Prepared in cooperation with the U.S. Army Corps of Engineers

Effects of Proposed Navigation Channel Improvements on Sediment Transport in Mobile Harbor, Alabama

Open-File Report 2018–1123

U.S. Department of the Interior
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U.S. Geological Survey
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Figures

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Volume	
cubic meter (m^3)	6.290	barrel (petroleum, 1 barrel = 42 gal)
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	0.0002642	million gallons (Mgal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
	Flow rate	
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).
Elevation, as used in this report, refers to the distance above the vertical datum.

Abbreviations

ADCP	acoustic Doppler current profiler
CoNED	Coastal National Elevation Database
DEM	digital elevation model
ECMWF	European Centre for Medium-Range Weather Forecast
HYCOM	Hybrid Coordinate Ocean Model
lidar	light detection and ranging
NGDC	National Geophysical Data Center
NOAA	National Oceanic and Atmospheric Administration
R^2	coefficient of determination
RMSE	root mean square error
SLR	sea level rise
U	through-channel velocity
V	cross-channel velocity

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Abstract

A Delft3D model was developed to evaluate the potential effects of proposed navigation channel deepening and widening in Mobile Harbor, Alabama. The model performance was assessed through comparisons of modeled and observed data of water levels, velocities, and bed level changes; the model captured hydrodynamic and sediment transport patterns in the study area with skill. The validated model was used to simulate changes in sediment transport for existing conditions and with the proposed modifications to the navigational channel (with-project), with and without accounting for 0.5 meter (m) of sea level rise (SLR). Each scenario was simulated for 1 year with a wave climatology representative of the year 2010 as well as for 10 years with a longer-term wave climatology spanning from 1988 to 2016. Bed level differences for the existing and with-project 2010 simulations were minimal, ranging from −0.11 to 0.11 m offshore of Pelican Island and −0.81 to 0.22 m offshore of the Fort Morgan Peninsula. For the simulations accounting for 0.5 m of SLR, differences in bed levels from −0.20 to 0.32 m near Pelican Island and −0.38 to 0.34 m offshore of the Fort Morgan Peninsula. The proposed modifications reduced the channel shoaling volume by 4.77 and 8.09 percent for the 2010 simulations without and with 0.5 m of SLR, respectively. For the 10-year simulations, bed level differences for the existing and with-project simulations ranged from −3.17 to 3.94 m for the simulation without SLR and −1.92 to 1.47 m for the simulation with 0.5 m of SLR. The with-project condition reduced the entrance channel shoaling volume by 5.54 percent for the simulation without SLR and 14.98 percent for the simulation with 0.5 m of SLR.

Introduction

Mobile Harbor is in southwest Alabama in the northern Gulf of Mexico (fig. 1). The U.S. Army Corps of Engineers (USACE) proposed to deepen and widen the existing navigation channel in Mobile Harbor as part of an economic analysis to determine the feasibility of channel improvements. To evaluate the potential effects of channel deepening and widening on the morphology of the ebb tidal shoal and adjacent areas, the USACE Mobile District requested the support of the U.S. Geological Survey in numerical modeling of waves, currents, and sediment transport for the Mobile Harbor General Reevaluation Report. A numerical modeling approach was implemented to quantify relative changes in sediment pathways and the morphological response on the ebb tidal shoal because of the increased channel dimensions. A Delft3D model was developed to simulate changes in sediment transport under existing conditions and accounting for 0.5 m of sea level rise, with and without modifications to the navigation channel. Each scenario was simulated for a 1- and 10-year period; the 1-year simulation used a climatology representative of the year 2010, and the 10-year simulation used a long-term wave climatology for the region. Model output was used to infer potential effects to sediment delivery at the inlet ebb tidal shoal and towards Dauphin Island, Alabama.

Modeling Approach

A Delft3D model was developed and used to quantify relative changes in sediment transport and the morphologic response on the ebb tidal shoal under existing conditions and with

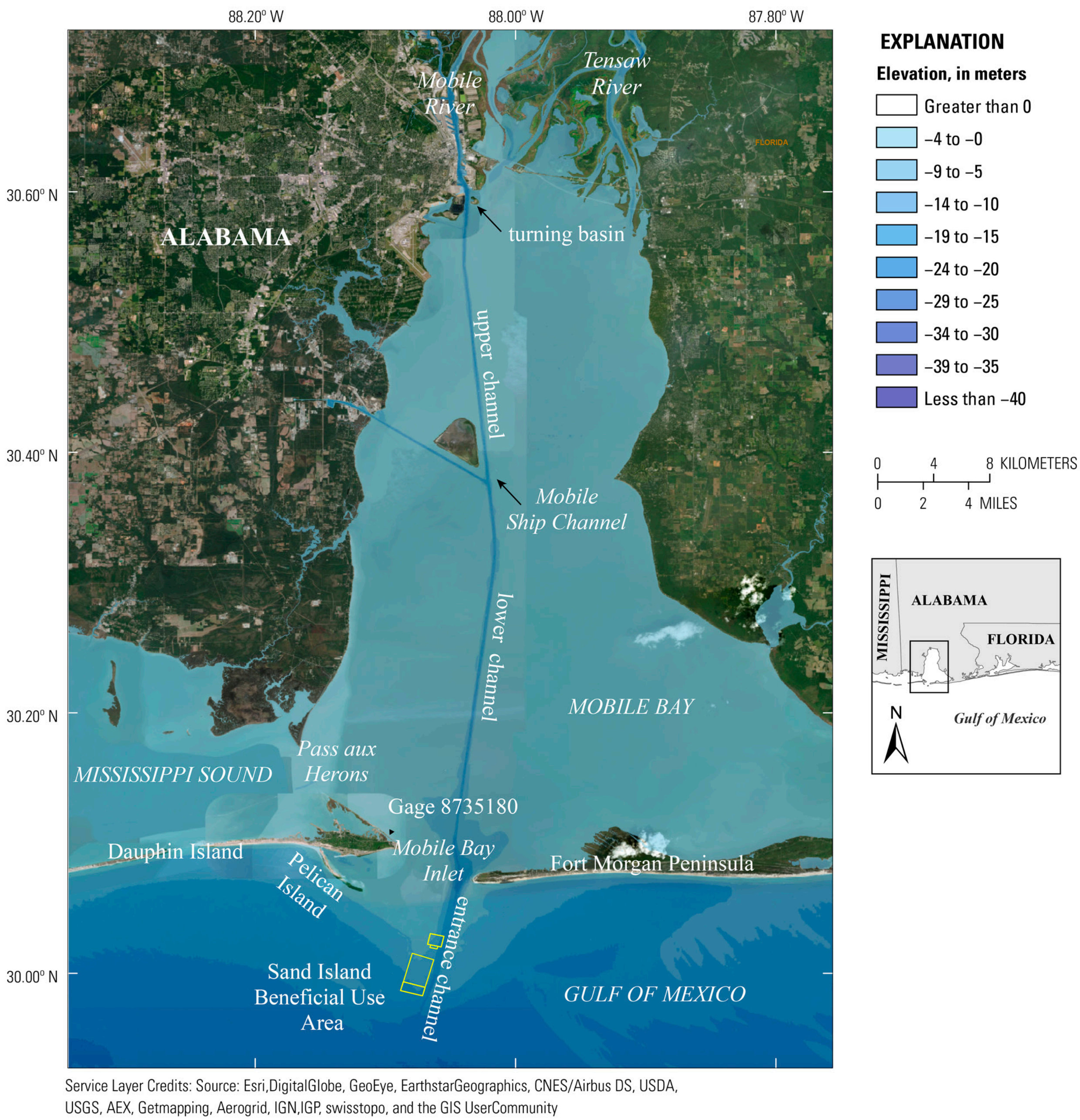

Figure 1. The Mobile Harbor study area, Alabama, including Mobile Bay and the navigational channel, which consists of the upper bay channel, the lower bay channel, and the entrance channel.

the proposed channel modification. Details on the development of the model grid, initial model elevations, and boundary conditions are provided herein. The model grid and initial elevations are provided in Passeri and others (2018).

Proposed Navigation Channel Modifications

Mobile Harbor includes Mobile Bay, which connects to the Gulf of Mexico through the Mobile Bay inlet bounded by the Fort Morgan Peninsula and Dauphin Island (fig. 1). North of Dauphin Island, Mobile Bay connects to the Mississippi Sound through Pass aux Herons (fig. 1.). The Mobile Harbor navigation channel spans the length of Mobile Bay and includes the entrance channel, which extends from the mouth of Mobile Bay southward into the Gulf of Mexico, and the lower and upper bay channels, which extend from the mouth of the bay northward (fig. 1). The existing depth at the entrance channel is 14.33 meters (m, North American Vertical Datum of 1988) with an additional 0.61 m for advanced maintenance (that is, additional dredging depth to avoid re-dredging) and 0.61 m for allowable overdepth dredging (total of 15.54 m). The existing depth in the lower and upper channels is 13.72 m with an additional 0.61 m for advanced maintenance and 0.61 m for allowable overdepth dredging (total of 14.94 m). The proposed project depths would deepen the entrance channel to 15.85 m with an additional 0.61 m for advanced maintenance and 0.61 m for allowable overdepth dredging (total of 17.07 m), and the lower and upper channels to 15.24 m with an additional 0.61 m for advanced maintenance and 0.61 m for allowable overdepth dredging (total of 16.46 m). The turning basin (fig. 1), at the northernmost part of the upper bay channel would be widened 76.2 m southward. The channel from the mouth of the bay northward for 8.04 kilometers would be widened from 121.92 to 152.4 m to include a passing lane.

Model Description

Delft3D (developed by Deltares; see Lesser and others, 2004) is an integrated process-based model consisting of multiple modules used to simulate wave propagation, wave and tidal currents, sediment transport, and morphologic change. The FLOW module (Deltares, 2018a) solves the nonlinear shallow water equations for incompressible free surface flows in two (depth-integrated) or three dimensions. The WAVE module (Deltares, 2018b) solves the spectral action density equation and computes wave radiation stresses and gradients that drive nearshore circulation. When coupled with the FLOW module, the WAVE module accounts for the effects of water level variations and wave-current interaction processes such as frequency shifting. The sediment transport module solves for suspended and bed load sediment transport. To calculate suspended load, the three-dimensional advection-diffusion equation is solved, accounting for sediment concentration, flow velocities, eddy diffusivity, and sediment settling velocity. For bed load transport of non-cohesive sediments, the transport equation is solved accounting for bed slope, bed composition, spatially variable bed friction coefficients, and concentration of available sediment. Breaking-induced shear stresses, mass flux, and bed shear stress are included in the transport of suspended sediments and fluxes from bed load sediments. The transport module evolves bed morphology on the basis of mass fluxes between suspended and bed load sediments. More detailed information on the Delft3D model is provided in Lesser and others (2004).

Delft3D was operated using the mormerge approach (Roelvink, 2006), which is a configuration of the model in which multiple simulations run simultaneously with identical initial bed conditions but with unique wave forcing. Each simulation is assigned a weight according to the percent occurrence of the wave conditions from a wave climatological assessment. At each half model time step, the current bathymetry from each of the simulation bins is combined using a weighted-average to form a new shared bathymetry that is passed back to each simulation and applied as the bathymetry for all the concurrent simulations for the next time step. The cumulative effect is a computationally efficient way to perform long-term morphological predictions.

Model Setup

For this study, three computational grids were used (see grid extents in fig. 2). The FLOW module uses a curvilinear grid consisting of 1,368 x 657 grid points. Cross-shore grid resolution ranges from less than 5 m over Dauphin Island and in the surf zone to greater than 300 m in the northernmost reaches of Mobile Bay. The alongshore grid resolution ranges from 40 m at Dauphin Island and across the Mobile Bay inlet to 100 m grid spacing at points in the southeastern quarter of the grid. The WAVE module uses two grids: a coarse outer grid and a nested fine grid. The coarse outer grid covers the study area with 245 x 449 grid points. It has variable alongshore resolution ranging from 250 to 325 m and variable cross-shore resolution ranging from 15 to 300 m. The spatial extent of the nested fine grid is limited in latitude to the mouth of Mobile Bay where substantial wave-current interactions are expected and higher resolution is required. The fine grid consists of 1,367 x 458 grid points with a variable cross-shore resolution less than 5 m

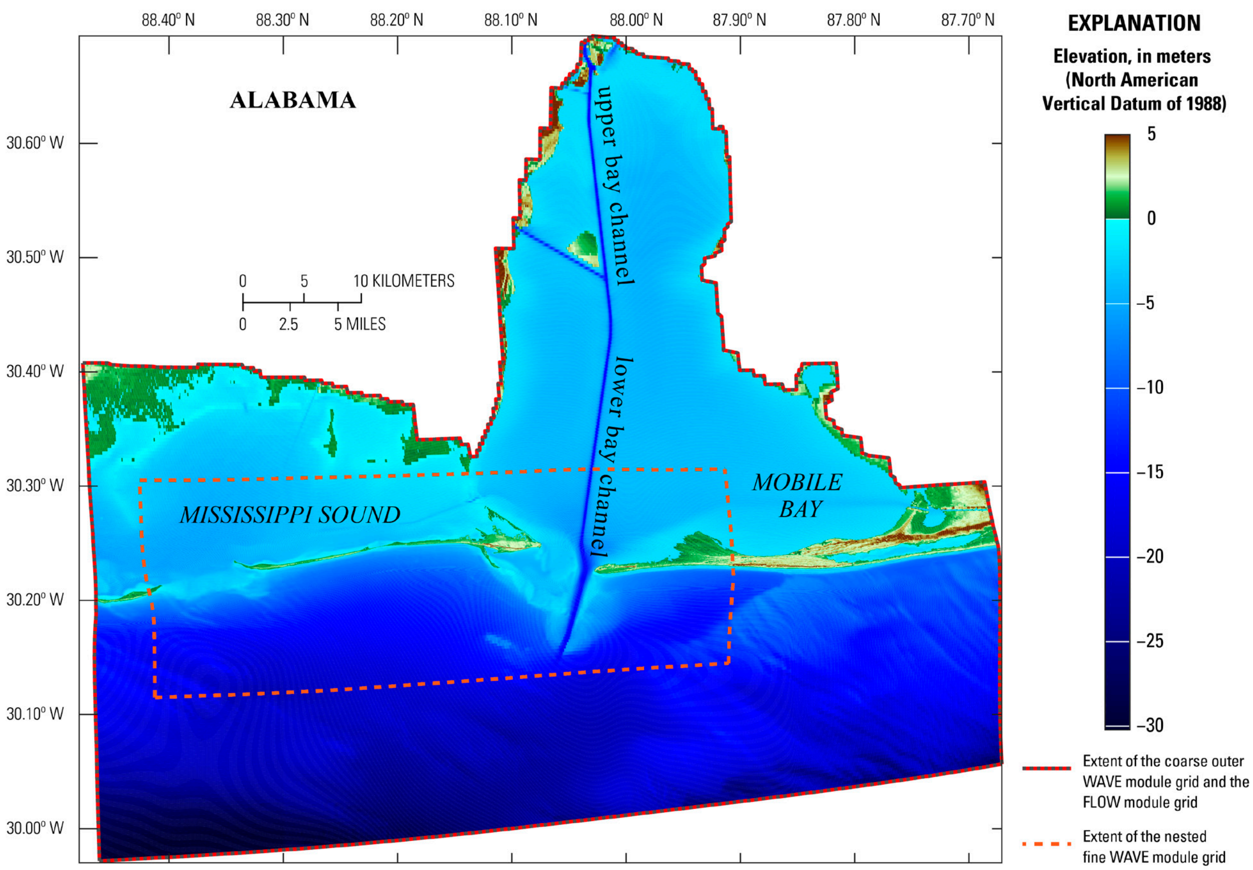

Figure 2. Delft3D model domains (computational grid extents) and initial elevations (existing condition), Mobile Harbor, Alabama.

at the mouth of the bay to more than 250 m offshore and to the north. The alongshore resolution of the fine grid is 100 m along Dauphin Island and becomes coarser east of the Mobile Bay inlet.

Two digital elevation models (DEMs) were created for this study and used to initialize the model to represent (1) the existing bathymetry of Mobile Harbor and the navigation channel and (2) the proposed channel modifications. The base DEM was derived by combining the Coastal National Elevation Database (CoNED) topobathymetric DEM for Mobile Bay (Danielson and others, 2013) and the National Geophysical Data Center (NGDC) coastal DEM (National Geophysical Data Center and others, 2009). The NGDC coastal DEM covers the full extent of the modeling domain and was used primarily for offshore regions that were not included in the CoNED DEM, which contains more recent elevations in the coastal areas. A 2015 bathymetric survey at Dauphin Island (DeWitt and others, 2017) and a 2015 airborne light detection and ranging (lidar) survey of Dauphin Island (U.S. Geological Survey, 2016), also were merged into the DEM using the controlled interpolation methods of Plant and others (2002). For updated coverage, the USACE Mobile District provided elevations within Mobile Bay, including the navigation channel, based on a composite of recent bathymetric surveys (taken by the district) for the existing condition in addition to the altered bathymetry for the proposed with-project condition. These data were incorporated within Mobile Bay east of Pass aux Herons and within the entrance channel limited to the south by the 16-m contour. For depths greater than 5 m, a region was defined using a contour of the minimum difference between the USACE depth and the underlying merged product of NGDC, CoNED, and the 2015 bathymetric and lidar surveys to ensure a continuous bathymetry. The USACE depth was then interpolated onto the FLOW grid and applied only to this defined region.

Boundary Conditions

Wave Climatology

The wave climatology was developed using output from the European Centre for Medium-Range Weather Forecast (ECMWF) ERA-Interim reanalysis model (Dee and others, 2011). For the 10-year simulations, significant wave height (*Hs*), peak wave period (*Tp*) and mean wave direction (*Dm*) from January 1, 1998, to January 1, 2016, at a model grid point at longitude −88.125 W and latitude 30.000 N were used to define the regional wave climatology. Periods with waves not directed towards shore between 110° and 250° (nautical convention) were assumed to minimally affect the study site and therefore were removed from the time series. To validate the model wave height, data from National Data Buoy Center buoy 42040 (National Data Buoy Center, 2018) and from an ECMWF model (Dee and others, 2011) grid point about 6 kilometers away from the buoy were compared for times of overlapping data. A linear regression analysis revealed that using a correction factor of 1.22 improved the modeled wave height; the coefficient of determination (R^2) was 0.86 and the root mean square error (RMSE) was 0.26 m. The Energy Flux Method of Benedet and others (2016) was then used to derive a binned (grouped) wave climatology where wave direction and height bin boundaries were defined such that all bins contained an equal amount of wave energy flux. The wave climate was divided into nine wave classes (three directions and three heights). For each defined bin, wave period is the mean period of the bin, wave direction is mean direction of the bin, and wave height is calculated from the mean wave energy flux in the bin assuming linear wave theory (table 1). For the 2010 simulations, the wave climate was derived similarly using ECMWF ERA-Interim data for 2010 (table 1).

Table 1. Characteristics and percent occurrence of wave conditions for each wave bin for 10-year climatology and 2010 climatology, Mobile Harbor, Alabama.

Row	Significant Wave height (*Hs*), in meters	Peak wave period (*Tp*), in seconds	Mean wave direction (*Dm*), in degrees	Occurrence, in percent
		10-year climatology		
Bin 1	0.59	6.24	129.2	26.2
Bin 2	0.59	6.43	154.01	25.4
Bin 3	0.58	5.75	199.77	28.9
Bin 4	1.21	7.3	128.1	5.3
Bin 5	1.18	7.49	154.48	5.4
Bin 6	1.23	7.22	195.49	5.2
Bin 7	2.65	9.09	126.94	0.9
Bin 8	2.17	8.6	155.06	1.4
Bin 9	2.26	8.68	198.13	1.3
		2010 climatology		
Bin 1	0.61	6.36	130.13	24.55
Bin 2	0.61	6.52	155.87	23.43
Bin 3	0.61	5.55	201.33	27.69
Bin 4	1.03	7.02	129.71	7.85
Bin 5	1.17	7.75	157.27	5.16
Bin 6	1.39	7.41	197.34	3.92
Bin 7	1.63	8.02	133.33	2.69
Bin 8	1.67	8.13	158.77	2.8
Bin 9	2.01	8.37	201.29	1.91

Morphological Tide

In addition to the wave forcing, a tidal time series or "morphological tide" was applied at the model boundaries to capture current velocities and morphological change associated with the neap-spring tide cycle. The morphological tide was calculated following the method of Lesser (2009), which is applicable in locations where the lunar diurnal K1 and O1 tidal constituents substantially contribute to the tidal signal, as is the case in the study domain. Tidal constituent amplitudes and phases were obtained from the National Oceanic and Atmospheric Administration (NOAA) tide gage (8735180) at the eastern end of Dauphin Island (fig. 1) and used to generate the amplitude and phases of the morphological tide. These were applied at the boundaries of each Delft3D simulation. For model stability, a consistent and progressive phase shift also was added to the morphological tide constituents of each successive wave bin.

Simulations

To assess the model performance, two deterministic simulations were conducted to compare modeled current velocities and water levels with collected data. Acoustic Doppler current profiler (ADCP) measurements were collected at the Mobile Bay inlet from August 27 through 29, 2015 (representing the flood tide), and December 19 through 11, 2015 (representing the ebb tide). For each deterministic simulation, the existing Mobile Harbor DEM was used as the initial depth input with boundary conditions of modeled wind, wave, and water levels from the NOAA Hybrid Coordinate Ocean Model (HYCOM) (Bleck 2002) and the NOAA Wavewatch3 model (Tolman 1989). In comparing the modeled HYCOM water levels to the observed water levels at the Dauphin Island tide gage (station 8735180), the HYCOM water levels on average were 0.21 m lower than the observed; therefore, an offset of 0.21 m was added to the HYCOM water levels. Each simulation was spun-up for 12 hours before the first observation. In addition, a 6-month deterministic simulation from June 19 through November 20, 2005, was done to compare modeled water levels with observations at the Dauphin Island tide gage (Center for Operational Oceanographic Products and Services, 2018).

For the 2010 and 10-year simulations, four scenarios were examined: existing conditions (that is, existing bathymetric conditions of the coastal nearshore areas with no channel modifications), with-project conditions (that is, with the proposed channel modifications), existing conditions with a moderate sea level rise (SLR) of 0.50 m, and with-project conditions with a moderate SLR of 0.50 m. For the 10-year simulations, the channel depths were reset to the initial depths at the start of each year, assuming annual dredging would take place. Additionally, a volume of 503,606.21 cubic meters (m^3) of sand was added to the DEM in the southern section of the Sand Island Beneficial Use Area, on the 10-m contour southeast of Pelican Island (fig. 1), at the end of each year to account for the average annual volume of maintenance dredge material placement during 1999–2015.

Modeling Results

The results of the Delft3D simulations are presented herein. To evaluate the model performance, output in the form of water levels, velocities, and bed level from the deterministic simulations were compared with observations. To assess the effects of the proposed channel modifications, the final bed levels were extracted as output from the model at the end of the 2010 and 10-year simulations, with and without 0.50 m of sea level rise (SLR). Model output from each simulation is provided in Passeri and others (2018).

Model Performance

Modeled Versus Observed Water Levels and Velocities

Modeled water velocities were interpolated to the ADCP transect at the Mobile Bay inlet. Modeled and observed water levels were rotated from their respective native coordinates to stream-wise coordinates so that the resulting velocity constituents were a stream-wise U (through-channel) velocity and a V (cross-channel) velocity. The R^2 and RMSE values between the modeled and observed U and V velocities in the Mobile Bay inlet are summarized in table 2. The R^2 values for the modeled and observed U velocities during ebb and flood tide are 0.93 and 0.66, respectively. The R^2 values for the modeled and observed V velocities during ebb and flood tide were 0.79 and 0.30, respectively. An additional comparison of modeled and observed volumetric fluxes calculated across the transect was done for the two ADCP observational periods (table 2). Fluxes were defined as stream-wise, depth-averaged velocities multiplied by water depth and integrated over the observation transect. A linear fit and R^2 value was calculated for the ebb and flood tide fluxes, resulting in values of 0.98 and 0.79, respectively. The high skill during ebb tides shows the model's ability to accurately capture the ebb-dominant behavior of the inlet, which affects sediment transport out of the bay.

The observed water levels at the Dauphin Island tide gage were compared with modeled water levels extracted from the closest grid point to the tide gage location (table 2). The R^2 value between the observed and modeled water levels was 0.68. Model error is likely due in part to the absence of lower frequency harmonic constituents in the boundary forcing.

Modeled Versus Observed Bed Level Changes

Modeled and observed changes in bed levels were compared to evaluate the model's capability to accurately simulate sediment transport. The USACE Mobile District provided changes in bed levels at various locations in the study area from the periods of 2009–14, 2002–14, and 2002–15 (the range of uncertainty is plus or minus [±] 0.61 m). The changes in bed level were calculated from bathymetric surveys by Byrnes and others (2012), Flocks and others (2017), and the NGDC (National Ocean Service, 2014). Changes in bed levels from 2002 to 2014 and 2002 to 2015 indicate erosion and deposition along the 5-m contour extending from Pelican Island, and deposition along the eastern edge of the navigation channel offshore of the Fort Morgan Peninsula (figs. 3A, 3B). These changes were compared with the modeled change in bed level at the end of the 10-year existing simulation (that is, the year 10 final bed level minus the year 1 initial bed level). The simulation shows similar patterns of erosion and deposition along the 5-m contour and along the navigation channel (fig. 4*A*). It is important to note that the simulation was not initialized with 2002 bathymetry, so the magnitude of differences is not expected to match exactly. Additionally, the magnitude of the sediment placed in the Sand Island beneficial use area is not expected to match exactly because an annual average was applied in the simulation.

Observed bed level changes on the ebb tidal shoal between 2009 and 2014 indicate plus or minus (±) 1 m erosion and deposition in between the 5- and 10-m contours (fig. 3*C*). For comparison, bed levels were extracted after year 5 in the 10-year simulation and used to calculate the change in bed level. Similar to the observation, there are patterns of erosion and deposition between the 5- and 10-m contours, as well as the dredge placement in the Sand Island Beneficial Use Area (fig. 4*B*). The magnitude of the difference is less than the observed data, but again, this

Table 2. Coefficients of determination and root mean square error values for through-channel and cross-channel velocity components during flood and ebb tide at inlet, volume flux during flood and ebb tide at inlet and water levels at the Dauphin Island tide gage, Mobile Harbor, Alabama.

[R^2, coefficient of determination; RMSE, root mean square error; *U*, through channel; m/s, meter per second; *V*, cross channel; m^3/s, cubic meter per second; m, meter]

Constituent	R^2	RMSE
Ebb *U* velocity	0.93	0.11 m/s
Ebb *V* velocity	0.79	0.06 m/s
Flood *U* velocity	0.66	0.12 m/s
Flood *V* velocity	0.30	0.07 m/s
Ebb tide flux	0.98	1.53×10^6 m^3/s
Flood tide flux	0.79	1.85×10^6 m^3/s
Water level	0.68	0.09 m

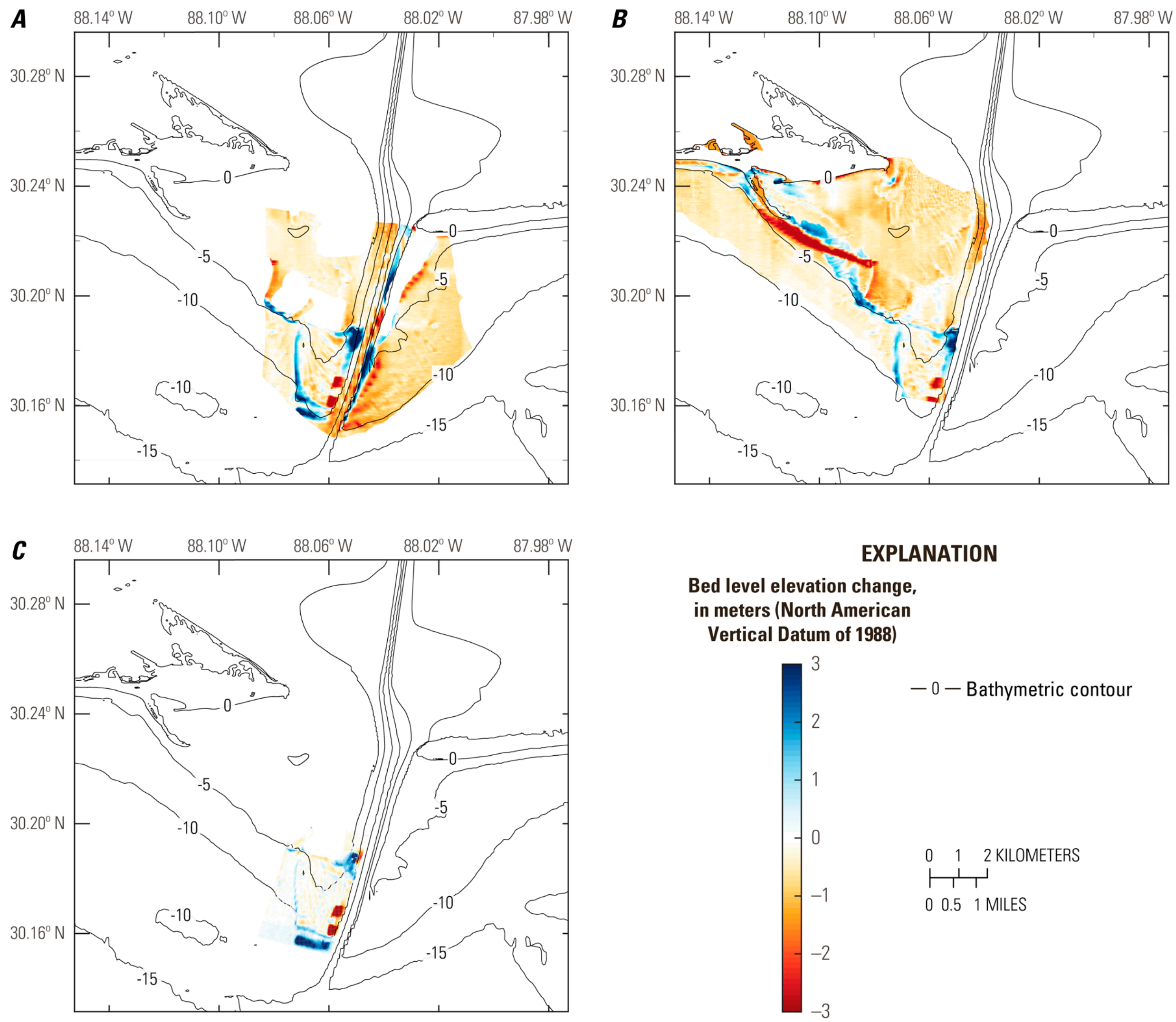

Figure 3. Observed bed level changes in Mobile Harbor, Alabama. *A*, from 2002 to 2014. *B*, from 2002 to 2015. *C*, from 2009 to 2014. Differences greater than 0 indicate deposition, and differences less than 0 indicate erosion.

simulation was not initialized with 2009 bathymetry and does not include tropical storms that would have occurred during this period.

2010 Climatology

The change in bed level at the end of the 2010 simulation for the existing and with-project conditions is illustrated in figures 5A and 5B. Both simulations indicate erosion and deposition along the 5-m contour extending out from Pelican Island, as well as offshore of the Fort Morgan Peninsula. The difference in the final bed levels between the existing and with-project conditions is shown in figure 5*C*. Results indicate that there are minor changes in bed levels near Pelican Island (ranging from −0.11 to 0.11 m) and offshore of the Fort Morgan Peninsula (ranging from −0.81 to 0.22 m) with the proposed channel modification; these changes were confined within the 5-m contour. Similarly, figures 6A and 6B illustrate the change in bed level at the

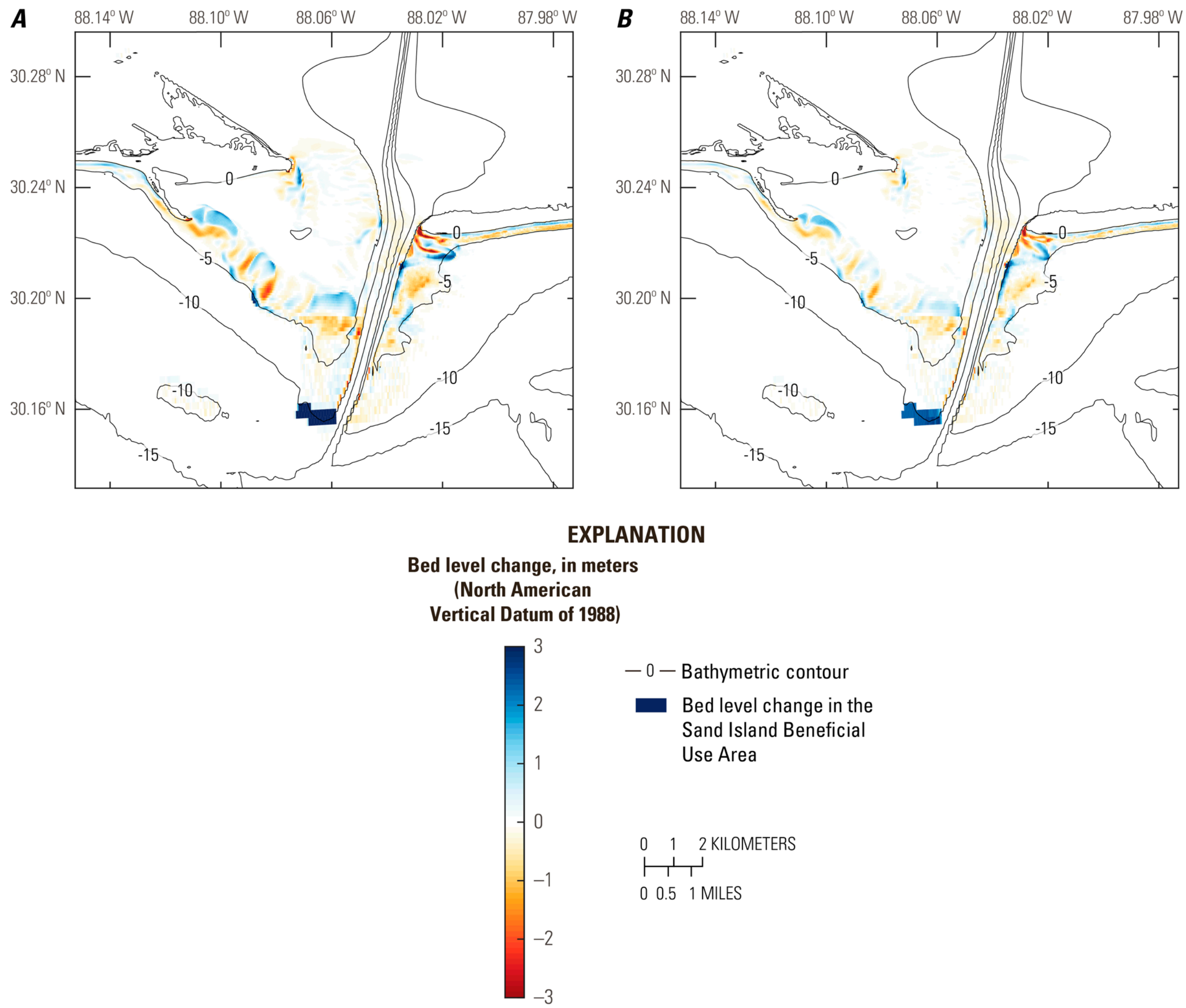

Figure 4. Modeled bed level change in Mobile Harbor, Alabama. *A*, after 10 years in the 10-year existing condition simulation. *B*, after 5 years in the 10-year existing condition simulation. Differences greater than 0 indication deposition, and differences less than 0 indicate erosion.

end of the 2010 simulation for the existing condition with 0.50 m of SLR and the with-project conditions with 0.50 m of SLR. Similar patterns of erosion and deposition can be seen along the 5-m contour offshore of Pelican Island and the Fort Morgan Peninsula. Again, there are minor changes in bed levels for the with-project conditions ranging from −0.20 to 0.32 m near Pelican Island and −0.38 to 0.34 m offshore of the Fort Morgan Peninsula within the 5-m contour (fig. 6*C*).

The volume of sediment eroded and deposited in the entrance channel at the end of the 2010 simulations was calculated by dividing the entrance channel into 15 sections of equal length. The volumes in each section and across the entrance channel are summarized in table 3; the percent change in each section is illustrated in figure 7. The change in volume across the channel for the existing and with-project scenarios is 45,860 and 43,670 m^3 respectively, indicating that the channel is shoaling (sand is being deposited in the channel) for both scenarios. The deeper channel (with-project condition) reduced the overall shoaling volume

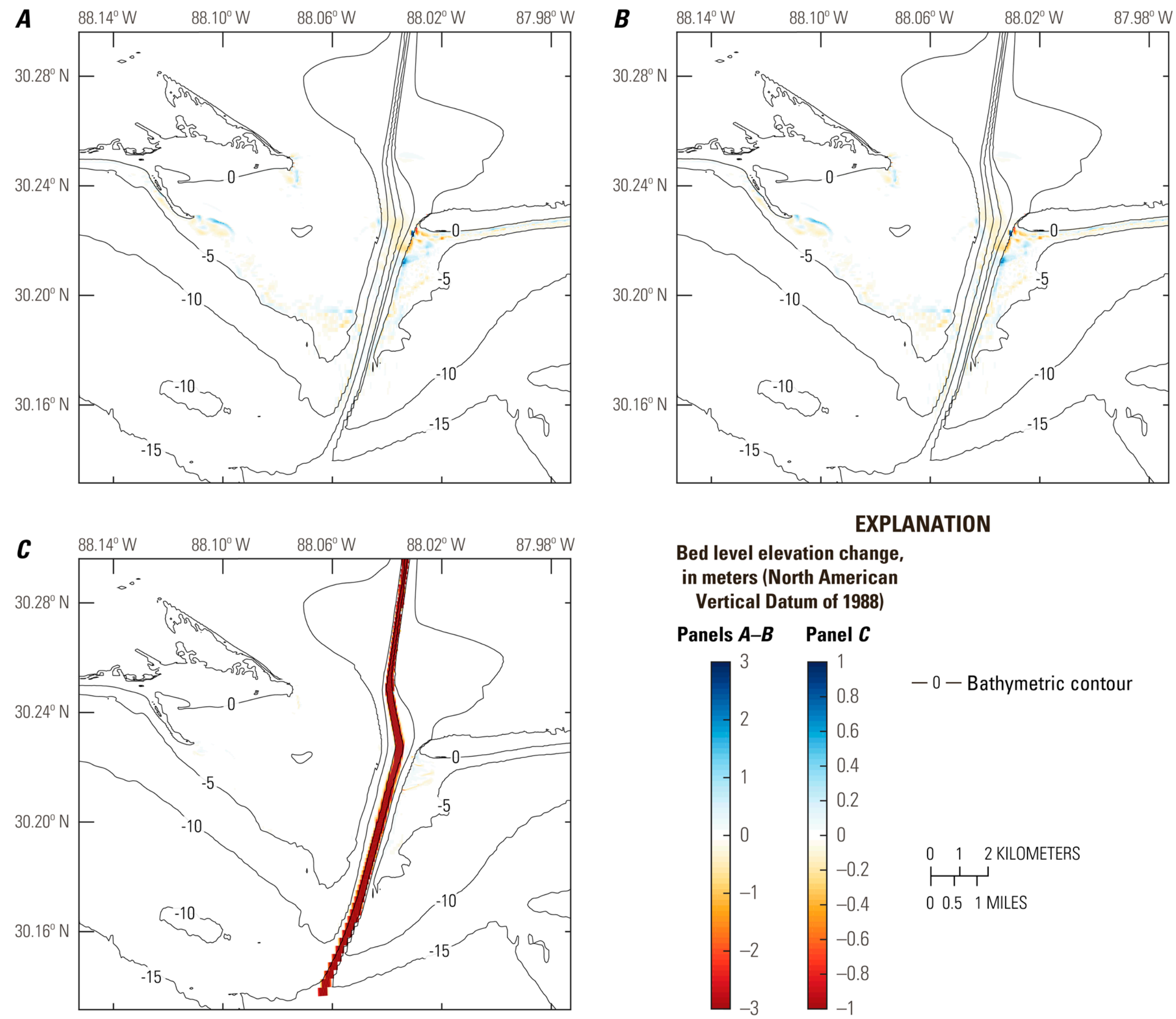

Figure 5. Changes in bed level for the 2010 simulations, Mobile Harbor, Alabama. *A*, existing conditions. *B*, with-project conditions. *C*, difference in final bed level between existing and with-project conditions. For *A* and *B*, differences greater than 0 indicate deposition, differences less than 0 indicate erosion. For *C*, differences greater than 0 indicate the with-project bed level is shallower, and differences less than 0 indicate the with-project bed level is deeper.

by 2,190 m^3 (4.77 percent). Under 0.50 m of SLR, there is less shoaling with channel volumes of 20,662 and 18,991 m^3 for the existing and with-project conditions, respectively. Similarly, the with-project condition reduces the channel shoaling volume by 1,671 m^3 (8.09 percent) from the existing condition. Changes in shoaling volume are negative at most sections of the entrance channel, meaning that less sand is deposited for the with-project condition, as shown in figure 7. However, a few sections in the middle of the entrance channel (6 through 9) and sections 13 and 15 have positive changes, indicating that more sand is deposited in these sections with the deeper (with-project) channel.

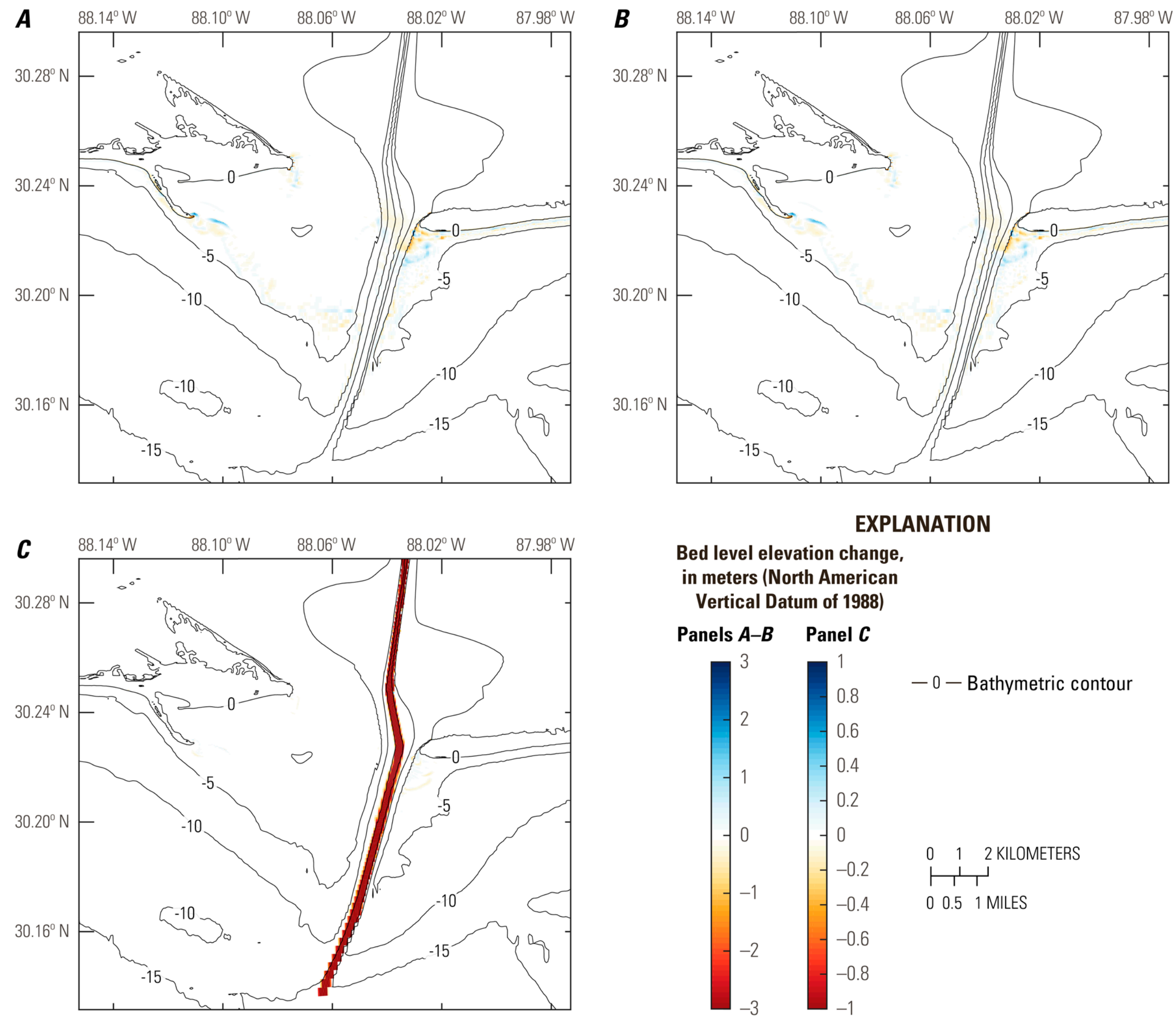

Figure 6. Changes in bed level for the 2010 simulations, Mobile Harbor, Alabama. *A*, existing conditions accounting for 0.5 meter of sea level rise. *B*, with-project conditions accounting for 0.5 meter of sea level rise. *C*, difference in final bed level between existing conditions accounting for 0.5 meter of sea level rise and with-project conditions accounting for 0.5 meter of sea level rise. For *A* and *B*, differences greater than 0 indicate deposition, differences less than 0 indicate erosion. For *C*, differences greater than 0 indicate the bed level for the with-project condition with 0.5 meter of sea level rise is shallower than the bed level for the existing condition with 0.5 meter of sea level rise, and differences less than 0 indicate the bed level for the with-project condition with 0.5 meter of sea level rise is deeper than the bed level for the existing condition with 0.5 meter of sea level rise.

10-Year Climatology

The change in bed level at the end of the 10-year simulation (that is, the difference between the final bed level at the end of year 10 and the initial bed level at the start of the simulation) for the existing and with-project conditions is shown in figures 8A and 8B. Similar to the 2010 simulations, there is erosion and deposition in both simulations along the 5-m contour extending out from Pelican Island, as well as from the Fort Morgan Peninsula. The difference

Table 3. Volume of sediment eroded or deposited in the entrance channel at the end of the 2010 simulations, Mobile Harbor, Alabama.

[Positive numbers indicate sand was deposited in the channel (shoaling); negative numbers indicate sand was eroded from the channel]

Section (figs. 7, 10)	Sediment volume change, in cubic meters			
	Existing conditions	With-project conditions	Existing conditions with 0.50 meter of sea level rise	With-project conditions with 0.50 meter of sea level rise
1	−171	−190	−85	−115
2	−1,144	−1,370	−563	−642
3	−13,012	−15,434	−6,668	−7,878
4	−12,306	−12,704	−6,458	−6,608
5	−21,733	−22,506	−10,157	−10,621
6	−21,858	−20,215	−12,144	−11,446
7	15,200	18,455	5,488	7,621
8	2,433	3,746	−1,569	−668
9	−3,903	−1,735	−6,546	−5,283
10	3,869	3,215	−1,891	−2,117
11	44,910	41,969	20,786	19,041
12	53,606	47,403	34,337	30,728
13	−4,859	−1,833	2,754	3,624
14	3,555	3,358	2,527	2,398
15	1,273	1,511	850	955
All sections	45,860	43,670	20,662	18,991

in the final bed levels between the existing and with-project conditions is shown in figure 8*C*. Results indicate that, with the proposed channel deepening, there are some changes in bed levels along the 5-m contour offshore of Pelican Island, ranging from −2.62 to 2.03 m. Offshore of the Fort Morgan Peninsula, there are larger changes in bed levels ranging from −3.17 to 3.94 m. The change in bed level at the end of the 10-year simulation for the existing and with-project conditions with 0.50 m of SLR is illustrated in figures 9A and 9B. There are similar patterns of erosion and deposition along the 5-m contour and near the Fort Morgan Peninsula for both simulations. With the proposed channel modifications under 0.50 m of SLR, changes in bed levels were smaller than for the 10-year simulations without SLR and range from −0.86 to 1.07 m offshore of Pelican Island and −1.92 to 1.47 m offshore of the Fort Morgan Peninsula (fig. 9*C*).

The volume of sediment in the entrance channel at the end of the year 10 was calculated at each of the 15 sections and across all sections of the channel (table 4); the percent change in each section is illustrated in figure 10. At the end of 10 years, the changes in volume across the entire channel for the existing and with-project scenarios are 40,035 and 37,816 m^3, respectively, indicating that the channel is shoaling (sand was deposited in the channel). The with-project condition reduced the overall channel shoaling volume by 2,219 m^3 (5.54 percent). The change in volume across the entire channel for the existing and with-project scenarios under 0.50 m of SLR is 17,849 and 15,175 m^3, respectively. The with-project condition reduced the overall channel shoaling volume by 2,674 m^3 (14.98 percent). Like the 2010 simulations, the negative changes shown in figure 10 illustrate that less sand is being deposited at most sections of the entrance

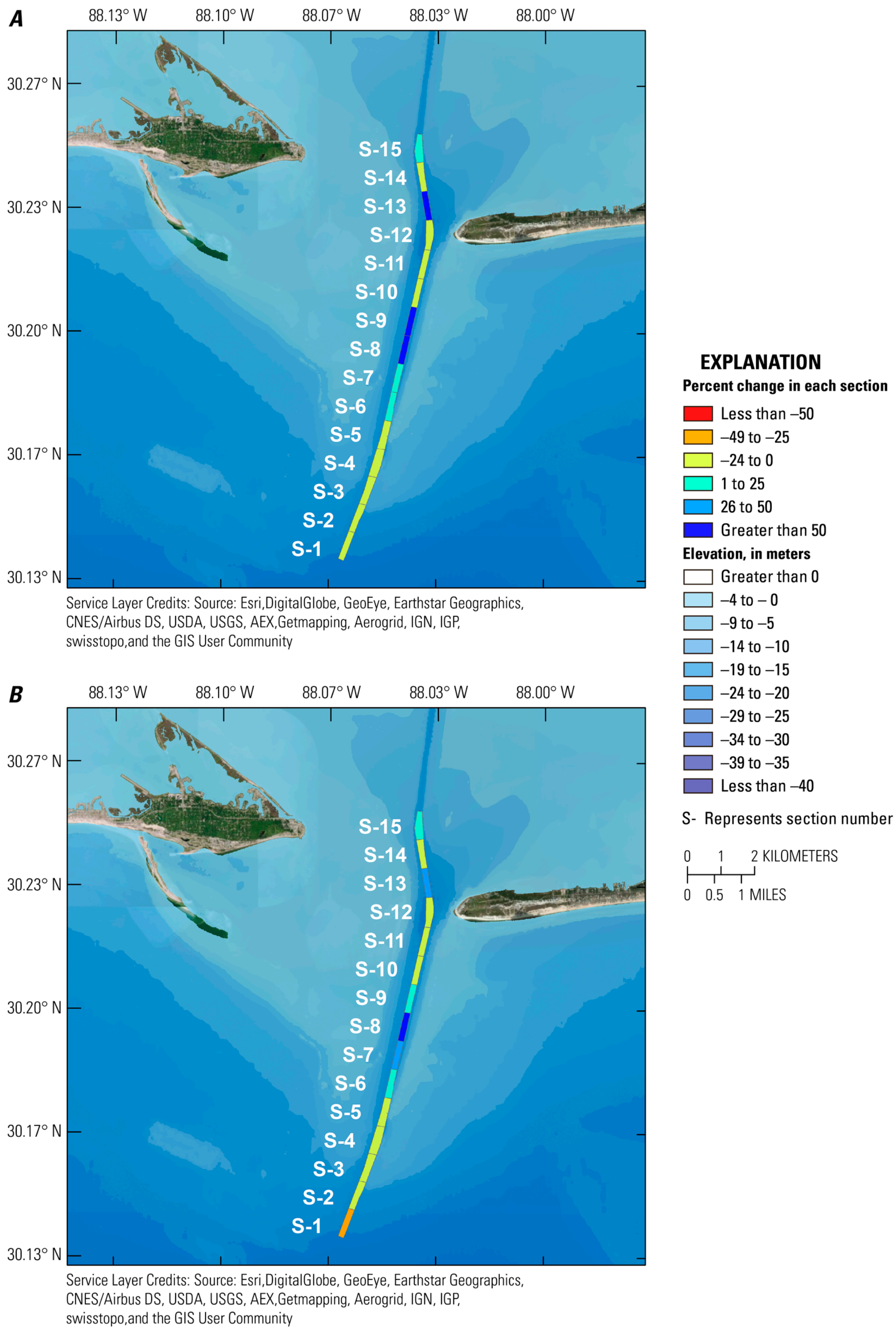

Figure 7. Percent change in the volume of sediment eroded or deposited in the entrance channel, Mobile Harbor, Alabama. *A*, between 2010 existing and 2010 with-project conditions. *B*, between 2010 existing with 0.50 meter of sea level rise and 2010 with-project with 0.50 meter of sea level rise.

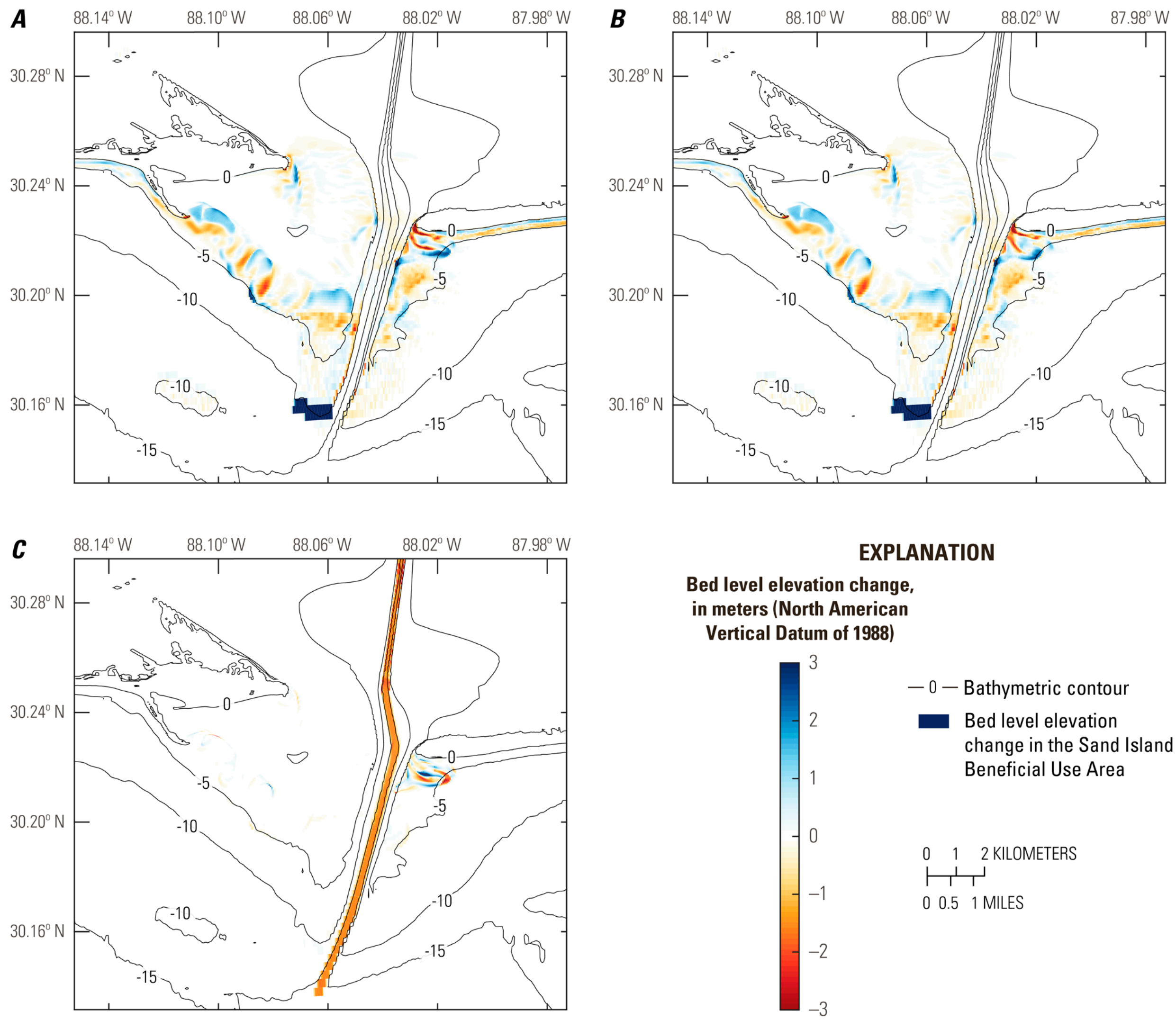

Figure 8. Changes in bed level for the 10-year simulations, Mobile Harbor, Alabama. *A*, existing conditions. *B*, with-project conditions. *C*, difference in final bed level between existing and with-project conditions. For *A* and *B*, differences greater than 0 indicate deposition, differences less than 0 indicate erosion. For *C*, differences greater than 0 indicate the with-project bed level is shallower, and differences less than 0 indicate the with-project bed level is deeper.

channel, especially at the southern end. Again, a few sections in the middle of the entrance channel (6 through 9) and sections 13 and 15 have positive changes, indicating that more sand is deposited in these sections with the deeper (with-project) channel.

The shoaling volume across the entire entrance channel also was calculated at the end of each year in the 10-year simulation (table 5). Although elevations in the channel were reset to the initial depth at the beginning of each year, the shoaling volume at the end of each year was not equal for all simulations; the percent change in the volume varied from a 1.47-percent decrease to a 9.99-percent increase from the previous year. These fluctuations indicate that as sand shifts in offshore areas (especially near the Fort Morgan Peninsula), the resulting sediment transport into the entrance channel changes.

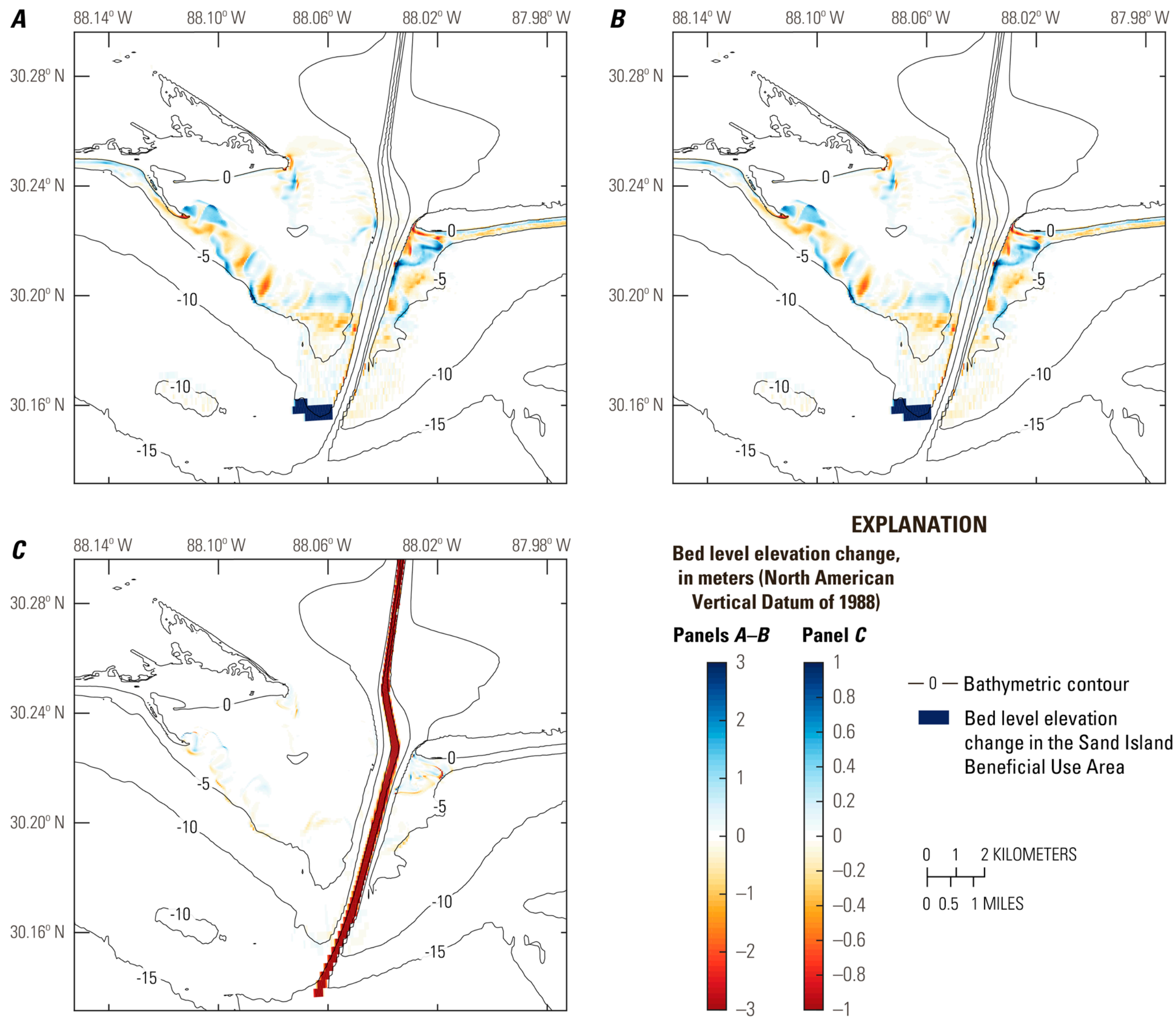

Figure 9. Changes in bed level for the 10-year simulations, Mobile Harbor, Alabama. *A*, existing conditions accounting for 0.5 meter of sea level rise. *B*, with-project conditions accounting for 0.5 meter of sea level rise. *C*, difference in final bed level between existing conditions accounting for 0.5 meter of sea level rise and with-project conditions accounting for 0.5 meter of sea level rise. For *A* and *B*, differences greater than 0 indicate deposition, differences less than 0 indicate erosion. For *C*, differences greater than 0 indicate the bed level for the with-project condition with 0.5 meter of sea level rise is shallower than the existing condition with 0.5 meter of sea level rise, and differences less than 0 indicate the bed level for the with-project condition with 0.5 meter of sea level rise is deeper than the existing condition with 0.5 meter of sea level rise.

Discussion

The results and patterns from the existing and future with-project conditions indicated some changes in the overall dynamics of the system, especially for the 10-year simulations. There were minimal differences in morphologic change in the nearshore areas of Dauphin Island and Pelican Island because of the channel modifications (figs. 8, 9). This suggests that sediment delivery away from the ebb tidal shoal to these areas is similar under these two scenarios and that

Table 4. Volume of sediment eroded or deposited in the entrance channel for the 10-year climatology simulations, Mobile Harbor, Alabama.

[Positive numbers indicate sand was deposited in the channel (shoaling); negative numbers indicate sand was eroded from the channel]

Section (figs. 7, 10)	Sediment volume change, in cubic meters			
	Existing conditions	With-project conditions	Existing conditions with 0.50 meter of sea level rise	With-project conditions with 0.50 meter of sea level rise
1	−1,328	−1,581	−596	−742
2	−534	−1,108	−63	−230
3	−15,532	−18,680	−9,042	−10,819
4	−11,984	−12,367	−5,618	−5,687
5	−24,782	−26,482	−10,693	−11,355
6	−29,023	−28,022	−14,088	−13,393
7	10,243	13,260	5,626	7,250
8	−2,156	1,450	−6,203	−4,547
9	−11,460	−8,587	−16,910	−15,473
10	24,661	21,423	21,054	18,829
11	54,818	54,185	23,400	22,004
12	52,207	44,659	24,076	21,709
13	1,052	4,897	3,727	4,458
14	4,562	4,446	2,402	2,297
15	1,619	1,969	777	876
All sections	52,364	49,462	17,849	15,175

shoreline positions are unlikely to be affected because of the modified channel. Although comparison of the two simulations shows some spatial shifting of sand offshore of the Fort Morgan Peninsula, the patterns of erosion and deposition in the two simulations are quite similar. Based on these results, it also seems unlikely that these changes would alter sediment delivery to the peninsula, and only minor effects to the terminal end of the peninsula closest to the channel could occur.

A limitation in the modeling framework is the exclusion of peak wave and storm surge characteristics associated with tropical storms. Although larger wave heights from storms are included in the full time series of the waves used to define the climatology, the nine bins were defined using mean characteristics of all waves within each bin. Therefore, the model was not forced with wave heights larger than 2.26 m, which is smaller than peak wave heights observed during tropical storms in the Gulf of Mexico (for example, see Bilskie and others, 2016). Additionally, the simulation of each bin contains a tidal time series but does not include storm surge, which is associated with individual storms rather than the wave conditions represented by each bin. River inflow from the Mobile and Tensaw Rivers (fig. 1) also was not considered for this study because it was assumed that riverine effects on hydrodynamics and marine sediment transport would be minor around the ebb tidal shoal and Dauphin Island.

To simulate morphological change over decadal time scales, two-dimensional depth averaged velocities were used in the Delft3D simulations. This neglects the effects of vertically varying velocity profiles and boundary layer processes on morphological change. Studies have

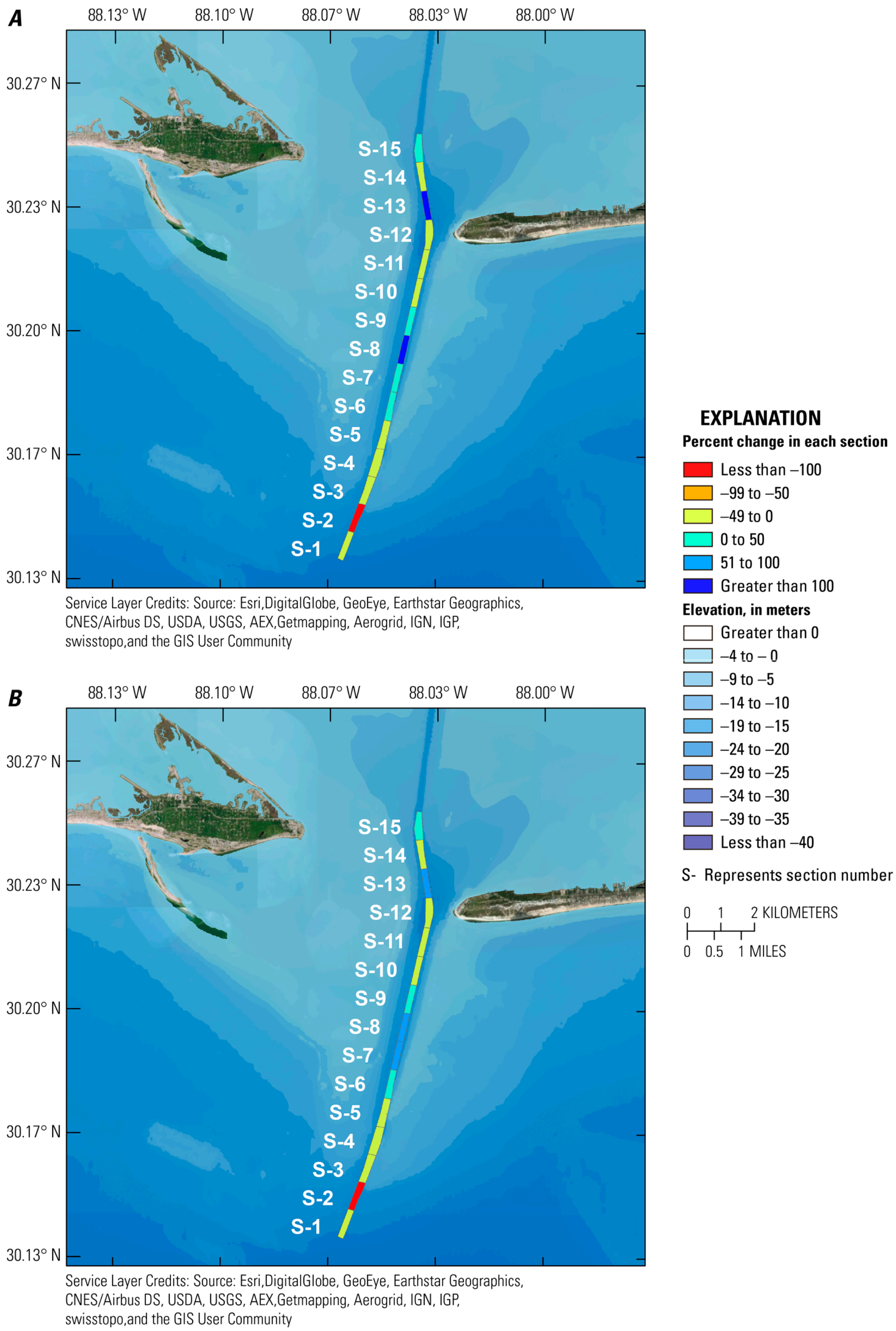

Figure 10. Percent change in the volume of sediment eroded or deposited in the entrance channel, Mobile Harbor, Alabama. *A*, between the 10-year existing and 10-year with-project conditions. *B*, between the 10-year existing condition with 0.50 meter of sea level rise and 10-year with-project condition with 0.50 meter of sea level rise.

Table 5. Shoaling volume in the entrance channel at the end of each year for the 10-year simulations, Mobile Harbor, Alabama.

Period	Shoaling volume, in cubic meters (percent change in volume from the previous year)			
	Existing conditions	**With-project conditions**	**Existing conditions with 0.50 meter of sea level rise**	**With-project conditions with 0.50 meter of sea level rise**
After year 1	38,442	37,482	15,459	12,808
After year 2	42,284 (9.99)	38,474 (2.65)	15,726 (1.73)	13,283 (3.71)
After year 3	41,705 (−1.37)	40,078 (4.17)	15,633 (−0.59)	13,268 (−0.11)
After year 4	41,583 (−0.29)	39,681 (−0.99)	15,879 (1.57)	13,509 (1.82)
After year 5	41,520 (−0.15)	39,677 (−0.01)	16,322 (2.79)	13,836 (2.42)
After year 6	41,470 (−0.12)	39,404 (−0.69)	16,687 (2.24)	14,234 (2.88)
After year 7	41,217 (−0.61)	39,035 (−0.94)	17,041 (2.12)	14,545 (2.19)
After year 8	40,798 (−1.02)	38,473 (−1.44)	17,218 (1.04)	14,651 (0.72)
After year 9	40,305 (−1.21)	37,907 (−1.47)	17,218 (0.00)	14,607 (−0.30)
After year 10	40,035 (−0.67)	37,816 (−0.24)	17,849 (3.66)	15,175 (3.89)

determined that overall sediment transport patterns and morphology change can be accurately simulated using depth-averaged velocities, but the inclusion of three-dimensional processes could change the patterns or magnitudes shown here (Hu and others, 2009; Lapetina and Sheng, 2015). However, the relative difference between simulations with and without project conditions would likely be comparable.

Summary and Conclusions

A Delft3D model was developed to evaluate the potential effects of proposed navigation channel deepening and widening in Mobile Harbor, Alabama. Comparisons of model output from deterministic simulations with observed data of water levels, velocities, and bed level changes indicated that the model was able to capture hydrodynamic and sediment transport patterns in the study area with skill (coefficient of determination [R^2] values were 0.93 and 0.66 for modeled versus observed through-channel (*U*) velocities during ebb and flood tide, respectively, 0.79 and 0.30 for modeled versus observed cross-channel (*V)* velocities during ebb and flood tide, respectively, 0.98 and 0.79 for ebb tide flux and flood tide flux, respectively, and 0.68 for modeled versus observed water levels). The model was then used to simulate changes in sediment transport with and without modifications to the navigational channel and accounting for 0.5 meter (m) of sea level rise (SLR). Each scenario was simulated for 1 year with a wave climatology representative of the year 2010 as well as for 10 years with a longer-term wave climatology spanning from 1988 to 2016. Comparisons of model output for the with-project and existing conditions for the 2010 simulations indicated differences in bed levels ranging from −0.11 to 0.11 m offshore of Pelican Island and −0.81 to 0.22 m offshore of the Fort Morgan Peninsula. For the simulations with 0.5 m of SLR, differences in bed levels ranged from −0.20 to 0.32 m near Pelican Island and −0.38 to 0.34 m offshore of the Fort Morgan Peninsula. The with-project condition reduced shoaling in the entrance channel by 4.77 and 8.09 percent for the 2010 simulations without and with 0.5 m of SLR, respectively. For the 10-year simulations, there were larger changes in bed levels with the proposed channel deepening; at the end of 10 years, the largest changes were offshore of the Fort Morgan Peninsula and ranged from −3.17 to 3.94 m for the simulation without SLR and −1.92 to 1.47 m for the simulation with 0.5 m of SLR. The with-project condition reduced the entrance channel shoaling volume by 5.54 percent for the simulation without SLR and 14.98 percent for the simulation with 0.5 m of SLR. Spatially, most of the entrance channel had less deposition except for the middle of the entrance channel, which had more deposition with the proposed channel modifications. Lastly, the shoaling volume at the end of each year in the 10-year simulations was not equal, indicating that offshore changes in bed levels especially around the Fort Morgan Peninsula affect the quantity of sediment that is transported into the channel.

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