequential gains and losses is not as consistent as seen in the S2 and S3 cell. The reginal sand volume gains of 2010, 2014, and 2016 persist in S4. Seasonal offsets between S4 and sand budget cells to the north indicate the role of sand movement in the littoral drift system. The interrelation of seasonal sand volume changes among the budget cells is examined in Section 3.3 of this report followed by the sand budget calculation in Section 3.4

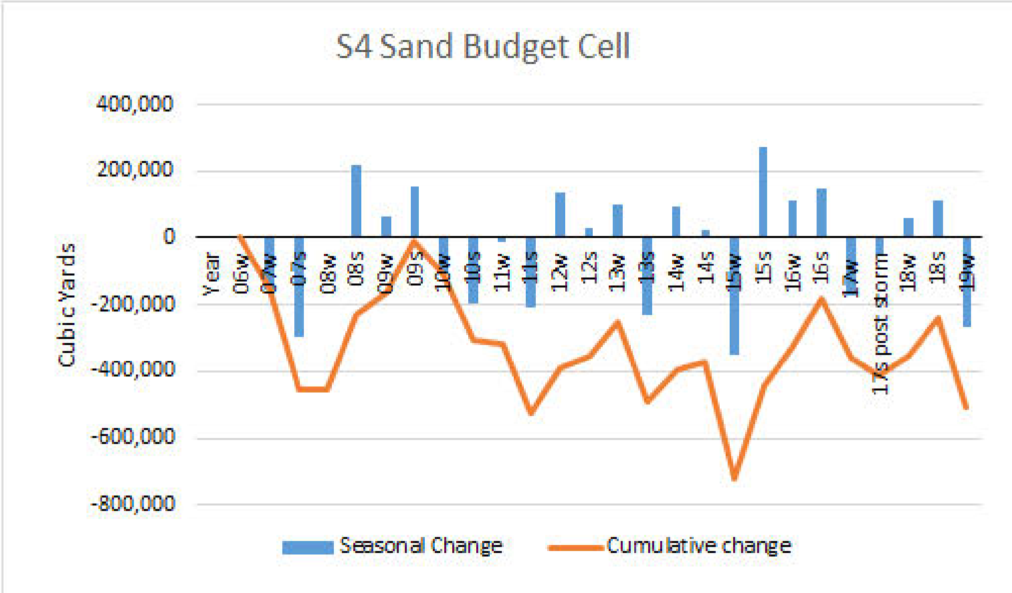


Figure 18. Volumetric evolution of the S4 sand budget cell 2006-2019.

3.3 Analysis of Sand Volume Changes, 2005 – 2019

Individual sand reservoirs and sand budget cells show short term changes that when integrated over time yield a net sediment budget when placed in an annualized format. Further, short-term changes can be spatially tracked though the barrier island-inlet system to observe how sand is moved from one compartment to another. Thus, in order to formulate a regional sand budget based on these data, it is important to consider temporal interrelation among the sand volume components of the Sebastian Inlet system. The time scale of a sediment budget should consider the dynamics of sand volume adjustments. Establishing a sediment budget on a very short time scale could reflect only abrupt changes from seasonal storms and not account for ongoing trends.

To view the interrelation, short-term exchanges, and trends among of the sediment budget cells Figures 19 compares sand volume changes in sediment budget cells on the north side of Sebastian Inlet(N4 – N1). The figure shows the seasonal volume changes along with the cumulative volume change over this time period. Events of larger sand volume changes that correlate among the cells are shown and grouped on the plots along with the occurrence of sand bypassing from the inlet sand trap. A linear first order trend line is added to the plots, which shows that sand volumes in each of the budget cells having a declining trend from 2006 to 2019.

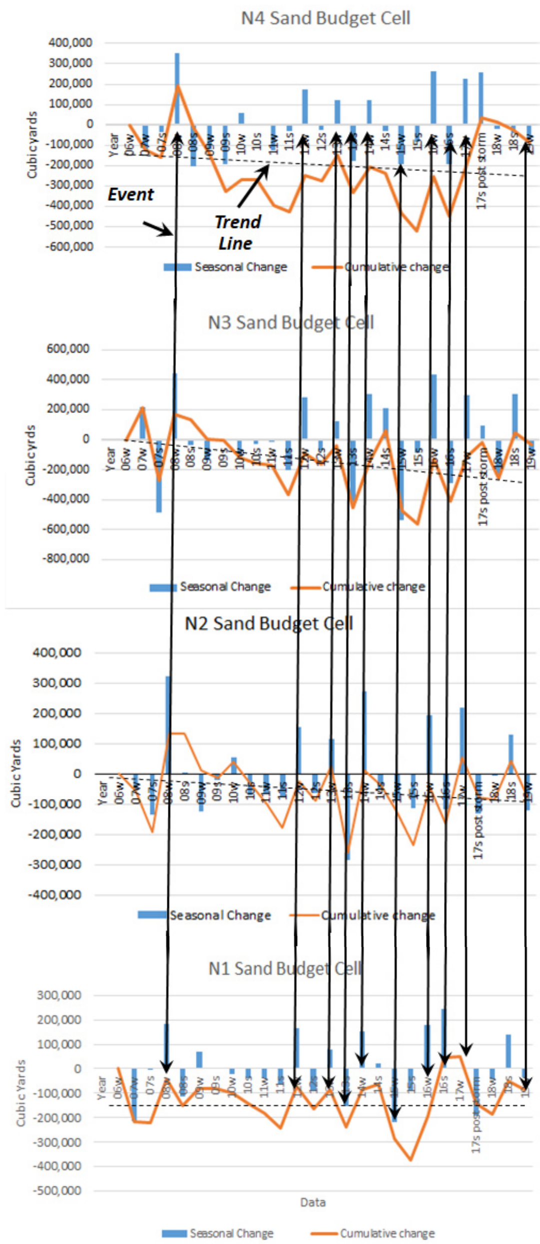


Figure 19. Comparison of sand volume changes within the Sebastian Inlet sediment budget cells N4 to N1 from 2006 to 2019.

The N2 budget cell adjacent to the north side of the inlet entrance had no trend over this period. Most major seasonal volume losses and gains correlate among the four sand budget cells. The largest of these is a sand volume gain about 200,000 cubic yards or more that occurred between the summer of 2007 and winter of 2008. This was followed by four years of mostly seasonal sand volume declines. From the winter of 2011 a pattern of alternating seasonal volume gains and declines continued until the present. The most recent seasonal changes was a decrease in sand volume among all four cells between the summer survey of 2018 and winter survey of 2019

Figure 20 compares sand volume changes among sand budget cells on the south side of Sebastian Inlet(S1 – S4). Sand volume trends lines are shown along with the occurrence of sand bypassing events by dredging of the Sebastian Inlet Sand Trap.

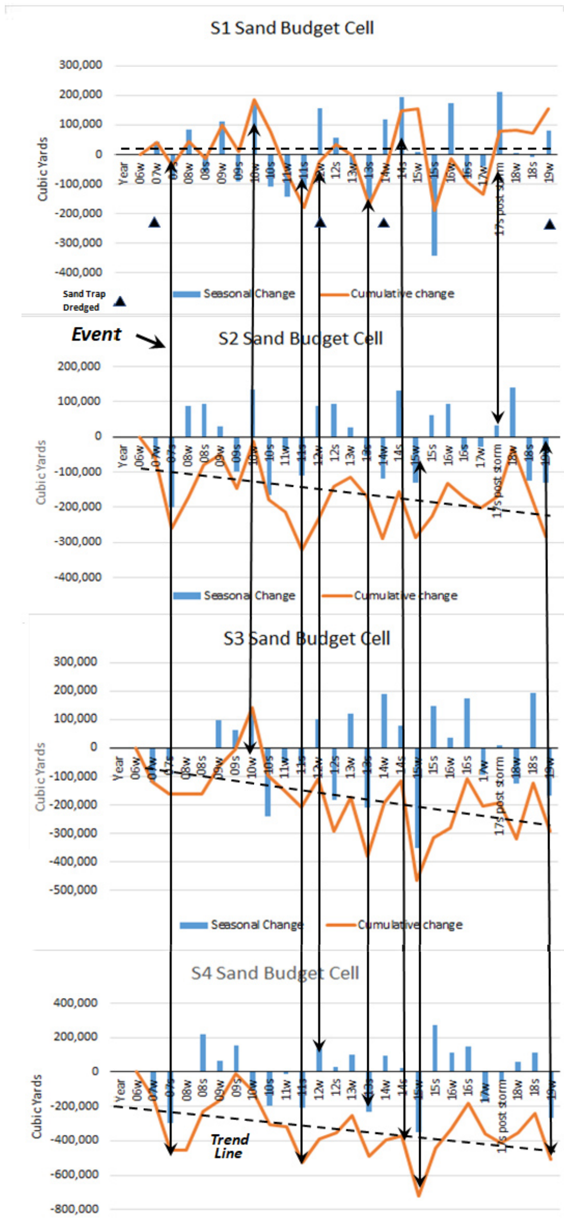


Figure 20. Comparison of sand volume changes within the Sebastian Inlet sediment budget cells S to S4 from 2006 to 2019.

A trend of decreasing sand volume is seen in cells S2 though S4. The trend line for cumulative sand volume changes in the S1 cell adjacent to the south side of Sebastian Inlet is flat for the 2006 to 2019 interval, similar to the lack of a trend in cumulative sand volume on the north side of the inlet. Most of the major seasonal changes in sand volume are correlated among the sand budget cells. A notable exception a large volume gain about 200,00 cubic yards in the S1 cell recorded by the post storm (Hurricane Irma) survey completed in November of 2017. A singular large volume gain of more than 100,000 cubic yards was recorded in the S2 cell by the next seasonal survey in the winter of 2018. This was followed by sand volume gains of 100,000 cubic yards or more in the S3 and S4 cells to the south by the summer of 2018. Large corresponding sand volume losses measured in the N1 and N2 sand budget cells in the post storm survey indicates that the sand volume gains in S1 and S2 in the immediate post storm period may be due to sand bypassing around the inlet by large waves generated by the storm. Later gains in the S3 and S4 cells indicate spreading of the bypassed sand to the south.

The latest survey results show large sand volume losses in excess of 100,000 cubic yards in the S2, S3, S3 , and S4 cells between the summer of 2018 and winter survey of 2019 , although approximately 113,500 cubic yards of sand were placed largely in the S2 cell between R-markers 10 and 17. This could be the result of the sand bypassed by the storm of 2017 moving further south. A sand volume gain of about 81,000 cubic yards in the S1 cell between summer 2018 and winter 2019 may indicate sand back passing from the fill template in S2. Alternatively, the increase in sand volume in S1 may have result in sediment eroded from the N2 and N1 cells on the north side of the inlet moving across the inlet and into the S1 cell.

To farther elucidate the movement of sand across Sebastian Inlet and resolve regional shifts in sand volume from local inlet related exchanges Figure 21 compares sand volumes in N1, Inlet, and S1 sand budget cells. These cells include all of the inlet reservoir cells as shown in Figure 3. The inlet budget cell includes the ebb shoal, flood shoal, sand trap, channel and throat sections as shown in Figure 4. The inlet budget cell also includes approximately 3,000 feet of beach and shoreface to the north and south of the inlet entrance, effectively including the north and south inlet fillet areas.

In Figure 21,major events that cover all three sand budget cells can be resolved from those that are positively coupled between the N1 cell and inlet cells or coupled between the S1 sand budget cell and the inlet cell. And events of sand volume gains across all three cells was measured by the winter 2008 survey. Sand volume gains across all three sand budgets also were also apparent in the winter surveys of 2012, 2014, and 2016. Sand volume losses events corresponding in all three cells were measured in the summer 2013 and summer 2015 surveys. Large sand volume gains/losses in two out of the three and budget cells corresponding to losses/gains in the remaining cell may indicated movement of sand across the inlet in the littoral drift system. As described earlier in this section one of these events indicates storm induced sand bypassing across the inlet storm waves generated by Hurricane Irma. This is noted in Figure 21 by sand volume loses in the N1 and inlet budget cells and a large sand volume gains in the S1 cell measured in the October post-storm survey of 2017. In the most recent topographic survey sand volume losses in the N1 and Inlet budget cells are on the order of 50,000 to 100,000 cubic yards. The recorded "loss" in the inlet cell can be largely attributed to dredging of the sand trap. The observed gain in the S1 cell of about 81,000 cubic yards could be attributed to a combination of sand bypassing across the inlet during the winter months and potential sand back passing from the sand trap fill material placed in largely in the S2 cell to the south.

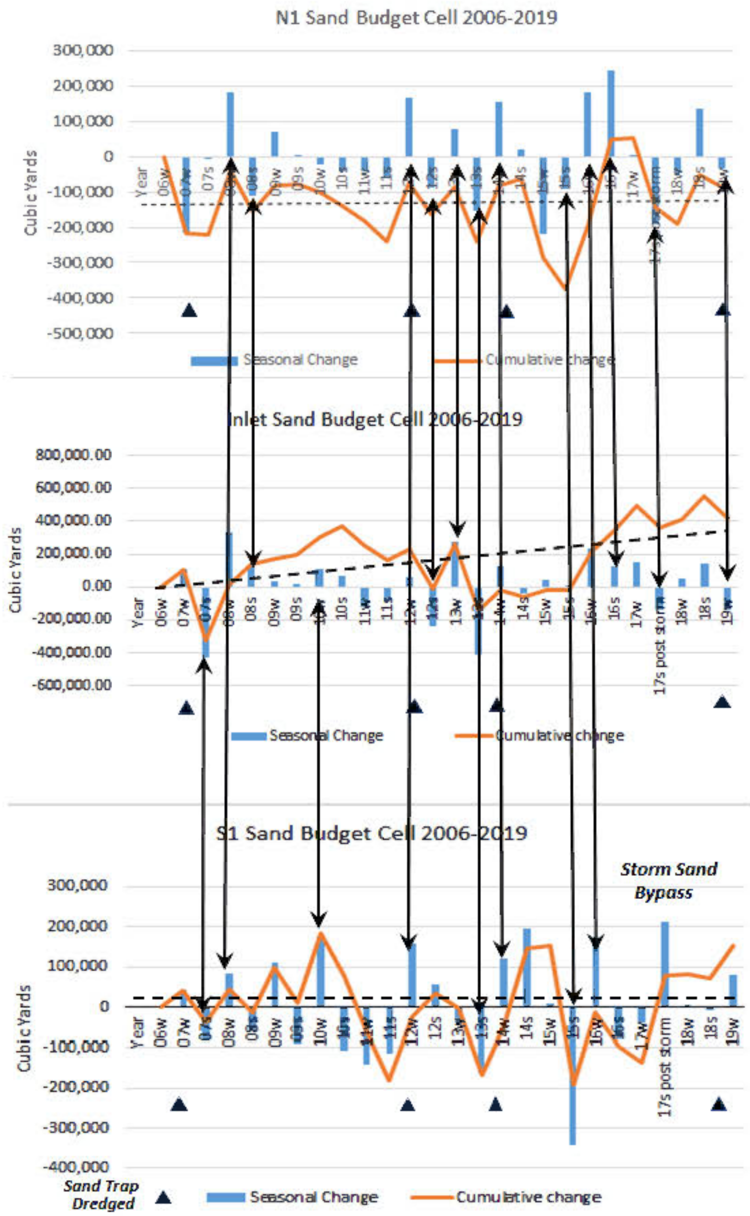


Figure 21. Comparison of sand volume changes within the sediment budget cells N1, Inlet and S1 from 2006 to 2019.

Figure 22 shows that cumulative volume changes over the 12-year period between 2006 and 2019 have a pattern of progressively increasing loss of volume from north to south (S1 to S4). As the cumulative sand volume is viewed over time, the S1 cell shows episodic positive values of sand accumulation. The other budget cells show a spatial downdrift (south) increase in loss within each survey date with the exception of cell S3 which had a net accumulation of about 150,000 cubic yards at the winter 2010 survey along with a gain of nearly 200,000 cubic yards in the S1 cell and about 15,000 cubic yards in the S2 cell. At this time cumulative sand volume losses in the S3 and S4 cells were at the lowest within the 12-year analysis period.

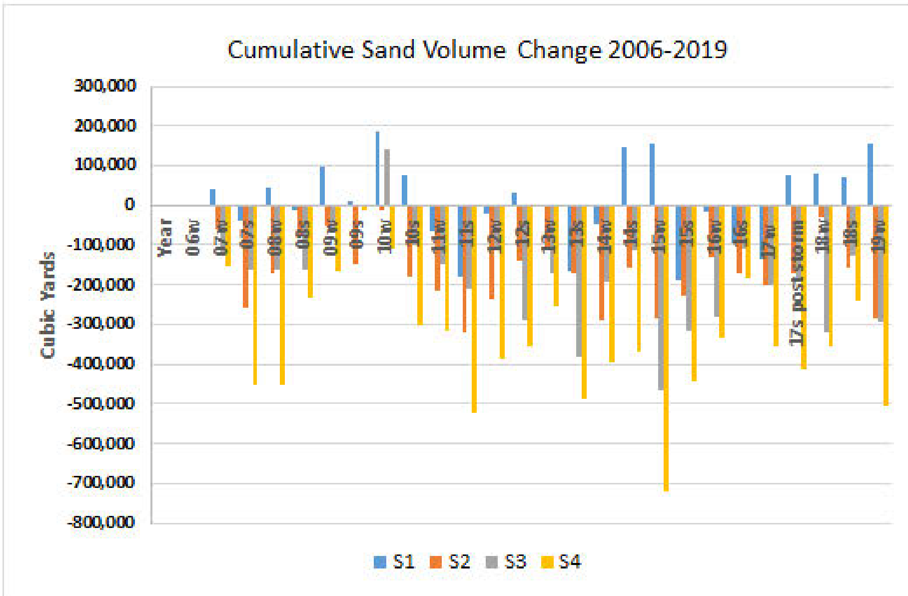


Figure 22. Cumulative sand volume changes in the sediment budget cells south of Sebastian Inlet, 2006 to 2019.

Figure 23 shows the same cumulative sand volume data as presented in Figure 22 along with the cumulative volume changes within the inlet sediment budget cell from 2006 through 2018. If sand accumulation within the inlet budget cell is directly linked to sand volume losses to the south of the inlet, there should an inverse relationship between sand volume changes within the inlet and volume changes to the south of the inlet. However, over most of the 2006 to 2018 period, the inlet sand volume change and volume changes to the south have a positive correlation. Increased sand volume within the inlet corresponds with increased sand volume or declining volume losses in the sand budget cells to the south. For instance, increases in the cumulative sand volume gains within the inlet cell during the summer 2008 to summer 2010 period correspond to sand volume gains and declining sand volume losses in all of the sand budge cells to the south of the inlet. This corresponded to one of the regional depositional events described in Section 3, of this report. Declining sand volume gains and sand volume losses in the inlet budget cell from summer 2013 to summer 2015 corresponded to a period of increase and volume losses in cells S2, S3, and S4. Gains in cell S1 were attributed to sand bypassing projects from the trap. The most recent period of increasing sand volume gains in the inlet cell from winter 2016 to summer 2017 correspond to a period of increasing sand volume loss from cells S2 to S4.

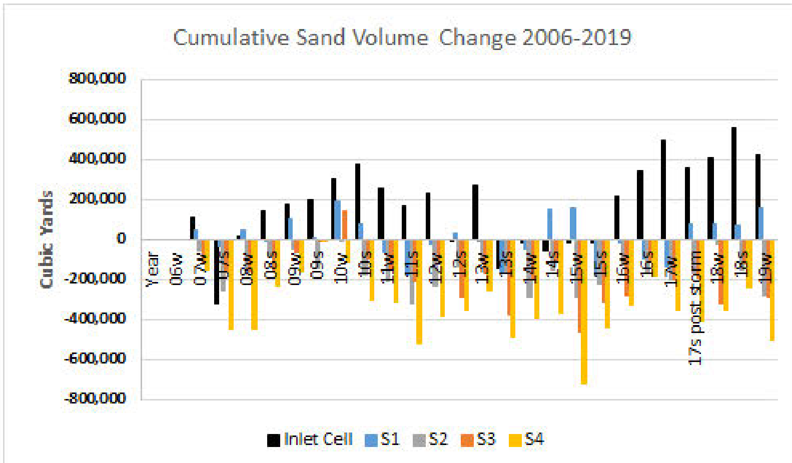


Figure 23. Cumulative sand volume changes in the sediment budget cell in comparison of cumulative volume changes in the Inlet sand budget cell and the S1 to S4 cells south of Sebastian Inlet, 2006 to 2019.

Figure 24 compares volume changes in the S1 to S4 budget cells with sea level changes from 2006 to 2018. Periods of declining decreasing cumulative sand volume losses or gains correspond to periods of sea level drop Periods of higher sea level correspond to periods of increasing sand volume losses. The sea level record for late 2017 and the first 5 months of 2018 may indicate that a period of rising sea level is beginning. This potentially indicates an upcoming period of increased loss of sand volume.

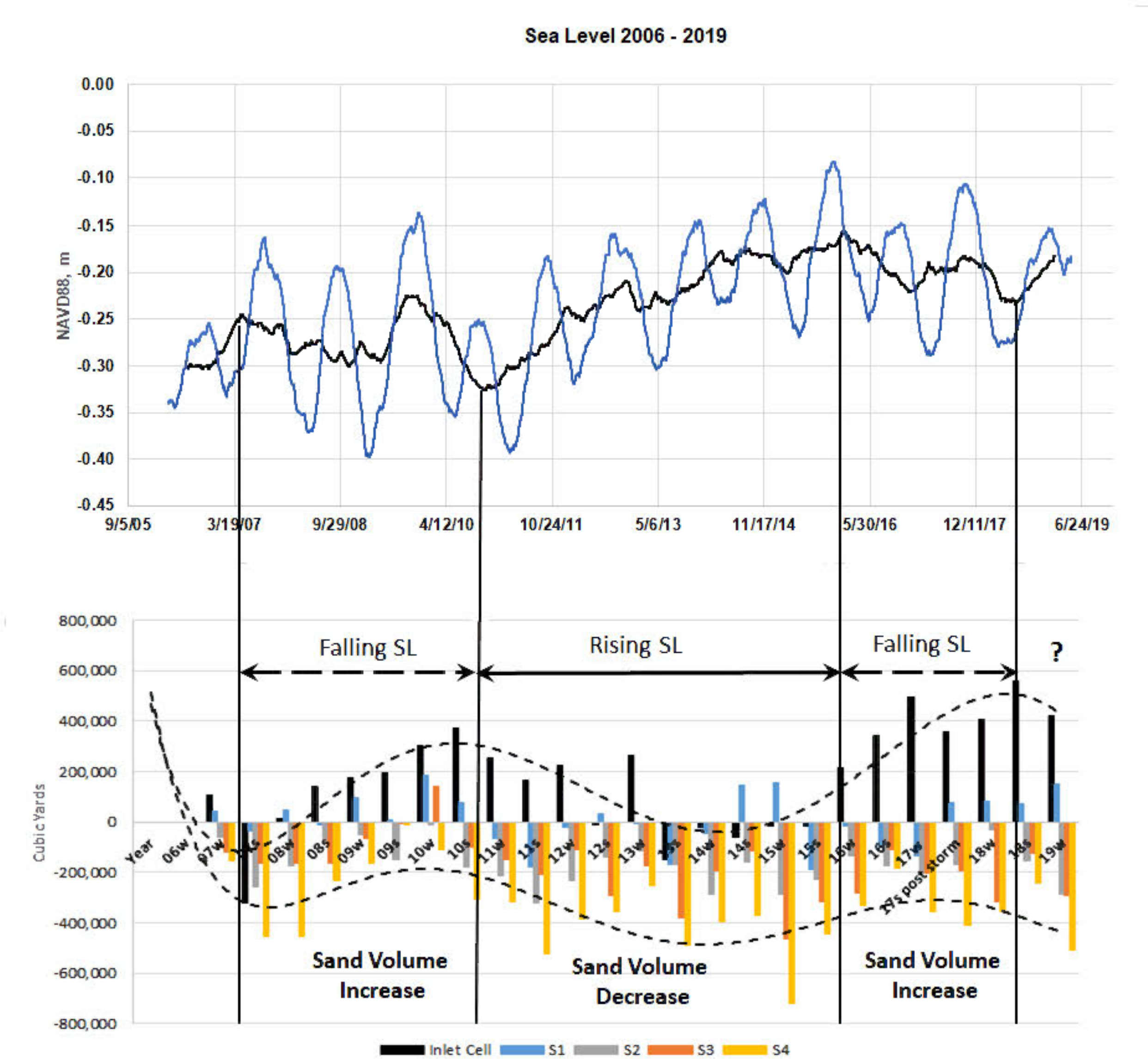


Figure 24. Comparison of sand volume changes in the S1 to S4 budget cells with sea level changes from 2006 to 2018. Solid arrows indicate periods of declining sea level and decreasing cumulative sand volume losses or gains. Solid arrow indicates periods of sea level rise and increasing cumulative sand volume losses

4.0 Sand Budget: Sebastian Inlet and Surrounding Barrier Segments

4.1 Methods

A sediment budget uses the conservation of mass to quantify sediment sources, sinks, and pathways in a littoral cell environment. It is used to quantify the effects of a changing sediment supply on the coastal system and to understand the large-scale morphological responses of the coastal system. The sediment budget equation is expressed as:

$$\sum Q_{source} - \sum Q_{\sin k} - \Delta V + P - R = residual \qquad \text{Equation 1}$$

The sources (Qsource) and sinks (Qsink) in the sediment budget together with net volume change within the cell (ΔV) and the amounts of material placed in (P) and removed from (R) the cell are calculated to determine the residual volume. For a completely balanced cell the residual would equal zero (Rosati and Kraus, 1999). +Figure 25schematically shows how calculations are made within each cell of the sediment budget model.

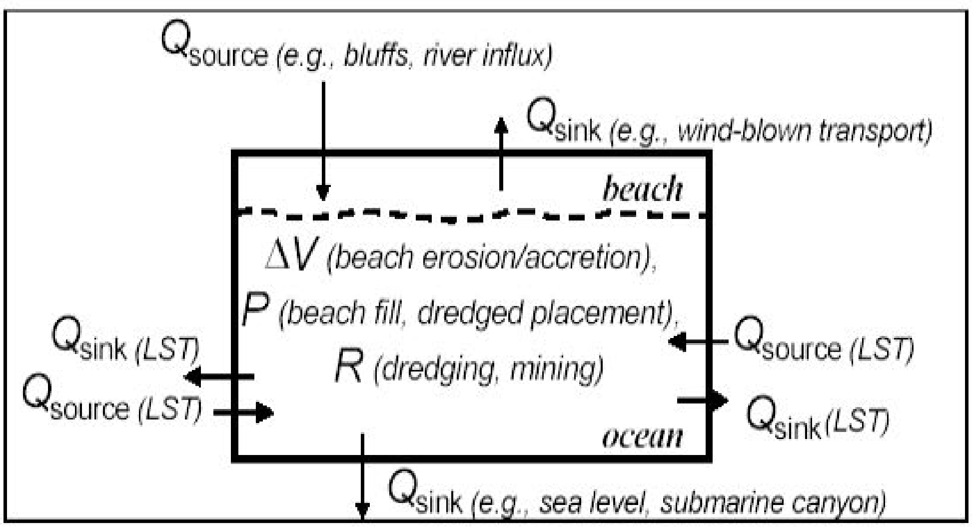


Figure 25. Schematics of a littoral sediment budget analysis (from Rosati and Kraus, 1999).

Determination of net volume change for the local sediment budgets for Sebastian Inlet was based on volumetric analysis masks presented in section 3.0. The sediment budget encompasses the area between monuments R189 in Brevard County to monument R30 in Indian River County.

Since variability of the seasonal sand volume changes can be larger than the average range of values in the sediment budget, the temporal scale of the calculations is based on several time periods ranging from three to ten years between 2008 and 2019. The computational cells (masks) that were used to establish the local sediment budget are schematically shown in the volumetric section (see Figure 3). Volume changes for each mask were determined according to the methods described above in the net topographic changes section and input into the Sediment Budget Analysis System (S.B.A.S) program, provided by the Coastal Inlet Research Program. Details of these procedures can be found in the technical report by Rosati et al. 2001. Based on super regional sediment budget calculations described in Zarillo et al, 2007, an initial input value (Qsource) of 150,000 yd3/yr. was chosen. However, for some time periods the initial input value was increased to 200,000 yd3/yr. to accommodate periods of larger transport rates bounded by winter seasons. The placement values (P) correspond to the beach fill projects that were included in the calculations. Most of this placement is to the south of Sebastian inlet in the S2 and S3 sand budget cell from either the Sebastian Inlet sand trap or from upland sources accessed by Indian River County. However, beginning in 2016, placement in the N4 and N3 cells are associated with post-hurricane repair of beaches in south Brevard County. Removal of sand (R) through mechanical bypassing was included to account for the 2012, 2014, and the 2019 dredging projects within the sand trap. However, removal of sand (R) through offshore losses was assumed to be zero for all cells since the boundaries of the masks extend beyond the depth of closure. This assumption is applied for the longer-term 10-yar sand budgets. In the shorter term it may be necessary to assume either import of sand from offshore sources or import of sand to balance short-term sand budgets at time scales of 3 to 5 years. Placement and removal values are annualized and presented in Table 2.

Table 2. Annualized placement and removal volumes for sand budget calculations. Units are in cubic yards per year

Time Period	Season	N4	N3	N2	N1	Inlet	S1	S2	S3	S4
2009–19	Winter	1572	2070	1493	1022	-44883	24080	19296	6831	13205
2008–18	Summer	1572	2070	1493	1022	-44883	24080	9470	5210	13205
2014 –19	Winter	3144	4140	2987	2044	-65366	22240	64516	5982	6600
2013–18	Summer	3144	4140	2987	2044	-32108	22240	5280	2740	6600
2016-19	Winter	5240	6899	4978	3406	-48667	0	41220	6870	0
2015-18	Summer	5240	6899	4978	3406	0	0	8800	1467	0

4.1 Sand Budget Results

The sand budget is presented on three distinct time scales ranging from a longer-term budget for the past 10-years to short term budgets that examine volume changes and sand flux over 5 and 3-year year periods. The budget uses calculated annualized volume change per cell as inputs (see Figure 3). Annualized beach fill material is accounted for in the N4 to N21 cell on the north side of Sebastian Inlet, the inlet cell, and the S1 to S4 cells a shown in Figure 3.

Interpretation of the fluxes, especially those leaving the southernmost cell (S2, R16-R30) must consider that the sand budget assumes a fixed input of either +150,000 or 200,000 cy/yd. entering the first north cell (N4). Sand transport was assumed to flow north to south. indicate a reversal of sediment transport to the next cell north. The components of the long-term sand budget are listed in Table 3 and covers the period from 2008 through 2019. A comparison is made between winter and summer-based budgets.

Table 3. Annualized volume changes per cell and flux (2008 – 2019).

Time Period	**Winter 2009 – Winter 2019 Qin=150,000 cy/yr.**		**Summer 2008 - Summer 2018 Qin=150,000 cy/yr.**	
Sediment Budget Cell	**V (cy/yr.)**	**Q (cy/yr.)**	**V (cy/yr.)**	**Q (cy/yr.)**
North 4	4,868	146,388	-837	152,409
North 3	-3,686	152,522	-8,871	163,350
North 2	-8,954	162,969	-8,985	173,828
North 1	-264	164,255	10,252	164,598
Inlet	**24,653**	**94,719**	**41,708**	**79,579**
South 1	5,434	113,365	11,597	8,443
South 2	-23,465	156,126	8,980	-7,591
South 3	22,652	140,305	-3,165	3,743
South 4	-34,034	187,544	4,121	-925

Figure 26 is a visual representation of the data listed in Table 3. Shown are the locations of the sand budget cells and the annualized volume changes, and sand fluxes calculated from the survey data. Refer to Figure 10 through Figure 18 for plots of sand volume changes in each of the sand budget cells. For each of these records the volume changes are annualized over the sand budget period and listed in Table 3.

The analysis results for the 10-year sand budget based on a winter to winter period show that all but three cells lost sand volume between 2009 and 2019. Sand budget cell N4 to the north of

Sebastian Inlet and cells S1 and S3 registered and volume gains over this period ,as well as the inlet sand budget cells. The remaining budget cells registered sand volume losses. The annualized sand volume losses were relatively small due to the placement from the sand trap and other sources and large littoral drift rates moving sand from north to south. The inlet cell gained an annual average of about 24,600 cubic yards of sand per year. When 2012, 2014, and 2019 sand trap excavations are combined, the annualized rate of sand removal from the inlet cell is about 44,900 cubic yards per year.

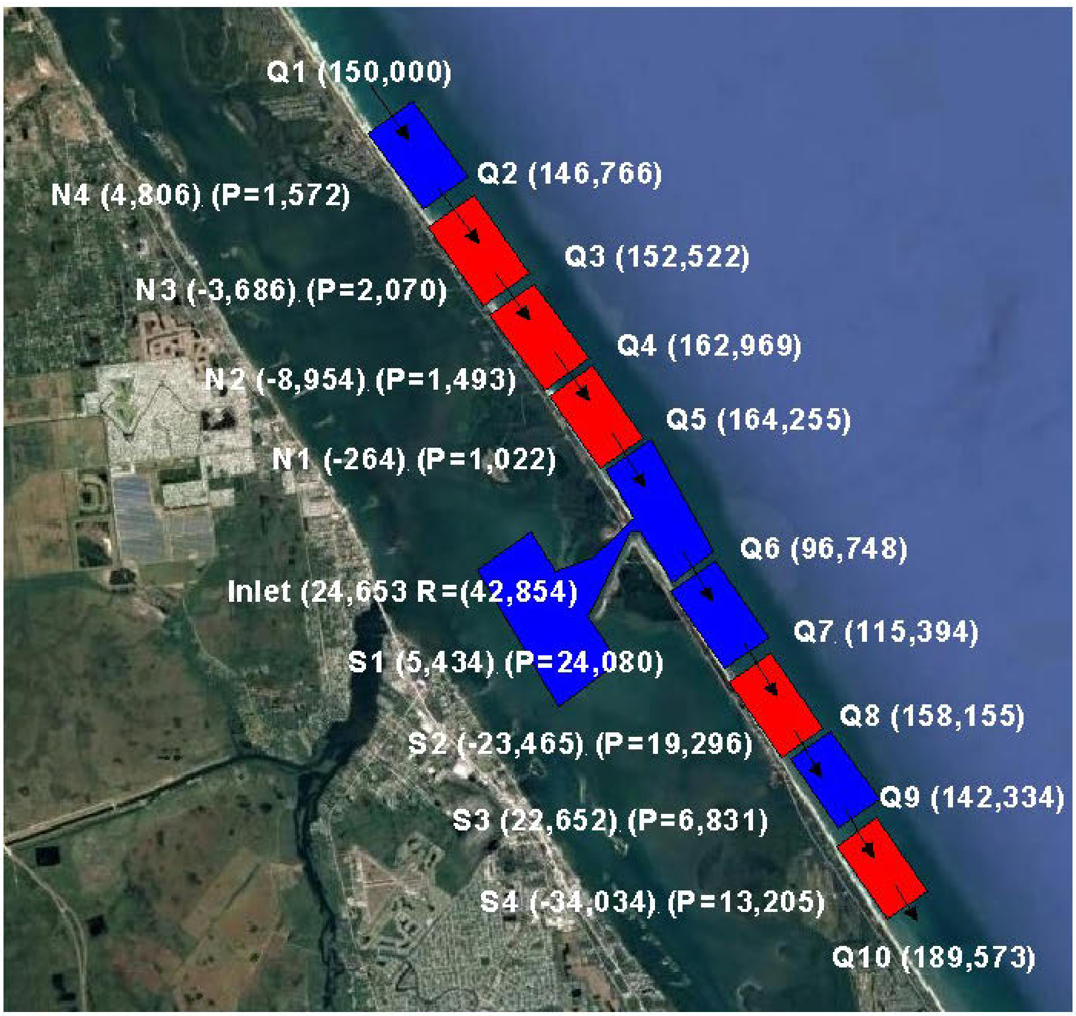


Figure 26. Annualized 10-year sediment budget for the winter 2009 to winter 2019 time period. Values on the west of the barrier island indicate sand volume changes and values on the east indicate calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss.

Figure 27 is the visualization of the summer to summer 10-year (2008 to 2018) sand budget. In this summer to summer analysis, the N1 and S1 sand budget cells adjacent to Sebastian Inlet had volume gains except, along with the inlet sand budget cell and the S3 cell to the south of the inlet. The N4, N3, and N3 cells to the north of the inlet registered sand volume losses, along with volume losses in the S2 and S4 cells to the south of the inlet. The magnitude of the annualized sand volume changes was smaller than the winter to winter changes and generally less than 10,000 cubic yards. Sand volume in the S1 to S4 cells were again aided by sand placement from the Sebastian Inlet sand trap and from upland sources used by Indian River County. The small annualized volumes of sand placement budget terms (P) in the N4 to N2 cells is derived from placement of about 30,000 cubic yards of sand on the beaches by Brevard County in the post storm period of 2017. The annualized gain of sand volume within the inlet budget cell for this period is about 41,700 cubic yards. This is largely offset by sand placement from the sand trap and upland sources in the S1 to S4 cells. Over the 10-year period between 2008 and 2018 a total of 520,670 cubic tards of sand was placed in these cells for an annual average of about 52,060 cubic yards.

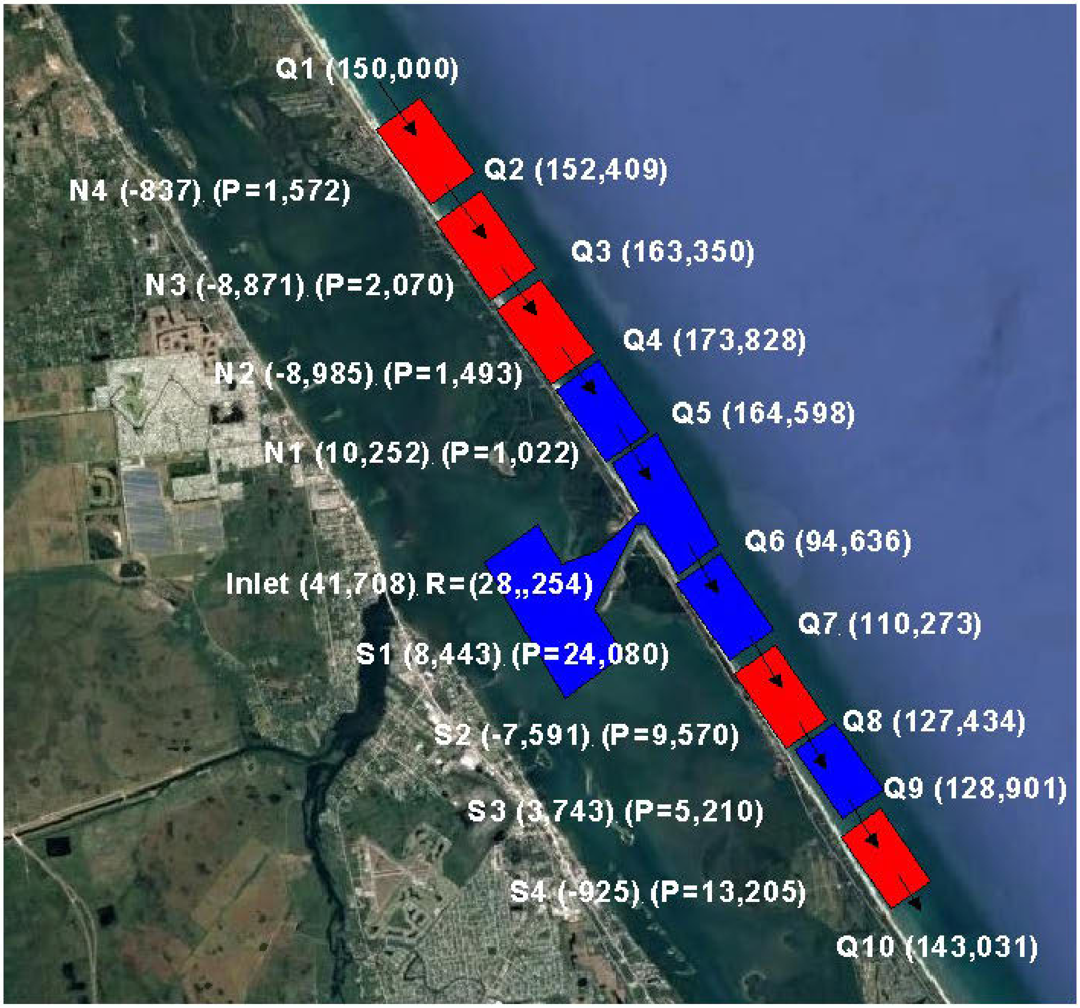


Figure 27. Annualized 10-year sediment budget for the summer 2008 to summer 2018 time period. Values on the west of the barrier island indicate sand volume changes and values on the east indicates calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss.

A 5-year sand budget was calculated to compliment the longer term 10-year calculation. Table 4 lists the results for the winter 2014 to winter 2019 and summer 2013 to summer 2018 five-year calculations. The winter sand budget begins with an annualized input of 200,000 cubic yards at the north sand budget cell N4. Similar to the 10-year winter to winter sand budget (Table 3, Figure 26), the calculated littoral drift sand transport rates to the north of the inlet are higher compared to the companion summer to summer sand budget. Within the individual cells, there is a mix of annualized volume gains and losses among the budget cells (Figure 28). Annualized sand volume gains in the N4, N3, inlet ,S1 and S2 sand budget cells combined with the beginning littoral transport valued of 200,000 cubic yards creates a deficit of sand volume available for littoral transport to the south. This requires either onshore transport of sand or a reversal of the littoral transport directions in the vicinity of the inlet. Another way to balance the sand budget would be simply assume no net littoral drift when the transport calculation becomes zero and the sand is added to budget cells. When viewed on a gross sand transport basis one can also make a judgment that the net transport is tending towards zero and the sand volume is moving north and south adding up to a net transport of near zero. This demonstrates the difficulty in calculating shorter term sand budgets. In this report we assume that there is an additional source of sand moving onshore from beyond the depth of the survey coverage. These additional sand sources could also correspond to temporary shifts to a lower sea level in the past few years as illustrated in Figure 24.

The annualized sand volume gain of about 88,233 cubic yards of sand within the inlet cell is more than offset by sand placement in the S1 to S4 cell from the sand trap and sources proved by Indian River County that totaled about 99,340 cubic yards per year. The five-year summer to summer sand budget listed in

Table 4 and illustrated in Figure 29 is depositional on an annualized basis. The 2013 to 2018 time period corresponds to a period of sand volume gains across the entire sand budget domain. As seen in Figure 24, the summer to summer 5-year sand budget includes a trend declining sand volume loss and increase in sand volume gains in the S1 to S4 cells even as the cumulative sand volume increased within the inlet sand budget cell. This period also corresponds to a period of declining sea level. In order to balance the sand budget and keep the calculated net littoral drift moving to the south at a rate of above 100,000 cubic yards per year, a net onshore transport of sand is assumed for all sand budget cells. Thus, the net annulate rate at the north end of the sand budget is assumed to be 200,000 cubic yards per year and the net south directed rate of sand movement calculated at the south end of the budget area is about 160,000 cubic yards per year. An alternative interpretation is that the net transport is low and the total littoral drift of sand is about equally divided between north and south directions.

Table 4. Five-year sand budget annualized volume changes per cell and flux

Time Period	**Winter 2014 – Winter 2019 Qin=200,000 cy/yr.**		**Summer 2013 - Summer 2018 Qin=200,000 cy/yr.**	
Sediment Budget Cell	**V (cy/yr.)**	**Q (cy/yr.)**	**V (cy/yr.)**	**Q (cy/yr.)**
North 4	23,993	179,151	61,515	16,6629
North 3	-22,597	160,694	100,180	14,5598
North 2	-17,745	181,426	61,012	16,2564
North 1	-184	183654	34,479	15,5129
Inlet	**28,234**	**55,055**	**140,896**	**107,125**
South 1	17,112	62,131	47,831	10,6534
South 2	1361	125,821	3,060	13,3754
South 3	-29198	141,919	25,659	13,5835
South 4	-20181	159,711	24,737	14,2698

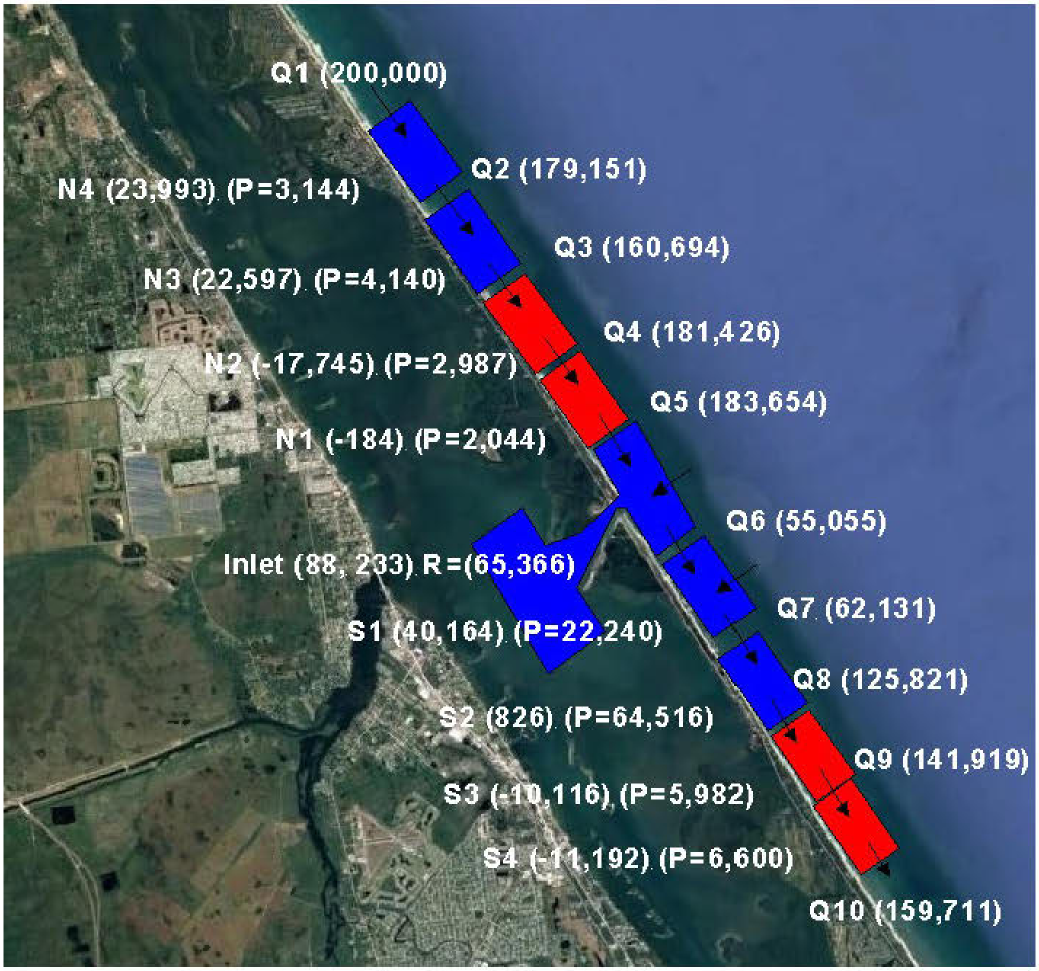


Figure 28. Annualized 5-year sediment budget for the winter 2014 to winter 2019 time period. Values shown to the west of the barrier island indicate sand volume changes and values on the east indicates calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss.

Figure 29. Annualized 5-year sediment budget for the summer 2013 to summer 2018 time period. Values on the west of the barrier island indicate sand volume changes and values on the east indicates calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss.

Two 3-year sand budgets are calculated to contrast sand exchanges among the budget cells during a time of stable or slightly increasing volume of the ebb shoal and during a time of declines in flood shoal volume (See Figures 5 and 8). Although short-term 3-year sand budget is not useful for regional sand management over longer periods, it provides insight on the role of episodic changes in the volume of sand reservoirs on the sand budget. As seen in Figure 5, the Sebastian Inlet ebb shoal has increased in volume by approximately 250,000 cubic yards between 2006 and 2019. However, the increase has not been continuous and is the integrated result of a series of seasonal sand volume losses and gains of about 50,000 cubic yards or less.

Figure 30 displays the results of calculating 3-year sand budgets from winter 2016 to winter 2019 when the volume of the ebb shoal gained about 3,500 cubic yards of sand (see Figure 5). The second 3-year period shown in Figure 31 is from summer 2015 to summer 2018 when the ebb shoal volume increased by about 14,500 cubic yards. In these time intervals the flood shoal lost about 37,700 cubic yards (2016-19) and 48,800 cubic yards (2015-2018). In this period sea level was on the average declining.

In both, 3-year time periods additional sand fluxes were required to balance the sand budget and keep annualized longshore transport rates at reasonable levels. In the 2016 to 2019 period, the input sand flux at the north boundary of the sand budget cells was specified at 200,000 cubic yards per year. Annualized sand volume gains in three sand budget cells were required to keep annual net littoral drift moving to the south and prevent littoral sand transport from reversing direction to the north. An annualized gain of 25,000 cubic yards was specified for each cell. Thus, the annualized budget began with the input of 200,000 cubic yards of sand on the north and ended with a calculated 206,401 cubic yards exiting the sand budget are on the south.

In the 2015 to 2018 summer to summer sediment budget all sediment budget cells gained volume on an annualized basis. The net gains ranged from about 3,000 to 100,000 cubic yards of sand per annuum. The budget calculations was initiated with an annual net south directed littoral drift rate of 200,000 cubic yards at the north boundary of the budget arear. In order to prevent the net littoral drift rate from decreasing to zero additional sand volume inputs from offshore were specified. These inputs ranges from about 25,000 to 100,000 cubic yards on an annualized basis. An alternative interpretation is the that the actual net littoral drift rate was near zeros as littoral sand transport changes directions during the 3-year periods. In either interpretation sand volume gains during this period were substantial. The 3-year sand budget, although not useful for long term planning and sand management, illustrates that depositional and erosional events can overwhelm the local to regional sand budget on a short-term basis.

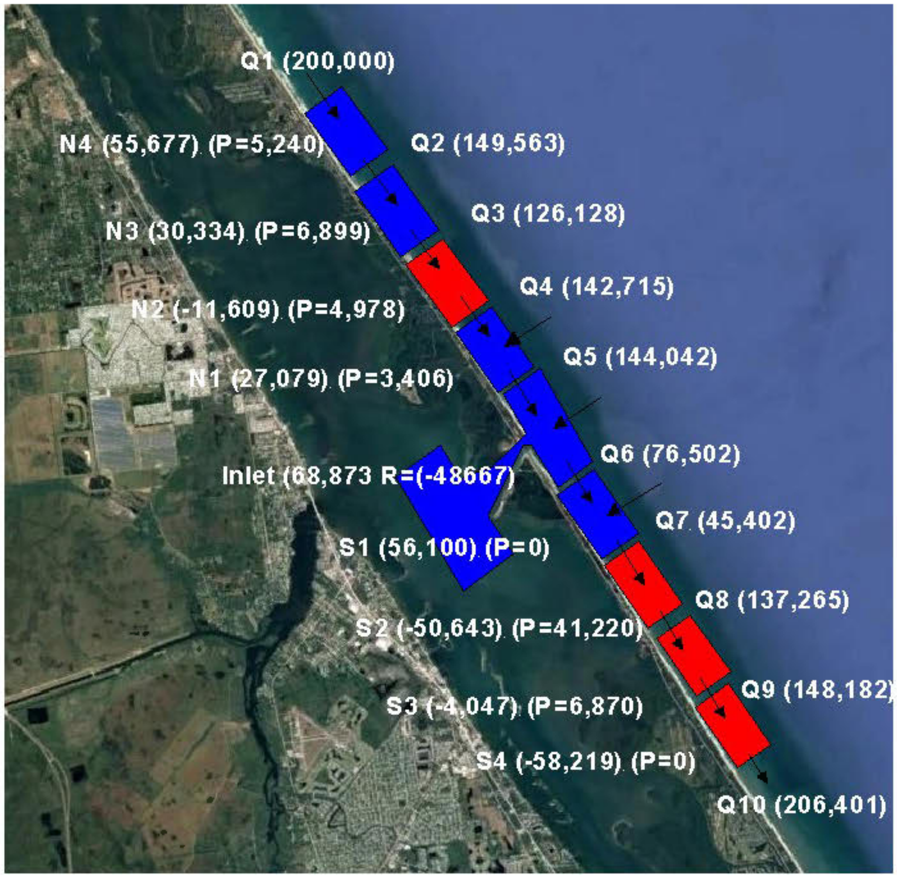


Figure 30. Annualized 3-year sediment budget for the winter 2016 to winter 2019 time period. Values on the west of the barrier island indicate sand volume changes and values on the east indicates calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss. Offshore transport from each of the cells was required to balance the sand budget.

Figure 31. Annualized 3-year sediment budget for the summer 2015 to summer 2018 time period. Values on the west of the barrier island indicate sand volume changes and values on the east indicates calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss. Onshore transport from cells N1 to N4 was required to balance the sand budget.

5.0 Morphologic Changes

5.1 Methods

The analysis uses the same datasets and overall methodology as the sand volume analysis and sand budget analysis described under Sections 3 and 4. The morphologic change section is subdivided according to the time period of analysis. The time interval covered in this report includes a longer time period of 2008 to either 2018 or 2019 and a shorter interval covering approximately 1 year to 18 months. The net morphologic changes over 5-year and 20-year periods are presented in the series of earlier report (Zarillo et al, 2007, 2012, 2013, 2016).

In the color convention for figures depicting topographic change; blue represents erosion, whereas red indicates deposition. Topographic changes were combined with results from shoreline changes and sand budget calculations for a better understanding of the sedimentation processes.

5.2 Topographic Changes

Figure 32 shows net topographic changes in the vicinity of Sebastian Inlet for the longest time period examined based on the winter 2009 and winter 2019 topographic surveys. As seen in Figures 5 and 8 in Section 2 of this report the net sand volume change of the flood shoal was minimal and the accumulation of sand within the ebb shoal area was about 160,00 cubic yards, which can be seen in Figure 32 as areas of 1 to 5 feet of shoaling. Sand accumulation within the S1 budget cell can be seen in the southeast section of the plot and correlates with sand volume accumulation of about 54,000 cubic yards seen in Figure 15, Section 3.2 of this report. The summer 2009 to summer 2018 comparison shown in Figure 33 is similar to the winter to winter comparison shown in Figure 32, especially over the ebb shoal. However, the volume loss shown in blue largely in the S1 sand budget cell is probably due to low sand bypass rates over the summer months. At the 10-year time scale dredging of the sand trap is more evident in Figures 32 and 34, which include the winter of 2019 when the latest project in the sand trap was completed. Sand volume accumulation in the S1 represented in Figures 32 and 34 are either due to sand bypassing by winter storms, backpassing from the fill template area largely in the S2 sand budget cell area, or a combination of both

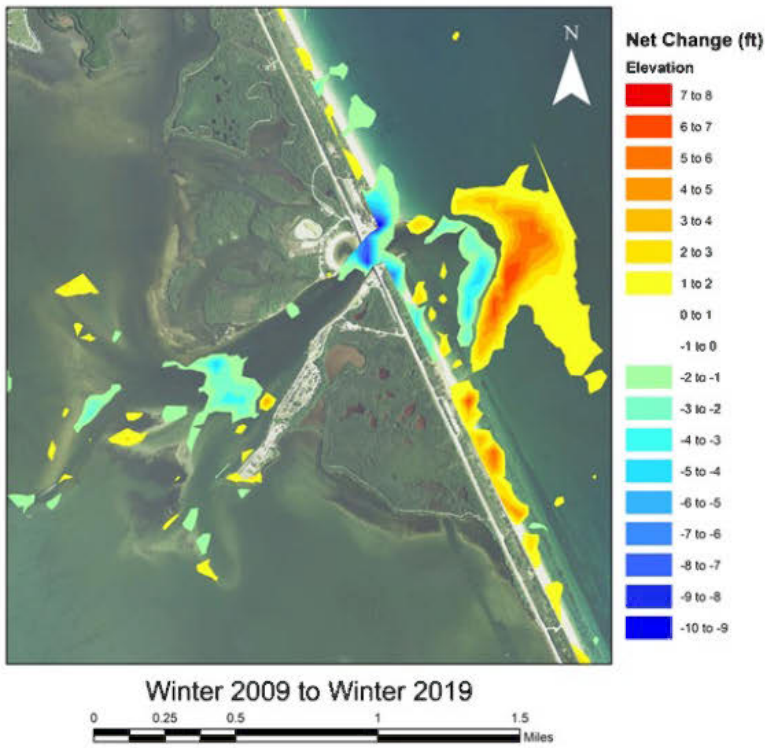


Figure 32. Topographic changes in the vicinity of Sebastian Inlet between the winter 2009 and winter 2019.

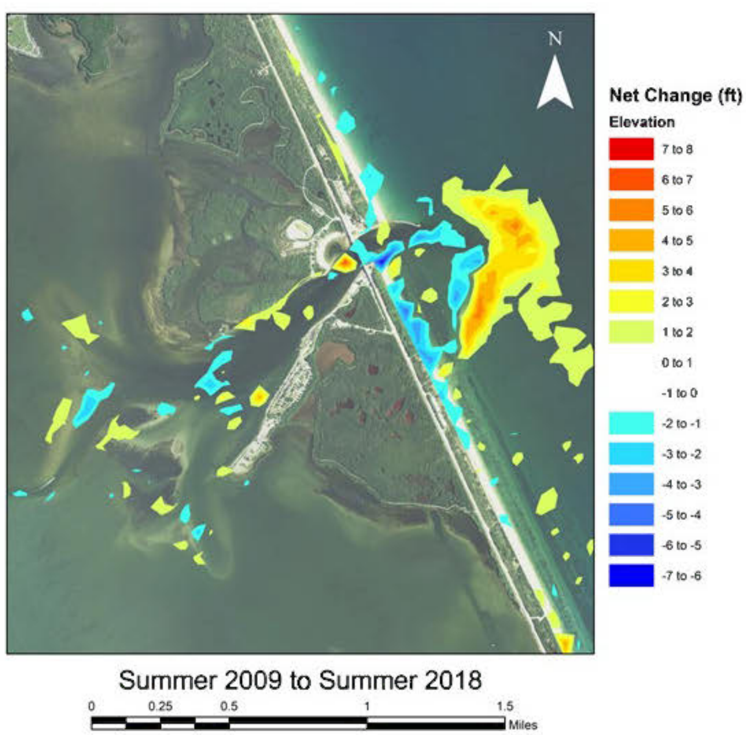


Figure 33. Topographic changes in the vicinity of Sebastian Inlet between the summer 2008 and summer 2018.

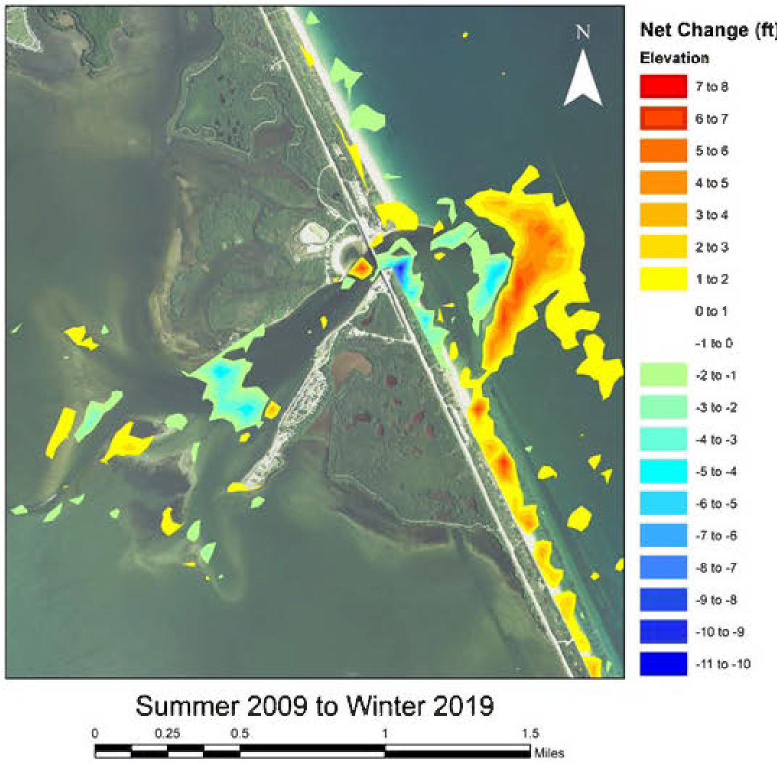


Figure 34. Topographic changes in the vicinity of Sebastian Inlet between summer 2009 and winter 2019.

Sand volume accumulations shown in Figure 35, similar to those shown Figure 33, are confine to the ebb shoal area. In this comparison of the 5-year period between summer 2013 and summer 2018 does not include the sand bypass from the 2019 sand trap project or natural sand bypassing by storms and higher energy waves of winter 2019.

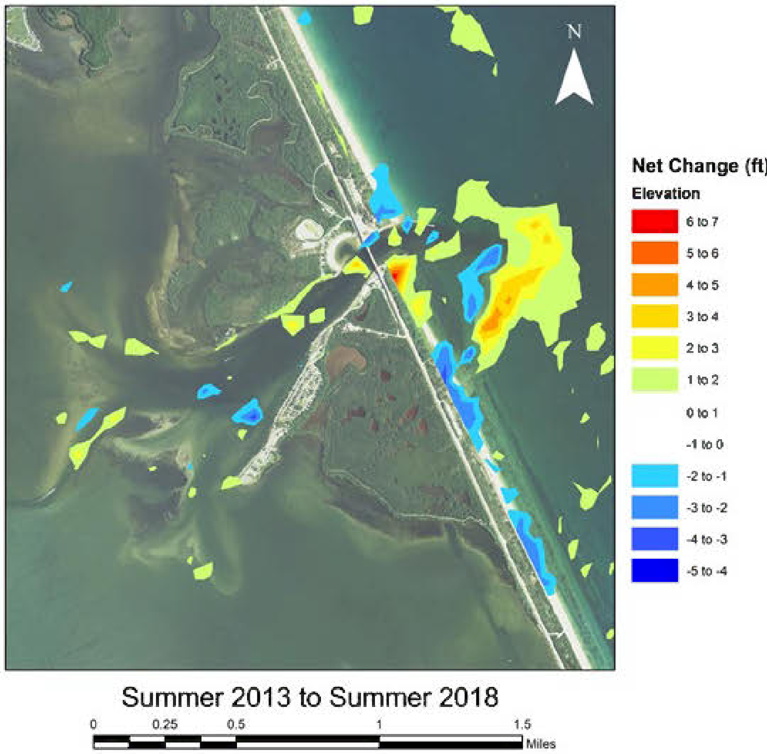


Figure 35. Topographic changes in the vicinity of Sebastian Inlet between summer 2013 and summer 2018.

Topographic changes over the 5-year period between winter 2014 and the topographic survey of winter 2019 show the impacts of sand trap projects of 2014 and 2019 (Figure 36). Excavation of the sand trap is marked by the volume losses represented in blue over the sand trap and possibly sand volume gains in the S1 cell on the south side of the inlet. Blue colors within the inlet throat section represent erosion and possibly scouring by strong currents in the vicinity of the south jetty and adjacent upper shoreface and beach.

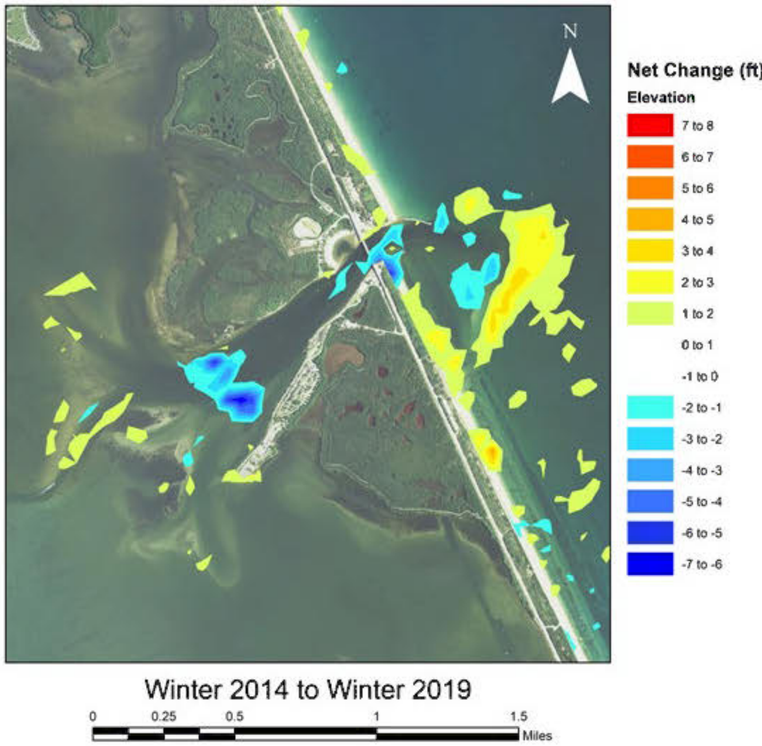


Figure 36. Topographic changes in the vicinity of Sebastian Inlet between winter 2014 and winter 2019.

Topographic changes at the seasonal time scale are shown in Figures 37 to 40. In this sequence of plots the natural inlet sand bypass process can be seen in combination with the effects of sand trap dredging and sand placement during the winter of 2019. In figure 37 depicting topographic changes between winter and summer of 2017, sand resources on the north side of Sebastian inlet appear to be depleted after a winter sand bypass driven by episodic storms. This sequence is entirely post Hurricane Irma. Figure 38 (summer 2017 - winter 2018)showing sand accumulating on the north side of the inlet, in the inlet throat and on the ebb shoal largely within the inlet budget cell. This is followed by the winter 2018 to summer 2018 comparison in Figure 39 showing accumulation on the south side of the inlet from natural sand by passing

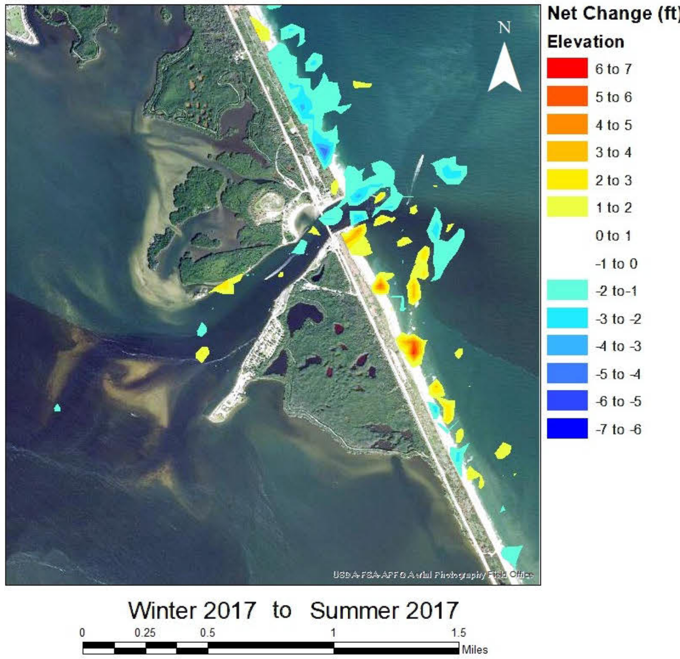


Figure 37. Topographic changes in the vicinity of Sebastian Inlet between winter 2017 and summer 2017.

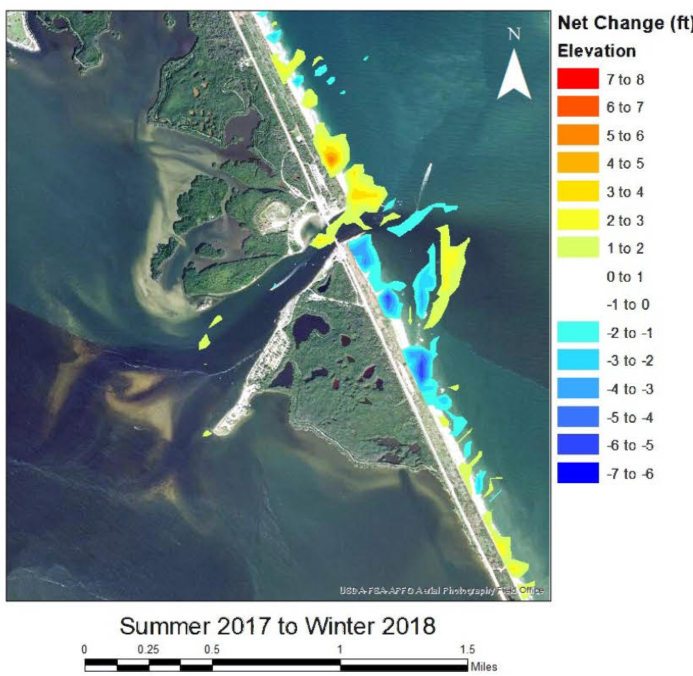


Figure 38. Topographic changes in the vicinity of Sebastian Inlet between summer 2017 and winter 2018.

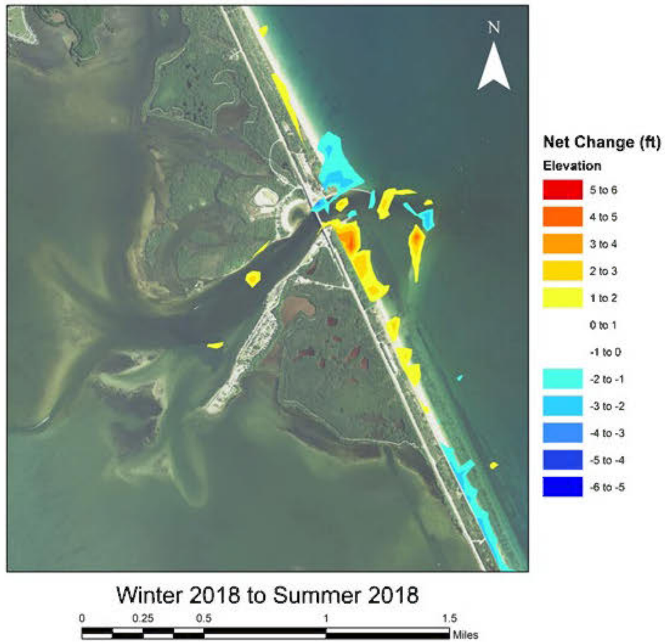


Figure 39. Topographic changes in the vicinity of Sebastian Inlet between winter 2017 and summer 2018.

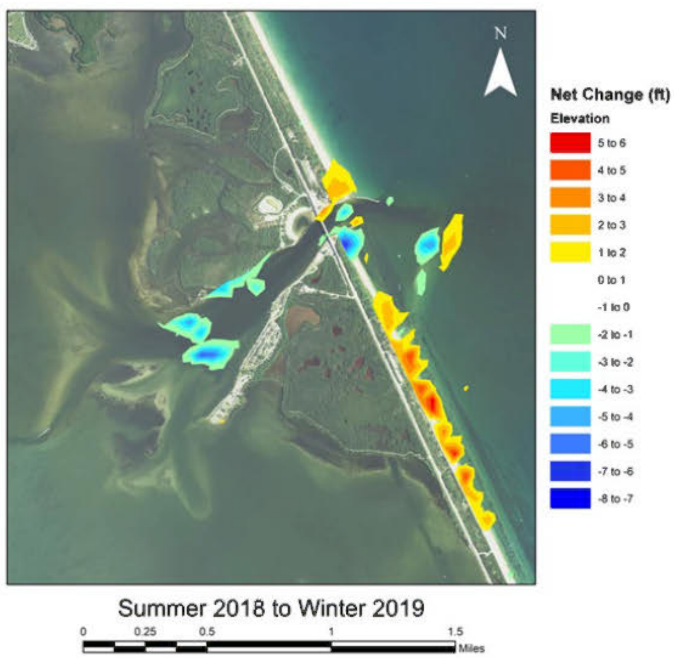


Figure 40. Topographic changes in the vicinity of Sebastian Inlet between summer 2018 and winter 2019.

In figure 40 the combined effects of natural sand bypassing and sand bypassing from the Sebastian Inlet sand trap are apparent. On the south side of the inlet and extending into the north end of the S1 budget cell. Sand is also seen beginning to accumulate on the north side of the inlet. This overall cycle of temporary accumulation on the north side of Sebastian Inlet accumulation and bypassing to the south side is likely to continue on a season to season basis.

6.0 Shoreline Changes

Shoreline positions identified by the wet-dry line on the lower beach were digitized from the geo-referenced aerial imagery for a domain covering approximately 7 miles north to 7 miles south of Sebastian Inlet, FL (~75,000 ft, Table 5). Changes to the shoreline position were determined by comparing 35 time series of transects generated every 25 ft along the coast. Table 5 indicates the extent of coverage for each of the time series used in the analysis according to the total number of transects and the alongshore distances. Table 6 shows the extent of coverage and the aerial image sub-cells (e.g. N1, S2, North) used for analysis within the full domain. Transects were generated using the BeachTools© extension for ArcGIS © from a standardized baseline (~SR A1A) to the wet/dry line (low-tide terrace). The change in shoreline position was determined by subtracting the distances along each transect between time-series of interest. Shoreline change rates were calculated using both the End Point Rate (EPR) and Linear Regression (LR) methods (Crowell et al., 1993; Morton et al., 2002). For details on the methodology the reader is referred to 2007's State of Sebastian Inlet Technical Report 2007-1. In the current updated version of the report, long-term changes and rates of change have been updated for the time spans of 1958-2018 (historical, sixty years) and an intermediate term analysis covered the years 2008-2018 (ten years). Additional short-term analyses are included to account for the changes occurring since the previous report, spanning from 2017-2018, as well as those changes occurring during the most recent five-year time span of 2013-2018.

Table 5. Summary of transect coverage.

Year	Extent of Coverage					North					South				
	#	Distance		Transects		#	Distance		Transects		#	Distance		Transects	
	Transects	feet	miles	start	end	Transects	feet	miles	start	end	Transects	feet	miles	start	end
1943	2442	61050	11.6	531	2972	950	23750	4.5	531	1480	1465	36625	6.9	1508	2972
1958	2300	57500	10.9	0	2299	1481	37025	7.0	0	1480	792	19800	3.8	1508	2299
1968	1853	46325	8.8	1118	2970	363	9075	1.7	1118	1480	1463	36575	6.9	1508	2970
1970	405	10125	1.9	1369	1773	112	2800	0.5	1369	1480	266	6650	1.3	1508	1773
1972	1349	33725	6.4	501	1895	934	*23350	4.4	501	*1480	388	9700	1.8	1508	1895
1974	2144	53600	10.2	831	2974	650	16250	3.1	831	1480	1467	36675	6.9	1508	2974
1978	2038	50950	9.6	935	2972	546	13650	2.6	935	1480	1465	36625	6.9	1508	2972
1980	1943	48575	9.2	1	1943	1480	37000	7.0	1	1480	436	10900	2.1	1508	1943
1981	2011	50275	9.5	964	2974	517	12925	2.4	964	1480	1467	36675	6.9	1508	2974
1983	1621	40525	7.7	25	1645	1456	36400	6.9	25	1480	138	3450	0.7	1508	1645
1984	1818	45450	8.6	1153	2970	328	8200	1.6	1153	1480	1463	36575	6.9	1508	2970
1986	1251	31275	5.9	536	1786	945	23625	4.5	536	1480	279	6975	1.3	1508	1786
1988	1777	44425	8.4	1124	2971	357	8925	1.7	1124	1480	1393	*34825	6.6	1508	*2971
1989	1757	43925	8.3	199	1955	1282	32050	6.1	199	1480	448	11200	2.1	1508	1955
1992	1989	49725	9.4	958	2946	523	13075	2.5	958	1480	1439	35975	6.8	1508	2946
1993	1891	47275	9.0	91	1981	1390	34750	6.6	91	1480	474	11850	2.2	1508	1981
1995	2975	74375	14.1	0	2974	1481	37025	7.0	0	1480	1467	36675	6.9	1508	2974
1996	1070	26750	5.1	1305	2374	176	4400	0.8	1305	1480	867	21675	4.1	1508	2374
1997	987	24675	4.7	1315	2301	166	4150	0.8	1315	1480	794	19850	3.8	1508	2301
1998	943	23575	4.5	1405	2347	76	1900	0.4	1405	1480	840	21000	4.0	1508	2347
1999	963	24075	4.6	1382	2344	99	2475	0.5	1382	1480	837	20925	4.0	1508	2344
2002	2973	74325	14.1	2	2974	1479	36975	7.0	2	1480	1467	36675	6.9	1508	2974
2004	2965	74125	14.0	10	2974	1471	36775	7.0	10	1480	1467	36675	6.9	1508	2974
2006	2972	74300	14.1	3	2974	1478	36950	7.0	3	1480	1467	36675	6.9	1508	2974
2007	2678	66950	12.7	176	2853	1305	32625	6.2	176	1480	1346	33650	6.4	1508	2853
2008	2693	67325	12.8	159	2851	1322	33050	6.3	159	1480	1344	33600	6.3	1508	2851
2009	2694	67350	12.7	153	2846	1328	33200	6.3	153	1480	1339	33475	6.4	1508	2846
2010	2694	67350	12.7	153	2846	1328	33200	6.3	153	1480	1339	33475	6.4	1508	2846
2011	2692	67300	12.7	155	2846	1326	33150	6.3	155	1480	1339	33475	6.4	1508	2846
2012	2692	67300	12.7	155	2846	1326	33150	6.3	155	1480	1339	33475	6.4	1508	2846
2013	2690	67250	12.7	155	2844	1326	33150	6.3	155	1480	1337	33425	6.4	1508	2844
2014	2694	67350	12.7	149	2842	1332	33300	6.3	149	1480	1335	33375	6.4	1508	2842
2015	2694	67350	12.7	149	2842	1332	33300	6.3	149	1480	1335	33375	6.4	1508	2842
2016	2690	67250	12.7	151	2840	1330	33250	6.3	151	1480	1333	33325	6.4	1508	2840
2017	2690	67250	12.7	151	2840	1330	32250	6.3	151	1480	1333	33325	6.4	1508	2840
2018	2690	67250	12.7	151	2840	1330	33250	6.3	151	1480	1333	33325	6.3	1508	2840

* 1972: gap in North: 1150 ft, id 808-853

* 1988: gap in South: 1800 ft, id 2034-2104

Note: Transects corresponding to actual inlet are 1481 to 1507 (a distance of 0.13 miles)

6.1 Results

The fundamental results of mapping shorelines from aerial imagery are presented in Table 7 and Figure 37. The results presented and discussed in this section on image-based shoreline change will focus on the linear regression (LR) method. However, results obtained through the use of the end-point-rate (EPR) method are also included despite its use being subject to several disadvantages. For example, if either shoreline is uncharacteristic, the resulting rate of change will be misleading; also, data between the endpoints ignored by the EPR method may indicate relevant shoreline change dynamics, thus the EPR method may produce rates that do not capture important trends or changes in trends, especially as temporal variation increases (Dolan et al. 1991). The reader is referred to the earliest version of the report (State of Sebastian Inlet Technical Report 2007-1) for more information on both methods used.

Table 6. Summary of transect coverage to extract shoreline data from aerial imagery

Domain	Transect ID	R Marker	Extent Covered in Miles
North	0 - 1480	180.5 - 219	7.0
South	1508 - 2974	0 - 37.5	6.9
N3	0 - 880	180.5 - 203	4.2
N2	880 - 1364	203 - 216	2.3
N1	1364 - 1480	216 - 219	0.6
Inlet	1365 - 1645	BC216 - IRC4	1.3
S1	1508 - 1627	0 - 3.5	0.6
S2	1627 - 212	3.5 - 16	2.3
S3	2120 - 2974	16 - 37.5	4.0

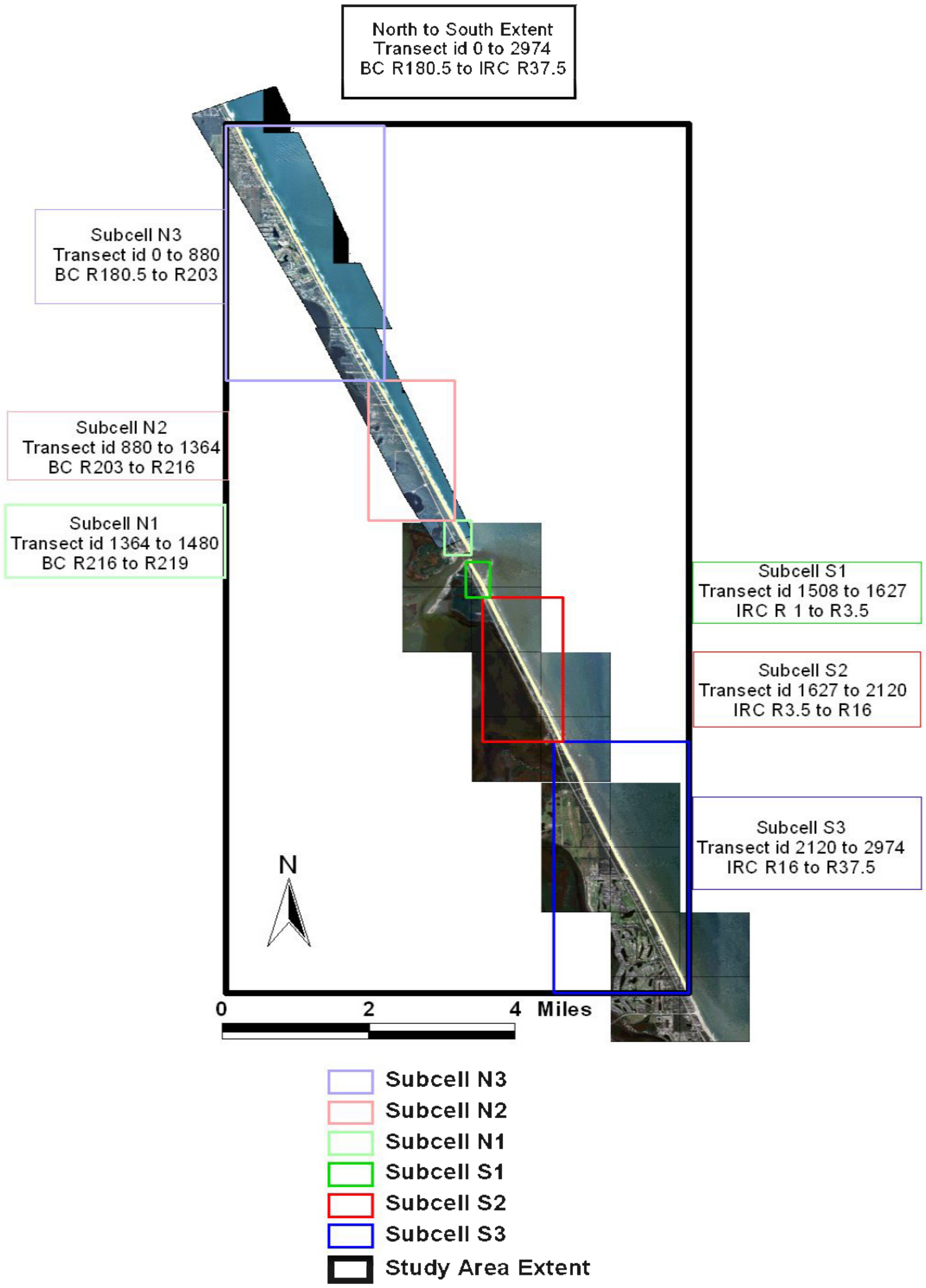


Figure 41. Aerial image shoreline-based coverage and areas (subcells) of study

Table 7. Average rate of change for EPR and LR methods (ft/yr.).

Extent		Method	('58-'18)	('08-'18)	('13-'18)	('17-'18)
N-S		EPR	-0.2692	-4.1000	-2.2651	-38.5524
		LR	0.3333	-0.8182	0.5505	-34.8389
Brevard Co.	N	EPR	-0.0165	-4.1707	-2.2857	-40.0532
		LR	0.5101	-0.7848	0.4881	-35.7531
Indian River	S	EPR	-0.6910	-4.0299	-2.2446	-37.0639
		LR	0.1525	-0.8464	0.6097	-33.6784
Brevard Co.	R180.5 – 203 (N3)	EPR	-0.2720	-3.8626	-2.0382	-42.7627
		LR	0.3918	-0.4577	0.8938	-35.0450
	R203 – 216 (N2)	EPR	0.3148	-4.2711	-1.8808	-38.2124
		LR	0.6620	-1.0204	0.7751	-38.2124
	R216 – 219 (N1)	EPR	0.1831	-5.6889	-5.5200	-31.0814
		LR	0.7663	-2.2949	-3.7766	-31.0814
Indian River Co.	R1 – 3.5 (S1)	EPR	1.1624	-2.3872	3.6748	-52.5067
		LR	2.7266	-0.3788	9.4539	-52.5067
	R3.5 – R16 (S2)	EPR	-1.0788	-6.3944	-3.7135	-40.1246
		LR	0.6950	-2.4327	-1.5098	-40.1246
	R16 – 37.5 (S3)	EPR	-0.8559	-2.6841	-2.2124	-32.4227
		LR	-0.5188	0.0025	0.6031	-27.3412
Inlet		EPR	0.6546	-3.7829	-0.8447	-41.7686
		LR	1.8782	-1.1852	2.9880	-43.4804

In general, both methods produce similar results (Table 7) in terms of the order of magnitude, with either a positive or negative trend mostly in concordance with each other (the EPR and LR methods). Results from the EPR and LR methods yield similar trends in all domains within the 2008-2018 and 2017-2018 time periods, while results for the 1958-2018 and 2013-2018 time periods trends (positive or negative) do not generally agree. However, the differences in those values are generally small and these seemingly opposite trends (positive or negative) maybe due to the difference in the methodologies employed. Taking the average of all the values (EPR and LR) accounting all segments for each of these time periods, results in all time periods showing a tendency towards erosion (negative values) except for 1958-2018 which tends towards accretion (positive values). Table 8 summarizes the overall average differences between the methods for each period.

Table 8. Average Difference between the EPR method and the LR method (ft/yr.).

Period	**('58-'18) in ft/yr.**	**('08-'18) in ft/yr.**	**('13-'18) in ft/yr.**	**('17-'18) in ft/yr.**
Average Difference (EPR – LR)	**-0.8465** -1.7738 at S2 to -0.3371 at S3	**-3.1155** -3.9317 at S2 to +2.0084 at S1	**-3.0406** -5.7791 at S1 to -1.7434 at N1	**-2.2586** -7.7177 at N3 to +1.7118 at Inlet

<u>Historical Period (1958-2018)</u>

The shoreline changes between the period of 1958 to 2018 (Figure 38) show shifts ranging from -126 feet (near R-marker 12) to +128 feet (near R-marker 1). Three major sections of shoreline recession alternate with three main areas of shoreline advancement, as seen in Figure 38. In segment N3, the first section denoting landward migration (recession) close to -87 feet is centered around R-186, within the same N3 segment the first section denoting seaward migration (advancement) close to +60 feet is centered around R-marker 196. Similarly, along segments N2, N1 and S1, an area of shoreline recession (close to -50 feet) around R-201 alternates with advancement of the shoreline up to +106 feet at R-208. Immediately south of Sebastian Inlet, an area of shoreline advancement is centered around R-3 with values of +111 feet while the widest contiguous section of landward migration (receding shoreline) of up to -126 feet at R-12 dominates most of S2 and the part of S3 that has data available for this analysis.

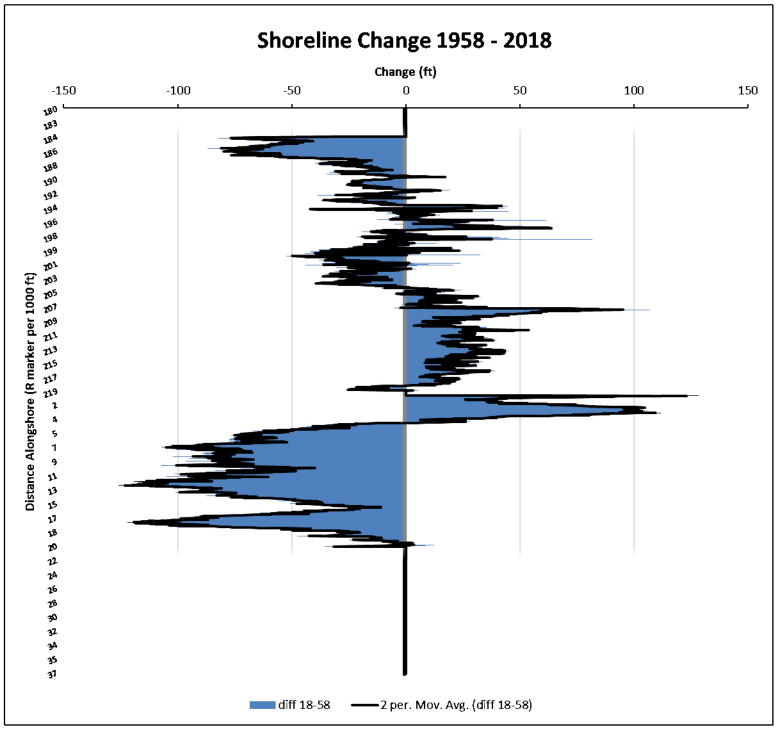


Figure 42. Change (ft) in shoreline position from 1958-2018.

Table 9. Summary shoreline changes for the historical period (1958-2018)

Extent	Range (ft/yr.)	Average LR (ft/yr.)	Erosion %	Accretion %
North to South	-1.7940 to +3.4696	+0.3333	24.07	65.18
North	-0.8126 to +1.8713	+0.5101	16.07	73.19
South	-1.7940 to +3.4696	+0.1525	32.58	58.28
N3	-0.8126 to +1.8713	+0.3918	25.65	56.30
N2	-0.1430 to +1.4615	+0.6620	2.68	97.32
N1	+0.4752 to +0.9997	+0.7663	0	100
Inlet	0.00 to +3.4696	+1.8782	0	90.39
S1	+1.9849 to +3.4696	+2.7266	0	100
S2	-0.1635 to +2.5296	+0.6950	4.86	95.14
S3	-1.7940 to +0.8798	-0.5188	53.10	31.23

The information listed in Table 9 correspond to shoreline change rates according to the LR method, the range of the shoreline change rates, and the percent of the shoreline undergoing erosion or accretion in each segment. Figures 39(a) and 40 aid in the interpretation of the values presented in Table 9.

Overall, the entire extent (North to South) for the 1958-2018 period presents accretion (65.18%). The North segment shows two sections within the N3 subcell where erosion occurs (16.07% erosion), otherwise accretion areas cover 73.19% of the North extent with an average rate of change of +0.5101 ft/yr. The South extent is where the maximum accretion rate occurs (+3.4969 ft/yr.) dominating segments S1, and extending to S2 and about one third of S3, however this area is also where the maximum erosion rate is found -1.7940 ft/yr. (S3). Results for the various distinct segments (Table 9 and Figure 39(a)) indicate that the area immediately north and south of the Inlet for this time period have undergone up to 100% accretion: N2 (97.32%), N1 (100%), S1 (100%), and S2 (95.14%).

Another way to visualize the results presented in Figure 39(a) is with a histogram plot which shows the frequency at which a value of the rate of change (slope) occurs throughout the study domain for the particular time period considered (Figure 40). In this case, the majority of the spread and peak frequencies occur around +0.78 ft/yr., a value that is seen to dominate Figure 39(a). In other words, the majority of the accretion rate (red dots in Figure 39 (a)) are centered around a value close to +1 ft/yr., but in close inspection and by taking the average LR (ft/yr.) values for each subcell (N3, N2, N1, S1, S2, an S3) and then calculating its mean, the value obtained is that of +0.78715 ft/yr. which is in agreement with values in Figure 40. The secondary grouping centered around -1.5 ft/yr. in Figure 40 is due for the most part to the erosion trends dominating S3, while the spread in values seen over +2 ft/yr. can be attributed for the most part to segment S1.

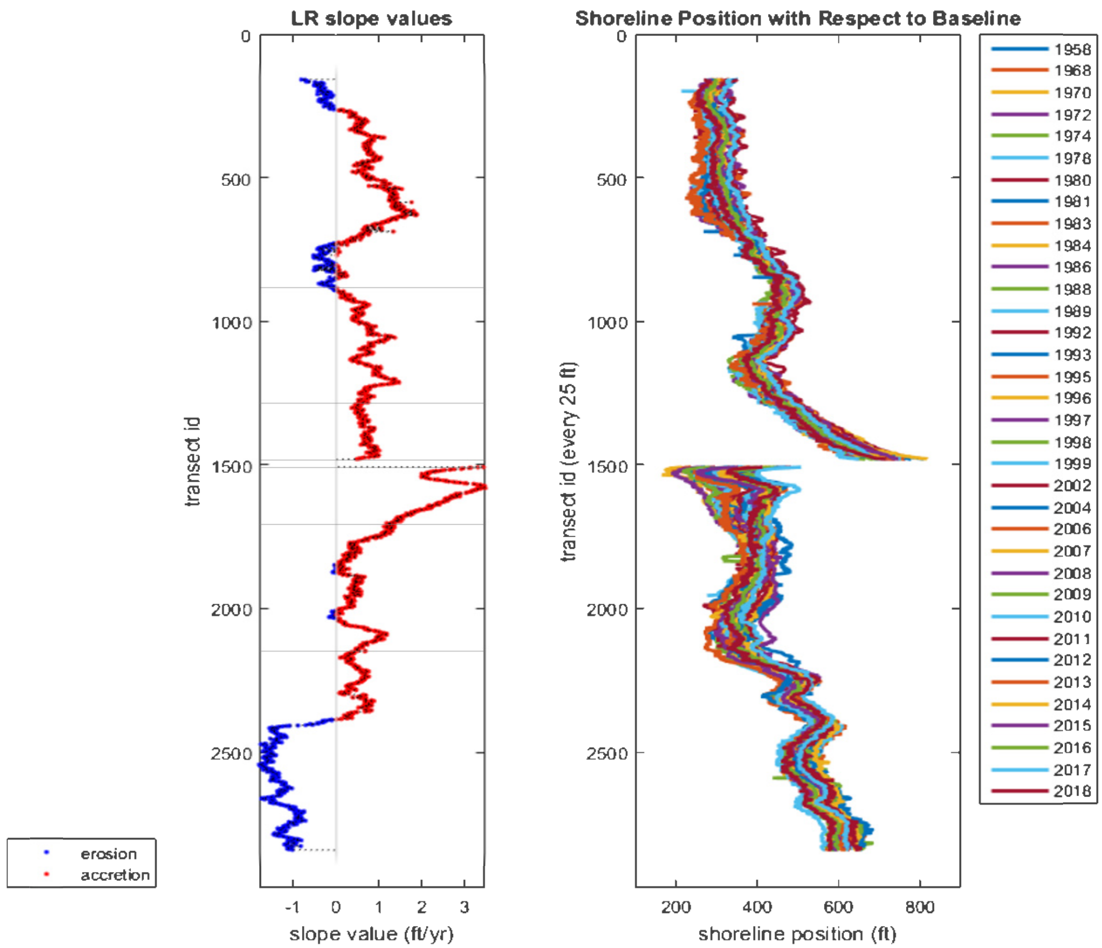


Figure 43. Period of 1958-2018. (a) Shoreline change rate in ft/yr. (according to LR method calculated for each transect); (b) Shoreline position in feet (from baseline to wet/dry line).

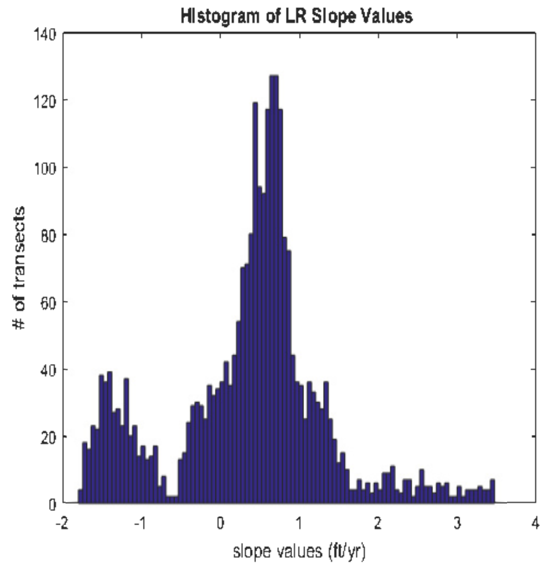


Figure 44. Frequency of rate of change (slope value in ft/yr.) for entire domain (1958-2018).

Intermediate Period (2008-2018)

The changes in shoreline position from 2008 to 2018 (Figure 41) show overall landward migration (recession) throughout the entire domain of up to -131 feet (at R-13), only very narrow sections in N3, S1 and S3 segments show minimal change indicating advancement (seaward migration) between +14 feet to close of +25 feet. The farthest landward retreat segment is found in S3 at R-13 with a value of -131 feet, followed by N3 segment also showing shoreline retreat (landward migration) around R-194 of -94 feet and -86 feet at R-186. An average shoreline change position of close to -50 feet is seen in N3 and N2. The S2 subcell encompasses the area showing farthest inland migration (retreat). An average of -20 feet recession can be seen in S3, this segment also contains a narrow section showing accretion of close to +15 (R-22). The segment immediately south of the Inlet (S1) includes a narrow area where the furthest seaward migration (advance) of close to +25 feet occurs.

Table 10 summarizes: shoreline change rates according to the LR method, the range of the shoreline change rates, and the percent of the shoreline undergoing erosion or accretion in each segment. The full extent from North to South show 60.27% erosion and 28.97% accretion with an average rate of change of -0.8182 ft/yr. Similarly, most segments show erosion ranging from 34.04% (S3 segment) to 100% (N1). Only segment S3 shows accretion slightly over 50%, however, the average rate of change for segment S3 is the smallest value (+0.0025 ft/yr.). Overall, the average rate of change is small and centered around -1.097 ft/yr. (Figure 42 (a) and Figure 43). The values from +2 ft/yr. and over can be attributed for the most part to segment S1; values below -2 ft/yr. can be attributed to segment S2.

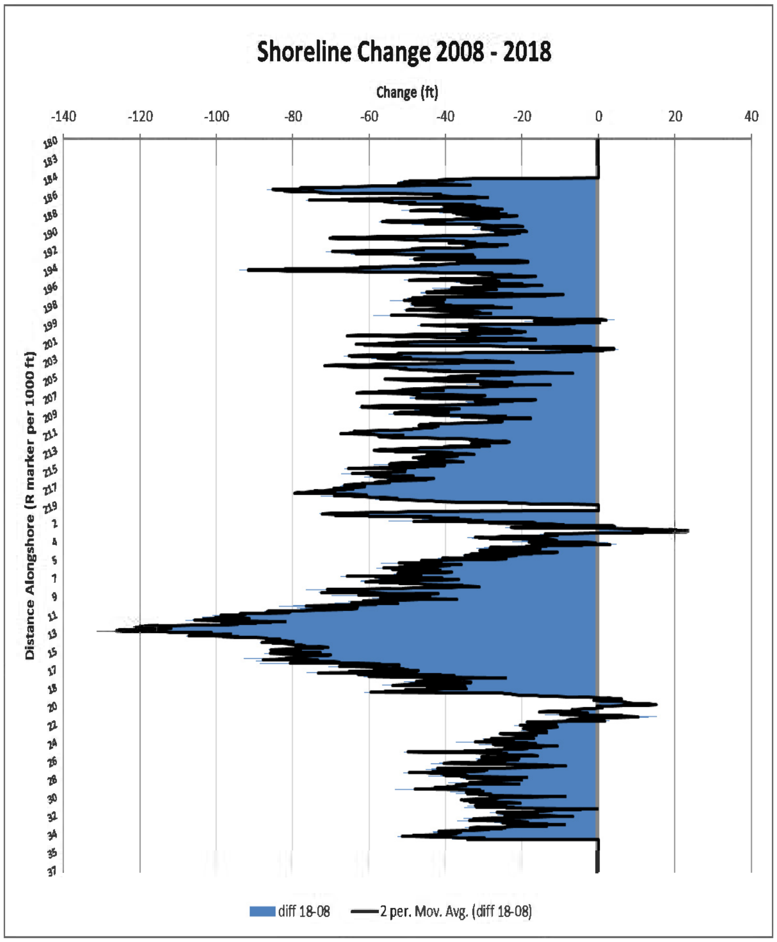


Figure 45. Figure 46. Change (ft) in shoreline position from 2008-2018.

Table 10. Summary of short-term changes for the recent period (2008-2018)

Extent	Range (ft/yr.)	Average LR (ft/yr.)	Erosion %	Accretion %
North to South	-7.1437 to +4.1493	-0.8182	60.27	28.97
North	-3.8554 to +2.0531	-0.7848	70.29	18.97
South	-7.1437 to +4.1493	-0.8464	51.26	39.60
N3	-3.8554 to +2.0531	-0.4577	54.60	27.36
N2	-3.0003 to +0.7158	-1.0204	91.75	8.25
N1	-3.5685 to -0.7763	-2.2949	100	0
Inlet	-3.5685 to +4.1493	-1.1852	66.55	23.84
S1	-3.2333 to +4.1493	-0.3788	58.33	41.67
S2	-7.1437 to +2.6316	-2.4327	79.35	20.65
S3	-4.6539 to +2.7679	+0.0025	34.04	50.29

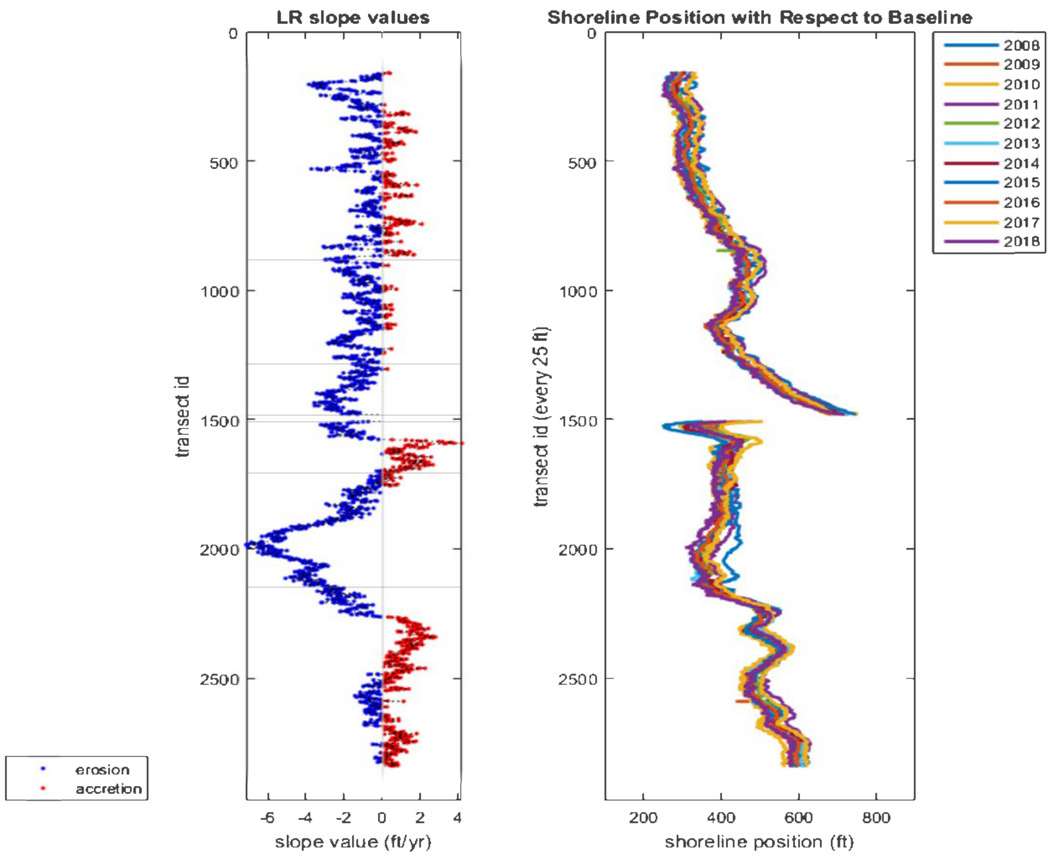


Figure 47. Period of 2008-2018. (a) Shoreline change rate in ft/yr. (according to LR method calculated for each transect); (b) Shoreline position in feet (from baseline to wet/dry line).

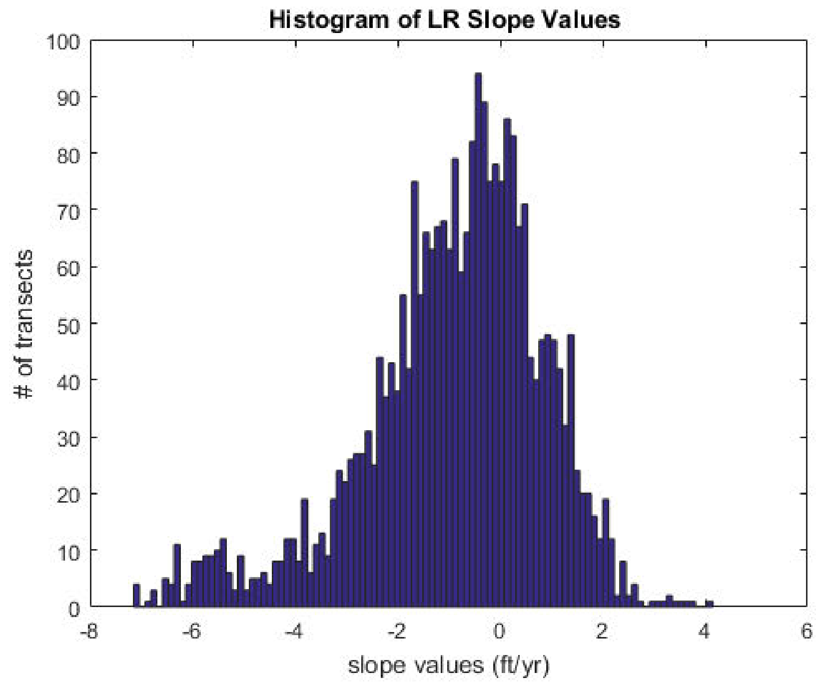


Figure 48. Histogram indicating number of transects per slope value (ft/yr.) for 2008-2018.

Recent Update (2013-2018)

Shoreline changes from 2013 to 2018 (Figure 44) show overall landward migration (recession) throughout the entire domain of up to -56 feet (at R-7), however, several segments show alternating sections of accretion and erosion, in particular subcells N3, N2, S1 and S3. The areas immediately north and south of the inlet, N1 and S1 respectively, present opposing trends in shoreline change. N1 shows overall landward migration (retreat) close to -45 feet, whereas S1 shows seaward migration (advancement) up to +58 feet at Rmarker-2. S2 section is predominantly receding with an average shoreline change of about -20 feet and a maximum landward migration of -56 feet at R-7, and only a small area showing advancement of +36 feet near R marker 16.N3 and S3, both predominantly retreating with alternating segments of advancement .

Shoreline change rates according to the LR method are summarized in Table 11, it lists the range of the shoreline change rates, and the percent of the shoreline undergoing erosion or accretion in each segment. Although difficult to determine by visual inspection of Figure 45(a), the full extent from North to South show 38.15% erosion and 51.09% accretion with an average rate of change of +0.5505 ft/yr., ranging from -8.7520 ft/yr. to +16.2823 ft/yr. N1 is the segment with the highest percentage of erosion equal to 92.31% and an average erosion rate of -3.7766 ft/yr., while S1 has 100% accretion with an average rate of +9.4539 ft/yr. Overall, the average rate of change is small and centered around +1.07325 ft/yr. (Figure 45 (a) and Figure 46)).

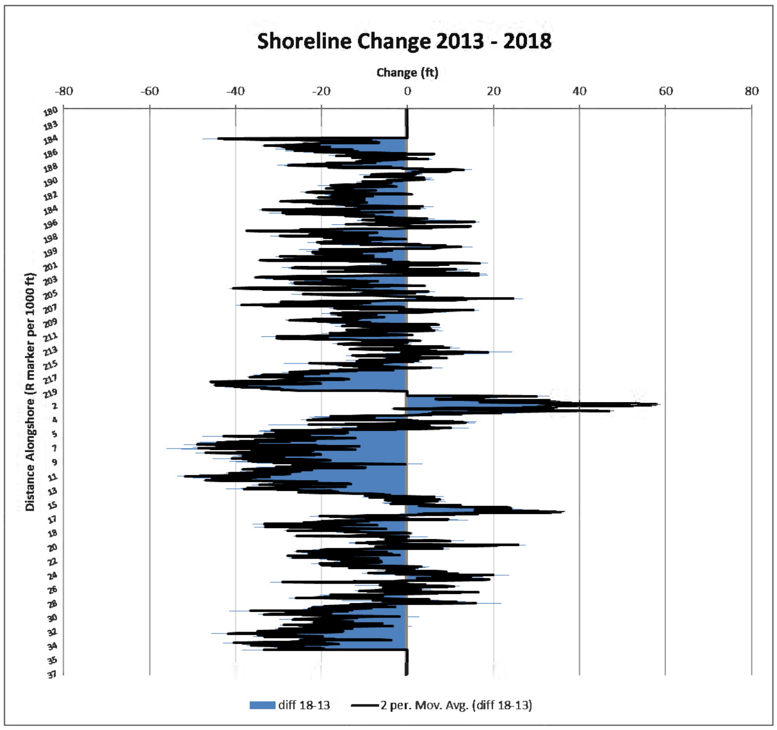


Figure 49. Change (ft) in shoreline position from 2013-2018.

Table 11. Summary of short-term changes for the latest update (2013-2018)

Extent	**Range (ft/yr.)**	**Average LR (ft/yr.)**	**Erosion %**	**Accretion %**
North to South	-8.7520 to +16.2823	+0.5505	38.15	51.09
North	-8.7520 to +6.2051	+0.4881	34.44	54.83
South	-8.6943 to +16.2823	+0.6097	42.60	48.26
N3	-3.7949 to +6.0526	+0.8938	26.22	55.73
N2	-4.4426 to +6.2051	+0.7751	35.46	64.54
N1	-8.7520 to +1.8357	-3.7766	92.31	7.69
Inlet	-8.7520 to +16.2823	+2.9880	39.50	50.89
S1	+0.3203 to +16.2823	+9.4539	0	100
S2	-8.6943 to +9.1169	-1.5098	69.23	30.77
S3	-4.8106 to +8.3809	+0.6031	33.10	51.23

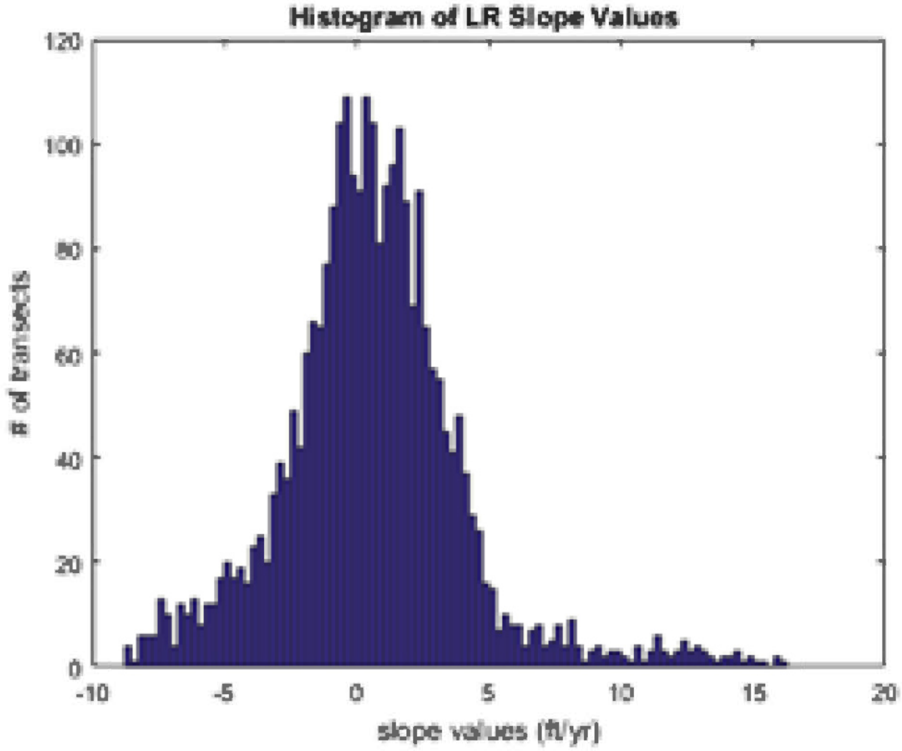


Figure 50

Annual Update (2017-2018)

The changes in shoreline position from 2017 to 2018 (Figure 47) show overall landward migration (recession) throughout the entire domain of up to -94 feet at the south jetty, only two very narrow sections in N1 and S3 segments show seaward advancement close to +9 feet. An average shoreline change centered around -40 feet is seen in every segment of this time period. This is confirmed with the values shown in Table 12 for the average rate of change and once again in Figures 48 (a) and 49 were values are centered around -40 ft/yr.

The full extent from North to South show 88.84% erosion and only 0.40% accretion with an average rate of change of -34.8389 ft/yr. Similarly, most segments show erosion ranging from 81.95% (N3 segment) to 100% (N2, S1, and S2). Only segments N1 and S3 show minimum of accretion at 4.27% and 0.82% respectively. Overall, the average rate of change is centered around -37.3852 ft/yr. (Figure 48 (a) and Figure 49). It is noted that retreat of the shoreline does not necessarily indicate sand volume losses, but could indicate changes in morphology. Figures 38 and 39, which plot morphologic changes on the upper shoreface in the between summer 2017 and summer 2018 indicate areas of sand volume accretion and sand volume loss.

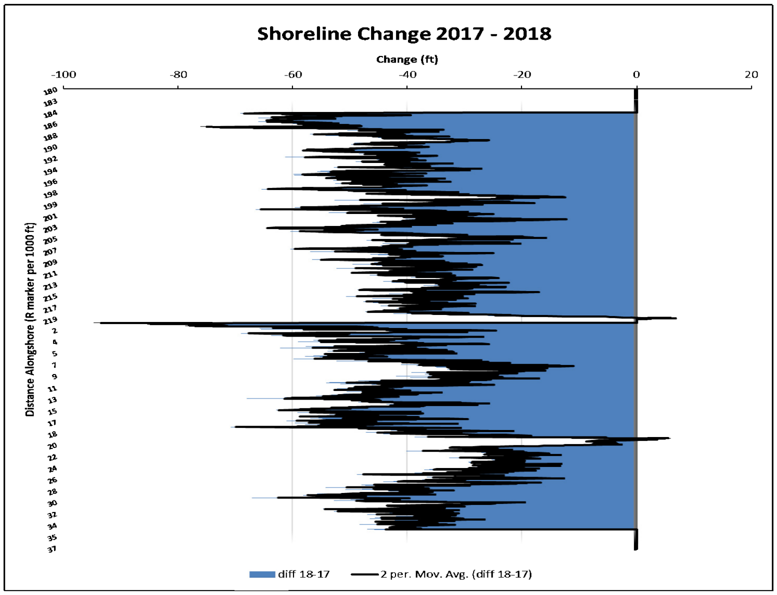


Figure 51. Change (ft) in shoreline position from 2017-2018.

Table 12. Summary of short-term changes for the recent period (2017-2018)

Extent	**Range (ft/yr.)**	**Average LR (ft/yr.)**	**Erosion %**	**Accretion %**
North to South	-94.8 to +7.06	-34.8389	88.84	0.40
North	-76.16 to +7.06	-35.7531	88.93	0.34
South	-94.80 to +5.97	-33.6784	90.39	0.48
N3	-76.16 to 0	-35.0450	81.95	0.11
N2	-64.53 to -15.66	-38.2124	100	0
N1	-47.66 to +7.06	-31.0814	95.73	4.27
Inlet	-94.80 to +7.06	-43.4804	88.61	1.78
S1	-94.08 to -22.78	-52.5067	100	0
S2	-68.00 to -1.56	-40.1246	100	0
S3	-70.78 to +5.97	-27.3412	83.51	0.82

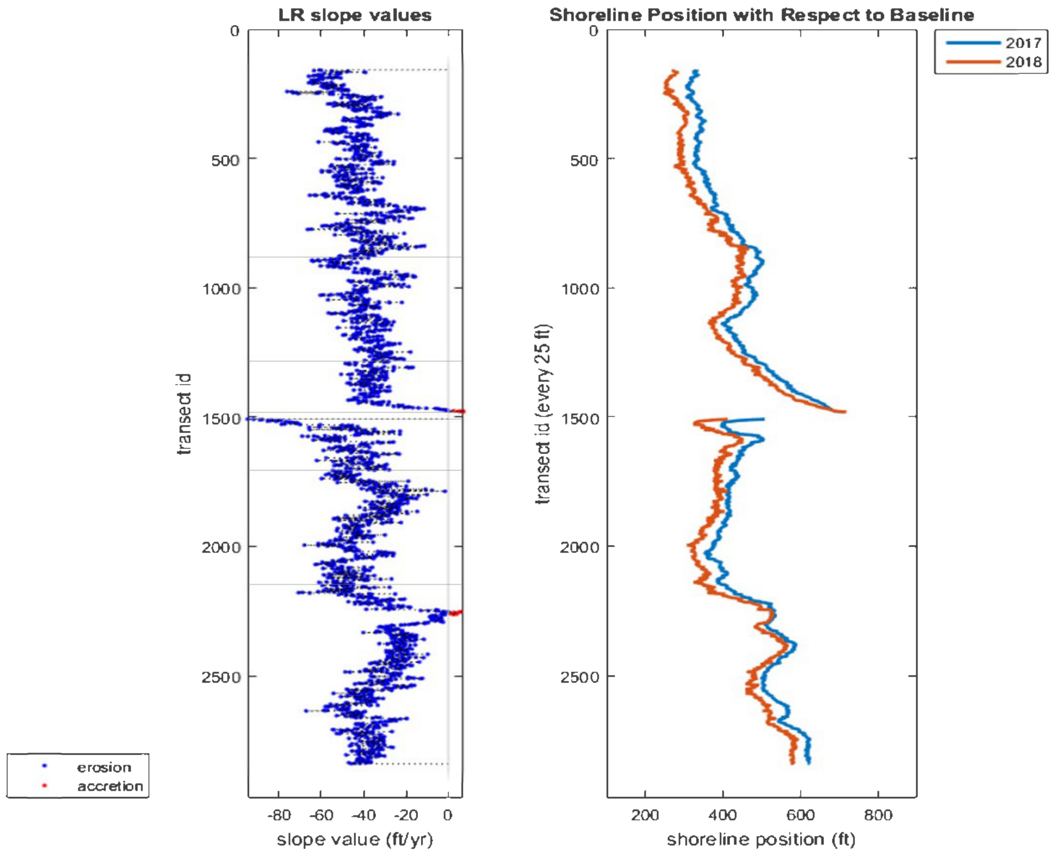


Figure 52. Period of 2017-2018. (a) Shoreline change rate in ft/yr. (according to LR method calculated for each transect); (b) Shoreline position in feet (from baseline to wet/dry line).

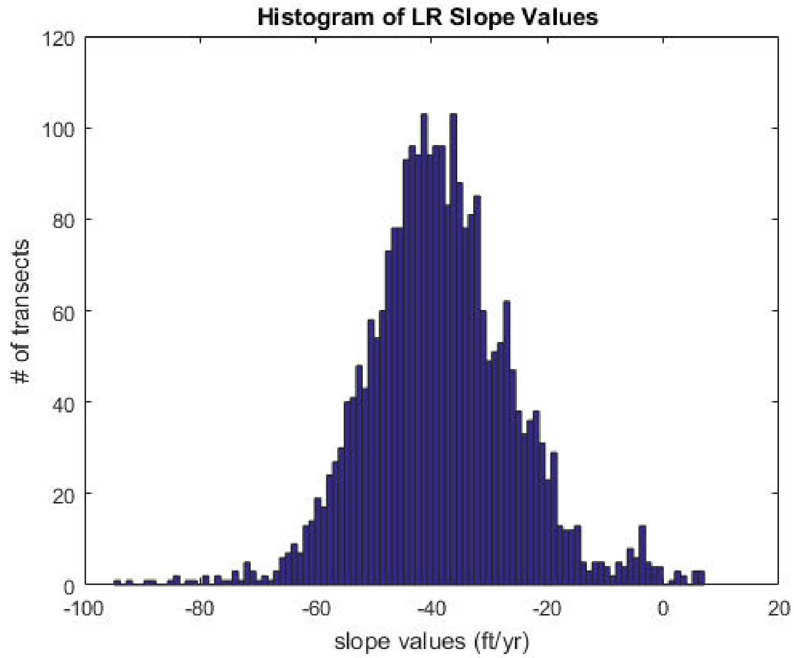


Figure 53. Histogram indicating number of transects per slope value (ft/yr.) for 2017-2018.

8.0 Hydrodynamic, Sediment Transport and Morphological Numerical Modeling: 2017 – 2018

8.1 Purpose

The goals for this modeling work are to evaluate the following:

1. Evaluate model's ability to reproduce Hurricane Irma;
2. Evaluate different methodologies to represent the north jetty within the model environment;
3. Calculate channel infilling after sand trap dredging.

Bottom Topography Development

The motivation behind updating the nearshore areas is twofold;

1. better represent the topography above and below the waterline to present condition,
2. improve model stability and performance in nearshore areas and near the boundaries.

Surveys performed by Land and Sea Surveying Concepts, Inc have been incorporated for each season to generate a Winter 2017 and Summer 2017 condition Digital Elevation Model (DEM) to use for the numerical model grids and evaluate model performance to measured morphology change. The latest LIDAR datasets collected by USACE FEMA have also been incorporated to the shoreface and dune areas to better represent the nearshore areas. Specifically, the 2017 Post Irma flight performed in October, 2017 has been added to the Summer 2017 topography dataset. The 2016 Post Matthew flight performed in November, 2016 has been used for the Winter 2017 dataset.

The Indian River Lagoon portions of the merged topography has been updated with the latest survey data of the Intracoastal Waterway (ICW). The survey data was provided by USACE Jacksonville District (SAJ) and the Florida Inland Navigation District (FIND). The ICW datasets were combined with a 1995 survey of the entire Lagoon performed by Morgan and Eckland. The coverage of these datasets and resulting navigation channel and bay area refinements are shown in Figure 53.

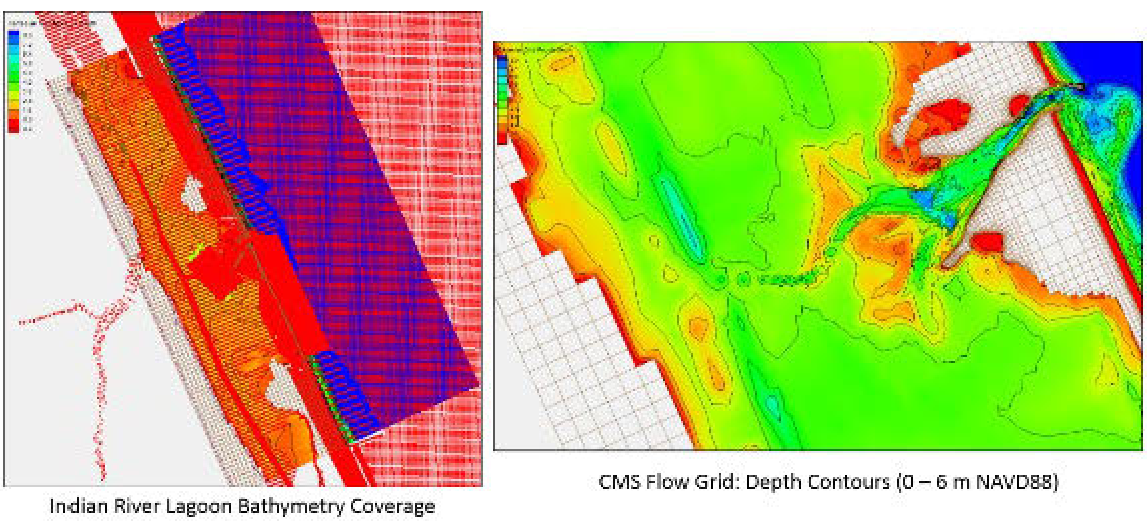


Figure 54. Indian River Lagoon Refined Bathymetry.

The merged topographic dataset is spatially referenced to NAD83 State Plane Florida East in meters and vertically to NAVD88 in meters.

8.2 Regional Wave Modeling

The regional wave modeling transforms offshore waves to the nearshore for use in the highly refined local model grids. To generate wave inputs for both the Winter and Summer time periods, this model configuration was run for 11 months spanning from January 2017 – October 2017. The structures are represented in the model as rubble mound structures which is defined in the model as a low permeable structure. A sensitivity analysis of the structure specification within the model will be performed in the Local Modeling efforts and described in later sections.

Regional Model Input Parameters

The model is driven with offshore waves and winds that are extracted from the NOAA Wave Watch III (WW3) 10 m grid. WW3 is hindcast data developed from global models for waves and winds (NOAA, 2018). Extracted data products include significant wave height, peak wave period, winds, and direction. The waves timeseries is presented in the top panel of Figure 54 and wave period follows in the lower panel. Wind speed timeseries is provided in Figure 55 and directional wave and wind plots are provided in Figure 56. Hurricane Irma can be observed in the timeseries for wave height and winds in early September. 2017 was an energetic year but compared well with 2016. Descriptive statistics of WW3 input data for this simulation year and previous years are presented in Table 13

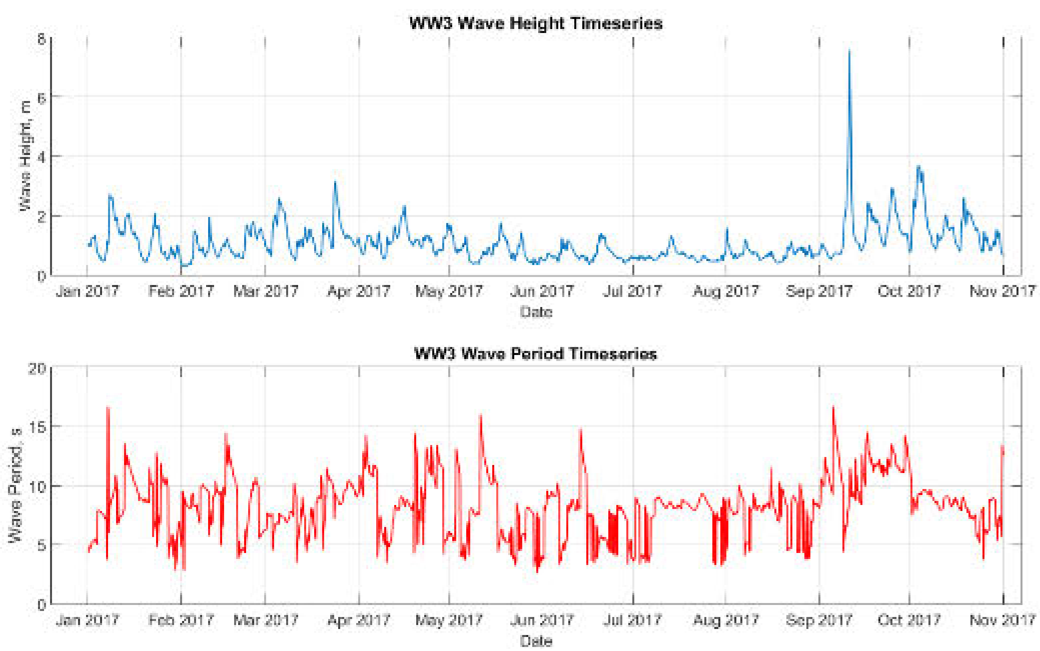


Figure 55. WW3 Wave Height (a, top) and Period (b, bottom) Timeseries.

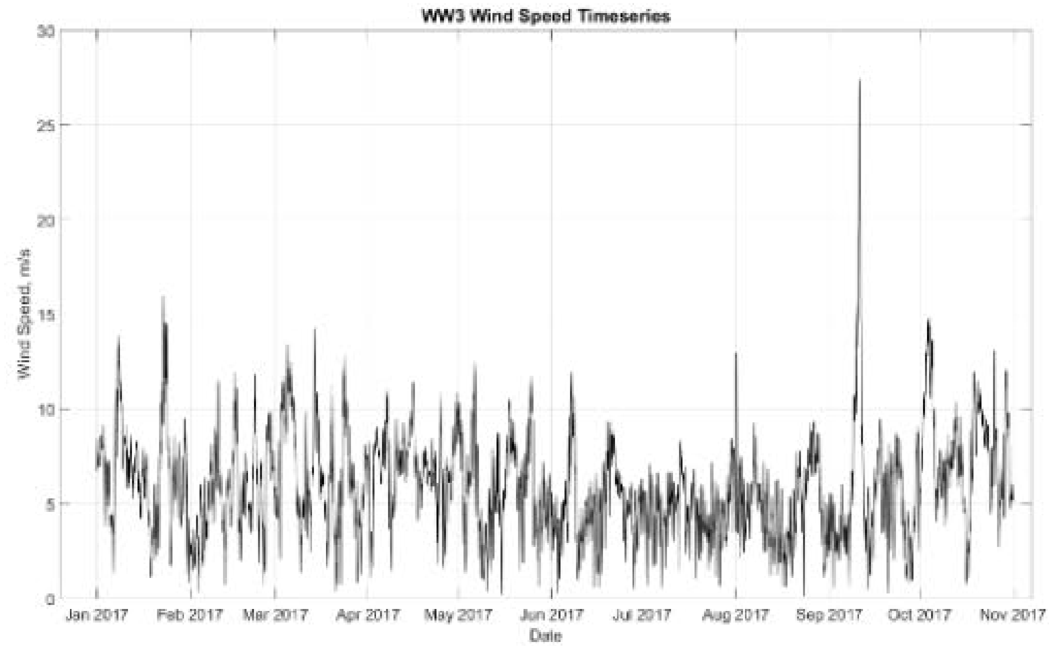


Figure 56. WW3 Wind Speed Timeseries.

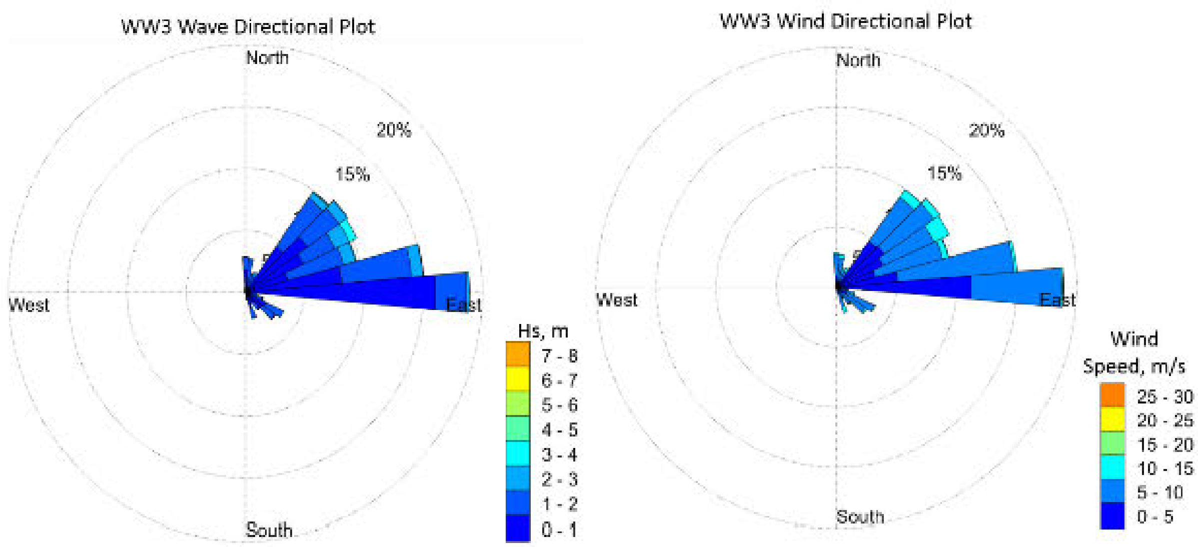


Figure 57. WW3 Wave Directional Plot (a, left) and Wind Directional Plot (b, right).

Table 13. Wave Watch 3 Descriptive Statistics during Simulation Period.

Year	Max Hs (m)	Avg. Hs (m)	Max Tp (s)	Avg. Tp (s)	Max. Wind Speed (m/s)	Avg. Wind Speed (m/s)	Time Period
2017	7.58	1.06	16.69	8.25	27.41	5.93	1/1/2017 – 11/1/2017
2016	7.93	1.14	15.68	8.34	32.05	5.89	8/1/2016 – 12/31/2016

Local Refined Model Input Parameters

Grid Configurations and Wave Input

Calculated wave information generated from the regional model run is used to drive the local, refined model set up. Data is extracted from the regional grid at the location corresponding to the offshore boundary condition of the local grid. Figure 57 depicts the spatial relationship between the regional and local grids.

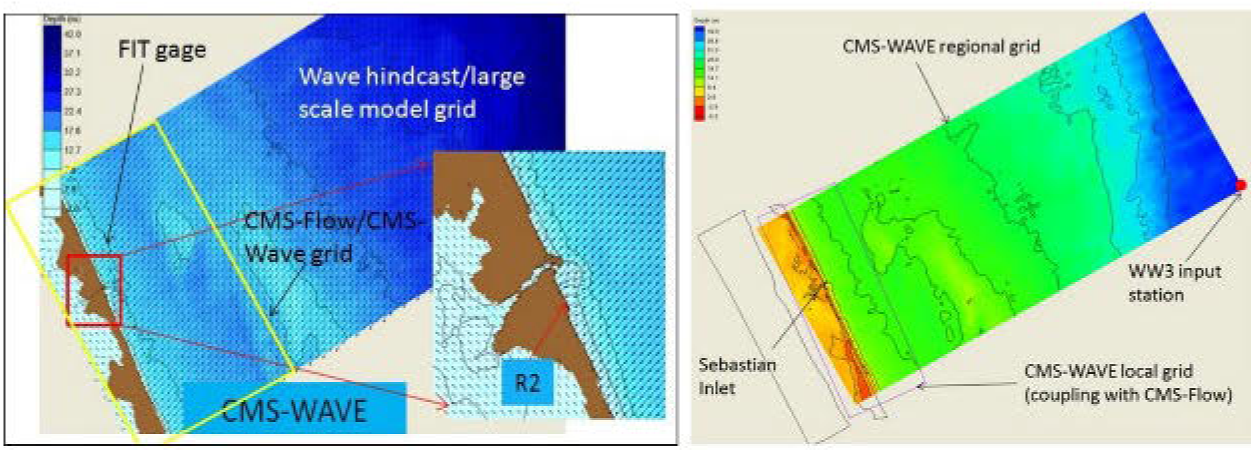


Figure 58. Regional Grid and Local Grid Configuration.

The local grid uses the telescoping grid approach and spans between 160x160 m grid cells to 5x5 m grid cells. The alongshore spatial coverage is nearly 18 km while the cross-shore distance is 105 km to a depth of 14 m at the offshore boundary.

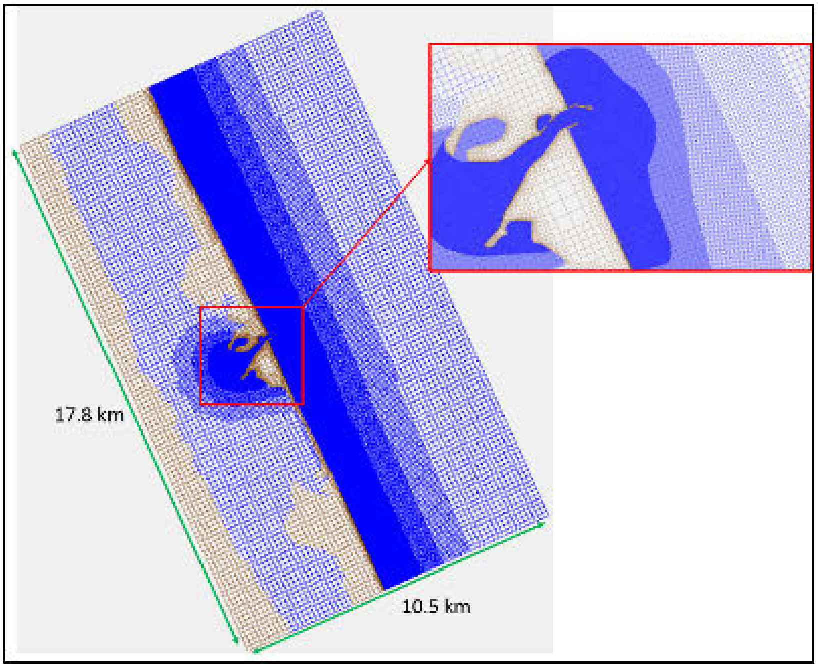


Figure 59. Local Grid Refinement Telescoping.

The telescoping flow grid contains ~160,000 of ocean cells and ~6,000 of land (non-computational cells) The nested wave grid for the local model configuration uses a rectilinear grid configuration using refine points to provide additional model resolution near the inlet and nearshore areas. The wave model includes “rubble mound” cells at the North Jetty, South Jetty and along the banks of the inlet throat to represent the presence of armor stone in these areas. The rubble mound structure selection assumes a low permeable structure

One of the research goals of this work is to investigate alternatives for representing the North Jetty within the model. Previously, the entire length of the jetty has been represented in the Flow model grid as non-computational cells with added roughness around the to represent the presence of the rocks. A model alternative was constructed to represent a more open configuration. The impermeable section closest to shore is represented as non-computational cells while the offshore portions of the north jetty are represented as 5x5 m ocean cells. This allows the cells to alternatively wet and dry with rise and fall of the tide and waves. Roughness factors are included over the appropriate portions of the jetty and expanded to include the new cells. This change added ~4,000 of cells which is a minimal addition compared to the previous north jetty configuration with active ocean cells at ~160,000 cells. These additional cells should not constitute a substantial increase in run time but add model stability since wetting and drying can add instability in a numerical model. Figure 59 presents a comparison of closed jetty and open jetty flow grid configurations plotted with the 2017 aerial imagery. A more in-depth discussion of the jetty configuration is presented in Model Skill and Results.

Figure 60. Solid (a, left) and Open Jetty (b, right) Grid Configuration (Aerial Imagery: Sebastian Inlet District, 2017).

The closed jetty configuration was used to impose a post dredge bathymetry condition since the grid has been used previously with good, stable model performance. This model configuration was run with the 2017 model year forcing to observe channel and sand trap infilling immediately post-dredge. Results of this analysis is provided in the model results section of this report.

Wind Field

Due to storms and equipment outages, the local wind field is a combination between the Sebastian Inlet North Jetty weather station, Trident Station (NOAA Trident Pier, Port Canaveral, FL: 8721604) and Vero Beach Municipal Airport (VBO).

Water Surface Elevation

Water surface elevation is observed at the North Jetty Weather Station and is used as the offshore boundary condition.

Model Skill and Results

This section presents the model skill results as compared to the available field data. At the time of this report, the field gauge has not been recovered. Therefore, the comparison between calculated and measured is not available for the entire simulation time period. But it is sufficiently long to evaluate model performance over a variety of conditions.

Table 14. Field Observations and Simulation Time Period.

	Start	End	Days
Field Observation (North Jetty ADCP)	5/9/2017	9/4/2017	118
Simulation Period	5/1/2017	11/1/2017	184

Parameter	RMSE (m)	NRMSE	MAE (m)	NMAE	Correlation Coefficient (R^2)	Bias
WSEL	0.102	5.52%	0.10	5.52%	0.95	0.01
Wave Height (m)	0.39	27.84%	0.40	27.84%	0.35	-0.37

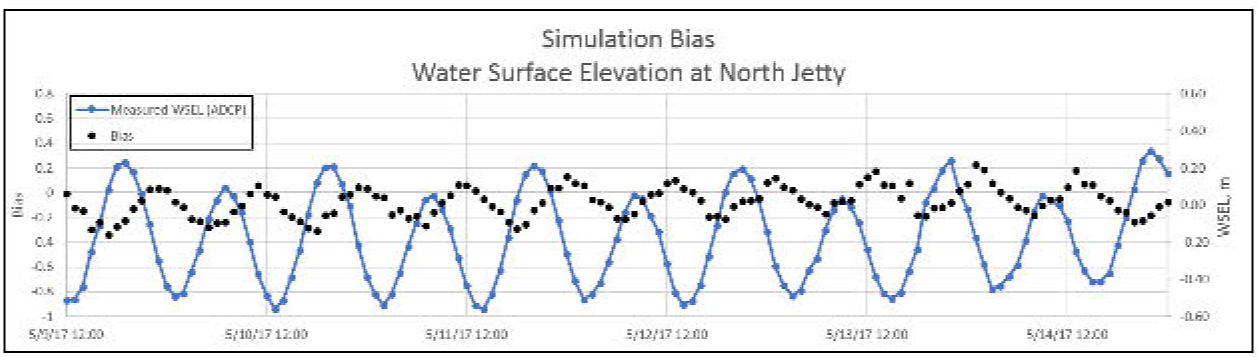


Figure 61. Simulation Bias: Water Surface Elevation.

Figure 61 compares the simulation bias to the measured wave heights from the ADCP located at the North Jetty to examine the model's ability to reproduce wave height with variations in forcing. Throughout the simulation, the model is underpredicting wave heights as indicated by a negative value for bias. This bias increases with peaks and troughs. Negative bias occurs during times of higher wave heights while lower wave heights are indicating positive bias.

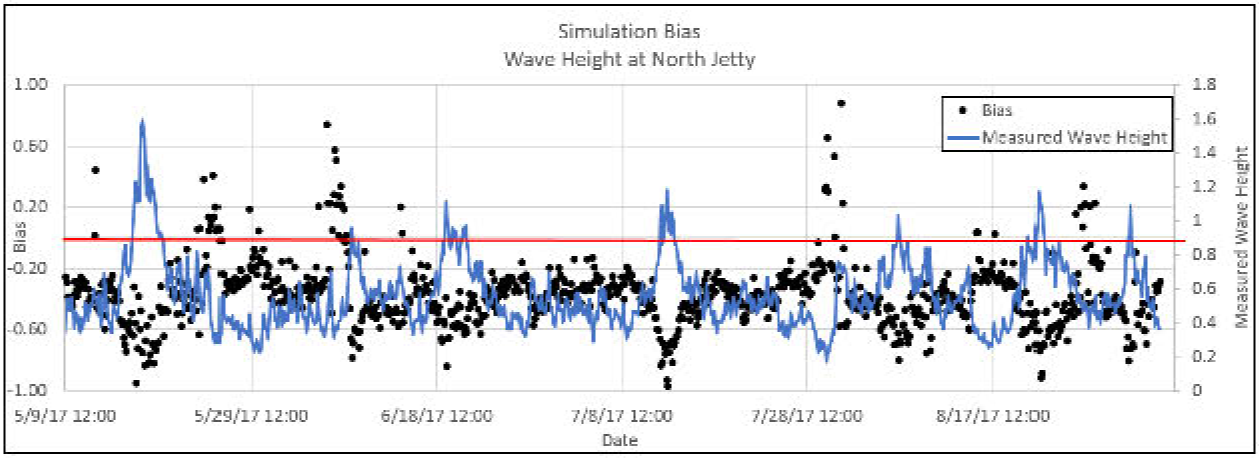


Figure 62. Simulation Bias: Wave Height

Channel Infilling

The Inlet District is interested in calculating the rate of infilling of the sand trap immediately post-dredge and examine the changes in current patterns as the trap begins to fill. These rates and morphology will be compared to a simulation run using the most recent bottom topography condition. The 2017 bottom topography is roughly 4 years into the dredging cycle and represents the latter half of the dredging cycle. Expansion of the sand trap took place in the Spring of 2014. Using 2014 merged bathymetry/topography data, the model was run with the present (2017) forcing conditions. The expectation is the immediate post dredge condition should yield higher rates of sedimentation and rates should slow in the 2017 bottom topography condition as the sand trap continues to fill. Additionally, the volumes in the existing condition should be larger than the 2014 post dredge condition. Morphology change will also be compared between the two runs to examine if patterns change through time and as the sand trap increases in volume. It should be noted that in order to represent immediately post dredge, the Spring 2014 dataset was used and some seasonal variability is to be expected as compared to the Winter 2017 dataset.

Channel infilling calculations were performed using the computed depth timeseries from CMS. A series of transects were constructed along the channel and a second series cross channel to quantify the channel shoaling at different locations in the sand trap. These transects were generated after initial qualitative examination of the calculated morphology change. Calculated morphology change at the sand trap is shown in Figure 62. Preferential deposition of material on the eastern (Inlet) side of the observation area can be seen as well as on the northern portion of the sand trap area. Less material is observed to deposit southward. This non-uniform deposition behavior gives rise to the need to evaluate the channel infilling at multiple location both along channel and cross channel. Cross sections are presented in Figure 63 with a total of 6 transects shown; three along channel and three cross channels. This design allows for observation of channel infilling across different portions of the sand trap.

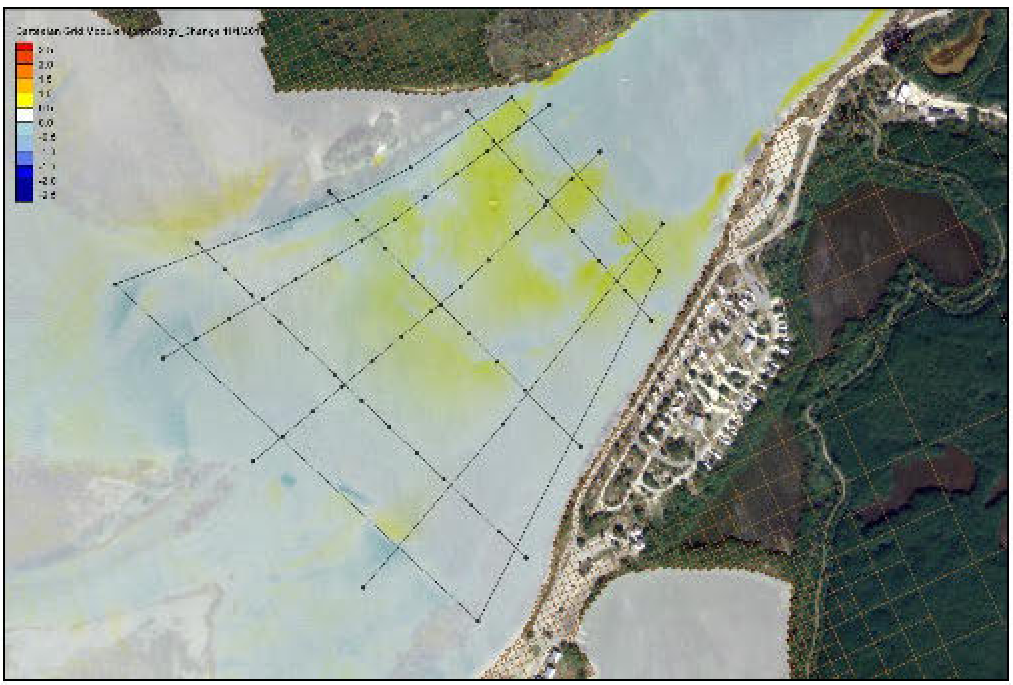


Figure 63. Calculated Morphology Change with Sand Trap Infilling Cross Sections (Post 2014 Dredge).

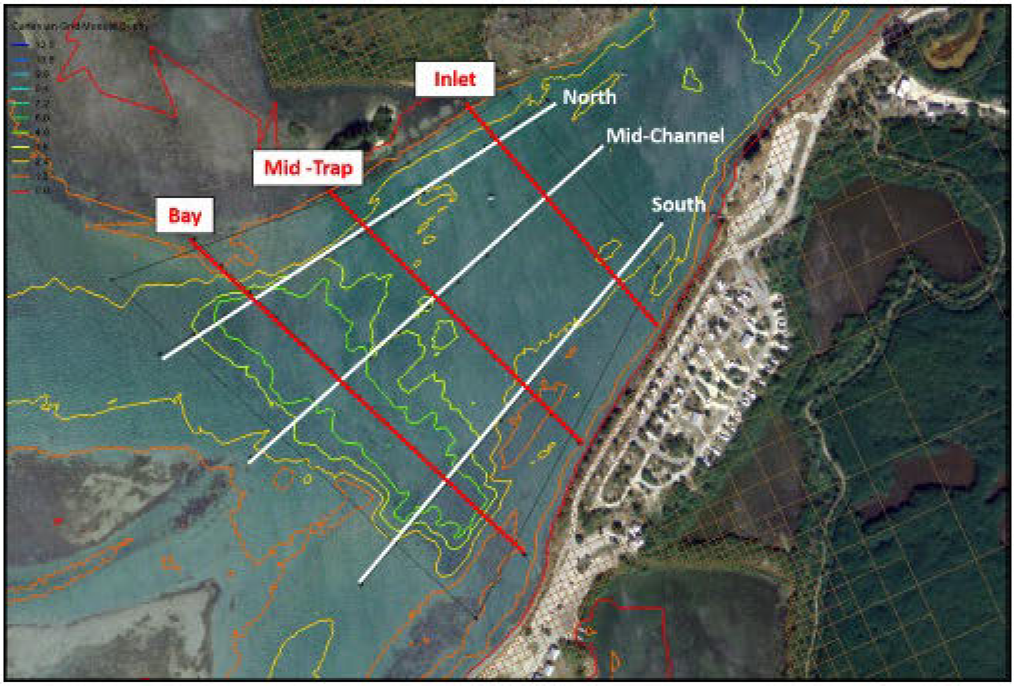


Figure 64. Sand Trap Infilling Cross Sections with Bottom Topography Contours (Aerial Image: LABINS, 2004).

The following series of plots detail the calculated channel infilling across various portions of the sand trap. Figure 64 and Figure 65 are the cross-channel arcs while Figure 66 and Figure 67 are along channel cross sections. For brevity, the mid channel and mid trap cross sections are presented in the appendices.

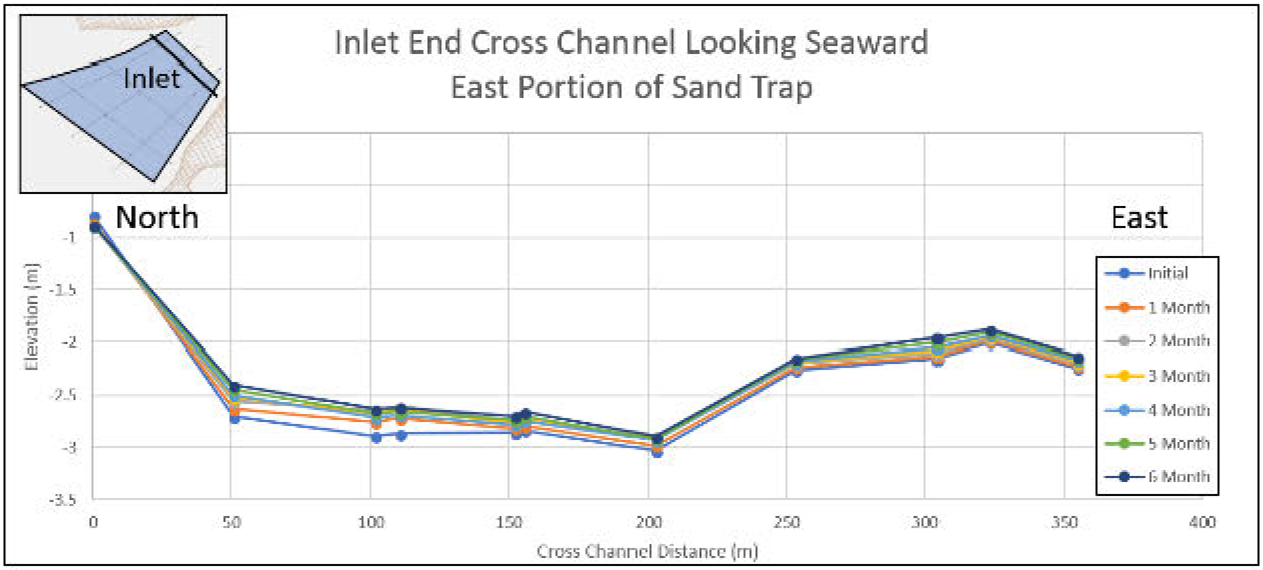


Figure 65. Channel Infilling: Inlet End Cross Section.

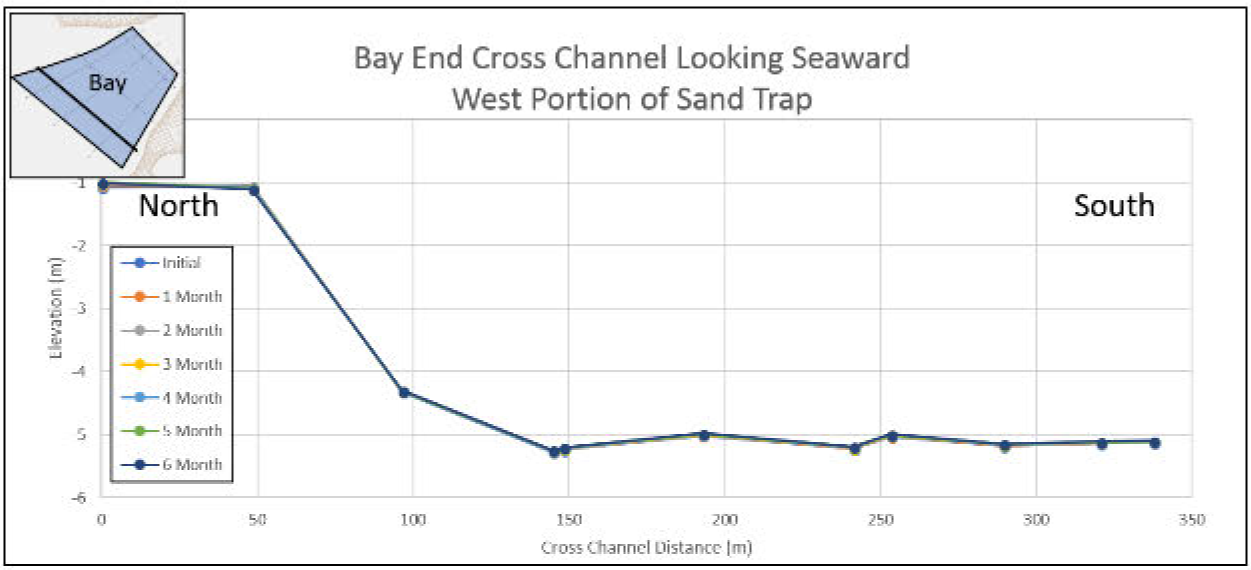


Figure 66. Channel Infilling: Bay End Cross Section.

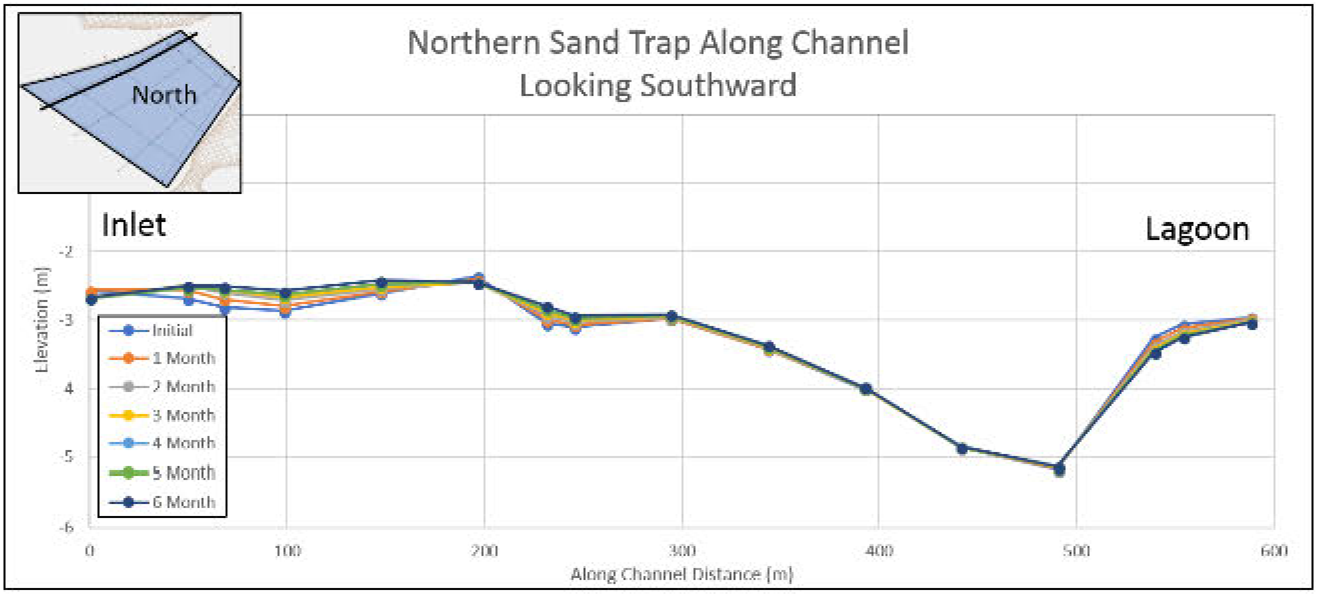


Figure 67. Channel Infilling: North Sand Trap Along Channel.

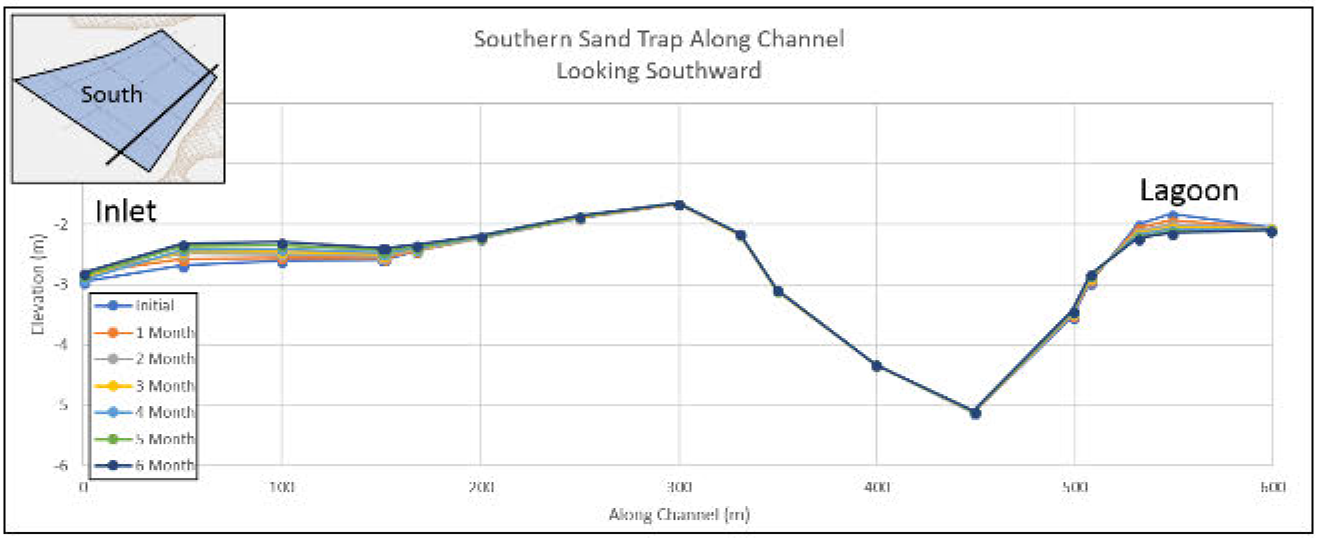


Figure 68. Channel Infilling: Southern Portion of Sand Trap.

The cross channel and along channel plots explicitly demonstrate the channel infilling and compliments the morphology change plot in Figure 62. The cross-channel profiles indicate that most of the deposition of sediment occurs on the inlet and mid sand trap sections where very little change is observed in the western portions of the sand trap. Similar behavior is observed in the along channel profiles however the western end of the along channel profiles extend into the flood shoal lobes which do show deposition throughout the simulation period. To illustrate this behavior further, Figure 68 presents the cross-channel infilling spatially across the sand trap and Figure 69 presents the along channel transects.

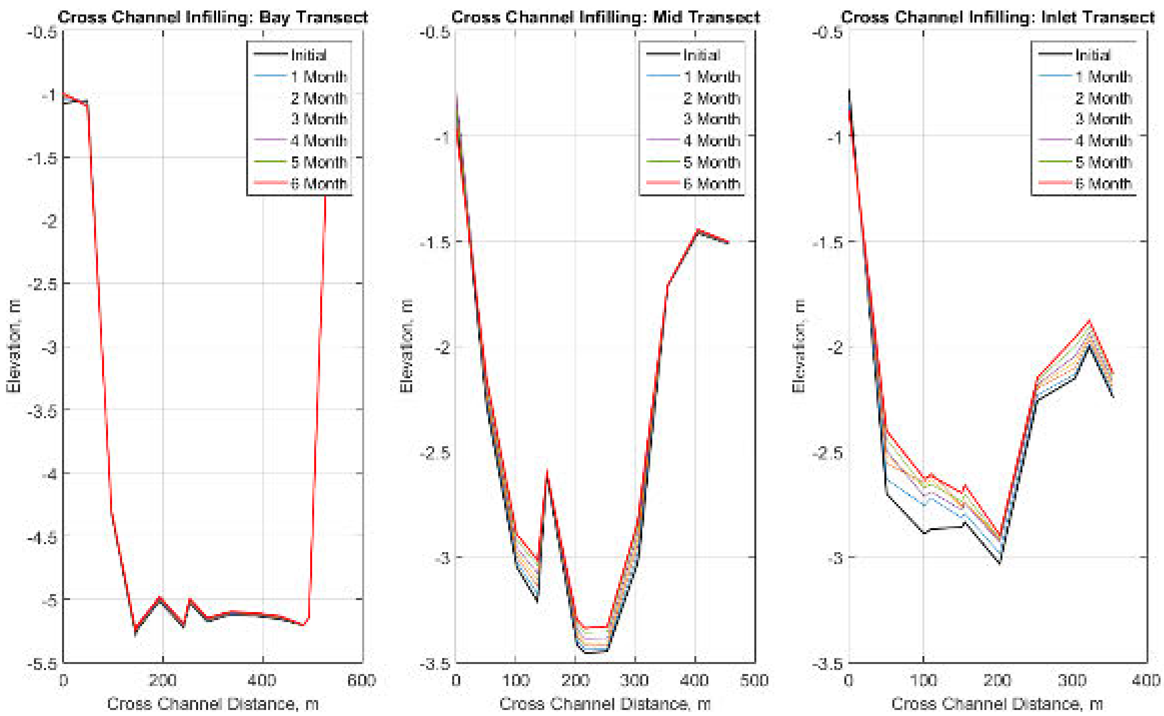


Figure 69. Cross Channel Infilling Variation across Sand Trap.

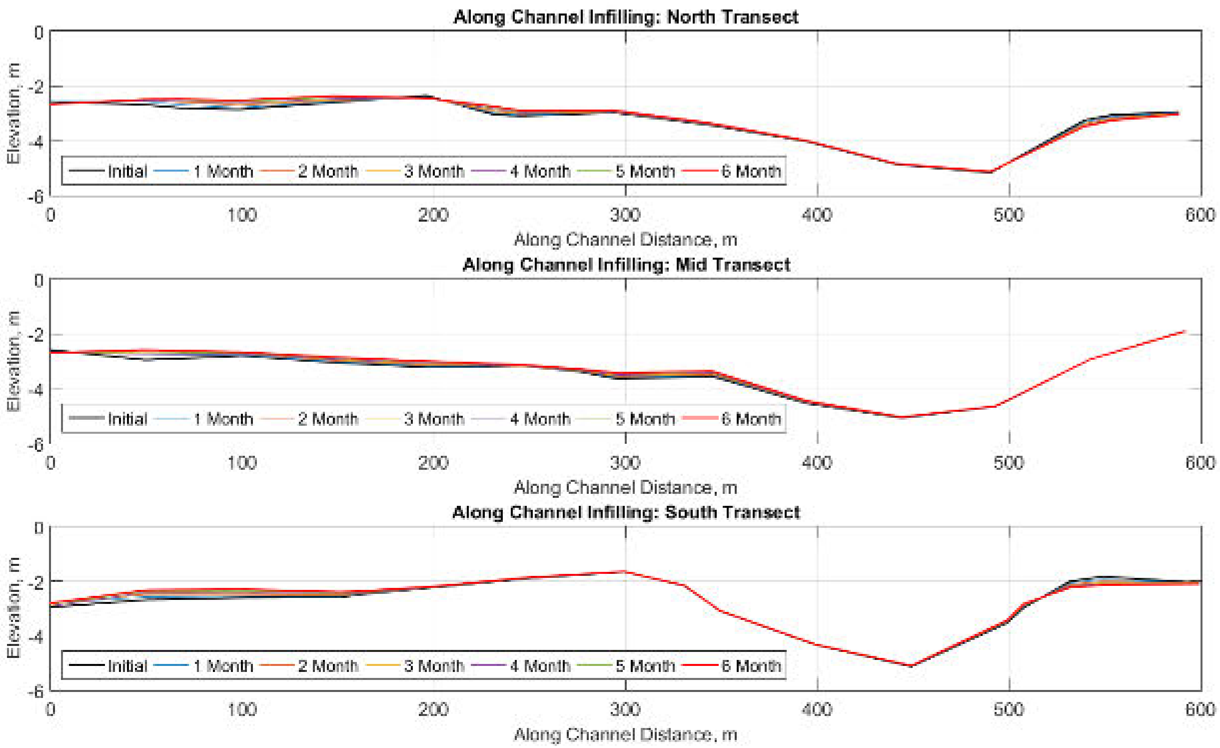


Figure 70. Along Channel Infilling Variation across Sand Trap.

A direct comparison of computed channel bottom topography changes to measured cannot be performed. The bottom topography from 2014 representing a post dredge condition was used with the 2017 model forcing conditions. This allowed for a comparison between immediately post dredge to present day bottom topography which is at the end of the proposed dredging cycle.

When the measured topography is compared between the 2014 Post Dredge (June) and Winter 2017, measured infilling is confined to the dredged portions of the sand trap region on the western ends of the sand trap area. Selected transects are presented in Figure 70 and Figure 71 demonstrating the sediment deposition occurring primarily in the western (Lagoon) side of the sand trap. Figure 72 presents a comparison between calculated morphology change for the Winter 2017 simulation period compared with measured morphology change between the Winter 2017 bottom topography surface and the Post Dredge June 2014 bottom topography.

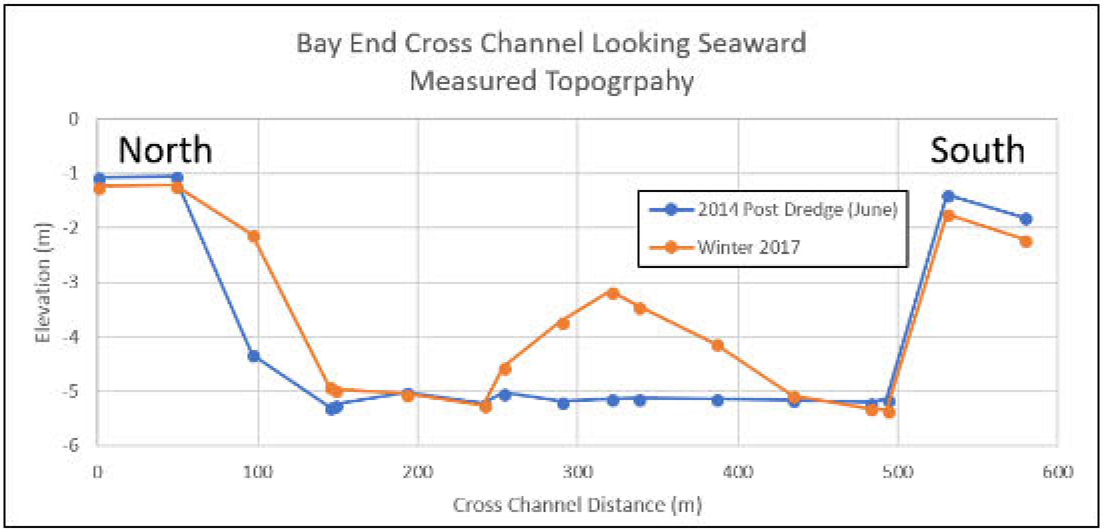


Figure 71. Measured Topography: Bay End Cross Channel.

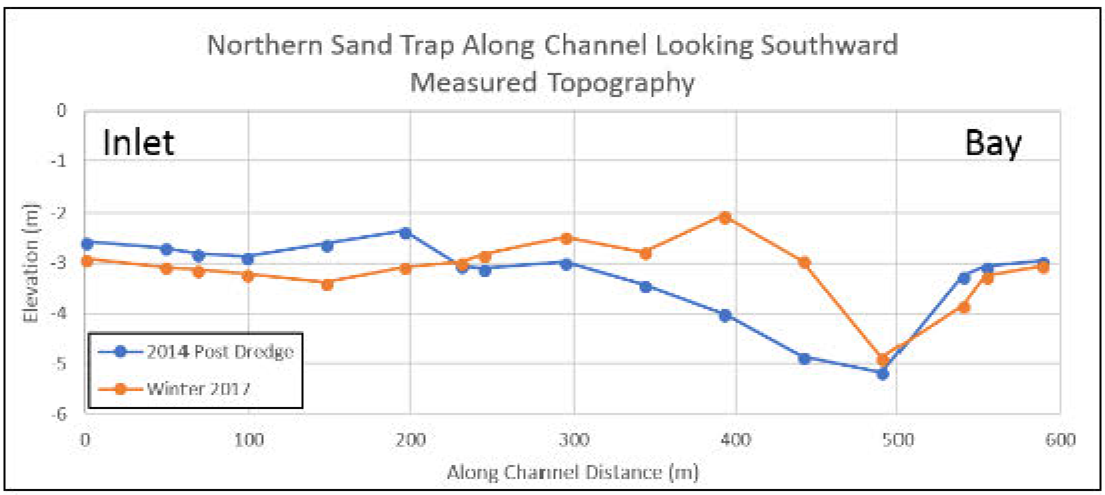
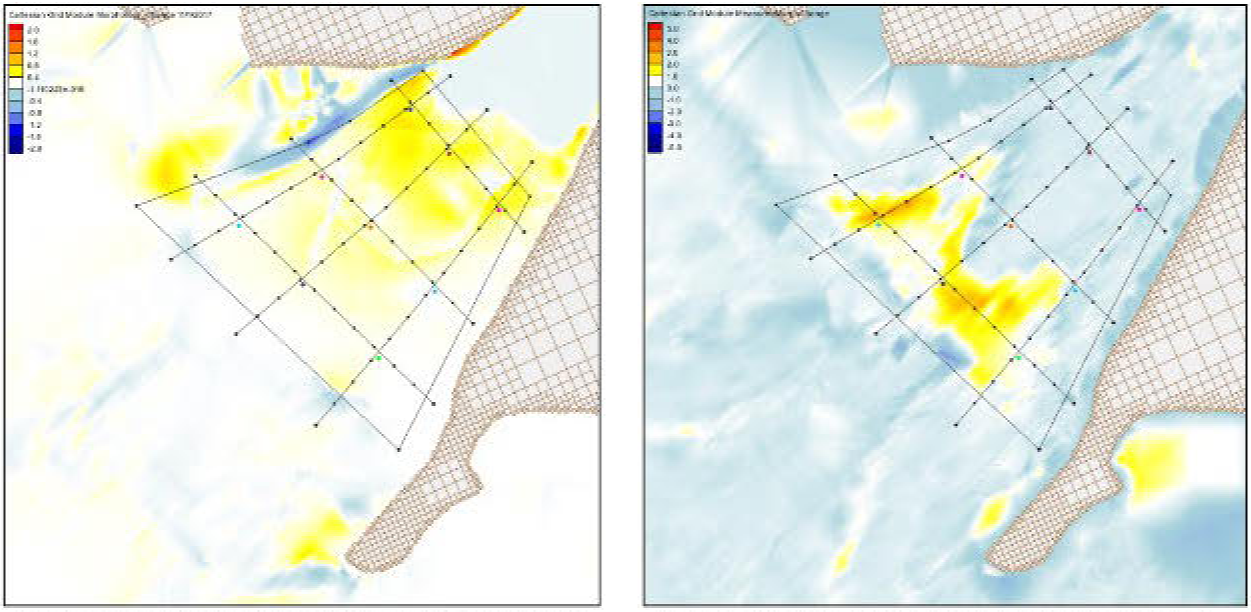


Figure 72. Measured Topography: North Sand Trap Along Channel.



Calculated Morphology Change: Winter 2017 Solid Jetty

Measured Morphology Change: Winter 2017 Solid Jetty – Post Dredge June 2014

Figure 73. Comparison between Calculated (left) and Measured (right) Morphology Change over Sand Trap [Winter2017 - Post Dredge 2014].

The model is predicting the sedimentation occurring at the inlet end of the sand trap area rather than in reality, closer to the flood shoal area and confined to the dredge template. This indicates that the model needs to be further calibrated for flow through the inlet itself. This can be achieved by a more complete representation of the bridge support structure and further experimentation with roughness factors to better represent the hard bottom that characterizes the inlet throat. The morphologic interpretation is that the model is slowing the currents down too quickly upon exiting the hydraulic influence of the confined channel causing the sediment to fall out of suspension too early. Upon investigation into the current magnitudes and direction, the speeds are reasonable for an inlet of this hydraulic and geometric configuration. However, no flow data exists for current speeds through the inlet throat so calibration would need to be driven by the measured morphology change rather than hydrodynamics. Traditionally, model calibration is performed in sequence beginning with water surface elevation, hydrodynamics (wave magnitude and direction, current speed and direction) and finally, sediment transport and/or morphology change. It should also be noted that this comparison spans several years and represent different season conditions which can also contribute to differences in observed morphology. This comparison is merely intended for a gross representation of preferential sediment deposition within the sand trap.

Computed Channel Infilling Rates

The computed rates of change elucidate variability in sedimentation rates with changes in flow forcing throughout the simulation period. The 2017 model forcing includes Hurricane Irma in the simulation period. This allows for the opportunity to observe sedimentation rates during more quiescent periods (May through August) and more energetic periods (September through October).

As anticipated in any morphological model run, higher rates of sedimentation are observed at the beginning of the run. This is due to the model smoothing out any rapid changes in bottom topography as the model comes to a numeric equilibrium. Colloquially, this can be referred to as “model spin up”. Computed sedimentation rates for each transect node are presented in the following tables. The first month is included for completeness. Values are presented as net change and independent of direction (shoaling or erosion) to observe variability in change throughout the simulation period.

Table 15 and Table 16 present the monthly depth changes for Inlet End and Mid Trap cross sections. The Bay End cross section results are presented in the Model Appendices for reference since most of the depth changes occur on the eastern portions of the sand trap (Figures77 through Figure 82).

Table 17 and Table 18 are the calculated monthly depth change for the North and Mid along channel transects respectively. Each value represents a node along the transect. Sedimentation across each transect is presented in the following graphs. The direction of observation is indicated in each title with compass or feature indicated on either end of the cross section.

Table 15. Inlet End Sand Trap Calculated Monthly Depth Change.

Calculated Monthly Depth Change – Inlet End Cross Channel					
May	**June**	**July**	**August**	**September**	**October**
1 Month	**2 Month**	**3 Month**	**4 Month**	**5 Month**	**6 Month**
0.07	0.02	0.00	0.00	0.00	0.00
0.07	0.08	0.04	0.02	0.06	0.04
0.14	0.11	0.02	0.04	0.04	0.04
0.15	0.12	0.03	0.06	0.03	0.04
0.04	0.06	0.01	0.01	0.04	0.04
0.04	0.06	0.00	0.01	0.04	0.04
0.05	0.06	0.01	0.02	0.02	0.02
0.03	0.03	0.01	0.01	0.02	0.01
0.02	0.03	0.03	0.03	0.04	0.04
0.01	0.02	0.02	0.02	0.03	0.03
0.02	0.02	0.02	0.02	0.02	0.02

Table 16. Mid Sand Trap Calculated Monthly Depth Change.

Calculated Monthly Depth Change – Mid Trap Cross Channel					
May	**June**	**July**	**August**	**September**	**October**
1 Month	**2 Month**	**3 Month**	**4 Month**	**5 Month**	**6 Month**
0.03	0.02	0.02	0.01	0.08	0.09
0.02	0.02	0.02	0.02	0.03	0.02
0.02	0.02	0.02	0.02	0.03	0.03
0.04	0.04	0.03	0.03	0.04	0.02
0.01	0.01	0.00	0.00	0.00	0.00
0.02	0.02	0.02	0.02	0.03	0.02
0.02	0.02	0.02	0.02	0.03	0.02
0.01	0.02	0.02	0.02	0.03	0.03
0.04	0.04	0.03	0.03	0.03	0.02
0.05	0.04	0.03	0.03	0.03	0.02
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00

Table 17. North Sand Trap Calculated Monthly Depth Change.

Calculated Monthly Depth Change - North Along Channel					
May	**June**	**July**	**August**	**September**	**October**
1 Month	**2 Month**	**3 Month**	**4 Month**	**5 Month**	**6 Month**
0.01	0.10	0.10	0.10	0.10	0.10
0.13	0.20	0.18	0.16	0.19	0.19
0.11	0.21	0.24	0.25	0.30	0.32
0.07	0.15	0.20	0.23	0.29	0.34
0.03	0.06	0.10	0.14	0.19	0.24
0.05	0.08	0.09	0.09	0.09	0.09
0.06	0.11	0.16	0.21	0.26	0.30
0.03	0.07	0.10	0.13	0.17	0.20
0.01	0.02	0.03	0.05	0.07	0.08
0.01	0.02	0.03	0.04	0.06	0.08
0.00	0.01	0.01	0.01	0.02	0.03
0.00	0.01	0.01	0.01	0.02	0.03
0.00	0.01	0.01	0.01	0.02	0.02
0.01	0.02	0.02	0.03	0.04	0.05
0.07	0.12	0.17	0.20	0.21	0.22
0.06	0.11	0.14	0.17	0.19	0.21
0.02	0.04	0.06	0.07	0.08	0.09

Table 18. Mid Sand Trap Calculated Monthly Depth Change.

Calculated Monthly Depth Change - Mid Channel					
May	**June**	**July**	**August**	**September**	**October**
1 Month	**2 Month**	**3 Month**	**4 Month**	**5 Month**	**6 Month**
0.05	0.10	0.10	0.10	0.10	0.10
0.21	0.30	0.24	0.21	0.29	0.36
0.03	0.09	0.09	0.08	0.12	0.16
0.02	0.07	0.07	0.06	0.10	0.14
0.02	0.07	0.07	0.07	0.10	0.14
0.03	0.07	0.11	0.13	0.17	0.20
0.03	0.07	0.11	0.14	0.19	0.22
0.02	0.02	0.02	0.01	0.02	0.03
0.01	0.03	0.04	0.05	0.08	0.10
0.04	0.08	0.11	0.15	0.19	0.22
0.03	0.06	0.09	0.12	0.16	0.19
0.01	0.03	0.04	0.05	0.08	0.09
0.00	0.01	0.01	0.02	0.03	0.03
0.00	0.01	0.01	0.02	0.02	0.03
0.00	0.00	0.00	0.01	0.01	0.01
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.01	0.01

Current speeds across the sand trap vary with maximum speeds occurring on the inlet end of the trap with a decrease to approximately half at the lagoon side of the area. Descriptive statistics were developed for each observation node and presented in Table 19.

Table 19. Descriptive Statistics of Current Magnitude within Sand Trap.

	Bay North	Mid North	Inlet North
Max	0.424	0.493	0.644
Min	0.424	0.002	0.004
Avg	0.154	0.201	0.258
	Bay Mid	**Mid**	**Inlet Mid**
Max	0.305	0.537	0.680
Min	0.001	0.002	0.002
Avg	0.108	0.216	0.281
	Bay South	**Mid South**	**Inlet South**
Max	0.206	0.389	0.592
Min	0.002	0.003	0.004
Avg	0.081	0.153	0.237

9.0. Adapting a New Modeling Scheme to Sebastian Inlet

A new model application is being developed that will provide a real time predictions of water levels and current around Sebastian Inlet. The real time simulations will be based on the Deltares, Inc. Delft3D modeling system that has been widely applied in the US and Europe. A similar application created at Florida Tech is now running at Pert Everglades, FL Eventually this model will include predictions of sand transport, salinity and water temperature. The following sections describe the initial model setup and testing. These include development of the model grid or mesh and examples of model calibration for water level at Sebastian Inlet.

9.1 Delft3D model setup

Bathymetry

High-resolution bathymetric-topographic data build by high-resolution Digital Elevation Models (DEMs) is obtained from NOAA's National Geophysical Data Center (NGDC). This data is useful for planning and modeling purposes. The grid spacings for the DEM's is 1/3 arc-second (~10 meters), Figure 1.

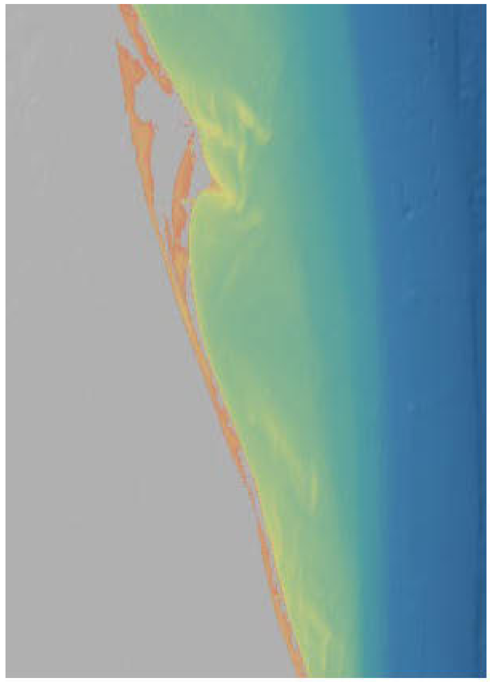


Figure 74. DEM's coverage

Shoreline

The shoreline, Figure 2, was created in SMS Aquaveo software using DEM's data for the use of Delft3d FM Suite in the process of mesh generation. The open boundary is semi-circular extending onto the Florida Continental shelf at a depth of 18 meters at $80.357°W$. The open boundary is extended 15.6 km north of Sebastian Inlet and 10.3 km south of Sebastian Inlet. The northern boundary is located at 192 Causeway inside the Indian River Lagoon (IRL), Melbourne and the southern boundary is located at 510 Causeway, Wabasso, inside the IRL.

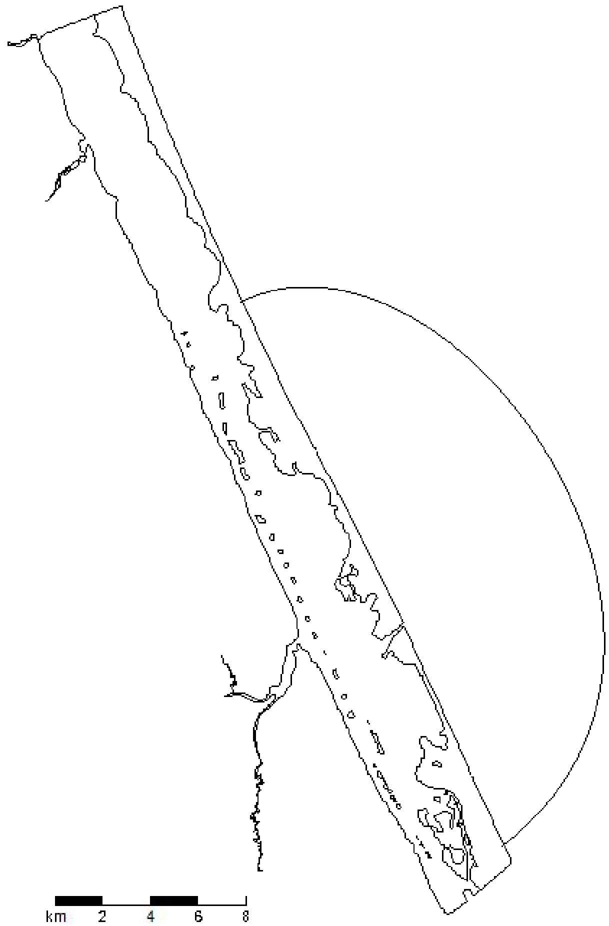


Figure 75. Shoreline

Unstructured mesh

The unstructured mesh, Figure 3, was developed in the RGFGRID module of Delft3D FM Suite. The mesh generation was initiated by importing the shoreline file in RGFGRID. Careful considerations were made to ensure that the mesh fulfills the criteria for stable and accurate modeling. The developed mesh has a minimum grid spacing of approximately 20 meters in channels and around complex geometries and a maximum spacing of approximately 1500 meters in the open ocean. The total number of grid points is 8409.
The coordinate system is set to geographical coordinate system WGS 84 throughout the generation of the shoreline file and the development of the mesh.

The bathymetric data is then interpolated to the grid points (mesh nodes) using the Map module in Delft3d FM Suite, Figure 4.

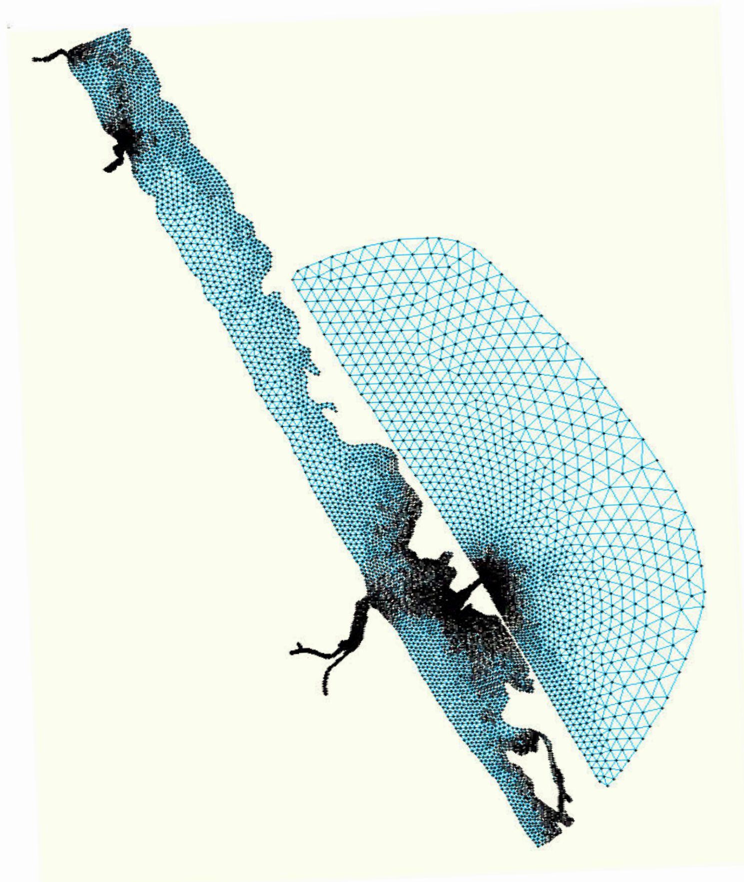


Figure 76. Unstructured mesh created in RGFGRID module of Delft3D FM Suite before bathymetric data was applied

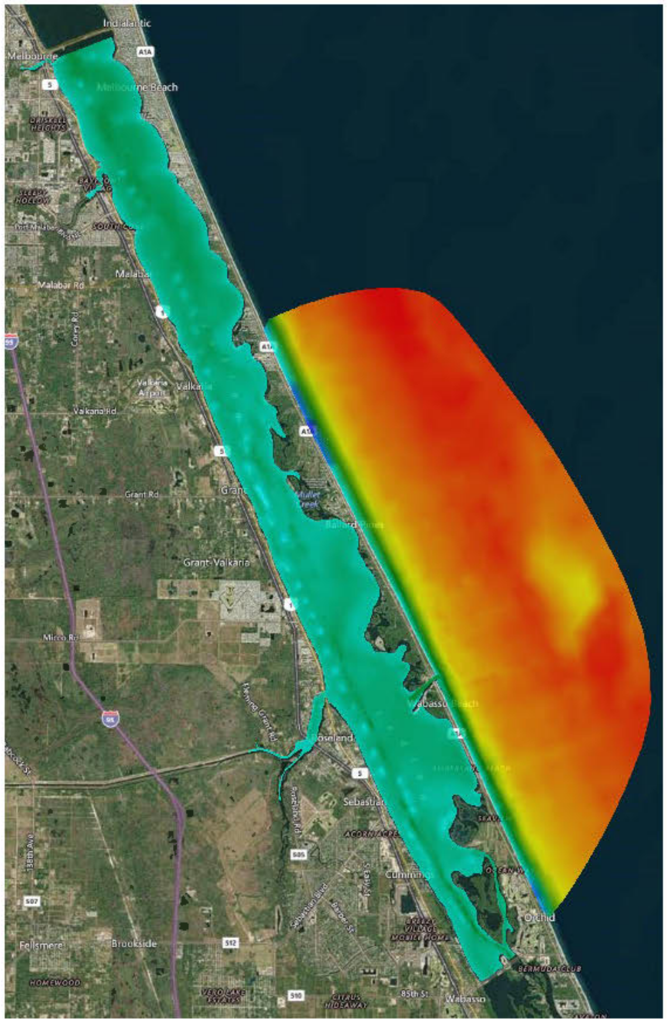


Figure 77. Bathymetric data is interpolated on the developed unstructured mesh in the Map module of Delft3D FM Suite.

9.2 Delft3D model test runs

The unstructured mesh is being tested in Delft3D FM Suite. The preliminary test runs are 3.5-day long (July 24th, 2019 00UTC to July 27th, 2019 12UTC). Test runs are two-dimensional (2D) barotropic simulations.

Boundary forcing

An open boundary is placed at the mesh boundary on the continental shelf, Figure 5 – blue line. The northern and southern boundaries are closed in the preliminary test runs, Figure 5.

The open boundary is forced at 10 evenly distributed points on the boundary by water level time series obtained from a 2D barotropic model (Advanced CIRCulation model known as ADCIRC) that was forced by tidal constituents at its open boundary located at $60°W$ as well as meteorological forcing. Figure 6 depicts the boundary condition interface in Delft3D FM Suite as well as water level time series forcing at one of these 10 points.

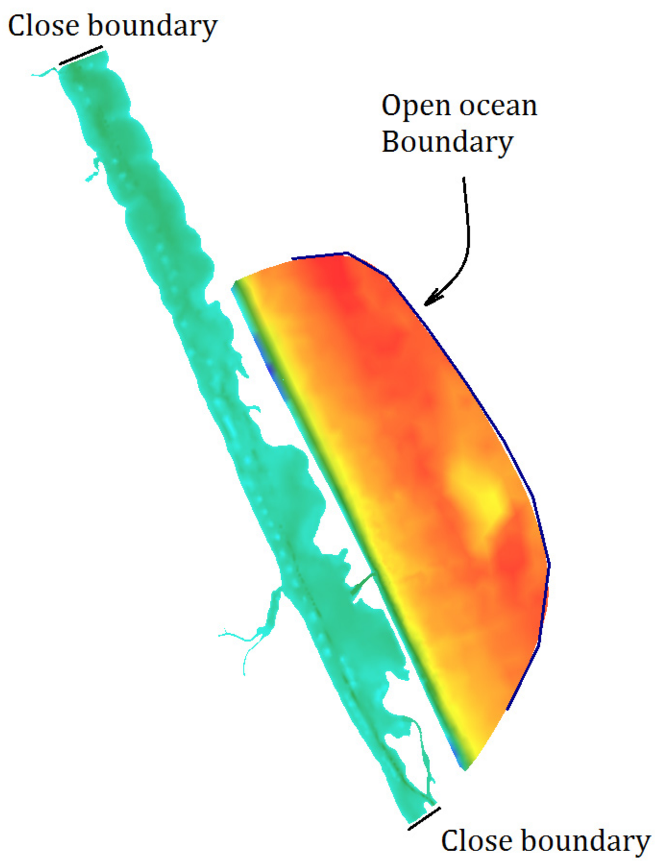


Figure 78. Boundaries in the preliminary test runs

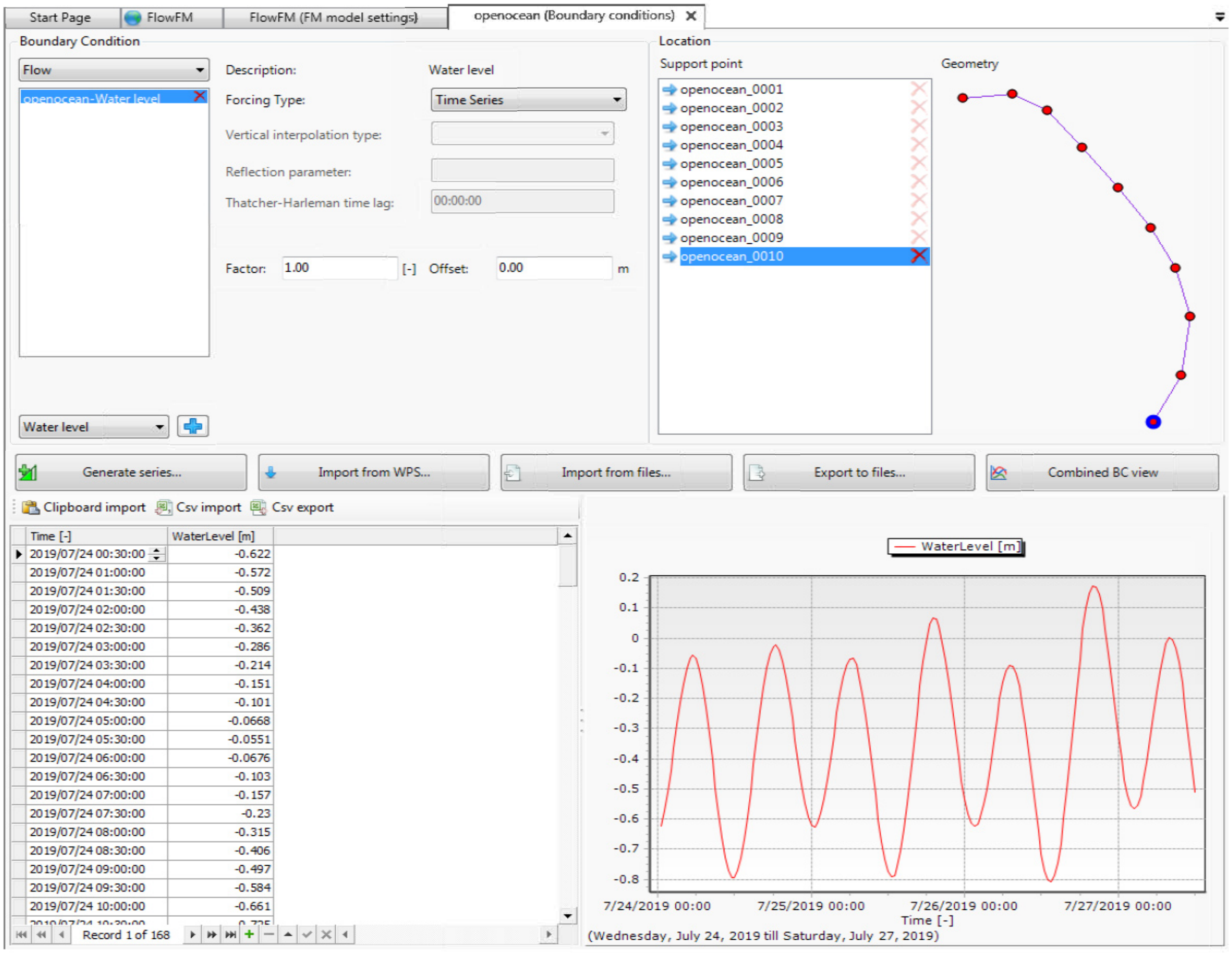


Figure 79. Boundary condition interface in Deflt3D FM Suite - Water level time series at one of the open boundary points (top right); tabulated time series on the lower-left panel and illustration on the lower-right panel.

Wind forcing

In the preliminary test runs, a spatially uniform wind forcing was created. The wind forcing was obtained from a weather forecast model called the North American Mesoscale (NAM) model. The forecast wind speed components at the Sebastian Inlet is used to force the entire domain. The wind forcing time interval is 30 minutes. Figure 7 shows the wind module of Delft3D FM Suite and the imported wind time series on the left and the wind components plots on the right.

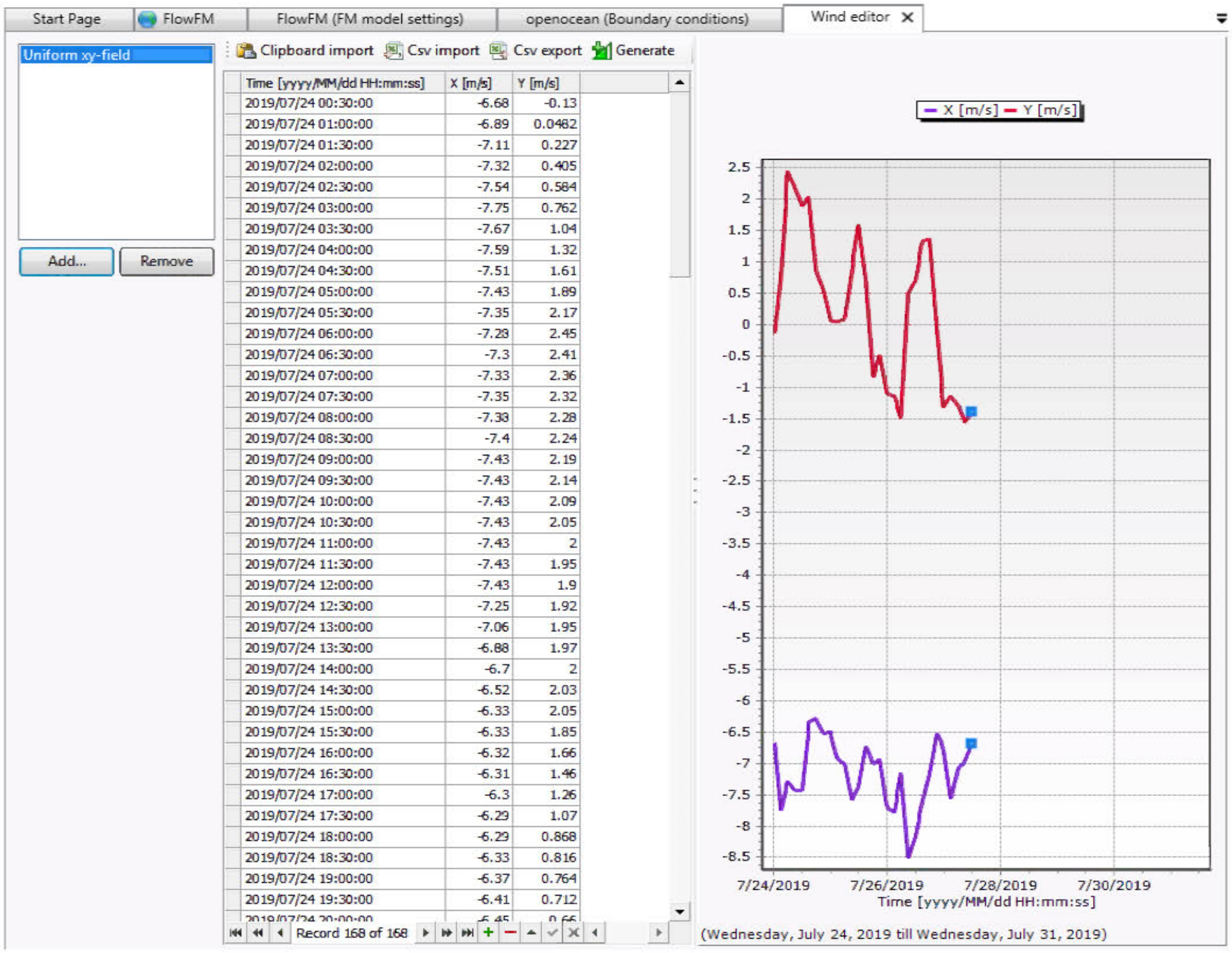


Figure 80. The Wind Interface of Ddelft3D FM Suite. The right panel of Figure 7 shows the U component (purple line) and the V component (red line) of the wind time series obtained from the NAM model at Sebastian Inlet.

9.3 Preliminary results

Model results can be viewed as 2D contours time series in Delft3D FM Suite as well as points time series. The Map module also allows for specifying observation points where model results can be extracted as CSV files. Figure 8 shows modeled water (blue line), U component of the modeled current velocity (red line), and V component of the modeled current velocity at Sebastian Inlet. Note that the modeled time-series signals are noisy during the first day of simulation. As the model spins up and reaches the state of equilibrium, noises disappear on July 25, 2019, 1200UTC.

Figure 9 demonstrates the model water level validated by the observed water level at Sebastian Inlet. The observing system is run by Coastal Process Research Group at Florida Tech. The correlation coefficient and the correlation of determination calculate between modeled and observed water level are 0.948 and 0.899, respectively.

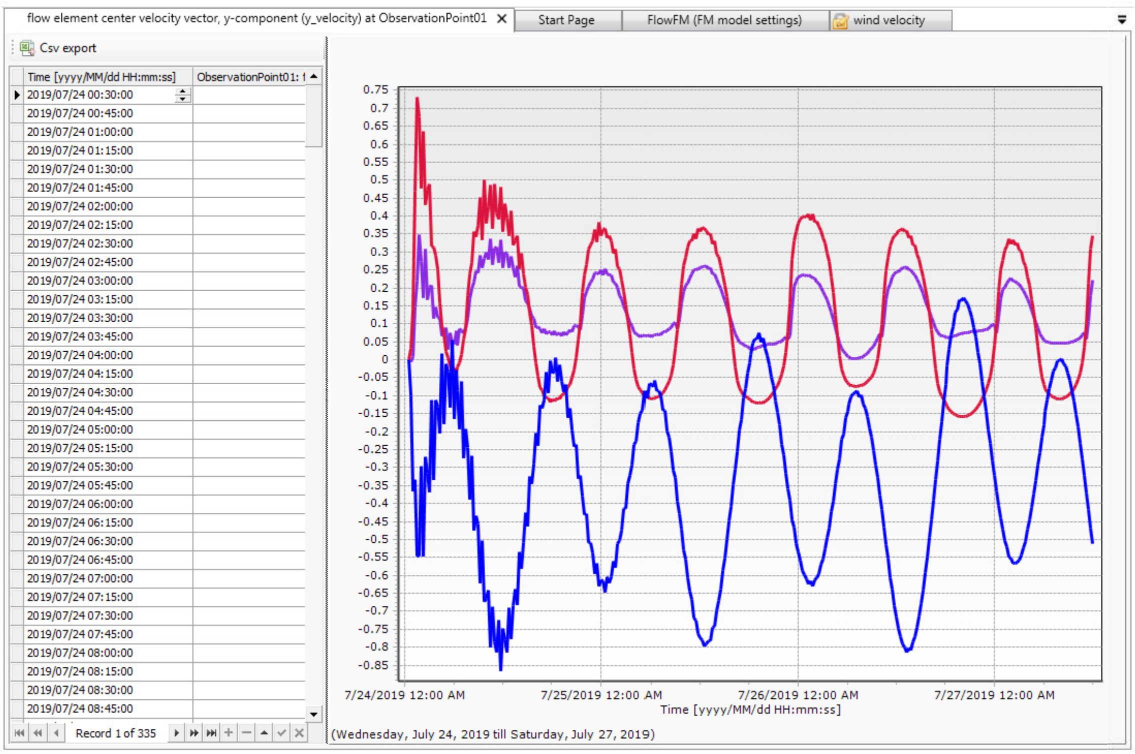


Figure 81. Modeled water (blue line), U component of the modeled current velocity (red line), and V component of the modeled current velocity at Sebastian Inlet.

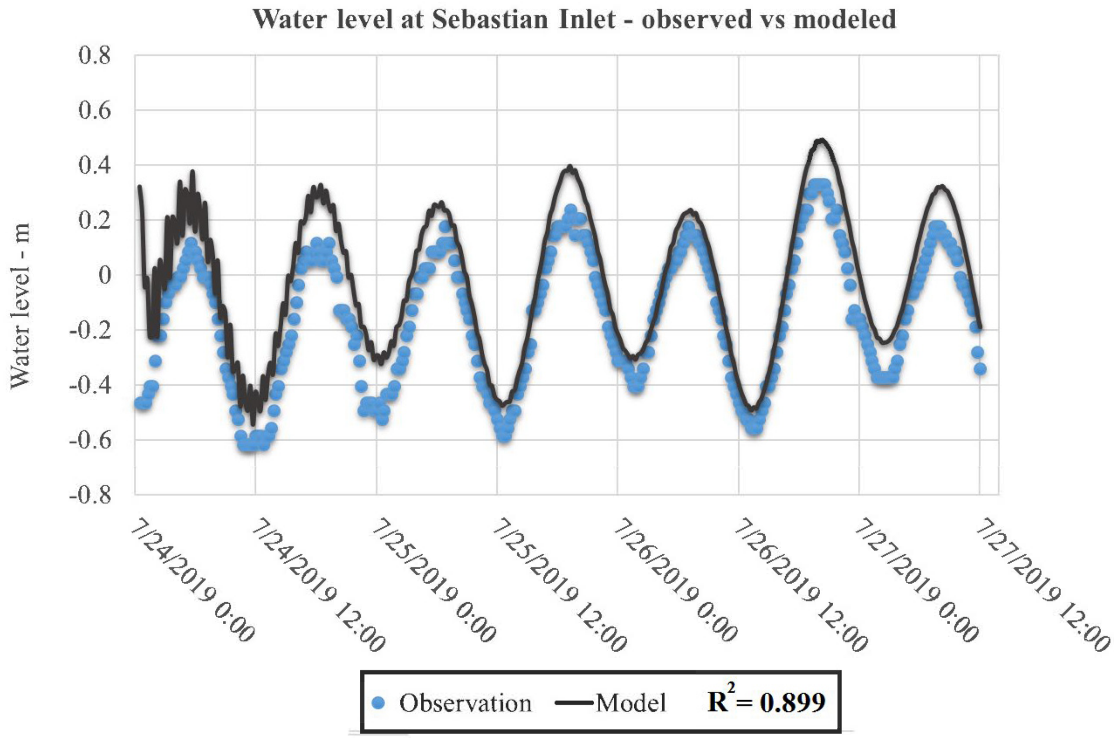


Figure 82. - the model water level validated by the observed water level at Sebastian Inlet. The blue dots are observations and the dark gray line is model water level.

10.0 Conclusions and Recommendations

The annual update of the State of Sebastian Inlet includes five major areas of work; 1) an update of the analysis of volume contained in the sand reservoirs of the inlet system, 2) analysis of the sand budget based on the results of the sand volume analysis, 3) analysis of morphologic changes within the inlet system, 4) an update of the shoreline change analysis, and 5) numerical modeling analysis of hurricane impacts sand infilling patterns of the sand trap.

- Similar to the volumetric analysis described in previous state of the inlet reports, most inlet sand reservoirs are in a long-term dynamic equilibrium characterized by occasional large seasonal changes in volume superimposed on longer term trends of a lower order of magnitude.
- Examination of coastal sea level changes and sand volume between 2006 and 2019 revealed two important processes.
    - It can be demonstrated that the Sebastian Inlet sand reservoirs and the beach and shoreface areas both to the north and to the south of the inlet undergo periods of regional sand volume losses and periods of and volume gains.
    - Large sand volume gains and losses cover the entire region rather than being inversely linked to gains or losses in adjacent subsections.
    - Examples are sand volume gains that peaked in 2010 and again in 2016 were preceded by periods of regional sand volume losses.
- When the sea level record measured at Sebastian Inlet is examined over the 13-year period between 2006 and 2019, it can be demonstrated that periods of increasing cumulative sand volume losses correspond to periods of rising sea level
- Periods of falling sea level correspond to periods of cumulative sand volume gains and lower cumulative sand volume losses.
- The sea level record for late 2017 to early 2019 indicates that another period of rising sea level is beginning. This indicates a potential for an upcoming period of increased loss of sand volume
- The dynamic equilibrium and trends of sand volume changes within the inlet sand reservoirs associated with Sebastian Inlet are also reflected in sediment budget calculations.
- The sand budget for the Sebastian Inlet region is reported at three-time scales, including a longer time scale of 10 years, a time scale of 5 years, and a shorter time scale of 3 years.

- The most useful time scale is considered to be 10 years since it integrates over seasonal sand volume changes that mask longer term trends.
- Over the time period of 2007-2019, the benefits of sand by-passing from the sand trap and beach fill placement projects to the south of the inlet can be shown to directly offset sand volume gains within the inlet.
- The impacts of rising and falling sea level are more apparent in the 5-year and 3 years and budgets analyses presented in this report.
- Similar to the sand volume analysis, the results of shoreline mapping from survey data and aerial imagery vary considerably by time scale.
- Over the 10-year time scale from 2008 to 2019, shoreline changes south of the inlet reflect the position of beach fill placement in 2007, 2011, 2012, 2014 and 2019, along with periods of regional sand volume gains and losses

Acknowledgments:

The project team acknowledges the Sebastian Inlet District Commissioners, the District Executive Director James Gray for their support.

10 .0 References

Brehin, F.G. and G.A. Zarillo. 2010. Morphodynamic Evolution and Wave Modeling of the Entrance Bar Surfing Break "Monster Hole": Sebastian Inlet, FL. 7th International Surfing Reef Symposium 2010, Sydney, Australia.

Buttolph. A.M., Reed, C.W., Kraus, N.C., Ono, N., Larson, M., Camenen, B., Hanson, H., Wamsley, T., and Zundel, A.K. 2006. Two-dimensional depth-averaged circulation model CMS-M2D: Version 3, Report 2, Sediment transport and morphology change. *ERDC/CHL TR-06-09,* U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.

Camenen, B., and M., Larson. 2007. A Total Load Formula for the Nearshore. Proceedings Coastal Sediments '07 Conference, ASCE Press, Reston, VA, 56-67.

Crowell, M., S.P. Leatherman, and M.K., Buckley. 1993. Erosion Rate Analysis: Long Termversus Short Term Data. Shore and Beach, 61 (2):13-20.

Dean, R. Dalrymple, R. (2003) Coastal Processes with Engineering Applications, Cambridge University Press. Cambridge, UK.

Dolan, R., M.S. Fenster, and S.J. Holme. 1991. Temporal analysis of shoreline recession and accretion. Journal of Coastal Research, 7(3):723-744.

USACE. 1994. Engineering Manual for Hydrographic Surveys EM 1110-2-1003 Change 1 (http://www.asace.army.mil) Accessed: October 2010.

Hoeke, R. K. G.A. Zarillo, and M. Synder. 2001. A GIS Based Tool for Extracting Shoreline Positions from Aerial Imagery (BeachTools).*ERDC/CHL CHETN-IV-37*, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Land Boundary Information System (LABINS) http://www.labins.org/index.cfm

Lin, L., H. Mase, F. Yamada, and Z. Demirbilek. 2006. Wave-Action Balance EquationDiffraction (WABED) model: Tests of wave diffraction and reflection at inlets. ERDC/CHL CHETN-III-73. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Lin, L., Demirbilik, Z., Mase, H., Zheng, J., Yamada, F. (2008) "CMS-Wave: A Nearshore Spectral Wave Process Model for Coastal Inlets and Navigation Projects" TR-08-13, Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS.

Morton, R. A. 2002. Factors controlling storm impacts on coastal barriers and beaches – A preliminary basis for real-time forecasting: Journal of Coastal Research (18):486-501.

National Oceanic and Atmospheric Agency (2018) National Weather Service, Environmental Modeling Center, NOAA WaveWatch III. http://polar.ncep.noaa.gov/waves/index2.shtml

NOAA National Geodetic Survey (NGS). Coastal Relief Model Offshore Data Sets. (http://www.ngs.noaa.gov) Accessed: October 2010.

Rosati, J.D., Carlson, B. D., Davis, J. E., and T. D., Smith. 2001. "The Corps of Engineers'National Regional Sediment Management Demonstration Program," ERDC/CHL CHETN-XIV-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Rosati, J.D. and N.C., Kraus. 1999. "Formulation of sediment budgets at inlets," CoastalEngineering Technical Note IV-15, U.S. Army Engineer Waterways Experiment Station,Vicksburg, MS.

Rosati, J.D. and N. C. Kraus. 2001. Sediment Budget Analysis System (SBAS). ERDC/CHL. CHETN- XIV-3. U.S. Army Engineering Research and Development Center. Vicksburg, MS.

Ruggiero, P., D, Reid, Kaminsky, G. and J. Allan. 2003. Assessing Shoreline Change TrendsAlong U.S. Pacific Northwest Beaches. July 22 to 26, 2007, Proceedings of Coastal Zone 07, Portland, Oregon.

Sanchez, A., Lin, L, Demirbilek, Z., Beck, T., Brown, M., Li, H., Rosati, J., Wu, W., Reed, C., Zundel, A., 2012. *in review*, Coastal Modeling System User Manual, ERDC/CHL.

Sanchez, A., Lin, L., Demirbilek, Z., Beck, T. M., Brown, M., Li, H.. Zundel, A. (2013). *Coastal Modeling System User Manual*. Retrieved from Vicksburg, MS.:

Sanchez, A., Wu, W., Li, H.., Brown, M., Reed, C., Rosati, J., Demirbilek, Z. 2014 Coastal Modeling System: Mathematical Formulations and Numerical Methods, ERDC/CHL TR-14-Vicksburg, MS.

Tolman, 2010: WAVEWATCH III (R) development best practices Ver. 0.1. NOAA / NWS / NCEP / MMAB Technical Note 286, 19 pp

U.S Army Corps of Engineers. 2015. SBEACH – Storm-induced BEAch CHange Model. Available Online: [http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=Software;31]. Last Accessed: March 3rd, 2015.

U.S. Army Corps of Engineers. 2002. Coastal Engineering Manual. Engineer Manual 1110-2-1100, U.S. Army Corps of Engineers, Washington, D.C. (in 6 volumes).

Wang, P., Kraus, N.C., David, R.A. 1998. Total Longshore Sediment Transport Rate in the Surf Zone: Field Measurements and Empirical Predictions. *Journal of Coastal Research*, 14(1), 269 – 282. Royal Palm Beach (Florida), ISSN0749 – 0208.

Wu, W., A. Sanchez, and M. Zhang. 2010. An Implicit 2-D Depth-Averaged Finite-Volume Model of Flow and Sediment Transport in Coastal Waters. June 30 – July 5, 2010, 32ndInternational Conference on Coastal Engineering (ICCE 2010) Shanghai, China.

Zarillo, G.A. and The Florida Tech Coastal Processes Research Group. 2007. State of Sebastian Inlet Report: An Assessment of Inlet Morphologic Processes, Historical Shoreline Changes, and Regional Sediment Budget, *Technical Report 2007-1*, Sebastian Inlet Tax District, FL.

Zarillo, G.A., Brehin, F.G., and TheFlorida Tech Coastal Processes Research Group. 2009. State of the Inlet Report: An Assessment of Inlet Morphologic Processes, Historical Shoreline Changes, Local Sediment Budget and Beach Fill Performance. Sebastian Inlet Tax District, FL.

Zarillo, G.A., Brehin, F.G, 2010. State of the Inlet Report: An Assessment of Inlet Morphologic Processes, Historical Shoreline Changes, Local Sediment Budget and Beach Fill Performance. Sebastian Inlet Tax District, FL.

Zarillo, G.A. and Bishop, J. 2008. Geophysical Survey of Potential Sand Resources Sebastian Inlet, Florida. Prepared for the Sebastian Inlet Tax District, 29p.

Zarillo, G.A. and Brehin, F.G. 2008. Wave Hind Cast Project Report. Submitted to the Sebastian Inlet Tax District, 18p.

Zarillo, G. A., et. al. "A New Method for Effective Beach Fill Design," *Coastal Zone '85,* 1985.

11.0 Model Appendices

Individual Channel Infilling Transects

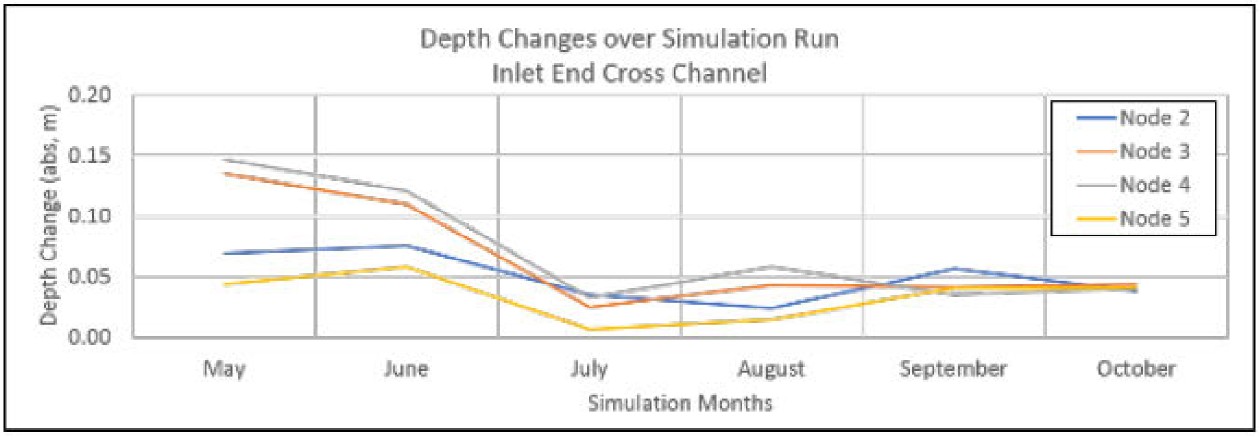


Figure 83. Depth Changes through Simulation Run: Inlet End Cross Channel.

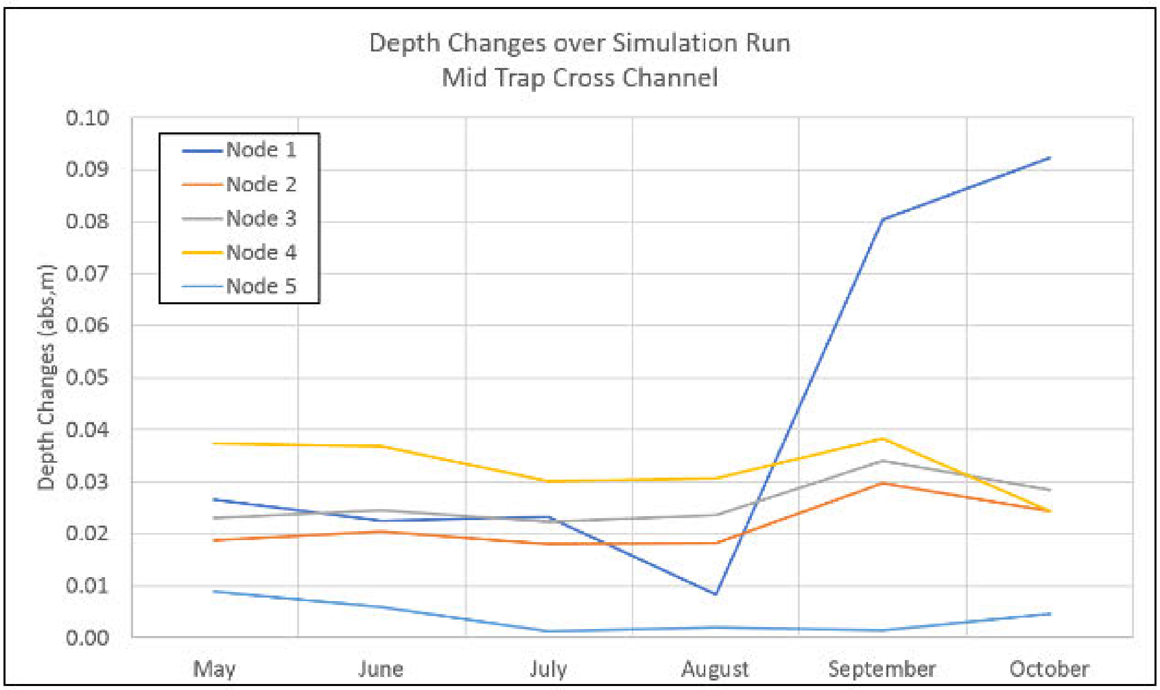


Figure 84. Depth Changes through Simulation Run: Mid Trap Cross Channel.

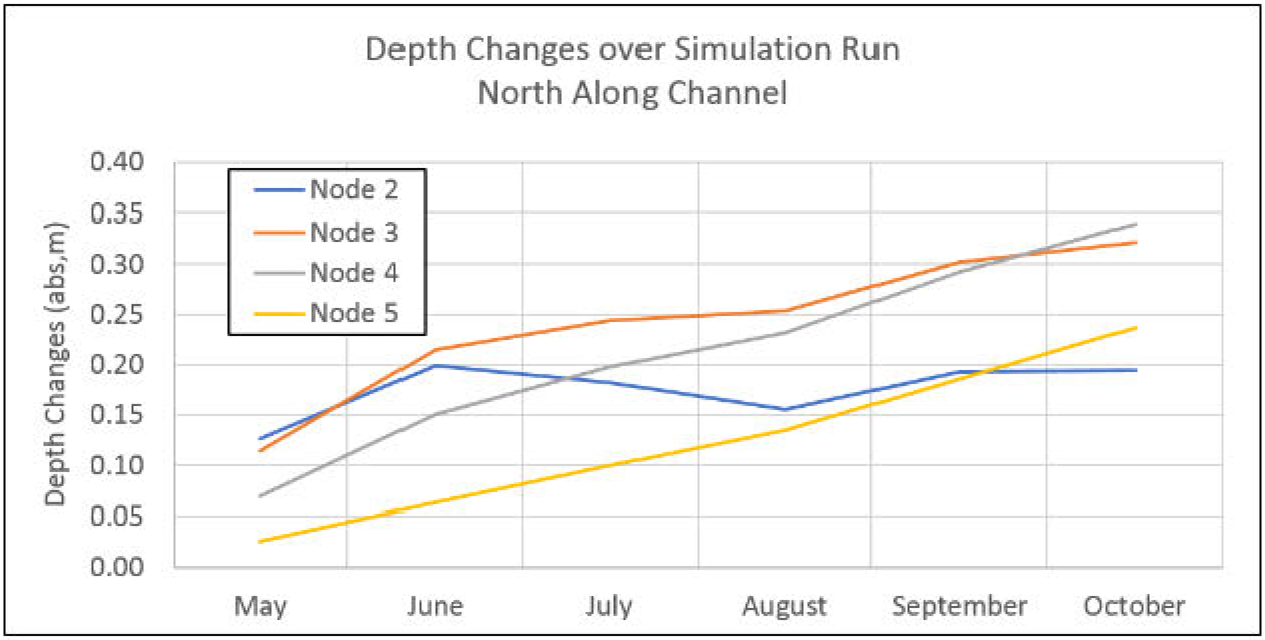


Figure 85. Depth Changes through Simulation Run: North Along Channel.

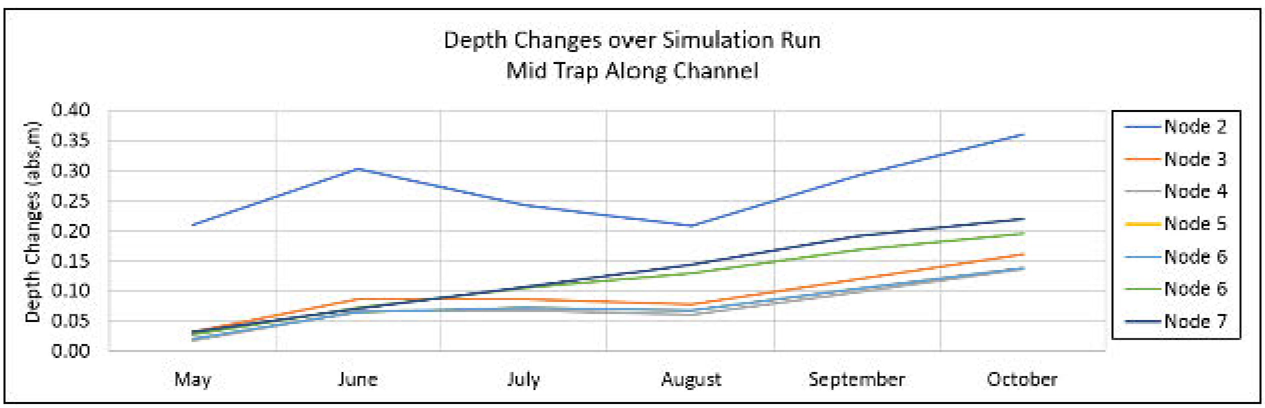


Figure 86. Depth Changes through Simulation Run: Mid Trap Along Channel. Computed Current Field at Sand Trap.

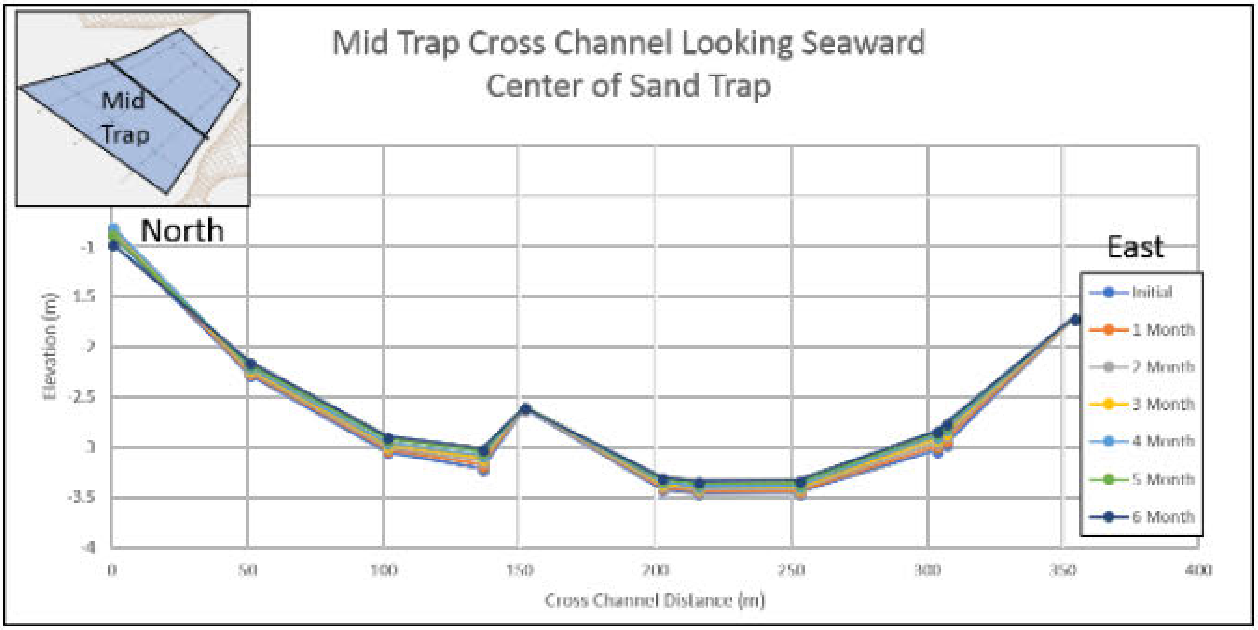


Figure 87. Channel Infilling: Mid Cross Section.

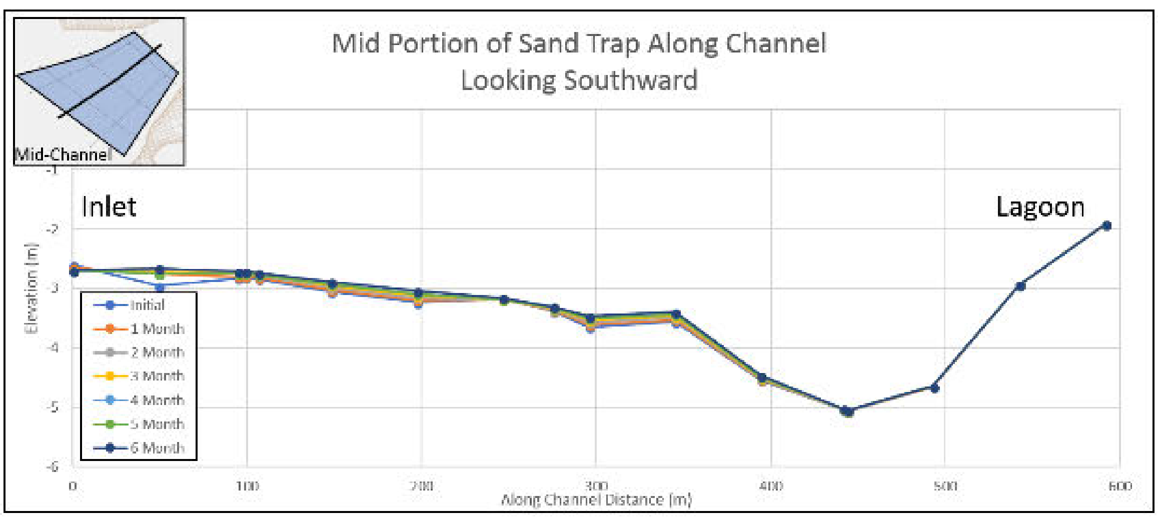


Figure 88. Channel Infilling: Mid Portion of Sand Trap Along Channel.

Calculated Monthly Elevation Change

Table 20. Bay End Calculated Monthly Depth Change

Calculated Monthly Depth Change – Bay End Cross Channel					
May	**June**	**July**	**August**	**September**	**October**
1 Month	**2 Month**	**3 Month**	**4 Month**	**5 Month**	**6 Month**
0.03	0.02	0.01	0.01	0.00	0.00
0.01	0.01	0.00	0.00	0.01	0.01
0.00	0.00	0.00	0.00	0.01	0.00
0.01	0.01	0.00	0.00	0.01	0.01
0.01	0.01	0.00	0.00	0.01	0.01
0.01	0.01	0.00	0.00	0.01	0.01
0.00	0.01	0.00	0.00	0.01	0.01
0.00	0.01	0.00	0.00	0.01	0.01
0.00	0.00	0.00	0.00	0.01	0.01
0.00	0.00	0.00	0.00	0.01	0.01
0.00	0.00	0.00	0.00	0.01	0.01