# Coastal Engineering Project Impact Assessment Using Long-Term Morphodynamic Change Analysis

Donald K. Stauble
U.S. Army Engineer Research and Development Center
Coastal and Hydraulics Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

## ABSTRACT

Coastal engineers must often assess the performance of coastal projects. Project impacts to the coast may accumulate over a long time frame and assessment of cause and effect require innovative approaches. This paper examines techniques to use long-term morphologic change to assess project impacts to the coast. Pre-project conditions need to be identified to compare with post-project change. This may require use of historical charts and maps dating back into the 1800's. Accuracy of the data and correction to common datums present a challenge. Modern GIS analysis techniques require as accurate historic data input as possible to make correct assessment on impacts. Techniques are presented to collect, prepare and correct older morphologic data of bathymetry and shorelines into a common datum. A case study is presented at Tybee Island, Georgia to show an example of how long-term morphodynamics can be used to evaluate a navigation project begun in the 1890's and its effects on the present coastal processes and responses of the shoreline. Accurate long-term morphologic assessment can supplement and verify modeling efforts at complex coastal areas.

## INTRODUCTION

To understand the impacts of coastal navigation and shore protection projects on a coastal area, long-term changes in the pre- and post- project shoreline and bathymetry need to be evaluated. Evaluation of pre-project change provides insight into the prevailing coastal processes and how the coast would have evolved without the project. Comparison with post-project evaluation provides a method to identify impacts that the project has had on the regional coastal system and determine if the project performed as designed. The challenge is to find long-term shoreline and bathymetry for the project area, especially for projects that have been in place for a long time. Pre-project data of this type are often hard to find and have datum or accuracy concerns. Analysis has been greatly simplified with the use of Geographic Information Systems (GIS), but care needs to be taken in geo-referencing both the vertical and horizontal datums for these older data into modern coordinate systems. Pre 1927 data has not been registered into one of the standard datums in many areas. Sea level rise has also changed the mean low water (MLW) datum since the early charts were made.

This paper discusses the problems locating and analyzing old historic shoreline and bathymetric surveys and the techniques needed to register the chart's horizontal and vertical datums with more recent standard datums, in order to accurately evaluate the coastal change and identify the project related impacts. This becomes important to design modifications to the project, to mitigate for impacts caused by the project and to assess the cost share responsibilities for these modifications.

## USE OF HISTORICAL BATHYMETRY

Historic bathymetric data sets are available from many sources. The National Oceanic and Atmospheric Administration (NOAA) has a program to scan old charts that are available for download from the internet in digital form. The depths on the digital map can then be digitized to an x, y, z format on screen with software to produce point data of the depths and horizontal locations (Figure 1). Additional historical x, y, z bathymetric survey data is available online from NOAA that can be imported into GIS as

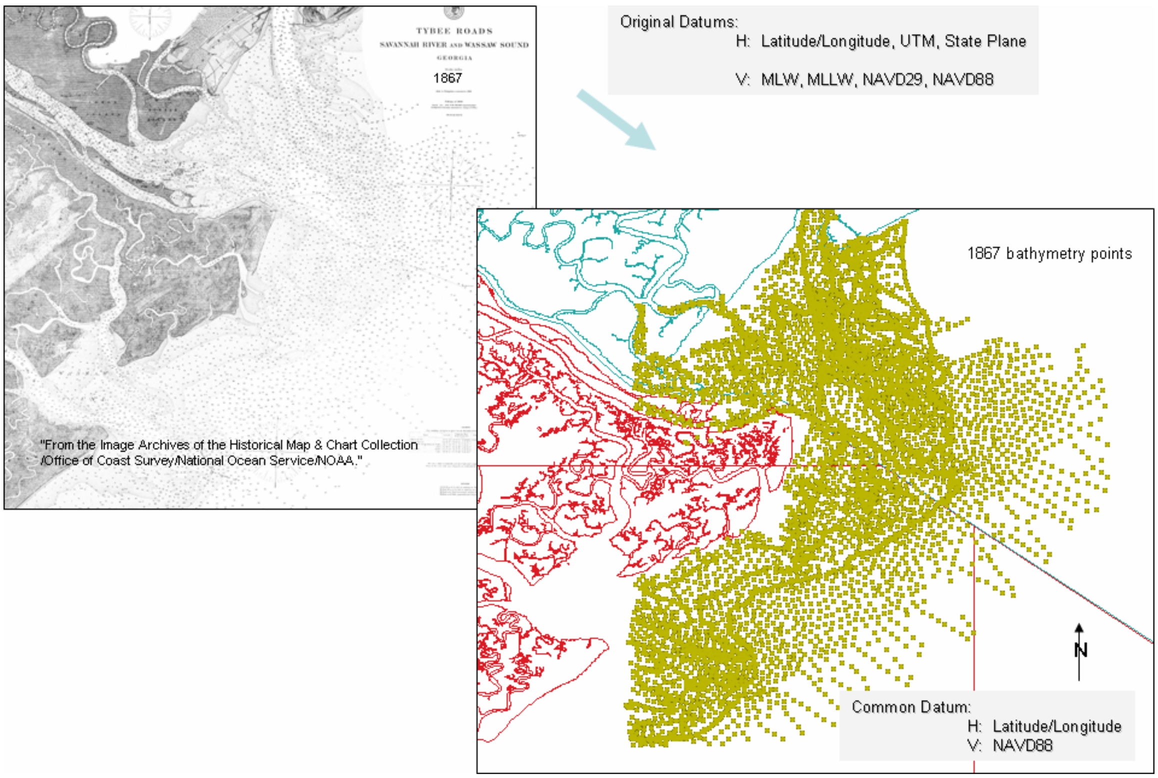


**Figure 1. Scanned historical H-Sheet digitized into point file for GIS analysis.**

point data. These point data can then be contoured in the GIS software. For example, to convert all Tybee Island data to a common datum of North American Vertical Datum of 1988 (NAVD88) in meters using the latest NOAA Tidal Epoch of 1983-2001 and latitude/longitude North American Datum 1983 (NAD83) horizontal datum, several conversions were required. This effort was necessary to perform shoreline and bathymetric change analysis. The early historical data, collected before the National Geodetic Vertical Datum of 1929 (NGVD29) vertical datum was established by NOAA, required several steps to convert the original depth readings into the common datum. A technique was used based on suggestions from NOAA's National Ocean Service (NOS) (Mr. James Hubbard, NOAA-NOS, personal communication, 15 April 2005). The best way to compute the pre-1929 bathymetry sets in the study area was to apply a reverse sea level trend using sea level data from the closest NOAA NOS tide gauge station (as an example the Ft. Pulaski tide gauge Station 8670870 located at the mouth of the Savannah River was used for the case study presented here as shown in Figure 2). Tidal station information can be found at http://tidesandcurrents.noaa.gov. The sea level trend for that station was downloaded from NOAA sea level online (accessed through same web site) and is shown in Figure 3 where the tidal level record starts in 1935 and extends to 1999. The sea level rise trend computed from NOAA at this station is 3.05 mm/yr (0.01 ft/yr) for the 64 years of record. The sea level correction was applied to each pre-1929 bathymetry data set that was older than the NGVD29 datum (in the case study this included an 1854, 1867, 1873, 1897, 1899, 1910 and 1920 bathymetry data sets). The point depth data were then converted into a common horizontal and vertical coordinate system for cross comparison and change evaluation. Triangulated Irregular Networks (TINs or three-dimensional surfaces) were constructed for each date.

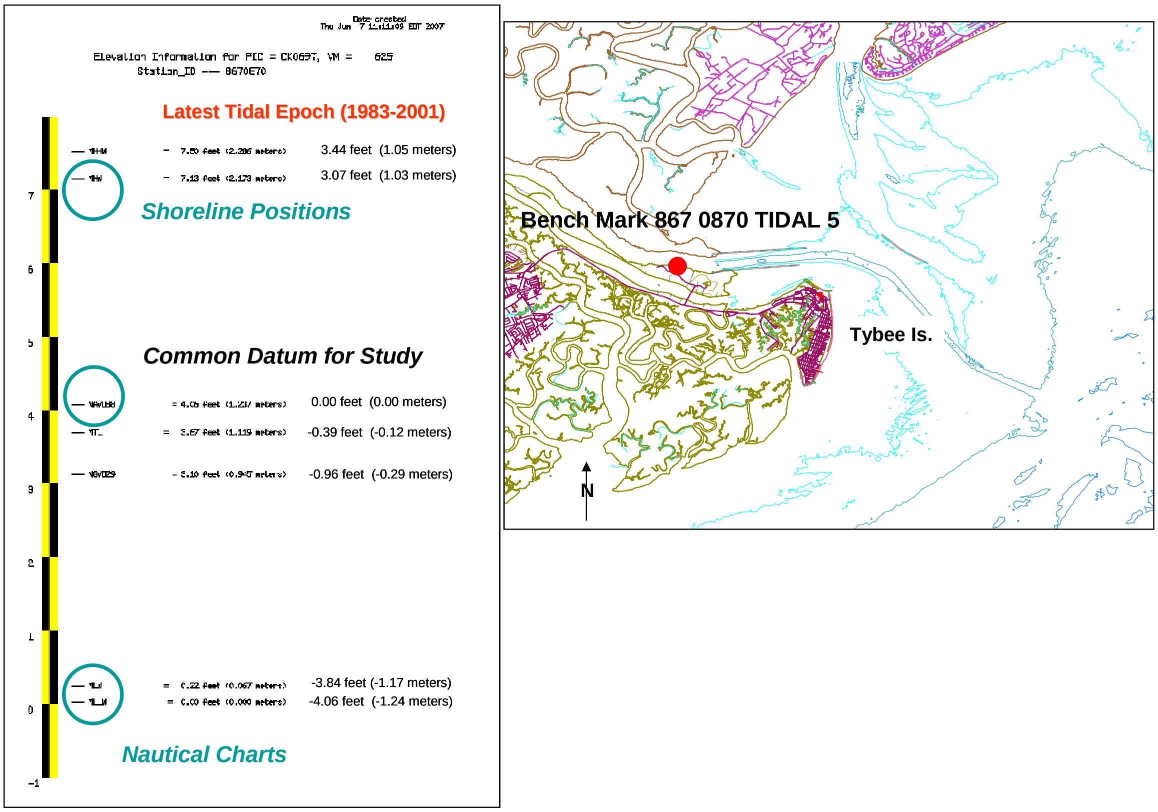


**Figure 2. Tidal datum information at the Ft. Pulaski, GA NOAA tide gage**

The early data were collected by NOAA NOS's predecessor, the U.S. Coast and Geodetic Service (USC&GS) using lead line survey methods. The accuracy of the surveys is the best of that day, approximately +/- 1 m. No standard datums were available at that time and the local datum of MLW at the time of survey was used on each chart. The data were transformed from each map to the present standard vertical datum of NAVD88 and a horizontal datum of latitude and longitude in NAD83. This transformation also included sea level corrections for data surveyed before the NGVD29 was established based on NOAA's sea level curves. The data were further transformed to the present NAVD88 datum based on the NOS latest tidal epoch of 1983-2001. All the data up until the 1970's were collected at a datum of MLW. NOAA switched to a vertical datum of mean lower low water (MLLW) around 1980. The conversion from MLLW to NAVD88 was 1.24 m (4.06 ft), MLW to NAVD88 was 1.17 m (3.84 ft) and NGVD 29 to NAVD88 was 0.29 m (0.96 ft). Each of these conversions has the potential to add uncertainty to the analysis, but care was taken to bring all of the data into a

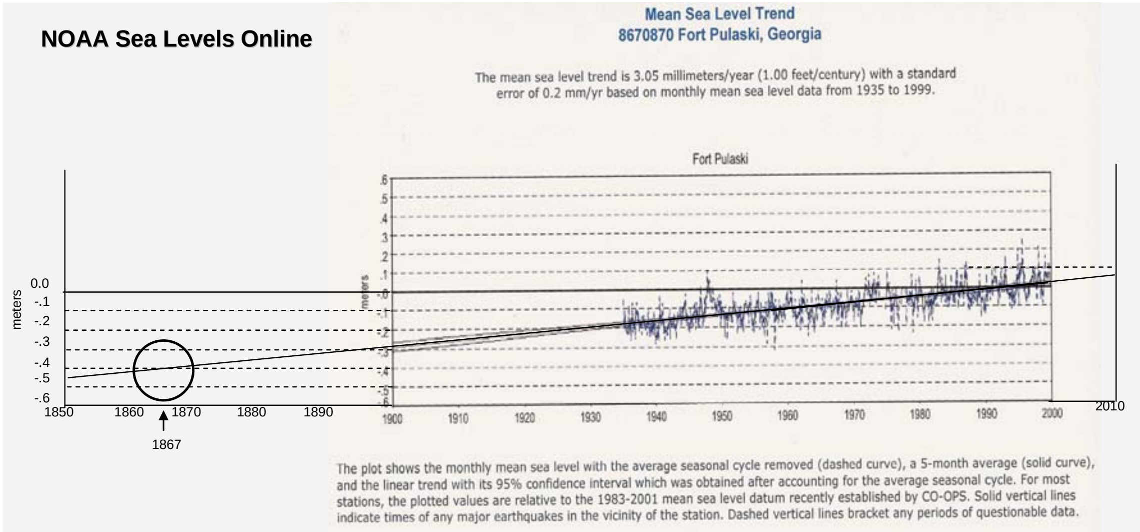


**Figure 3. Mean sea level trend at the Ft. Pulaski, GA, tide gauge from NOAA with calculation of historic chart datums based on linear trend in sea level rise.**

common horizontal and vertical datum for analysis. Once the data were in a common datum for both the vertical and horizontal, cross comparisons of depth change could be made, channel position changes could be measured and changes in morphologic features such as shoals could be evaluated.

## USE OF HISTORICAL SHORELINE DATA

In most cases, historic shoreline position data will be available from many sources and in various forms. Early shoreline position data is often derived from NOAA nautical charts, know as Hydrographic Sheets or H-sheets. The NOAA, NOS, Office of Coast Survey (OCS) has embarked on a program to digitize historic paper H-sheets which contain a local mean high water (MHW) shoreline and make them available in a digital GIS shapefile format. Prior to 1995 the H-sheets were digitized from the depth points or shoreline lines on the paper copy. After 1995 the paper charts were scanned to create raster charts.

Another source of shoreline data is from NOAA Coastal Survey Maps or Topographic sheets (called T-sheets). These recent and historic shorelines are available online from the NOAA Shoreline Data Explorer for use primarily in nautical charting, but are also available in shapefile formats for use in GIS. Historical shorelines are being digitized by the NOAA Coastal Services Center for various dates at selected locations. Digital shorelines are available from the NOAA, NGS Shoreline Data Explorer at http://www.ngs.noaa.gov/newsys_ims/shoreline/index.cfm. Other sources for shoreline data include the US Army Corps of Engineers (USACE) and US Geological Survey (USGS).

All shorelines are not the same. Care must be taken to identify what line is mapped as the shoreline and what horizontal and vertical datums are used. Most of the early shorelines are from NOAA sources (T- and H-sheets) and they are usually in latitude and longitude decimal degrees and the MHW line as identified by tidal elevation at the time of survey. Shoreline positions can also be mapped from aerial photography. NOAA since the 1980’s has mapped the shoreline from tidal controlled aerial photography. Other aerial photography is available that is not tidally controlled and several shorelines can be mapped such as the dune/vegetation line, the debris line around the maximum runup on the day of photography, the wet/dry line which identifies the line between saturated and unsaturated sediment on the beachface and the waterline at the time of photography. These are not necessarily all the MHW line. Shorelines can also be extracted from beach profile data sets as long as the profiles are referenced to a known tidal beachmark. GIS has the ability to contour a set of profile lines and map a MHW line between the profile lines related to the closest tidal benchmark. With the advent of LIDAR in the 1990's, the entire three-dimensional beach topography and nearshore bathymetry can be measured in great detail. Topographic LIDAR elevation data of land above the water line is measured with a different laser than bathymetric LIDAR, which measures depths both above and below the waterline to a given depth, depending on clarity of the water. Both the topographic and bathymetric LIDAR data is usually referenced to a tidal datum and the MHW shoreline can be contoured in GIS since these data sets provide continuous surface elevations points along long stretches of the coast.

## EVALUATE MORPHOLOGY CHANGE AND PATTERNS
## CASE STUDY – TYBEE ISLAND, GA

A case study is presented of the Savannah Harbor Deep Draft Navigation Project located at the mouth of the Savannah River at Tybee Island, GA (Figure 4). The goals were to assess the impact of the Savannah Harbor navigation project on the regional morphology and to quantify the influence of the navigation project on losses of beach sand along Tybee Island and deflation of the nearshore shelf. These impacts were quantified through a combination of shoreline change analysis and bathymetric volume change calculations, and were augmented with hydrodynamic and sediment transport modeling (Smith et al., 2008). Congress authorized construction of the Federal navigation project at Savannah Harbor, which began in 1874 with river channel dredging. The construction of two jetties at the mouth of the Savannah River entrances was completed in 1896, and an offshore breakwater was completed in 1897 at the south end of Barrett Shoals. The methodology used in this project included comparison of a sediment budget of pre-project conditions and present post-project conditions. To determine the pre-project conditions and processes meant going back to changes that occurred before 1897. Sediment budgets were developed for pre-project and post-project conditions. The sediment budget is an accounting of where the sediment has gone through the identified time periods. The budgets are the key elements for assessing the impact of the project. The accuracy of the sediment budgets is dependant on the quality and quantity of the bathymetry and shoreline data available for the region. Sediment budgets were developed for the period 1854 to 1897 (pre-project) and 1897 to 2007 (post-project). These dates were chosen based on the best available survey data. Data from other time periods were used to augment these data to supply trends in change patterns. Bathymetry changes were calculated over both of these time periods. The technique described above was used to correct the early data for datum conversions and sea level rise to more accurately compare this early data to the present conditions. Numerical modeling, which included waves, currents, water levels, and sediment transport rates, was performed for pre-project bathymetry and post-project bathymetry to corroborate the processes at work during both time periods. This model output was used to identify sediment pathways and

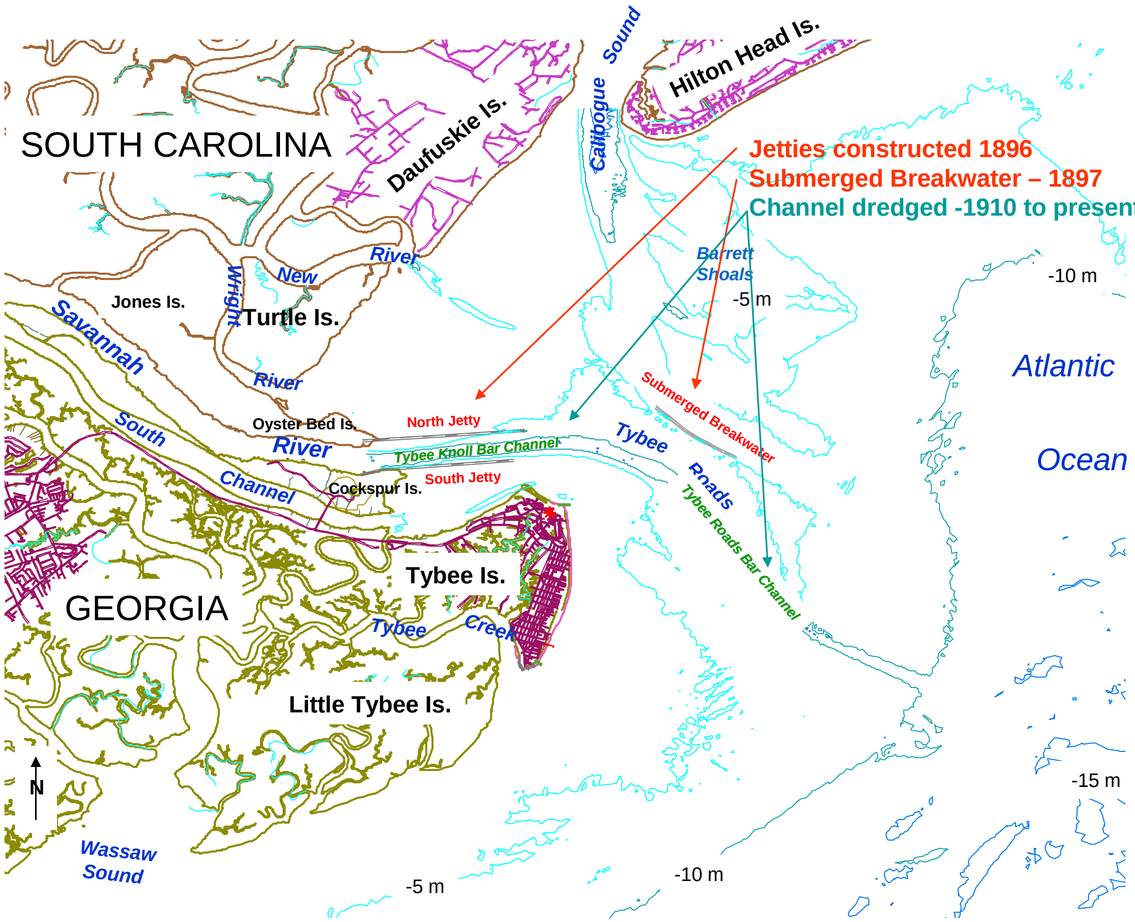


**Figure 4. Location map of case study at Tybee Island, GA.**

changes to wave, current, and sediment transport patterns as a result of the project. Both the morphologic change analysis and sediment budget calculations along with the modeled processes were used to support the study findings (Smith et al., 2008).

### Bathymetry Change Analysis

Historic bathymetry was collected from several sources and in various horizontal and vertical datums. NOAA NOS historic charts were scanned and digitized to supply bathymetry for the early pre-project dates 1854, 1867, 1873, and 1897. Additional early post-project charts included 1899, 1910 and 1920. All of these charts were in latitude and longitude horizontal datum and a local MLW at the time of each chart vertical datum. Later x, y, z, point historic bathymetric data sets were collected from NOAA‘s GEODAS database of NOS hydrographic surveys of coastal waters in the study area and were referenced either to MLW or MLLW depending on date of collection of either 1934, 1970-83 composite or 1994. The US Army Engineer District, Savannah, supplied before and after dredging surveys, as well as condition surveys of the navigation channel in 2005 and a February 2005 beach and nearshore survey off Tybee Island in Georgia State Plane East horizontal and MLLW vertical datums. NOAA NOS provided some recent surveys of the channel area that they collected during 2006 for hazards to navigation requirements. A recent survey of the area off Tybee Island was lacking so in March 2007 the Savannah District Survey Section collected beach profiles and bathymetry lines of the beach and nearshore of Tybee Island. The 2005 channel survey was combined with the 2006 NOAA spot surveys and the 2007 Savannah District surveys to produce a composite bathymetry of the recent beach and nearshore shelf off Tybee Island.

To understand the impact of the construction of structures and dredging of the Federal navigation channel has had on the Savannah River Entrance area, a comparison was made between the conditions that existed before bar channel improvements to conditions that exist after dredging to deepen and widen the channel and construction of navigation improvement structures. The project was initiated with dredging of the channel in 1874, but no records are available until 1910 of dredging volumes and depths of the channel. The dredging operations have deepened the channel five times from 3.8 m (21.5 ft) in the 1900's to the present 13.4 m (44 ft) MLW. Each time the channel was deepened or widened new dredging was initiated and required removal of larger quantities of sediment from the channel. Almost annual maintenance has been required to keep the channel at the design depth. Most of this dredged sediment was placed on the Offshore Dredge Material Disposal Site in deep water seaward of the 10-m contour, except for a beach fill in 1993/94 which placed the dredged sediment on the beach.

The pre-project study period has been defined as the period between 1854 and 1897 (Figure 5a and b). This period was defined based on available data and the fact that the Savannah River Entrance jetties were completed in 1896 and the Tybee Roads submerged breakwater was completed in 1897. To study the "natural" changes that took place in the morphology of the Tybee Roads area before the project was implemented, a change analysis was done between the 1854 to 1897 bathymetries. The 1897 bathymetry was presumably the as-built survey and was not thought to have any major effects of the project realized in such a short time after construction. The 1854 survey coverage was sufficient to include the entire sediment budget cell area. The 1897 survey was limited to the Savannah River Entrance area. To increase the area for comparison with the 1854 bathymetry, selected areas on the outer edges of the study area were supplemented with the next available pre-project survey of 1873. These areas included the Daufuskie/Turtle Island shelf, Barrett Shoals and the southern portion of Tybee Island platform. This new composite bathymetry is shown in Figure 5a.

The difference map of change between 1854-1897/73 is shown in Figure 5c. The main loss of material over this pre-project 43-year period is found where the channels have changed location. The three channels from Calibogue Sound have shifted to the south with erosion in the present location of the centerlines (red shades in figure show loss of sediment) and a filling in of the older channel locations (green shades in figure show gain of sediment). The New River entrance channel has scoured out a deeper channel in its original location. The south end of Barrett Shoals has lost sediment with the merged northern leg of the Wright River, main Savannah River and South Channel trending east on its southern tip. A second channel (which will become the main dredged navigation channel) is located in the lower Tybee Roads Bar Channel area. A gain was found in the Tybee Knoll Bar Channel and the South Channel, just at their mouths. The change in the Tybee Island shoreline and the beginning of the removal of a bulge of sand on the northern end of Tybee has resulted in gain of sediment on the North Tybee Shoal

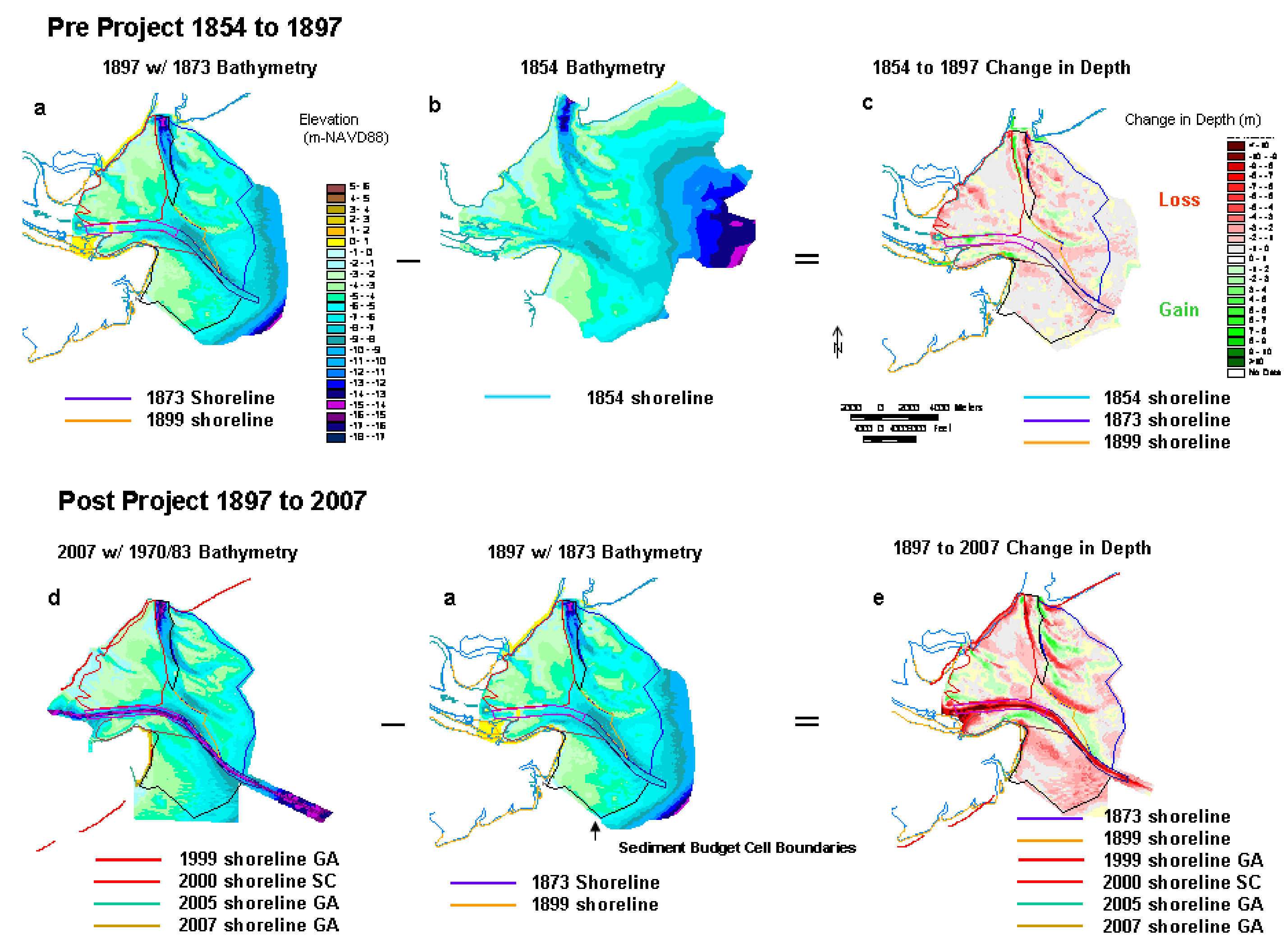


**Figure 5. Bathymetry change analysis of pre- and post-project bathymetry datasets.**

and beach front. The Tybee Island Shelf was losing sediment, particularly on its northern portion, even before dredging and structure construction (Figure 4 shows locations).

The post-project period from 1897 to 2007 required comparison of the bathymetry and shoreline change from those periods. Coverage of the most recent bathymetry was limited to the 2005 condition survey of the channel, 2006 survey of selected shelf areas of Tybee Roads (Breakwater Shelf area) and 2007 survey of the North Tybee Shoal and the Tybee Island Shelf. To assess the changes in sediment elevation over this post-project period, a composite bathymetry was constructed by filling bathymetry gaps with survey data from the 1970/83 time frame (Figure 5d). This included the northern area of the study, Daufuskie/Turtle Island shelf, Calibogue Sound and Barrett Shoals. The main dredged navigation channel orientation is now distinct and has been fixed in the location to the southeast through dredging. The deflation of the shelf in front of Tybee Island can be seen with a recurved spit of sediment forming within the North Tybee shoal.

The post-project difference map that was generated in ArcView from the composite 1897/73 and 2005/06/07 (with portions of 1970/83) is shown in Figure 5e. The erosion patterns in the Calibogue Sound and Barrett Shoals area are a result of reorientation and shift to the south of the multi-channels coming off the main Calibogue Sound channel (red areas show scour of the present channels and green show deposition in the paleo-channel positions). The long dredging history of the main Savannah River navigation channel is reflected in the loss of sediment in the channel throat section. Deflation of the Tybee Island Shelf has occurred on the seaward edge of the shelf and an erosional wedge is present on the northern edge of the Tybee Island Shelf. The shoreline adjacent to the north end of the island in the vicinity of the wedge also shows erosion. Sediment gains are found in the recurved spit growing in the North Tybee Shoal cell. Sediment deposition on the southern portion of the Daufuskie/Turtle Island shelf is due to a more northward reorientation of the channel out of the New River and accretion in the paleo-channel to the south.

### Shoreline Change Analysis

Data were acquired from various sources to evaluate the shoreline change history of both Tybee Island on the Georgia side of Savannah River Entrance and Hilton Head, Daufuskie and Turtle Islands on the South Carolina side of the entrance. All of the early data were digitized field surveys from NOAA T-sheets. The Savannah District supplied some of the data from their digital files that were derived from the NOAA T-sheets. Additional charts were obtained in digital scanned form from NOAA, NOS, Office of Coastal Survey image archives of historical maps and charts, and the shorelines were digitized using the Diger 2 software at the US Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL). Some of the shorelines were digitized by Coastal Carolina University from paper maps from a previous joint NOAA/Coastal Engineering Research Center (CERC) shoreline movement study covering Tybee Island, Georgia, to Cape Fear, North Carolina (Anders et al., 1990). These shorelines were compiled by NOAA from field survey T-sheets, and the 1982 shoreline was from aerial photography and is archived at CHL. The USGS completed a study on long-term shoreline change along the Southeast Atlantic coast using four shoreline periods to calculate change rates (Miller et al., 2005). This analysis used the

NOAA/CERC shorelines from 1863, 1920 (South Carolina beaches only) and 1963 shorelines, and NOAA T-sheets from 1925 for Georgia beaches (Tybee Island). The 1999 Georgia and 2000 South Carolina shorelines were derived from LIDAR surveys conducted by the USGS. The Savannah District supplied a set of beach profiles surveyed in February 2005. An additional set of profile surveys were collected for this study by Savannah District in March 2007. The MHW shoreline was derived from the MHW elevation of 0.94 m (3.07 ft) above NAVD88 from each profile data set based on the NOAA Ft. Pulaski tide station. The MHW shoreline was contoured using ArcView GIS software. The latest shoreline was digitized off an October 2005 high-resolution digital air photo in the GIS using the local high water mark visible on the air photo.

The 1854 pre-jetty through 1925 post-jetty historical shoreline positions generated for this study for Tybee Island are shown in Figure 6a. The shoreline position was relatively stable from 1854 to 1873. A distinct change in shoreline orientation can be seen between the 1873 shoreline and the 1899 shoreline. A bulge in the northern Tybee shoreline evident in the 1854 to 1873 shoreline was removed by landward retreat of the north end of the island by 1920. The loss of this large volume of sand is likely due to changes in the transport patterns related to the project. The circulation and sediment transport modeling (Smith et al., 2008) show a current gyre in this area during pre-project times that pushes sediment from the shallow south channel on the north end of Tybee Island back toward the beach. After the project was constructed this gyre is pushed north and cannot effectively circulate sediment out of the deepened navigation channel and back toward the beach. Increased hurricane activity at that time may have also contributed to the erosion of the bulge (Smith et al., 2008).

After the project was initiated, the island grew southward at its southern tip and accreted seaward south of the budge. At the same time, the ocean shoreline reoriented itself between 1899 and 1925. The northern end of the island also expanded to the north and west. The post-project shoreline change over time along Tybee Island is illustrated in Figure 6b. The general trend is for the north tip of Tybee Island to migrate northward into the southern channel of the Savannah River and also to progressively move westward over time. The central portion of Tybee Island has shown erosion of the bulge between 1867 and 1899 thru 1900, 1910, and 1920 to 1925 with a movement of sand in this central portion of the island mostly to the south. A “hot spot” (region of increased erosion) is located between 1$^{st}$ and 6$^{th}$ Streets where the shoreline has rotated around a nodal point in the vicinity of 2$^{nd}$ Street. South of the nodal point the shoreline has moved seaward over time. The southern part of the island has grown to the south and seaward over the historic period with the most change taking place between 1899 and 1925. After 1925, the shoreline position was more stable, with the most marked changes due to the construction of shore protection structures and beach fill placement.

Numerous seawall and groin structures were constructed from 1912 to 1941 to protect the upland from erosion. In 1976 the North Terminal Groin was constructed and a 2.2 mil cu yd beach fill was placed on the beachfront from the groin south to 18$^{th}$ Street. The South Terminal Groin was constructed in 1986-87 and the North Terminal Groin was rehabilitated. A second 1.2 mil cu yd fill was placed on the beach between the two terminal groins at that time as well as placement of 0.157 mil cu yd of fill to the south of the South Terminal Groin. Fill material was placed between the North Terminal Groin

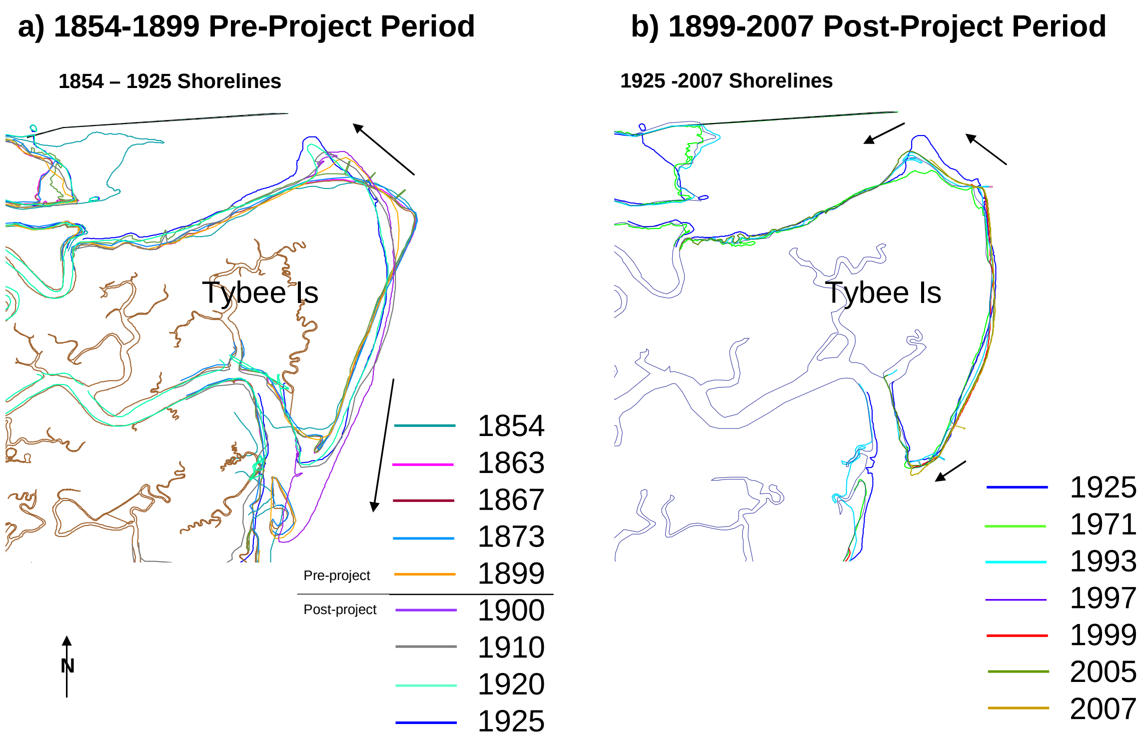


**Figure 6. Shoreline change along Tybee Island pre- and post- project.**

and 3rd Street in 1993 to mitigate for the hot spot erosion. Erosion persisted at the south end of the island so two T-Head groins and a L-Head groin were constructed in 1994 south of the South Terminal Groin to help retain sand. In 1995, 0.285 mil cu yd of fill was placed on the southern end of the island between 13th Street and the South Terminal Groin and 50,000 cu yd of fill was placed between that groin and the L-Head groin. Another 1.5 mil cu yd of fill was placed between the two terminal groins in 2000, with an additional 0.2 mil cu yd of fill placed between the South Terminal Groin and the L-Head Groin on the south end.

The USGS has recently completed a study of the long-term change in shoreline position along the southeastern US East Coast from North Carolina to Florida (Miller et al., 2005). Change rates of shoreline position, in units of m/yr, were calculated at 50-m transect spacing using linear regression applied to shoreline positions from their earliest (1863) to their most recent (1999/2000) data using the USGS developed Digital Shoreline analysis System (DSAS) program in Arc View. Linear regression was selected because it has been shown to be the most statistically robust quantitative method when a limited number of shorelines are available and it is the most commonly applied statistical technique for expressing shoreline movement and estimating rates of change. Uncertainties for the long-term rates represent a 90-percent confidence interval for the slope of the regression line, meaning with 90 percent statistical confidence that the true rate of shoreline change falls within the range of ±2.7 m/yr (±8.9 ft/yr) along the Georgia coast (Miller et al. 2005). A modified DSAS analysis was done on the available shorelines from 1863 that the USGS used in their study with the 1899 shoreline available for the Tybee Island area. Using their 50-m alongshore spaced transects the difference was calculated between the two pre-project shorelines. The change in shorelines is shown in Figure 7a. There was little change in shoreline position between the 1863 and 1899 shorelines for South Carolina so the analysis focused on Tybee Island. The beginnings of the retreat of the bulge on the north end of the island can be seen with erosion between -0.5 to -6.2 m/yr (-1.6 to -20.3 ft/yr) over this 36-year period on the northern 1300 m (4265 ft) of shoreline. The central 2500-m (8202-ft) long shoreline showed little shoreline change from -0.5 to 0.4 m/yr, (-1.6 to 1.3 ft/yr) averaging a slight -0.02-m/yr (-0.07-ft/yr) change. A spit located at the southern 100 m (328 ft) of Tybee Island in 1863 was eroded away by 1899 for a loss of between -0.9 and -3.3 m/yr (-3.0 and -10.8 ft/yr).

The post-project shoreline change was done using the 1899 shoreline representing an immediate post-project shoreline and comparing it with the latest 2007 shoreline calculated from the recent 2007 beach profiles and ground-truthed with a digitally rectified October 2005 aerial photograph. The north end of Tybee Island shows the erosion of the bulge and the movement of the spit to the north. The analysis starts where the USGS analysis did at the northward limit of the 1863 shoreline. Erosion ranging from -0.6 to -3.2 m/yr (-2.0 to -10.5 ft) (average -1.64 m/yr (5.4 ft)) was measured over the northern 1400 m (4600 ft) of shoreline starting at the north terminal groin (Figure 7b). The nodal point of little change extends for 250 m (820 ft) alongshore had change rates ranging from -0.5 to +0.5 m/yr (-1.6 to +1.6 ft/yr) with an average of -0.03 m/yr (0.1 ft/yr). The southern 2200 m (7200 ft) of shoreline showed a gain in sand and seaward movement of the shoreline over the 108-year period between +0.6 and 1.9 m/yr (2.0 to 6.2 ft/yr) with an average seaward movement of 1.81 m/yr (5.9 ft/yr). An additional 600 m (2000 ft) of shoreline gain was seen south of the south terminal groin as sediment was trapped by the new T-head and L-head groins.

### Bathymetric Pattern Evolution

The general trends in morphologic change in the nearshore can be illustrated with the change in the -5-m (-16.4-ft) and -10-m (-32.8-ft) depth contours. The change in contours for the pre-project conditions was analyzed from 1854 to 1897. The -5-m contour best represents the platform evolution of both Barrett Shoals to the north and Tybee Island Shelf to the south. Figure 8a shows the pre-project change in the two contours. The 43 years prior to jetty construction shows a southerly shift in the -5-m contour on the south end of Barrett Shoals consistent with the general trend of southerly sediment transport along the South Atlantic coast. The channels trending eastward from the main Calibogue Sound channel have also migrated south. The -5-m contour outlines the channel edges out of the Savannah River on the shelf platform in front of Tybee Island and the outline of the shoal platform. Little change can be seen in the position of contours along the channel, but the offshore edge has migrated slightly offshore. Of interest is the fact that the -10-m (-32.8 ft) contour has remained relatively stable over this same time period.

After construction of the jetties and the submerged breakwater and commencement of nearly annual dredging of the navigation channel a different trend is observed. Figure 8b shows the 100 years of post-project contour changes from 1897 to 2007. On the north side, the Barrett Shoals -5-m contour has migrated to the south. All of the contours by date are not completely shown due to limits of the surveys, but the arrows indicate the

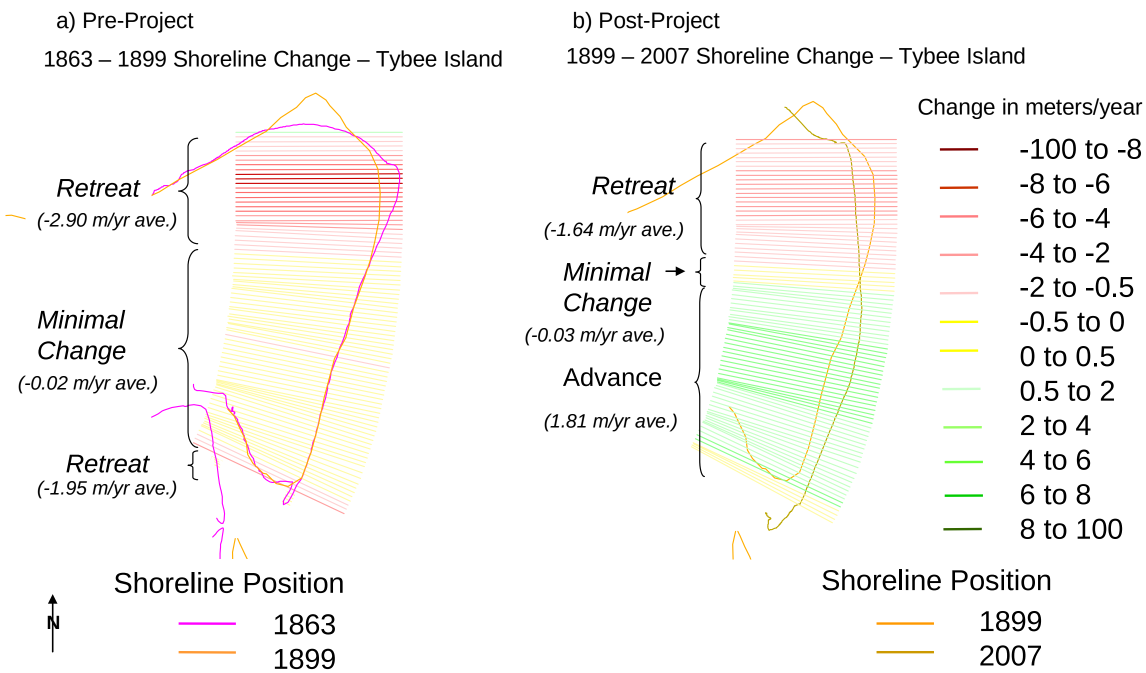


**Figure 7. Shoreline change rate pre- and post-project at Tybee Island.**

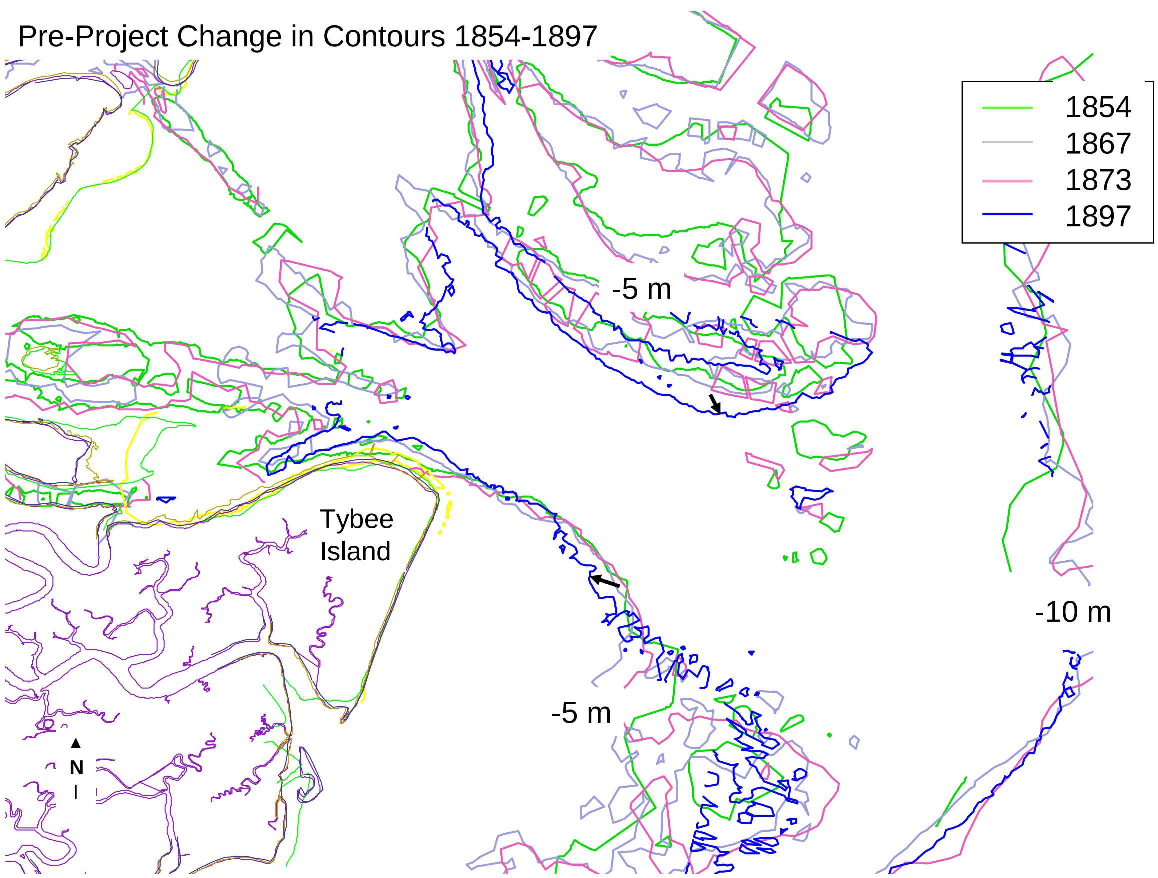


**Figure 8a. Pre-project -5 and -10 m contour change**

trend in migration. The -5-m contour on Tybee Island Shelf shows the onshore retreat as the platform has become depleted. Along with this landward migration, the northern edge of the shoal has formed a wedge shape indicating landward retreat toward the shoreline of northern Tybee Island. A recurved spit of sediment has grown from the wedge into the North Tybee Shoal area and is growing back to the southeast along the edge of the navigation channel. The spatial progression of this change in morphology has been consistent over time with retreat of the northern edge of the platform and evolution of the recurved spit back toward the platform. Circulation and sediment transport modeling are consistent with this morphological change (Smith et al., 2008). Again, the -10-m contour offshore has remained in a relatively constant position. The -10-m contour outlining the navigation channel has formed with the dredging of the channel to a depth past -10 m (-33 ft) after 1945.

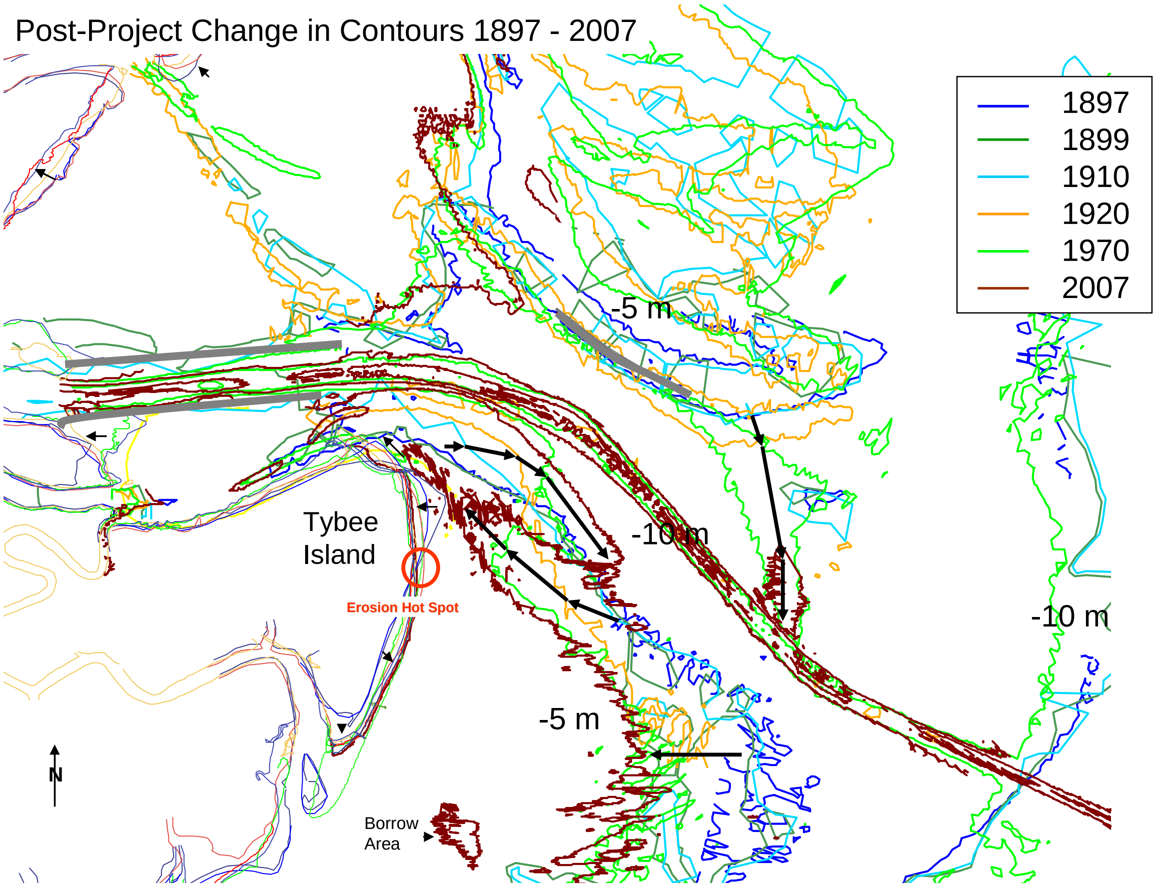


**Figure 8b. Post-project -5 and -10-m contour change (arrows show -5-m contour progression in time).**

### Channel Evolution

A summary of the changes to the channels from the river entrances show that the channel centerlines have migrated south over the study period (except New River, which has migrated north). Figure 9 shows the positions of the channel centerlines mapped from the pre-project (1854) bathymetry. The locations of the channels associated with Calibogue Sound have remained relatively stable and only their seaward ends have migrated to the south in the pre-project time period. The main Savannah River Entrance, South Channel and the New River Channel all converge on a single fifth channel on the south. There is high variability in channel position through time and there is some interaction between channels 4 and 5. Post-project (1899-2007), there are several changes that have evolved. The first channel off Calibogue Sound to the north has split into two channels (labeled 1a and 1b on Figure 9). All of the channels generally migrate to the south over time. Since the construction of the submerged breakwater, channels 3 and 4 have merged together and there is little interaction between channels 4 and 5. These channels migrate to the south consistent with net movement of sediment to the south along Barrett Shoals. By the 1970's the Savannah River entrance navigation channel had become fixed in its present location. The main navigation channel of the Savannah River entrance has moved north in the Tybee Knoll range as the jetties have controlled this part of the channel location. The South Channel has also migrated northward as sand that has accumulated in the North Tybee Shoal has migrated northward, consistent with northward movement of sand at north Tybee due to changing tidal flow patterns reshaping the nearshore in front of north Tybee Island.

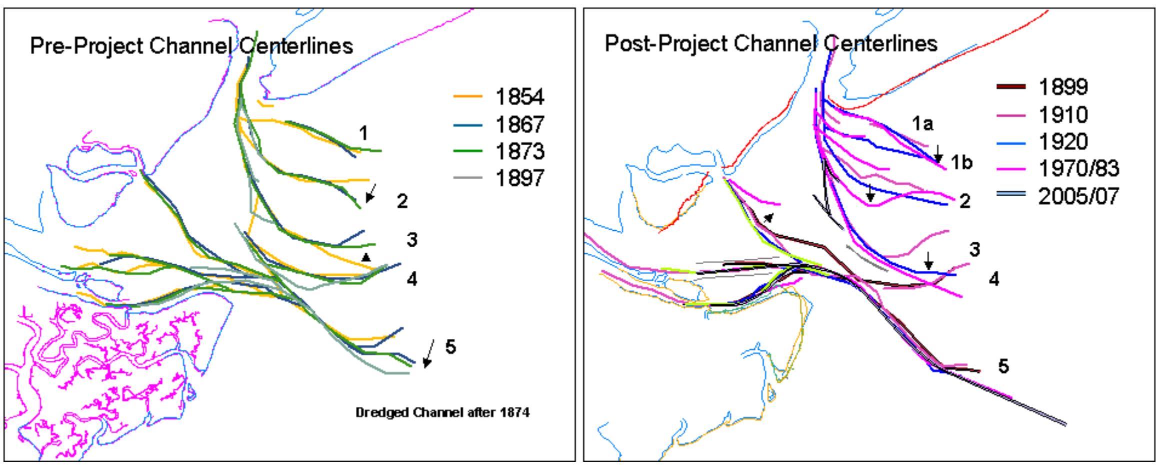


**Figure 9. Pre- and post- project channel centerline changes.**

### Sediment Budget Calculations

A sediment budget was calculated using the pre-project and post-project shoreline and bathymetry changes. Lack of a full survey just prior to the project in 1896 made it difficult to establish baseline pre-project conditions, and uncertainty in rates of some key pathways. While sediment volume changes within the budget cells were calculated using the data in the study, source and sink data at the boundaries of the budget were not available. A conceptual sediment budget was produced for both time periods with a general assumption of input and output to indicate the probable movement of sediment between the cells within the study area. These inputs and outputs were estimated based on volume changes and the numerical modeling of transport (Smith et al., 2008). The pre-project budget was constructed from 1854 to 1897, to include as long of time period as possible to improve the reliability of the difference calculations prior to impact of the project. The post-project budget was constructed for 1897 to 2007. The post-project budget shows significant changes from the pre-project budget. These changes occurred over a long period of time as the navigation channel was successively deepened. This budget includes the integrated effects of the project on the regional morphology over the past 110 years.

## CONCLUSIONS

This case study was an example of a challenging project due to the long time period covered and lack of directly compatible historical data. The impact of the project was evaluated as the difference in volume loss rates (post-project minus pre-project) for the Tybee Island Shelf cell of the sediment budget plus the estimated shoreline change rate (converted to a volume). The Tybee Shelf is part of a large ebb shoal complex associated with the Savannah River inlet. Ebb shoals form as a balance of sediment jetted out of an inlet by offshore (ebb) currents and returned to the inlet by onshore (flood) currents and waves. Ebb shoals are the pathway for sediment to travel around an inlet to the downdrift shoreline (Tybee Island). Disruption of the pathways and deflation of the ebb shoal lead to erosion of the downdrift shelf and shoreline because natural sand bypassing around the inlet is interrupted. Long-term morphodynamic change analysis was able to suggest the processes and responses to the coast due to project dredging and construction of navigation structures.

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## REFERENCES

Anders, F.J., Reed, D.W., and Meisbeurger, E.P., 1990. Shoreline Movements, Report 2, Tybee Island, Georgia to Cape Fear, North Carolina, 1851-1983. Technical Report CERC-83-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg,

Miller, T.L., Morton, R.A. and Sallenger, A.H., 2005. The National Assessment of Shoreline Change: A GIS Compilation of Vector Shorelines and Associated Shoreline Change Data for the U.S. Southeast Atlantic Coast, USGS Open File Report 2005-1326, United States Geological Survey, St. Petersburg, FL.

Smith J.M., Stauble, D.K., Williams B.P. and Wutkowski, M.J., 2008. Impact of Savannah Harbor deep draft navigation project on Tybee Island shelf and shoreline, ERDC/CHL TR-08-xx, US Army Engineer Research and Development Center, Vicksburg, MS.