Alabama Barrier Island Assessment - Littoral Sediment Budget from 1985/88 to 2010/16

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Final Report

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Abstract

An updated sediment budget analysis was performed for the Alabama Gulf coast, by the U.S. Army Corps of Engineers, Mobile District, to quantify transport of littoral sediments, both natural and human induced, into and out of the region over the time period from 1985 to 2016. The analysis provides valuable information that can be used to assess the need and determine effective beneficial use of dredged material within the region.

Overall, the ebb shoals at the passes were net depositional (sediment sinks). Beach and nearshore environments were net erosional (sediment sources). The dominant direction of littoral transport was east-to-west, and sand from the beaches and nearshore areas along the Alabama Gulf coast supplied material to downdrift barrier islands and inlets.

Human induced transport of sediments within the littoral system included numerous sand mining and beach nourishment efforts as well as the dredging and dredged material placement actions at four navigation projects. The most extensive sand mining efforts occurred within Baldwin County, Alabama. For these projects sand was removed from outside the littoral system, with sand placement along the coast merely serving as a source. In Mobile County most sand mining efforts occurred within the active littoral system and served as sediment sinks as well as sources. The most extensive navigation channel dredging occurred within the Mobile Harbor Entrance (Bar) channel. Sediment deposited within the Mobile Harbor Bar channel was primarily bypassed to the adjacent western ebb shoal system over the period of analysis. The benefits of this bypassing are reflected in the near balanced sediment cell and increased sediment flux to Dauphin Island from the Mobile ebb shoal system over the time period of analysis.

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Preface

This study was conducted as part of a collaborative effort between the U.S. Geological Survey (USGS), U.S. Army Corps of Engineers (USACE), and the State of Alabama funded, by the National Fish and Wildlife Foundation (NFWF) to investigate viable, sustainable restoration options that enhance and restore the natural resources of Dauphin Island, Alabama.

The work was performed by the USACE, Mobile District (SAM) but recognition is given as the study could not have been possible without the analysis for which it built upon. This work included prior sediment budget analyses completed by Applied Coastal Research and Engineering, Inc., sea floor and shoreline change studies conducted by the USGS and updated bathymetric datasets collected and processed by the USGS and USACE. In addition, foundational to this study was the existing USGS and USACE tools available for coastal analysis to include the digital shoreline analysis system (DSAS), Joint Airborne Lidar Bathymetry Technical Center of Expertise (JABLTX) volume change analysis, Sediment Budget Analysis system (SBAS), USACE Hydrographic Surveys (EHydro) and Channel Shoaling Analysis tools (CSAT).

Unit Conversion Factors

Multiply	By	To Obtain
cubic yards	0.76455	cubic meters
cubic yards per year	0.76455	cubic meters
feet	0.3048	meters
miles (statute)	1.609344	kilometers
inches	25.4	millimeters

1.0 Introduction

Dauphin Island is a barrier island situated along the northern Gulf of Mexico off the coast of Alabama (Figure 1). It serves as the only barrier island providing protection to much of the state's coastal natural resources. The size of the system spans over 3,500 acres of barrier island habitat including beach, dune, overwash fans, intertidal flats, wetlands, maritime forest, and freshwater ponds and lakes. In addition, Dauphin Island provides shelter to approximately one-third of the Mississippi Sound and estuarine habitats including oyster, reefs, marshes, and seagrasses.

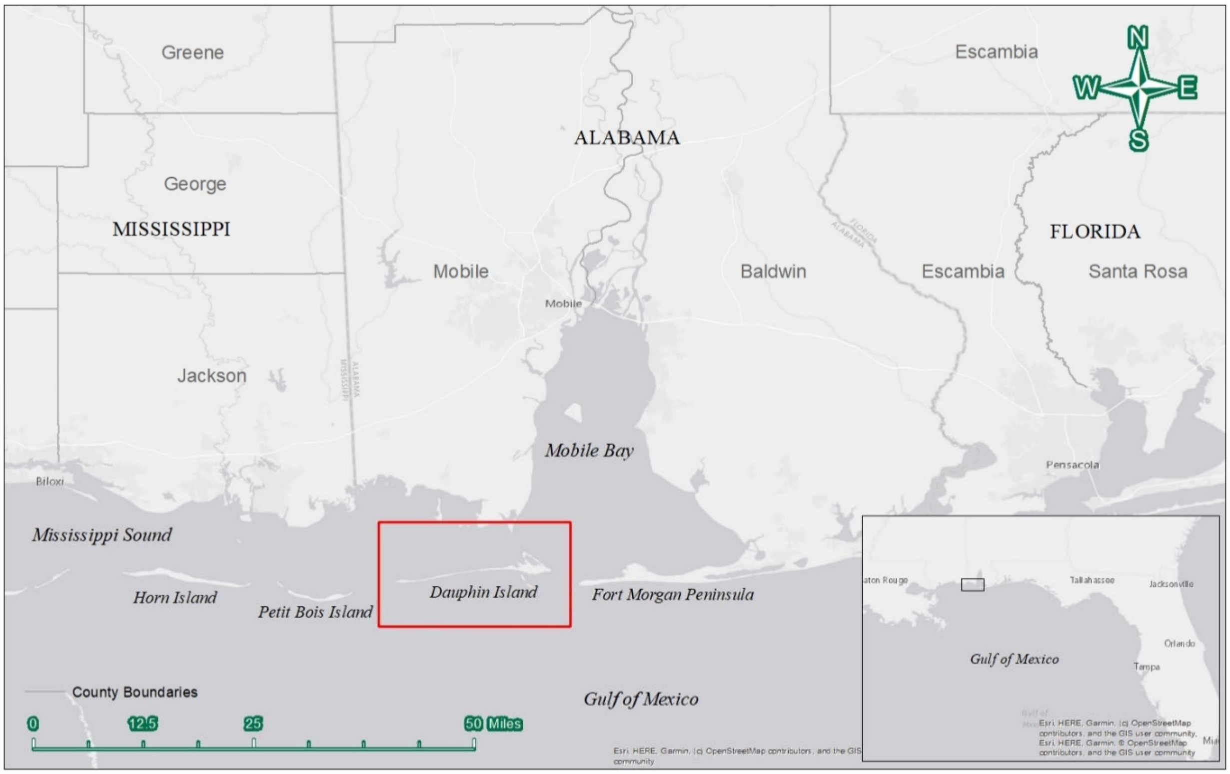

Figure 1. Dauphin Island Location Map

Dauphin Island and the remainder of the barrier islands fronting the Mississippi Sound have been historically losing surface area and their capacity to protect mainland natural resources and infrastructure is diminishing (Byrnes et al., 2010). Rising sea levels, severe and frequent storms, and engineering activities; that involve such things as removal of wetlands, dunes and backbay habitats all threaten the sustained subaerial presence (Twichell et al., 2013; Byrnes et al., 2012; Morton et al., 2008). Moreover, loss of barrier island area threatens the estuarine ecosystem of the Mississippi Sound, its resources and exposes the mainland coast to increasing saltwater intrusion and damage from future storms and storm surge (USACE, 2009).

Island changes associated with extreme episodic events over the past several decades along with the impact of the 2010 Deepwater Horizon (DWH) oil spill on the environment prompted the State of Alabama to engage the US Geological Survey (USGS) and the US Army Corps of Engineers (USACE) to investigate viable, sustainable restoration options for Dauphin Island for the benefit of habitat and

species impacted by the 2010 DWH oil spill. This collaborative effort was made possible through a grant from the National Fish and Wildlife Foundation (NFWF), Gulf Environmental Benefit Fund.
This report presents the results of an updated sediment budget performed as part of the wider Alabama Barrier Island Restoration Assessment Study to identify modern sediment sources and sinks along with estimates of natural and human induced littoral transport of sediments within the region of Dauphin Island, Alabama. The analysis provides valuable information that can be used to assess the need and determine effective beneficial use of sediments within the system.

2.0 Methods

The sediment budget analysis was conducted utilizing the application of the USACE Sediment Budget Analysis System (SBAS) (Rosati and Kraus, 2001; Dopsovic et al., 2002; USACE, 2020). SBAS is a software tool for calculating and displaying local and regional sediment budgets that can include single or multiple inlets, estuaries, bays, and adjacent beaches.

A sediment budget is an accounting of sediment gains and losses, or sources and sinks, within a specified cell or in a series of connecting cells over a time period of interest. The difference between sediment sources and sinks in each cell or over the entire study area must equal the change in sediment volume within the cell or region, accounting for dredging and placement activities over the period of analysis.

The algebraic expression for the sediment budget is given by the following equation:

$$\Sigma Q_{source} - \Sigma Q_{sink} - \Delta V + \Sigma P - \Sigma R = \text{Residual} \quad (1)$$

where *Qsource* and *Qsink* are the sources (inputs) and sinks (outputs) at the boundary to the control volume, respectively, and ΔV is the net change in volume within the cell. *P* and *R* are the amounts of material placed into and removed from the cell, respectively. *Residual* represents the degree to which the cell is balanced. For a balanced cell, the residual is zero.

For a region consisting of many contiguous cells, the budgets for each cell must balance to achieve a balanced budget for the entire study area. The terms used in Equation (1) are in consistent units, either as volume or as volumetric rate of change. For the present study, all units used for the formula are expressed as rate of change in cubic yards per year (cy/yr). Figure 2 schematically illustrates typical parameters included in the sediment budget. Sources include longshore sediment transport and dredged material placement within the nearshore, where the source of the placed material is located within the nearshore system. Typical sediment budget sinks include longshore and cross-shore sediment transport, channel dredging, and losses to inlet shoals. It should be noted that a source to one cell often represent a sink from other cells.

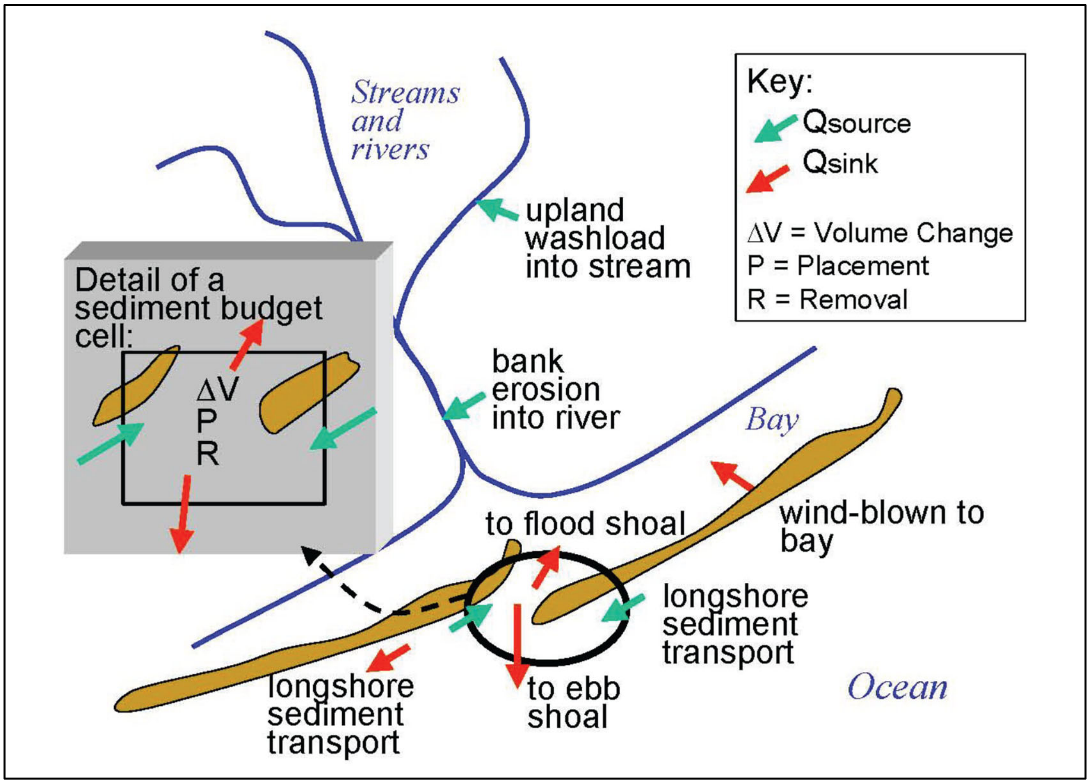

Figure 2. Typical sediment budget parameters (after Dopsovic et al., 2002)

2.1 Data Sources

Elevation measurements, complied from historical hydrographic surveys, were used to identify sea floor morphology and change to quantify sediment transport pathways and rates relative to natural and engineering activities. Nine elevation data sets were compiled from National Oceanic and Atmospheric Administration (NOAA), USGS, South Coast Engineers, Olsen Engineering and USACE to document seafloor changes between 1985/88 and 2010/16. The time periods considered contain good spatial survey data coverage for the study area that partially overlap and extend the time periods considered in Byrnes et al. (2010) and coincide with the time periods considered in Flocks et al. (2018). In addition, three topographic/bathymetric lidar data sets obtained from NOAA's digital coast and shoreline datasets from Smith et al. (2018) and Himmlestoss et al. (2017) were used to assess episodic storm induced overwash from Hurricanes Georges, Ivan and Katrina.

Table 1. Elevation Datasets

Survey Dates	Data Sources	Comments and Map Numbers	Vertical Datum	Units	Horizontal Datum	Projection
8 August 1982 to 7 January 1988	NOAA National Centers for Environmental Information, NOS Hydrographic Survey Collection: Scale: 1:20,000 (H-10041, H-10114, H-10151A, H-10151B, H-10179, H-10226, H-10247) and 1:40,000 (D-00078).	Regional single beam bathymetric survey: 8 Aug 1982 to 10 Oct 1985 - Vicinity of Perdido Pass (H-10041); 1 Sept 1983 to 29 April 1985 - Gulf Shores to Perdido Pass and Offshore (H-10114); 6 Aug 1984 to 24 March 1986 - Seaward of Little Lagoon (H-10151A, H-10151B); 1 Jan 1984 to 31 Dec 1987 inside Mobile Bay (D-00078); 24 May1985 to 3 June 1987 – East of Fort Morgan and offshore (H-10179); 17 Sept 1986 to 7 Jan 1988 - offshore Mobile Bay entrance and eastern Dauphin Island (H-10226); 18 June to 11 Nov 1987 - Offshore Dauphin Island and Petit Bois Pass (H-10247).	MLLW	meter	North American Datum 27	Projected Polyconic
10 October to 09 November 1998	NOAA/USGS/NASA Airborne LiDAR Assessment of Coastal Erosion (ALACE) Project	Topo/Bathy lidar data along the coasts of Louisiana, Mississippi, Alabama, and Florida	NAVD88 Geoid 12a	feet	North American Datum 1983	Projected Alabama State Plane, West Zone
19 April to 3 July 2002	USACE, Mobile District beach profile and hydrographic channel survey	Beach profile data collected at 1,000 ft intervals from the western end of Dauphin Island to Perdido Pass. Profile data extends approximately 3 miles offshore. Single frequency hydrographic data collected in Mobile Bay Entrance area and in Mobile Bay channel.	NAVD88 Geoid 09	feet	North American Datum 1983	Projected Alabama State Plane, West Zone
01 April 2004 to 25 September 2004	2004 US Army Corps of Engineers (USACE) Topo/Bathy Lidar: Alabama, Florida, Mississippi and North Carolina	Topo/Bathy Lidar: Alabama, Florida, Mississippi and North Carolina	NAVD88 Geoid 12a	feet	North American Datum 1983	Projected Alabama State Plane, West Zone

Survey Dates	Data Sources	Comments and Map Numbers	Vertical Datum	Units	Horizontal Datum	Projection
19 September 2004	2004 USGS/NASA Experimental Advanced Airborne Research Lidar (EAARL): Northern Gulf of Mexico, Post-Hurricane Ivan	Topo/Bathy Lidar: Alabama, Florida and Mississippi	NAVD88 Geoid 12a	feet	North American Datum 1983	Projected Alabama State Plane, West Zone
12 October to 11 December 2005	2005 US Army Corps of Engineers (USACE) Post-Hurricane Katrina Topo/Bathy Project for the Alabama, Florida, Louisiana and Mississippi Coasts	Topo/Bathy Lidar: Alabama, Florida, Louisiana and Mississippi Coasts	NAVD88 Geoid 12a	feet	North American Datum 1983	Projected Alabama State Plane, West Zone
18 September to 15 December 2006	NOAA National Centers for Environmental Information, NOS Hydrographic Survey Collection, 2006-12-14 and 2006-12-15: 1:10,000 (H-11621, H-11622)	Dual frequency side scan bathymetry of Mississippi Sound to include nearshore areas of Dauphin Island and Grand Bay to Petit Bois Pass.	MLLW	meter	North American Datum 1983	Projected UTM 16
01 January 2007 to 25 March 2007	NOAA National Centers for Environmental Information, NOS Hydrographic Survey Collection, 2007-03-25: Scale 1:20,000 (H-11626 and H-11627)	Dual frequency side scan and multibeam acoustic backscatter of Alabama Fairways to include nearshore areas of Mobile Point to Perdido pass.	MLLW	meter	North American Datum 1983	Projected UTM 16
26 January to 4 February 2010	Coastal Planning & Engineering, Inc., 2010 Dauphin Island Annual Monitoring, Topographic and Hydrographic Survey	Topographic RTK profile data of west and east end Dauphin island extending south and east along Pelican Island and single frequency bathymetric data of Mobile Pass ebb tidal shoal. The survey consisted of 40 profiles with intermediate profiles spaced at approximately 500-foot intervals.	NAVD88 Geoid 12b	feet	North American Datum 1983	Projected Alabama State Plane, West Zone

Survey Dates	Data Sources	Comments and Map Numbers	Vertical Datum	Units	Horizontal Datum	Projection
09 July 2014 to 31 January 2015	NOAA National Centers for Environmental Information, NOS Hydrographic Survey Collection, 2014-10-10 and 2014-10-12: Scale 1:20,000 (H-12654, H-12655 and H-12656)	Dual frequency side scan and multibeam acoustic backscatter of approaches to Mobile Bay to include 4NM South of Mobile Point, 2NM South of Fort Gaines and areas North of Dauphin Island.	MLLW	meter	North American Datum 1983	Projected UTM 16
July-September 2015	USGS and USACE Hydrographic survey	Single and multibeam bathymetric surveys of the nearshore and offshore regions of Dauphin Island.	NAVD88 Geoid 12a	meter	North American Datum 1983	Projected UTM 16
23 July 2015 to 10 October 2016	2016 USACE NCMP Topobathy Lidar: Gulf Coast (AL, FL, MS, TX), https://inport.nmfs.noaa.gov/inport/item/49738	Classified topo/bathy lidar data along the coasts of Alabama, Florida, Mississippi, and Texas	NAVD88 Geoid 12a	meter	North American Datum 1983	Projected Alabama State Plane, West Zone
June 2016	Olsen Engineering, 2016 Orange Beach/Gulf State Park/Gulf Shores Annual Monitoring Topographic and Hydrographic Survey	Topographic RTK profile data Orange Beach/Gulf State Park/Gulf Shores. The survey consisted of profiles spaced at approximately 1,000-foot intervals.	NAVD88 Geoid 12a	feet	North American Datum 1983	Projected Alabama State Plane, West Zone

2.2 Survey Coverage

The area considered in the sediment budget extends along the Alabama Gulf coast from Perdido Pass westward to encompass the Mobile ebb tidal delta and Dauphin Island, Alabama. Figures 3 and 4 display the study area and the bathymetric survey data extents detailed in Table 1 by time periods considered within the seafloor and volume change for the sediment budget analysis.

1985-88 Survey Coverage:

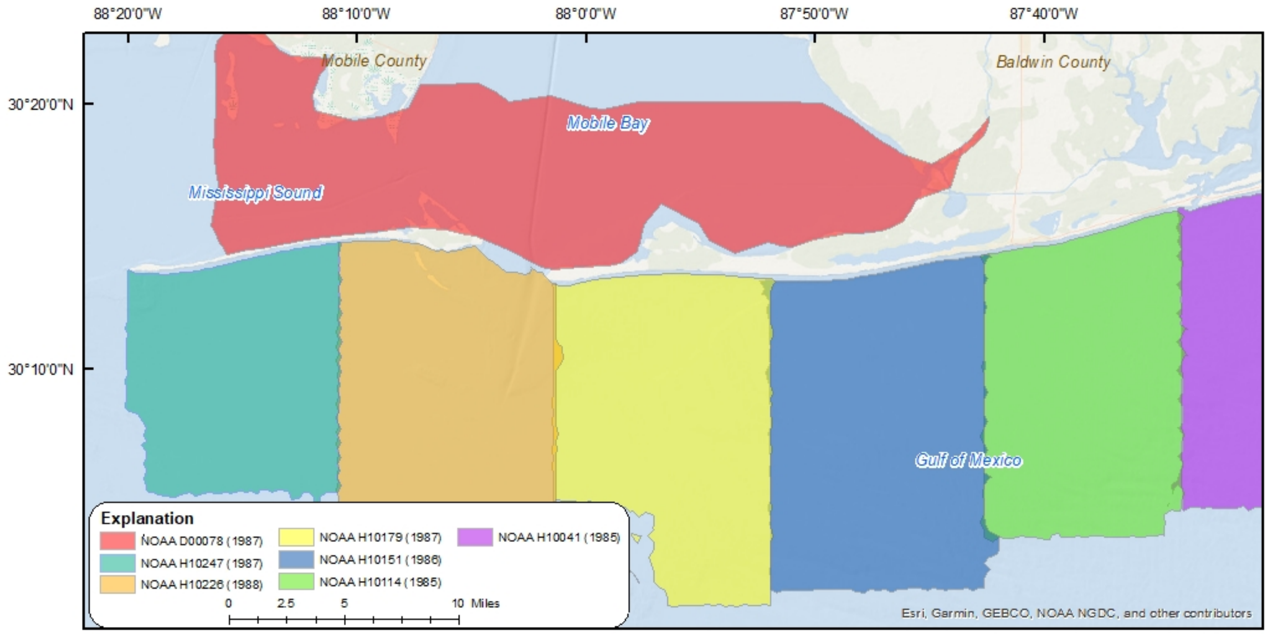

Figure 3. Survey extents and identification from NOAA 1985–88 (https://maps.ngdc.noaa.gov/viewers/bathymetry/) hydrographic survey data.

2010-16 Survey Coverage:

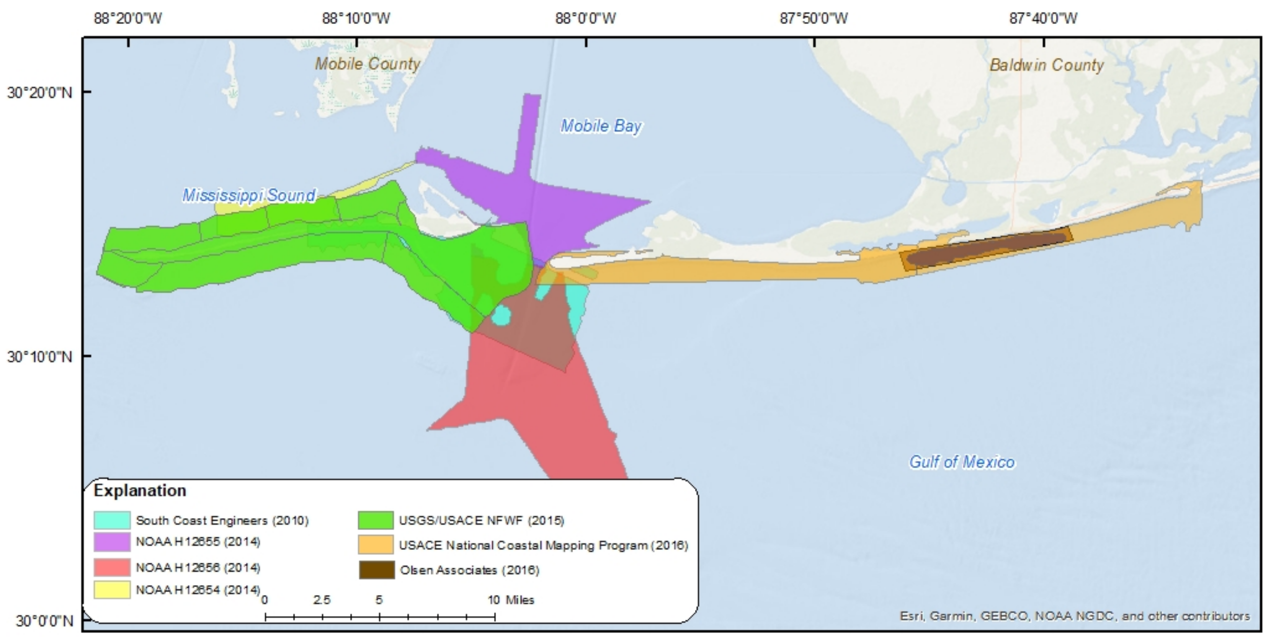

Figure 4. Survey extents and identification from South Coast Engineers 2010, NOAA 2014 (https://maps.ngdc.noaa.gov/viewers/bathymetry/), USGS/USACE NFWF 2015 hydrographic survey data, Olsen and Associates 2016 USACE 2016, National Coastal Mapping topographic and bathymetric Light Detection and Ranging (LIDAR) survey (https://coast.noaa.gov/dataviewer/).

2.3 Survey Adjustments

2.3.1 Vertical Adjustments

As detailed in Table 1 elevation datasets of the seafloor were collected in various vertical datums and units. Therefore, adjustments to depth measurements were made to bring all data to the common plane of reference and unit of measurement. Data sets were converted to Mean Lower Low Water (MLLW) with units of feet. Vertical adjustments to MLLW were made to each data set based on the original vertical reference datum using NOAA's (VDATUM) vertical datum transformation software version 4.0.1 (http://vdatum.noaa.gov/).

In addition, adjustments to depths to account for sea level change were made based on the time of data collection. Figure 5 below shows the relative sea level trend of 3.94 mm/yr (0.16 in/yr) with a 95% confidence interval of +/-0.58 mm/yr (0.02 in/yr) based on monthly mean sea level data from 1966 to 2019 which is equivalent to a change of 0.4 feet over the 34 year period of record considered in this analysis (1985-2016). Table 2 below summarizes the sea level adjustments applied for each survey coverage.

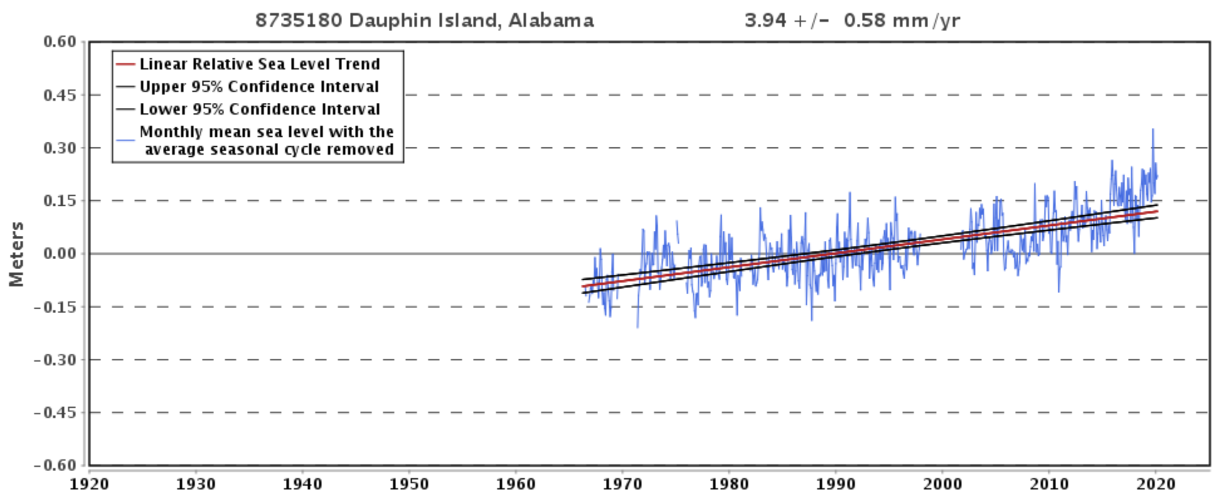

Figure 5: Relative Sea Level Trend 9735180 Dauphin Island, Alabama (Source: https://tidesandcurrents.noaa.gov/sltrends/)

Table 2. Vertical Datum Adjustments to Survey Data

Survey Date	Sea Level Rise Adjustment (ft)
1985-88	-0.4
2002	-0.2
2006-10	-0.1
2014-16	0

2.3.2 Horizontal Adjustments

As detailed in Table 1, elevation datasets were also collected in various horizontal datums. Therefore, adjustments were made to bring all data to the common horizontal reference frame. Data sets were converted to North American Datum 1983, Alabama State Plane, West Zone state with units of feet based on their original horizontal datum and projected using Environmental Systems Research Institute (ESRI), professional Geographic Information System (ArcGIS Pro) desktop application, spatial analysis horizontal projection tool.

2.4 Survey Measurement Uncertainty

Quantifying measurement error and uncertainty estimates for volumetric change calculations gives bounds for the reliability of identified erosion and accretion areas, determination of sediment transport pathways, magnitude of sediment transport estimates and validity of sediment budget estimates (Byrnes et al., 2002). Measurement error and surface uncertainties were evaluated for the broad survey coverage used in this study as part of Byrnes et al., (2010 and 2012) and Flocks et al., 2019. Based on the uncertainty analysis a value of +/- 2 feet were used to delineate areas considered to represent no meaningful change.

2.5 Surface Modeling

Digitized soundings and shorelines were used to create digital elevation models of the seafloor for the periods from 1985/88 to 2010/16. The Triangulated Irregular Network (TIN) method was used in this study to form surfaces of continuous connected triangular planes based on irregular points (Petrie, 1991). TINs of each survey period were generated using ArcGIS pro three-dimensional (3D) spatial analysis tools that triangulated the survey points into a vector-based digital geographic dataset of the seafloor morphology using Delaunay triangulation interpolation methods. The input survey data points from seafloor elevation datasets described in section 2.1 and shorelines obtained from Smith, et al. (2018) and Himmelstoss, et al. (2017) were used to generate the position nodes and edges in the TIN for the representative time periods. This allowed a TIN to preserve all the precision of the input data while simultaneously modeling the values among known points (ESRI, 2020). The elevation change between each period was then determined by subtracting the older period from the more recent period using the ArcGIS Pro spatial analysis triangulated surface difference tool. The resulting calculated elevation differences between the two surface models were then stored as TIN and raster datasets. TIN model surfaces were used for all calculations of seafloor elevation and volume change discussed in section 3.4; while the raster grid surfaces were generated for graphic displays used throughout the report.

3.0 Results

3.1 Sea Floor Morphology

The prominent geomorphic features observed within the regional bathymetric surfaces in figures 6 and 7 below include the channels and shoals associated with the Perdido and Mobile ebb shoal systems. The convenience of sand can be observed along a relatively narrow band off the coasts of Orange Beach, Gulf Shores and Dauphin Island that broadens at the passes out to approximately the 30-foot contour. Most geomorphic features observed in the regional bathymetric surfaces are found within the Mobile Pass system. These features include the Dixie Bar shoals along the eastern lobe and the Sand and Pelican Island ephemeral, subaerial sand deposits and shoals along the western lobe. In addition, overwash fans associated with Hurricanes Ivan and Katrina are also notable features that can be observed along the lee side of Dauphin Island in the 2010/16 regional bathymetric surface (Figure 7). This includes a large region of overwash located along the central western segment of Dauphin Island associated with a breach known as Katrina Cut.

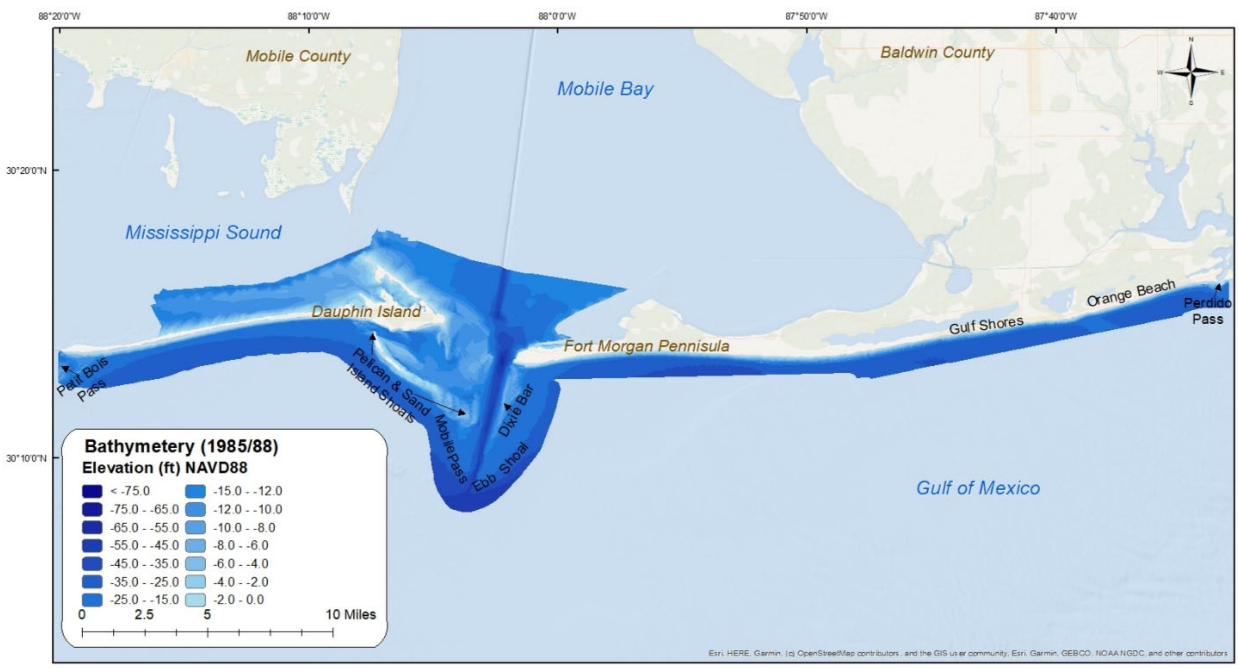

Figure 6: Regional bathymetric surface for the study area, 1985/88

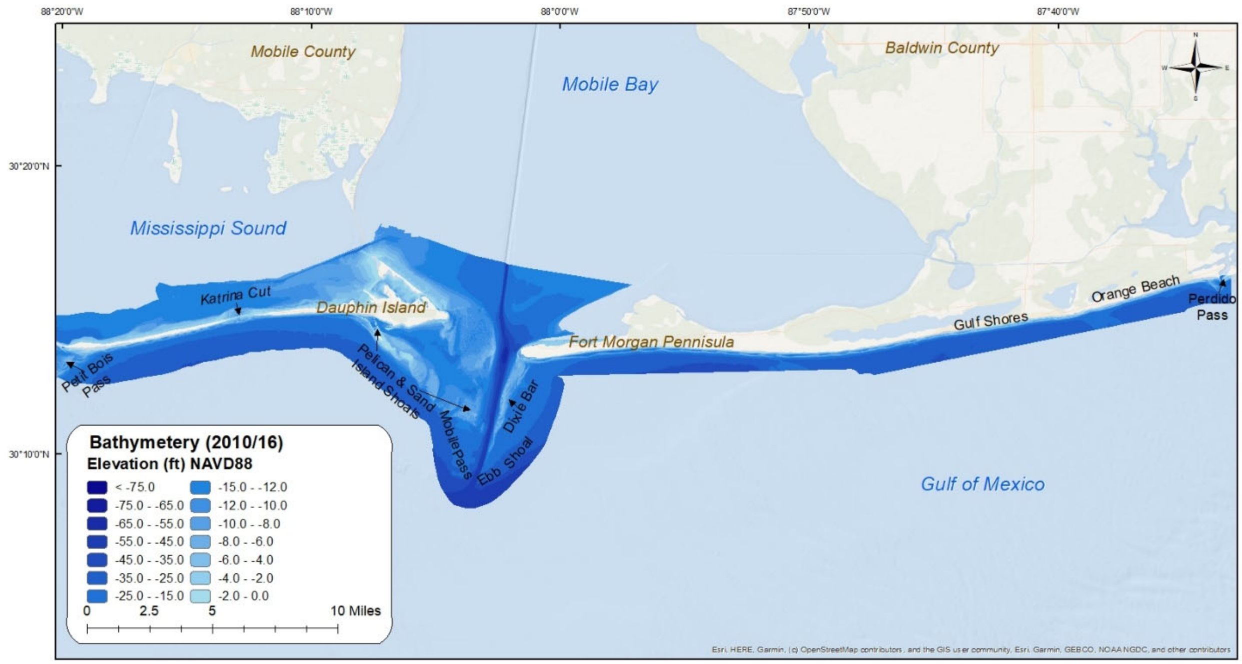

Figure 7: Regional bathymetric surface for the study area, 2010/16

3.2 Sea Floor Changes

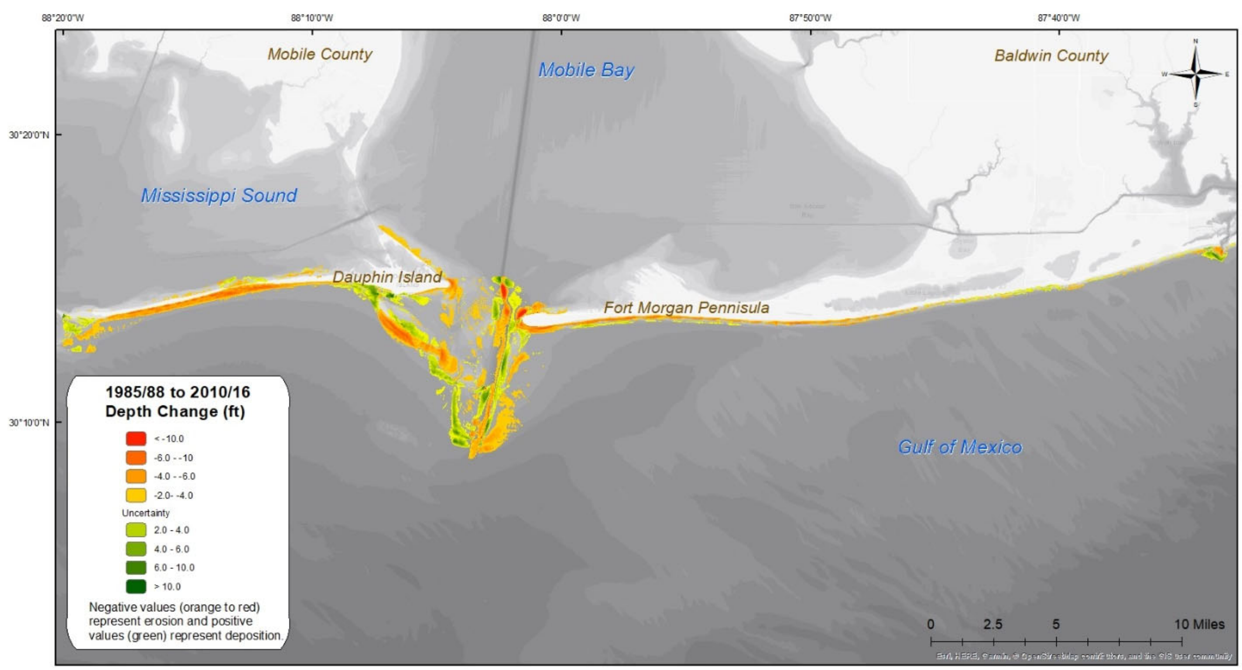

Figure 8: Regional bathymetric surface depth changes *1985/88 to 2010/16*

3.3 Sediment Sources and Sinks

The primary source of sediment to Dauphin Island over the period of analysis was sand transported westward from Fort Morgan Peninsula and Mobile Pass ebb shoal complex. The eastern end of the island is a relict Pleistocene barrier ridge (Otvos, 1981). This stable portion of the island provides a location from which large volumes of littoral sand from the Mobile Pass ebb shoal can be transported west, sourcing the barrier islands and inlet shoals of western Alabama and Mississippi (Otvos and Giardino, 2004). The Perdido and Mobile Pass ebb shoal systems act as conduits (sources) as well as sediment sinks for the sand transport to the west. The beaches and nearshore areas of Baldwin County, as well as Pelican and Dauphin Islands in Mobile County become local sources of sediment, as the sand is eroded and transported west and redeposited in adjacent passes. In addition, tropical cyclone overwash and breaching provided a source of sand to backbarrier habitats along the more low-lying areas of the coast.
Over the time period of the analysis 7 of the top 10 total water level producing tropical cyclones are on record at the NOAA, Dauphin Island gauge 08736180 for the area (Table 3). It is worth noting that the Dauphin Island NOAA station did not capture the storm surge water levels from Hurricane Georges in 1998. According to a USGS water-resources investigation report 4321 by Turnipseed, et al., 1998 water levels recorded at Dauphin Island from Hurricane Georges were on the order of 5.6 feet, which would have made the top 10 list below.

Table 3. Ten Highest Water Levels, 08736180 Dauphin Island, AL (1966 to 2017)

Tropical Cyclone	**Date**	**Elevation in feet above (MHHW)**
Fredrick	09/16/1979	7.96
Ivan	09/16/2004	5.94
Katrina	08/29/2005	5.17
Elena	09/02/1985	3.36
Ike	09/11/2008	3.13
Isaac	08/29/2012	3.08
Nate	10/08/2017	3.02
Opal	10/04/1995	2.98
Isadore	09/26/2002	2.9
Camille	08/18/1969	2.75

Source: NOAA/Center for Operational Oceanographic Products and Services

Descriptions of the island level change due to storm-induced coastal processes have been well documented in published literature for Dauphin Island [Hardin et al., 1976; Meyer-Arendt, 1988; Nummedal, et al., 1980; Smith et al., 1997; Wilson, 2004; Fronde, (2005, 2006, 2009); Morton et al., 2007; Hansen and Sallenger; 2007, Byrnes et al., 2010, Passeri et al., 2018]. With notable storms during the study period, being hurricane Georges (1998), Ivan (2004), and Katrina (2005) that resulted in significant documented impacts to the structure of the island (i.e. erosion, overwash and breaching) (Fronde, (2005, 2006, 2009) and Hansen and Sallenger, 2007). In a recent publication, Passeri et al., (2018), performed dynamic modeling of barrier island response to hurricane storm surge and sea level change for Dauphin Island. In this study subaerial island volume losses as a result of Hurricanes Ivan and Katrina were documented. For Hurricane Ivan, Passeri et al., (2018), estimated approximately 56 percent dune overwash with an estimated 5.1 percent (950,000 cy) loss in subaerial volume. This volume compared well to pre and post Ivan volume change estimates of approximately 872,000 cy made using lidar datasets. For Hurricane Katrina the study documented a far greater impact with approximately 80 percent dune overwash with an estimated 12 percent (2.3 mcy) loss in subaerial volume along the island. This volume could not be directly compared with pre and post Katrina subaerial volume change estimates using lidar, due to survey coverage, which did not capture the complete area of change. It should also be noted that neither method was able to document the complete loss, which would include island breaching. Estimates of losses within the breach footprint were; however, made by differencing post Hurricane Georges and pre and post Hurricane Ivan lidar datasets with 2010 USACE bathymetric surveys of the Katrina Cut breach prior to artificial closure. Estimates from these surveys indicated losses due to breaching that were upwards of approximately 3.5 mcy.

Events such as Hurricane Ivan and Katrina were able to carry significant volumes of sand across the island, but they were not the only events with documented cross-shore overwash that occurred during the period of analysis. Other storms such as Isaac (2012), Ike (2008), Isadore (2002), Georges (1998), Opal (1995) and Elena (1985) generated storm surge and wave run up levels, which exceeded the beach crest height along the island. An empirical formula from Nguyen et al., (2016) for calculations of coastal overwash, was used to estimate volumes of cross shore sediment transport by wave run up and inundation for tropical cyclones. Estimates were compared to observations when post storm survey data were available (Table 4).

The empirical formula for overwash volume from Nguyen et al., (2016) is given by the following equation:

$$Q = 0.0011(\frac{H_c}{R} * \frac{t_D}{T} * (R - H_c)^2 \quad (2)$$

where Q is the total sediment transport volume, R is the wave run up height, Hc is the berm crest height referenced to the still-water level, T is the wave period, and T_D is the overwash duration. Estimates for the wave run up were made using the empirical formula for extreme run up from Stockton et al. (2006). The empirical formula for extreme run up from Stockton et al., (2006) is given by the following equation:

$$R_2 = 1.1(0.35\beta_f(H_0L_0)^{0.5} + [H_0L_0(0.563\ \beta_f^2+0.004)]^{0.5}/2 \qquad (3)$$

where $R2$ is the 2 percent wave runup, β_f is the foreshore slope and H_0 and L_0 are the deepwater wave heights and wavelengths.

For these equations water levels were obtained from NOAA's stations located at Dauphin Island, AL (08736180) and Pensacola, FL (8729840). Wave data were obtained from station (73151) of the hindcast Wave Information Studies, located south of Dauphin Island. Nearshore slopes were estimated from the 2016 topo/bathy lidar survey.

Table 4 Empirical Overwash Formula Estimates for the West End of Dauphin Island

Summary of Perdido Pass Channel Dredging Volumes (1985 to 2016)		
Storm	**Nquyen's Coastal Overwash Formula (1) (cy)**	**Measured Overwash (cy)**
Elena (1985)	39,000	-
Opal (1995)	127,000	-
Georges (1998)	319,000	551,200
Isadore (2002)	229,000	-
Ivan (2004)	267,000	872,600
Katrina (2005)	455,000	-
Ike (2008)	330,000	-
Isaac (2012)	300,000	-

Note: (1) Nquyen's formula does not account for breaching, which leads to estimates that under-predicted observed data by 40 to 70 percent.

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3.3.1 Channel Shoaling and Dredge Material Placement

Four navigation projects involving routine maintenance dredging of littoral sands traverse the survey coverage area (Figure 9). These four projects include two outer bar channels known as Perdido Pass and the Mobile Harbor entrance channel (bar channel) and two inner harbor channels known as Fort Gaines and Pass Drury. The outer bar channels are located along the eastern boundary of the study area between Perdido Key and Orange beach as well as the western region of the study area between Fort Morgan Peninsula and Dauphin Island. The inner harbor channels are also located in the western region of the study area along the eastern tip of Dauphin Island, positioned between Dauphin Island and Little Dauphin Island (Figure 9).

Figure 9: Federal Navigation Channels

Dredge and placement records were compiled for each of these projects to document placement zones and compute average dredge rates for estimates of flux rates in the sediment budget. Tables 5-7 summarize the dredge records and placement zones for each project. In addition, the Corps' Channel Shoaling Analysis Tool (CSAT) and ehydro datasets were used as additional resources in identifying regions of shoaling and estimates of flux rates into the channel for the sediment budget. Regions of shoaling within each channel framework are displayed in figures 10-12 below.

Maintenance dredge records indicate that approximately 5.3 mcy was extracted from Perdido Pass and deposition basin between 1985 and 2016. Evaluation of CSAT and ehydro datasets indicated the primary region of shoaling within the Perdido Pass channel was adjacent to the deposition basin. Other sources of shoaling appear to have been Florida Point and the inner flood shoals and islands. Records of dredge material placement indicate that material was deposited within a combination of nearshore and beach placement sites, with roughly 3.1 mcy placed downdrift on the west side in placement areas 1, 7 and 8 and 2.0 mcy placed updrift on the east side of the inlet in area 6 during the time period of analysis. The remaining 0.2 mcy of the reported dredged amount was placed in various areas of the Pass interior. Channel limits, channel shoaling areas and placement zones are displayed in Figure 10.

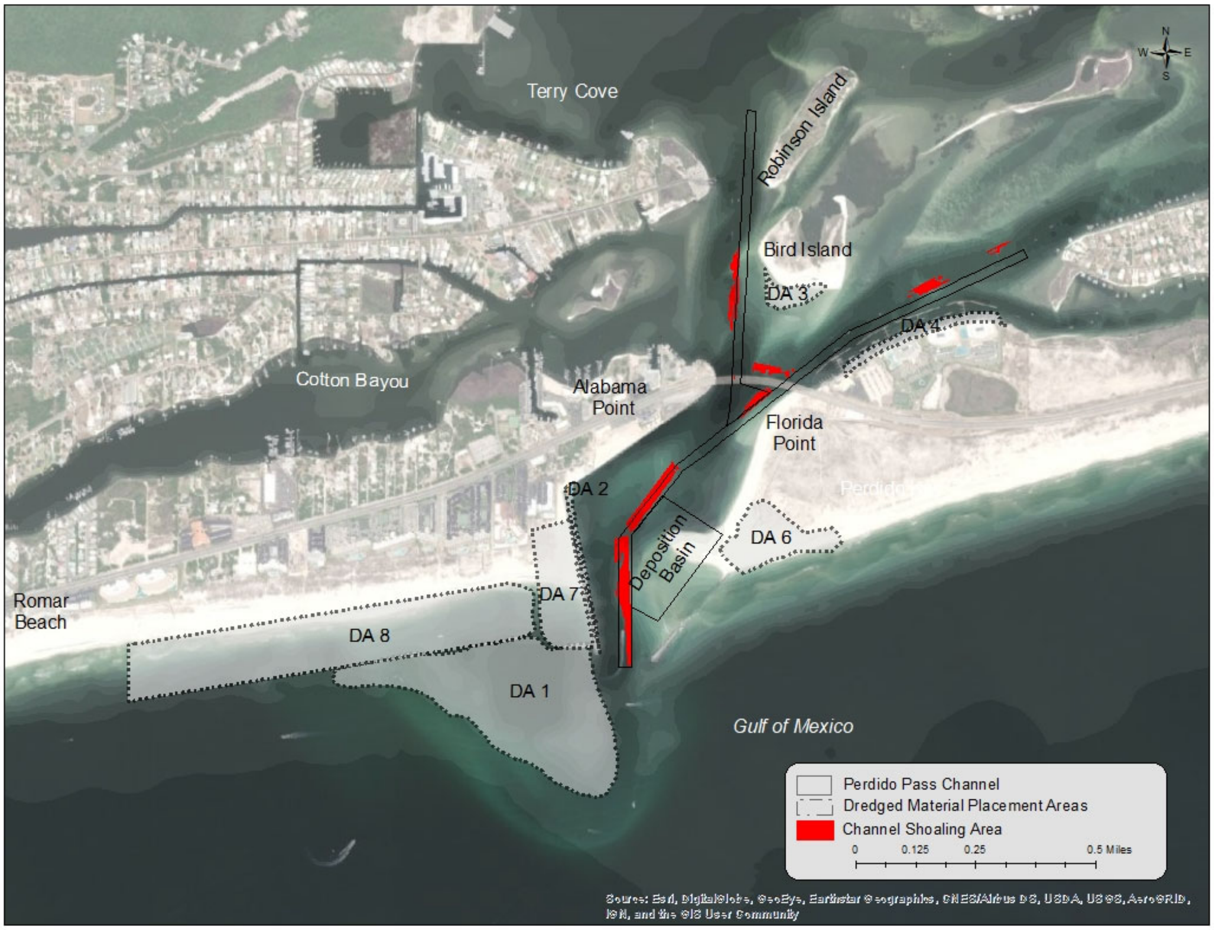

Figure 10: Perdido Pass Federal Navigation Channel, Shoaling Regions, and Dredge Material Placement Areas

Table 5. Perdido Pass Channel Dredging Volumes

Summary of Perdido Pass Channel Dredging Volumes (1985 to 2016)		
Date	**New Work (cy)**	**Maintenance (cy)**
1986		661,416
1989		547,487
1992		432,416
1995		464,760
1997		352,441
1999		365,000
2002		99,396
2003		415,991
2005		996,341
2006		46,150
2009		679,146
2012		33,047
2015		232,571
Total Dredging		*5,317,700*
Summary of Perdido Pass Placement Volumes (1985 to 2016)		
Dredge Material Placement Site		**Placement (cy)**
DA 1,7 and 8 - Beach and Nearshore Placement		3,137,300
DA 6, cy		1,979,800
DA 2, 3 and 4, cy		200,600

Sources: United States Army Corps of Engineers Dredge Records and Olsen Engineering, Inc.

At the Mobile Harbor Bar channel, dredge records indicate that approximately 9.8 mcy of new work and 15.2 mcy of maintenance material was extracted from the navigation channel and the sediment trap between 1985 and 2016. Evaluation of the CSAT and ehydro datasets show the primary regions of sedimentation within the channel were adjacent to the Dixie Bar. However, secondary regions of shoaling were observed on the east side of the channel north and south of the lighthouse as well as the northside of West Bank shoal (Figure 11).

Of the estimated 25 mcy of documented dredged volumes, an estimated 3.1 mcy of new work along with 10.7 mcy of maintenance material was placed within the Sand Island Beneficial Use Area (SIBUA) and feeder berm dredged material placement site located on the western ebb shoal lobe. The remaining 11.3 mcy of which 6.8 mcy consisted of new work was placed in the offshore dredge material disposal sites (ODMDS) prior to the designation of SIBUA in 1999 (Figure 11). It is important to note that new work material consists of relic sediment deposits that are not considered part of the modern littoral sediment transport along the coast and based on geotechnical records may consisted of silts and clays. Based on this only the dredged maintenance volumes were considered in the sediment flux calculations; however, both maintenance and new worked material placed within the active littoral sediment transport system were considered a source in the analysis.

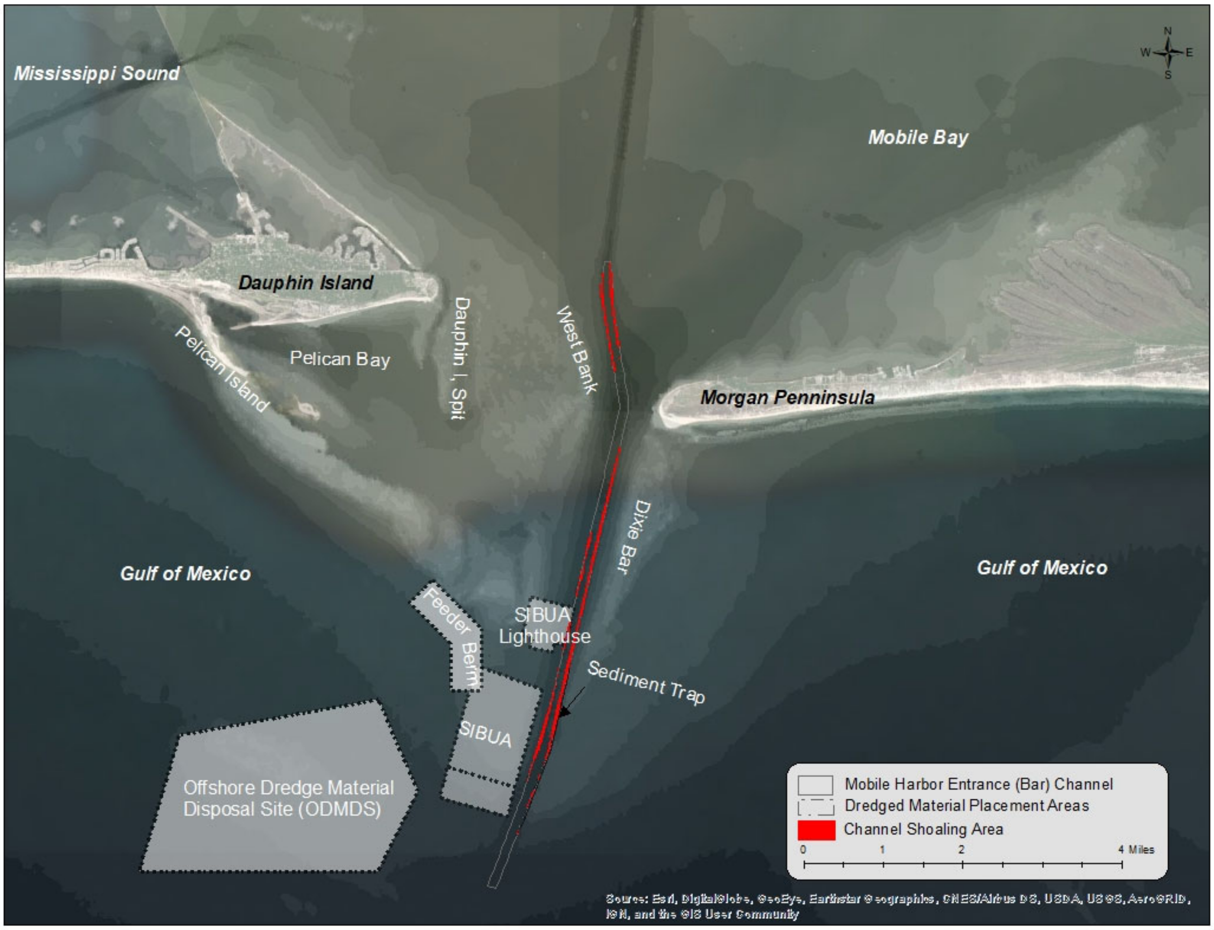

Figure 11: Mobile Harbor Entrance (Bar) Federal Navigation Channel, Shoaling Regions, and Dredge Material Placement Areas

Table 6. Mobile Pass (Bar) Channel Dredging Volumes

Summary of Mobile Harbor Bar Channel Dredging (1985 to 2016)		
Date	**New Work (cy)**	**Maintenance (cy)**
1985		1,386,536
1987		656,089
1990	6,755,352	
1992		466,607
1995		621,172
1997		710,996
1998		1,279,815
1999	3,061,598	125,980
2000		758,280
2002		92,820
2004		1,414,927
2005		1,808,765
2006		487,975
2007		1,011,998
2008		649,500
2009		942,817
2011		472,988
2012		899,493
2015		1,412,078
Total Dredging	*9,817,000*	*15,198,800*
Summary of Mobile Pass (Bar) Placement (1985 to 2016)		
Dredge Material Placement	**Placement (cy)**	**Placement (cy)**
Sand Island Beneficial Use Area (SIBUA)	*3,061,600*	*9,951,600*
Feeder Berm		*710,700*
Offshore Dredge Material Placement Site	*6,755,400*	*4,536,500*

Sources: United States Army Corps of Engineers Dredge Records and Applied Coastal Research and Engineering, Inc.

For the Fort Gaines and Pass Drury Channels maintenance dredge records indicate that approximately 1.8 mcy was extracted from these channels between 1985 and 2016. Evaluation of CSAT and ehydro datasets showed the primary regions of shoaling within the channel were in the lee of Little Dauphin Island and on the north side of the channel along the southeastern tip of the island. Records of dredge material placement indicate that material was placed within a combination of beach placement sites, with roughly 1.8 mcy placed along Little Dauphin Island. The remaining 0.9 mcy of the reported dredge amount was placed along the East End of Dauphin Island (Figure 12).

Figure 12: Fort Gaines and Pass Drury Federal Navigation Channel, Shoaling Regions, and Dredge Material Placement Areas

Table 7. Fort Gaines and Pass Drury Channel Dredging Volumes

Summary of Fort Gaines and Pass Drury Channel Dredging (1985 to 2016)		
Date	**New Work (cy)**	**Maintenance (cy)**
1986		18,640
1987		9,616
1989		80,013
1992		49,231
1993		17,970
1996		23,271
2001		26,061
2003		2,432
2004		21,060
2005		29,084
2006		61,307
2009		25,359
2013		43,982
2015		1,439,417
Total Dredging		*1,847,400*
Summary of Fort Gaines and Pass Drury Placement (1985 to 2016)		
Dredge Material Placement	**Placement (cy)**	**Placement (cy)**
Little Dauphin Island		*1,755,875*
East End Dauphin Island		*91,568*

Sources: United States Army Corps of Engineers Dredge Records

3.3.2 Offshore Shoal Mining and Beach Nourishments

During the time period of analysis (1985 to 2016) several sand mining and placement actions occurred within the Gulf of Mexico offshore/nearshore regions of Alabama as well as the back-bay systems of Dauphin Island. The mining activities provided sand for beach restoration along Dauphin Island and Baldwin County shorelines as well offshore placement around the Sand Island Lighthouse. A summary of these projects and their general locations are provided in Figure 13 and Table 8 below. This information was incorporated into the sediment budget as either a source for placement actions or a sink for borrow area (sand mining) actions located within a corresponding sediment budget cell. It should be noted that while 2015 Coastal Impact Assistance Program (CIAP) East End placement occurred during the period of the sediment budget analysis it was not captured within the 2015 elevation data sets and therefore was not incorporated as a sink or source within the sediment budget.

Table 8. Fort Summary of Placement Actions Along Mobile and Baldwin County Beaches

Summary of Sand Placement Actions Along Alabama's Gulf Coast			
Year	**Name**	**General Placement Location**	**Placement Volume (cy)**
1991	Natural Gas Platform Construction and Sand Placement	Park and Beach Board-Pier	12,000
2000	Federal Emergency Management Agency (FEMA) Emergency Berm	Gulf shoreline from Ponce De Leon Court and extending westward to the end of Bienville Boulevard	221,000
2001	Orange Beach/ Gulf State Park / Gulf Shores Beach Restoration	Eastern Gulf Shores only (~ 3.1 miles)	1,635,000
2004	FEMA - Ivan Sand Removal from Road	Gulf shoreline Ponce De Leon Court and extending westward to the end of Bienville Boulevard	300,000
2005	FEMA - Katrina Sand Removal from Roads	Gulf shoreline Ponce De Leon Court and extending westward to the end of Bienville Boulevard	45,000
2005-06	Orange Beach/ Gulf State Park / Gulf Shores Beach Restoration	Orange Beach/ Gulf State Park / Gulf Shores (~ 15.3 miles)	7,340,000
2006	Dauphin Island post Storm Canal Dredging and Sand Placement	Eastern Dauphin Island Gulf Shoreline	100,000
2007	FEMA Emergency Berm	Gulf Shoreline Ponce De Leon Court and extending westward to the end of Bienville Boulevard	526,632
2010	Deep Water Horizon Berms	Went end 4 miles within Bienville Boulevard right of way	350,000
2011	Deep Water Horizon Sand Island Light House Placement	Sand Island	1,500,000
2011	River Sand Pilot Study -East End	Fort Gaines Gulf Shoreline Placement Area	5,000
2016	CIAP East End Project*	Gulf shoreline fronting the Dauphin Island Sea Lab and United States Coast Guard Property	325,000
2012-13	Orange Beach/ Gulf State Park / Gulf Shores Beach Restoration	Orange Beach/ Gulf State Park / Gulf Shores Shorelines (~15.3 miles)	2,300,000
		Total:	***7,319,600***

Sources: Town of Dauphin Island, United States Army Corps of Engineers and Olsen Engineering, Inc.
Note. The 2016 CIAP project was not captured with the 2015 sea floor elevation data sets used in the sediment budget.

The largest documented nourishment actions in Baldwin County occurred along Perdido Key, Orange Beach, the Gulf State Park and Gulf Shores as part of the Orange Beach/ Gulf State Park / Gulf Shores Beach Restoration. This project placed a total of approximately 11.3 mcy of sand along the coast to restore the beach and dunes between 2001 and 2013. Of this total 5.5 mcy was estimated to be placed west of Perdido Pass along Perdido Key or in the upper beach and dune profile outside the areas of volumetric change used in the sediment budget. For Mobile County the largest nourishment actions occurred as part of the 2010 DWH or Federal Emergency Management Agency (FEMA) actions following Hurricane Georges (1998), Isadore (2001), Ivan (2004) and Katrina (2005). These actions combined placed an estimated 2.9 mcy of sand along the Sand Island Light house and the western end of Dauphin Island between 2000 and 2011 (Figure 13). Of this total 0.4 mcy was estimated to be placed in the upper beach and dune profile outside the areas of volumetric change used in the sediment budget.

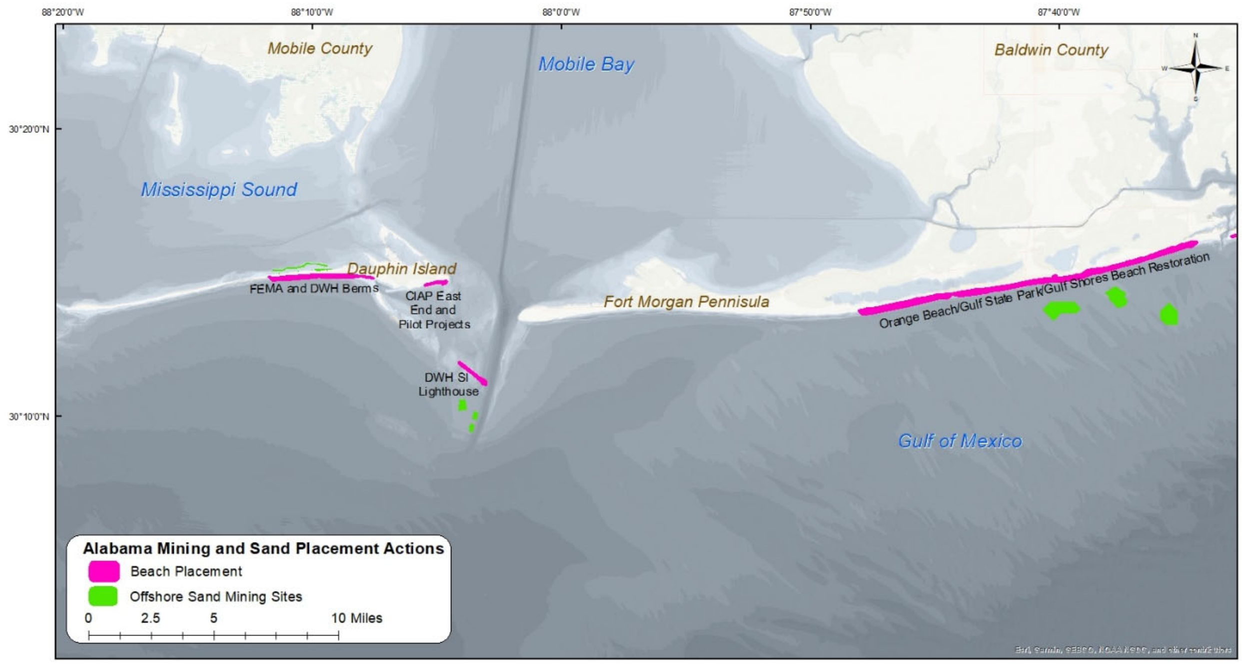

Figure 13: Sand Mining and Placement Actions Along Alabama's Gulf Coast

3.4 Sediment Budget: 1985/88 to 2010/16

3.4.1 Macro Trends

Net deposition and erosion along Dauphin Island for the period of 1985/88 to 2010/16 as shown in Figure 8 were determined by differencing the 1985/88 and the 2010/16 bathymetric surfaces to isolate polygons of erosion and accretion. This period encompasses a time of channel dredging at Mobile Pass and bypassing within the Sand Island Beneficial Use Area (SIBUA). In addition, it includes a period with 7 of the top 10 total water level producing tropical cyclones on record at the NOAA, Dauphin Island gauge 08736180 for the area (Table 3).

Figure 14 illustrates the macro-scale sediment budget for the study area, which summarizes details from four (4) control areas along the Alabama Gulf coast for assessing net sediment flux throughout the system. These four control areas represent general morphologic zones of shoreface and ebb shoal regions. Black arrows signify the direction of net sand movement and numbers reflect the magnitude of sediment flux in thousands of cubic yards per year. Red numbers document net additions or losses from each control area for the period of record. P is the volume of sand placed in the littoral zone as a result of maintenance dredging (Rm), new work dredging (Rn) or nearshore sand mining (Rnm) detailed in section 3.3 above.

Starting at Perdido Pass, net westerly sand transport at the eastern boundary of Box 1 was estimated to be 165,000 cy/yr. This volume was determined by Olsen Associates Inc. using a Family of Solutions technique (Bodge, 1999 and CEM, 2003) for the 2012 Perdido Pass Inlet Management Study. Overall, the area encompassed within Box 1 was a net source of sediment to downdrift beaches with benefits of inlet bypassing and beach nourishments, which placed an estimated 355,000 cy/yr along the coastline below mean high water (MHW). While, overwash during storms was a factor, estimated at 75,000 cy/yr, west directed transport was the dominate direction of transport with an estimated net sediment flux entering Box 2 of 190,000 cy/yr. Box 2 was also a net source of sediment to downdrift shorelines and inlet systems through nearshore and beach erosion, supplying net westward directed sediment transport estimated at 282,000 cy/yr to Box 3.

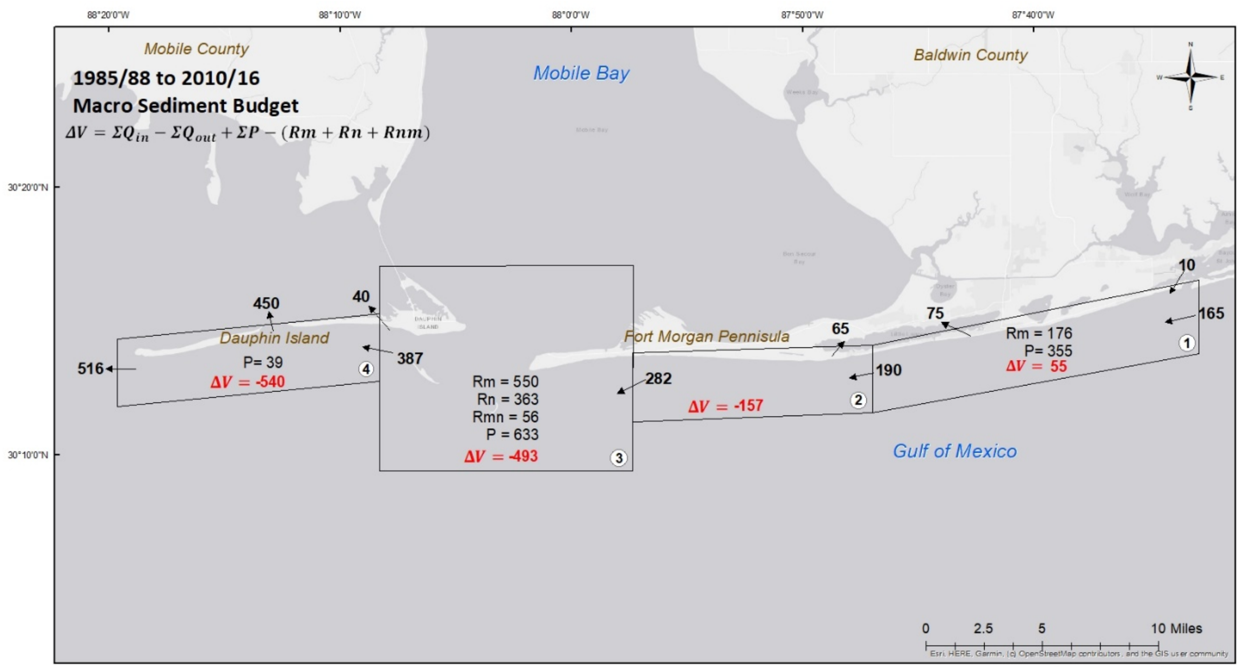

Figure 14: Macro-Scale sediment budget along Alabama's Gulf Coast, 1985/88 to 2010/16. Arrows illustrate the direction of sediment movement throughout the system and numbers reflect the magnitude of net sediment transport in thousands of cy/yr.

Within Box 3 large quantities estimated at 487,000 cy/yr were deposited in the Mobile Harbor Bar channel from both east and west directed wave and tidal current induced transport during the survey coverage period of the ebb tidal shoal (1988 to 2015). In addition, approximately, 63,000 cy/yr were deposited in the Pass Drury and Fort Gaines channels primarily through overwash and breaching along Little Dauphin Island. A total of 458,000 cy/yr maintenance material and 113,00 cy/yr of new work dredged volumes from the Mobile Harbor bar, Pass Drury and Fort Gaines channels were placed within the western ebb shoal system as well as along the shoreline of both Dauphin and Little Dauphin Island. In addition, a few sand mining and placement actions occurred within the cell placing 56,000 cy/yr sand along the Sand Island Lighthouse and approximately 7,000 cy/yr along the Eastend of Dauphin Island. The remaining

92,000 cy/yr of maintenance along with 250,000 cy/y of new work conducted during the survey coverage period were deposited in the ODMDS.

Within Box 4, significant overwash and breaching along the low-lying segments of Dauphin island occurred, with an estimated 450,000 cy/yr transported to the leeside of the island and sound as a result of a number of significant tropical cyclone events that overtopped the island as documented in Table 3 above; however, the longshore flux westward continued to increase by 129,000 cy/yr with a total flux of 516,0000 cy/yr supplied to the downdrift Petiti Bois Pass inlet system.

3.4.2 Detailed Sediment Budget

Four sediment control boxes were identified in the previous section when describing net sand flux throughout the Alabama Gulf coast from 1985/88 to 2010/2016. Detailed sediment cells within each control box were developed from regions of erosion and accretion. There regions are discussed in further detail below.

Figure 15 illustrates the net changes within Box 1 for the Perdido Pass, Orange Beach, Gulf State Park and Gulf Shores areas. Ebb shoal growth at Perdido Pass absorbed about 18 percent of the sediment flux from Perdido Key suppling roughly 135,000 cy/yr downdrift. Beach and nearshore erosion from Orange Beach to Gulf Shores provided an approximate 40 percent increase in sediment flux downdrift to Morgan Peninsula. This erosion was offset by extensive beach nourishments conducted as part of the Orange Beach/ Gulf State Park / Gulf Shores Beach Restoration projects in 2001, 2005-06 and 2013, which supplied an estimated 185,000 cy/yr to the system below mean highwater.

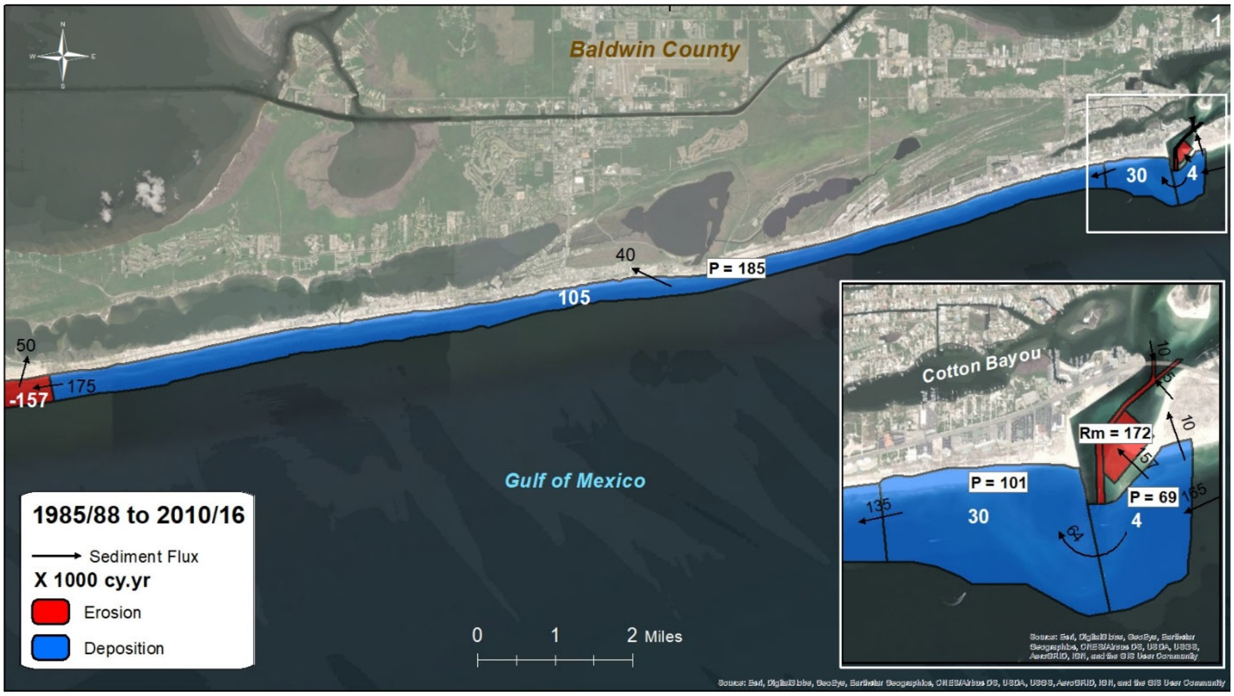

Figure 15: Detailed sediment transport pathways and quantities for Box 1 of the macro-scale sediment budget, 1985/88 to 2010/16. Arrows illustrate the direction of sediment movement throughout the system and numbers reflect the magnitude of net sediment transport in thousands of cy/yr.

Figure 16 illustrates the net changes within Box 2 for the Morgan Peninsula. Despite documented overwash and breaching that occurred at Pine Beach, shoreline loss and nearshore erosion along this stretch of coast provided an approximate 48 percent increase in sediment flux from 190,000 cy/yr to 282,000 cy/yr, downdrift to Fort Morgan.

Figure 16: Detailed sediment transport pathways and quantities for Box 2 of the macro-scale sediment budget, 1985/88 to 2010/16. Arrows illustrate the direction of sediment movement throughout the system and numbers reflect the magnitude of net sediment transport in thousands of cy/yr.

Figure 17 illustrates the net changes within Box 3 for the Mobile Pass region. Large quantities estimated at 487,000 cy/yr were deposited in the Mobile Harbor Bar channel from both the east and west as a result of wave and tidal current induced sediment transport during the survey coverage period of the ebb tidal shoal (1988 to 2015). A total of 395,000 cy/yr of maintenance material and 113,00 cy/yr of new work dredged volume from the Mobile Harbor bar channel was bypassed to the western ebb tidal shoal within the areas known as SIBUA and the feeder berm placement sites during this time period. The remaining 92,000 cy/yr of maintenance that occurred during the survey period along with 250,000 cy/y of new work were deposited in the ODMDS prior to 1999. Additional, sand mining and placement actions along the western Mobile ebb shoal, estimated at approximately 56,000 cy/yr occurred as part of the DWH Sand Island Lighthouse placement project. This material was both removed and deposited within the limits of SIBUA. Despite a large removal of sediment through dredging and the offshore placement of 92,000 cy/yr of active littoral sediments from the maintenance dredging, the flux of sand west from the Mobile ebb shoal to Dauphin Island was nearly in balance with a slight 0.5 percent increase. The near balance of sediment entering the Mobile Bar Channel from the west ebb shoal of 385,000 cy/yr and the 387,000 cy/yr transporting to Dauphin Island, reflects the benefits of active bypassing that has occurred along the Mobile ebb shoal system over the time period of analysis.

Along Little Dauphin Island sediment transport was predominately southeast; however, storm induced overwash was nearly of equal contribution to the beach and nearshore erosion. Overwash from Little Dauphin Island was the primary source of shoaling within the Pass Drury and Fort Gaines channels, providing an estimated 89 percent of the total 163,000 cy/yr of required dredging. Sediments dredged from Pass Drury and Fort Gaines were placed along Little Dauphin Island at a total of 60,000 cy/yr as well the east end of Dauphin Island estimated at approximately 3,000 cy/yr. Additionally, two small beach placements that included the River Sand Pilot Study and Dauphin Island Post Storm Canal Dredging and Sand Placement occurred along the east end, which increased the total placed volume along this region of the coast during the period of analysis to approximately 8,000 cy/yr.

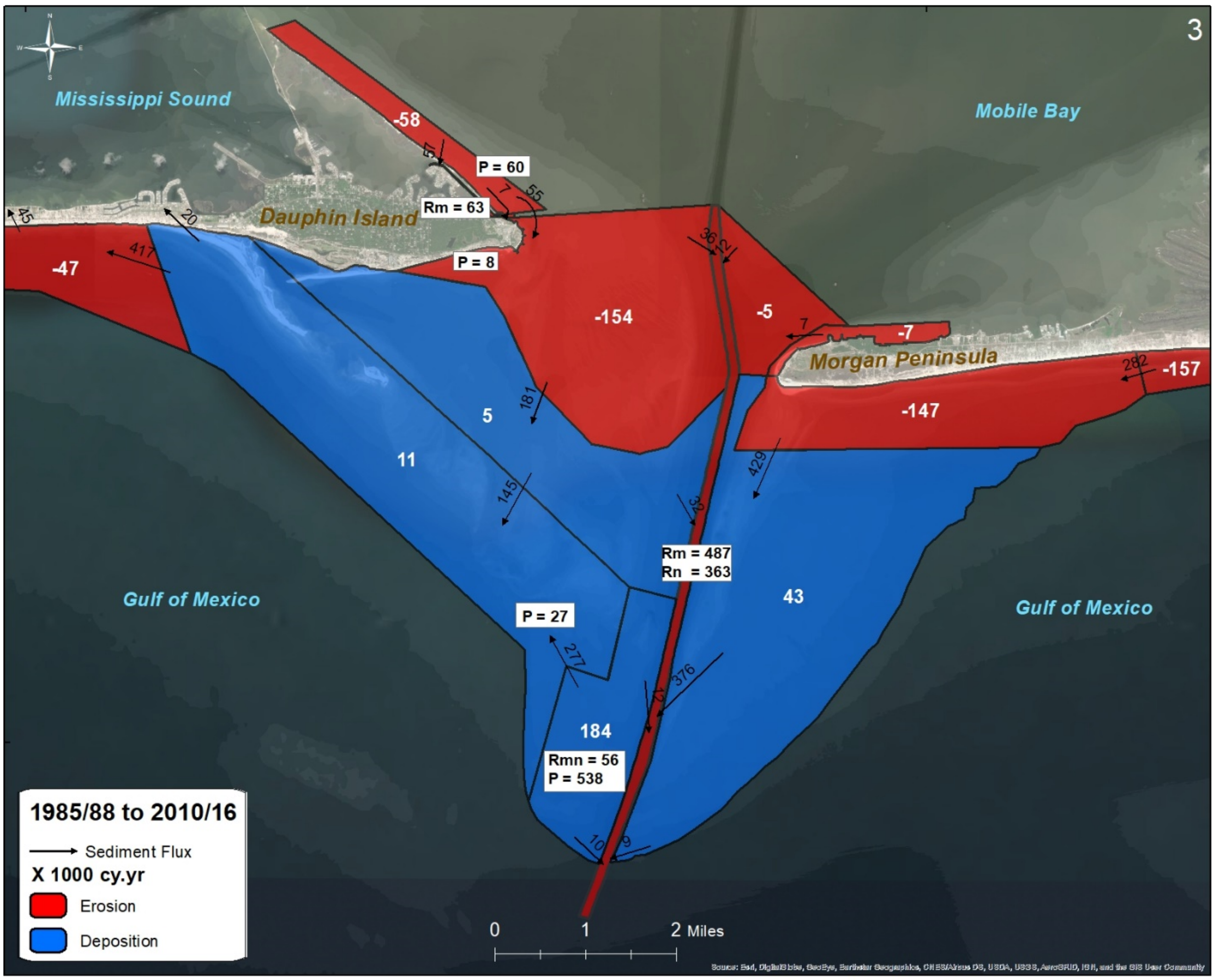

Figure 17: Detailed sediment transport pathways and quantities for Box 3 of the macro-scale sediment budget, 1985/88 to 2010/16. Arrows illustrate the direction of sediment movement throughout the system and numbers reflect the magnitude of net sediment transport in thousands of cy/yr.

Figure 18 illustrates the net changes within Box 4 along the western segment of Dauphin Island. Despite the large sediment flux estimated at 387,000 cy/yr from the Mobile ebb shoal, significant beach and nearshore erosion occurred along the western approximate 11 miles of Dauphin Island. The cell immediately west and downdrift of the attachment point of Pelican Island to Dauphin Island contained the lowest estimated losses during the survey coverage period. This region benefited from an extensive shoreline protuberance from Pelican Island that is the result of the large influx of sediment volume onshore from the Mobile ebb shoal as Pelican Island has unilaterally dispersed to the west. The highest losses over the period analysis were in the vicinity of Katrina cut and west along the undeveloped segment of the island. In this region sediment influx increased to approximately 408,000 cy/yr, but was reduced by nearly 15% as a result of cross-shore losses estimated at roughly 300,000 cy/yr. Increased losses were largely due to documented overwash and breaching during Hurricanes Georges, Ivan and Katrina in 1998, 2004 and 2005 respectively. These events caused erosion of the nearshore and Gulf fronting shorelines as they supplied sediment to the back-barrier systems. The disruption in longshore sediment transport caused by the breach acted as a sink reducing the sediment flux westward. The extensive beach and nearshore erosion immediately downdrift; however, supplied the 168,000 cy/yr increased flux that provided the sediment needed for the westward island extension and shoal accretion within Petiti Bois Pass.

Figure 18: Detailed sediment transport pathways and quantities for Box 4 of the macro-scale sediment budget, 1985/88 to 2010/16. Arrows illustrate the direction of sediment movement throughout the system and numbers reflect the magnitude of net sediment transport in thousands of cy/yr.

4.0 Summary

Sediment erosion and accretion volumes were quantified for the period 1985/88 to 2010/16 for sediment budget development. Zones of erosion and accretion were identified throughout the sediment budget control areas based on bathymetric and shoreline change. Overall, the ebb shoals at the passes were net depositional (sediment sinks). Beach and nearshore environments were net erosional (sediment sources). The dominant direction of littoral transport was east-to-west, and sand from the beaches and nearshore areas along the Alabama Gulf coast supplied material to downdrift barrier islands and inlets.

The east-to-west littoral sediment transport, driven by a prevailing southeast wave climate along with the storm dominated response of geomorphologic features were the main drivers of sediment transport dynamics and seafloor change within the system over the period of analysis. These geomorpologic responses and drivers included: attachment of Pelican Island to Dauphin Island from unilateral disbursement; island overwash deposits and breaching due to storm surge overtopping and inundation; as well post storm recovery of the system aided by the east-to-west littoral sediment transport.

Human induced littoral transport of sediments with the system included numerous sand mining and beach nourishment efforts as well as the dredging and dredged material placement actions at four navigation projects involving routine maintenance dredging of littoral sands. The most extensive sand mining efforts occurred within Baldwin County, Alabama. For these projects sand was removed from outside the littoral system, with sand placement along the coast merely serving as a source. In Mobile County most sand mining efforts occurred within the active littoral system and served as sediment sinks as well as sources. The most extensive navigation channel dredging occurred within the Mobile Harbor bar channel. Sediment deposited within the Mobile Harbor Bar Channel, was primarily bypassed to the adjacent west Mobile ebb shoal over the period of analysis. The benefits of this bypassing are reflected in near balanced sediment cell and increased sediment flux to Dauphin Island from the Mobile ebb shoal system over the time period of analysis.

Regional sediment management and beneficial use options that are consistent with this analysis include maintaining and bypassing sand at the four navigation projects involving routine maintenance dredging of littoral sands traversing the survey coverage area. As a natural sink with large volumes of sediment contained within the existing ebb shoal systems mining may be a viable source for future sand needs along some of the most critical eroded portions of the system; however, evaluation of any affects to the sediment transport system would be needed.

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