SAND BORROW AREA DESIGN REFINEMENT TO REDUCE MORPHOLOGICAL IMPACTS: A CASE STUDY OF PANAMA CITY BEACH, FLORIDA, USA.

Luana Taiani[1]; Lindino Benedet[2]; Lucas Silveira[3]; Stephen Keehn[4]; Nicole Shap[5]; and Rafael Bonanata[6];

The coastline of Panama City Beach, Florida (FL) has been stricken by several hurricanes during the last decades, especially after 1995. In 1998, beach nourishment projects started being implemented to address the impacts of the hurricanes on the coast. Sources of sand for that purpose are commonly from borrow areas located just offshore of the nourishment site. Impacts of these nearshore dredge pits on adjacent coasts will depend on incident wave conditions, nourishment sediment characteristics and some features of the borrow pit (distance from the shore, depth of cut, cross-shore extent, alongshore extent and orientation - Bender & Dean, 2003; Benedet & List, 2008). The practical goal of the current study was to mitigate for the negative potential effects by discovering the less impactful design of dredge pit geometries on the Borrow Area S1 in Bay County-FL. Five different cut widths and excavation depths within the permitted limits were herein evaluated. Evaluation of morphological impacts on adjacent beaches was carried with the processed-based morphodynamic model Delft3D, calibrated and simulated for a period of 13 years. Results were evaluated in terms of beach volume changes compared against a baseline simulation (no action).Switching from Alternative 1 (6,260,000 m³) to Alternative 2 (5,380,000 m³) does not result in a substantial reduction of the borrow area's projected impact. The cut depth is still deep, and the surface area is unchanged. Alternative 3 (3,555,000 m³) is able to provide more substantial reductions in the borrow area's impact. By reducing the acreage of the borrow area and switching to a uniform cut depth, the projected impact of the borrow area decreases 39% for 1.56 km along the downdrift beach. Under Alternatives 4 (3,060,000 m³) and 5 (2,755,000 m³), the impacts of the borrow area are projected to be less than 3.75 m³/m/yr. While both alternatives are viable, Alternative 5 minimizes potential impacts, and has a uniform cut depth and a volume that still satisfies the project's requirements. Given these considerations, Alternative 5 is the preferred alternative. Additionally, all the alternatives increase the net-accretion along 6.5 km of Shell Island between 0.25 to 1 m³/lm/yr., a valuable side effect in a region with high net erosion. By conducting various simulations an optimal borrow area design has been identified that reduces its effects on the adjacent beaches.

Keywords: dredge pit; erosion hot-spot; Delft3D.

INTRODUCTION

Study area and beach nourishment history

Panama City Beach is located in Bay County, Florida –USA on the Gulf of Mexico Coast (Figure 1). Most of the west and panhandle coasts of Florida are marked by strongly seasonality of the wave climate. During most of the year predominant conditions are low to moderate energy. However, from beginning of June to the end of November is the official hurricane season. The loss of beach sand from berm and dune due to high waves and surge is a universal phenomenon associated with sporadic storm activities, and since in the study area the predominant wave climate is mild, after the storms during recovering times, the wave energy may not be sufficient to promote reconstruction of the beach before the next hurricane season starts. For this reason beach nourishment has become a common approach to address the impacts of the hurricanes on the shoreline of Florida.

On Bay County, the 1998 and the 2005 beach nourishment programs (in response to Hurricane Opal and Ivan, respectively) placed almost 10 million cubic meters of sand along approximately 29 km of shoreline. Now that the easiest to find and dredge sand was used up during the last programs, beach quality sand is a challenge to find because the sand has to be white in addition to the proper grain size, both of which are in short supply. Keehn et al, (2008) identified several potential borrow areas which may be used in the next nourishment program. Most of them lie on the nearshore, so care must be taken in evaluating the more adequate borrow area for that purpose.

Benedet & List (2008a) studied the effects of borrow areas dredged about 30 years ago near Delray Beach, Florida to provide sand for a nourishment project. It was proved that they had a significant influence on project performance and formation of erosion hot spots. The removal of large quantities of

[1]Shaw Brasil, 8.600, Rod. José Carlos Daux , St. Antonio de Lisboa, Florianopolis,SC,88050-001,Brazil
[2] Shaw Brasil, 8.600, Rod. José Carlos Daux, St. Antonio de Lisboa, Florianopolis,SC,88050-001,Brazil
[3] Shaw Brasil, 8.600 , Rod. José Carlos Daux , St. Antonio de Lisboa, Florianopolis,SC,88050-001,Brazil
[4] Coastal Planning & Engineering, Inc.,A Shaw Group Company, 2481 N.W. Boca Raton Blvd., Boca Raton, FL, 33431,USA
[5] Coastal Planning & Engineering, Inc.,A Shaw Group Company, 2481 N.W. Boca Raton Blvd., Boca Raton, FL, 33431,USA
[6] Shaw Brasil, 8.600, Rod. José Carlos Daux , St. Antonio de Lisboa, Florianopolis,SC,88050-001,Brazil

sand needed for such projects can introduce anomalies on the sea-bed bathymetry through the creation of borrow pits or by modifying existing shoals (Bender & Dean, 2003). The modified bathymetry in the borrow area can induce changes on the wave field and the influence of the modified wave field may in turn impact the shoreline. But a borrow area impact analysis involves more than just changes wave height because, impacts do not always occur in the most obvious places. They may be positive or negative, and may or may not be manageable.

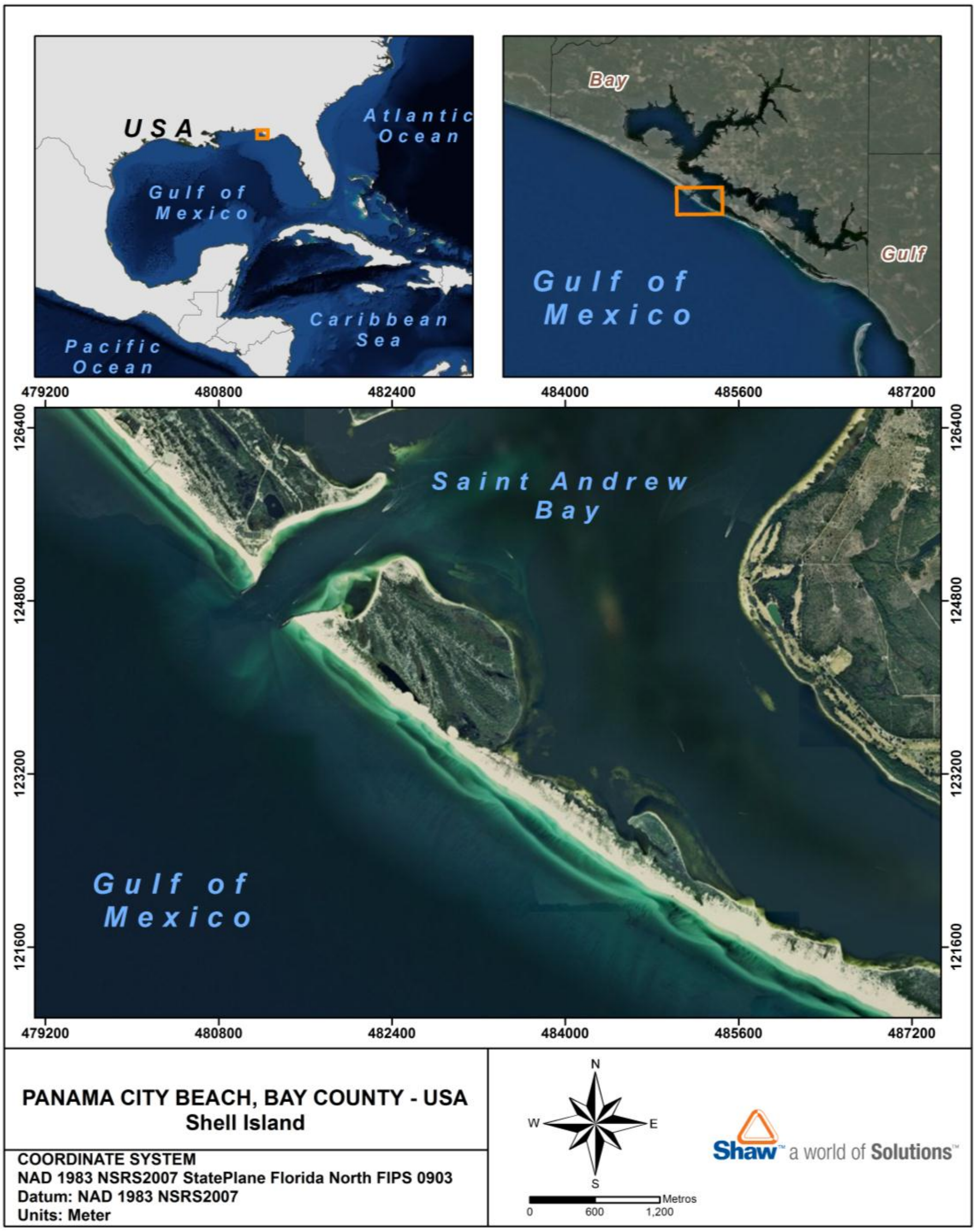

Figure 1. Location of the study area.

Benedet & List (2008b) stated that the magnitude of potential impacts from nearshore borrow areas on adjacent beaches depend on a range of parameters including seabed geomorphology, local wave climate, and borrow area design characteristics such as distance from the shore, depth of cut, cross-shore extent, and alongshore extent. The authors conducted a sensitivity analysis to investigate the impacts of borrow area design parameters on potential beach response.

Borrow area design, hence, can be optimized to reduce or eliminate impacts. Numerical models can play an important role in assisting the design process. Morphodynamic modeling tools such as Delft3D are playing an ever increasing role in the design, impact assessment and maintenance strategies for interventions in the coastal environment (Walstra *et al,* 2005). They can predict the effects of borrow areas on wave heights, flow velocities, sediment transport, and beach erosion and sedimentation. The primary focus of the work presented in this paper was to mitigate for the negative potential effects by discovering the less impactful design of dredge pit geometries on the Borrow Area S1 in Bay County-FL.

BORROW AREA DESCRIPTION

Shell Island Borrow Area S1 is located 1.6 km offshore of Shell Island, in Panama City Beach in approximately 10 m of water. This borrow area has 1.35 km², and is subdivided into five sectors. Each one of them can be dredged up to a depth limit, ranging from -15 to -16.5 m NAVD, yielding a total volume of approximately 6,260,000 m³ (see Figure 2). However, the minimum volume needed from Borrow Area S1 is in order of 2,750,000 m³. Hence, reductions in the size of the borrow area can be made to minimize impacts on the adjacent beaches. Different cut widths and excavation depths within the limits were herein evaluated.

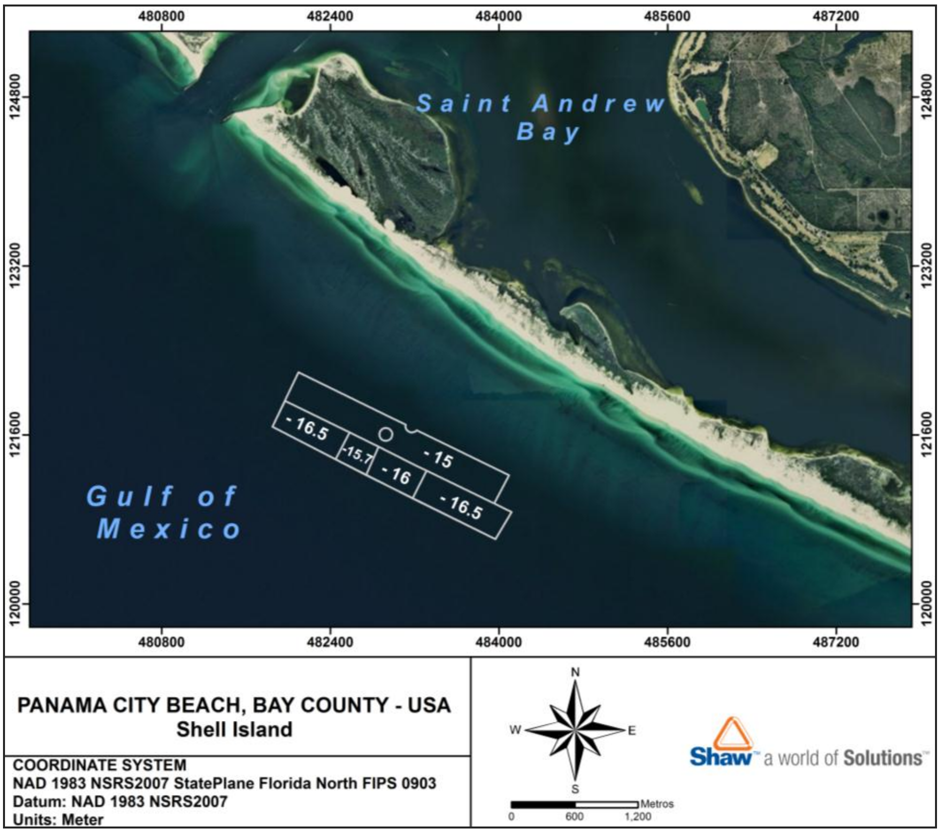

Figure 2. Location and characteristics of the Borrow Area S1.

METHODOLOGY

Numerical Modeling Setup and Calibration

The Delft3D modeling package was originally selected due to its ability to simulate a large number of physical processes in a comprehensive manner, such as wave refraction, wave damping due to bottom friction and whitecapping, wave diffraction, wind stress, tidal flows, longshore currents, the associated sediment transport, and the resulting erosion and deposition. During the SANDPIT program (Sand transport and morphology of offshore mining pits) the quality of hydrodynamic and morphological model predictions made by Delft3d were assessed. The results have shown that the model is able to give satisfactory predictions of the depth-averaged velocities inside and outside the pit.

Moreover, the 3D model provided very accurate predictions of the longshore and cross-shore vertical velocity profiles (Walstra, et al, 2003).

Wave transformation in Delft3D was estimated using the Simulating Waves Nearshore Model (SWAN 40.72AB, Delft University of Technology, 2008). Flow, sediment transport, erosion, and deposition within Delft3D were simulated using Delft3D-FLOW 3.60.01.7844. The two models were coupled together, exchanging information with each other every 1 to 4 hours.

Computational Grids and Settings

Four different computational grids were created and nested to evaluate the impact of dredging the nearshore borrow areas on waves, currents, sediment transport and beach morphology, using the Delft3D numerical model. Three grids were used to simulate the wave propagation process, both regionally and locally, along the study area (increasing the resolution towards the coast, see Figure 3 – upper panels).

A fourth grid was created to compute the circulation patterns in the coastal and estuarine region, and the morphological changes at Panama City Beach Figure 3 – lower panel). To accommodate the complex geomorphic setting of the study area, the curvilinear grid included St. Andrews Inlet and the remnants of East Pass, with a surface area of approximately 422 m^2 and an increasing grid resolution towards the borrow area site and surf-zone.

Sources of Input Data

For the modeling conducted in this assay, bathymetry data was obtained from a variety of sources:

1. The 2009 beach profile surveys from the Florida Department of Environmental Protection (FDEP) (http://www.dep.state.fl.us/beaches/data/his-shore.htm).
2. Light Detection and Ranging (LIDAR) surveys flown by the U.S. Army Corps of Engineers (USACE) and distributed by NOAA (http://www.csc.noaa.gov/digitalcoast/data/coastallidar/download.html):
3. Digital Elevation Models (DEMs) of Bay County and St. Andrews Bay, complied the U.S. Geological Survey (USGS) and NOAA. These were made available at http://data.labins.org/2003/MappingData/DEM/dem.cfm and http://estuarinebathymetry.noaa.gov/eastgulf.html. These data sets were generally compiled from older (i.e. pre-2000) sources; and
4. The U.S. Coastal Relief Model of Divins and Metzger (2007), also known as the NOAA "Design-a-Grid", http://www.ngdc.noaa.gov/ mgg/gdas/gd_designagrid.html. This data set was also compiled from older sources.

Within the various modeling grids, the data sets were used in chronological order, from the most recent to the oldest. Transformations between the original datums of the various datasets and the datum of the model were performed using Corpscon and the NOAA tidal datums available at http://tidesandcurrents.noaa.gov/.

Measured water level data was obtained from NOAA station PCBF1 8729210 located in the Panama City Pier. Deepwater wave information was obtained from NOAA's WAVEWATCH III (WWIII) forecasts (http://polar.ncep.noaa.gov/waves/index2.shtml). These forecasts were based on wave models that cover several study areas, including a worldwide domain. The selected hindcast node from which information was extracted was located at 28o59'50" N and 086o15'4" W (about 128 km offshore of Panama Beach in 300 meters of water). The wave data was extracted at this location due to the limitations of the WAVEWATCH model, which did not address conditions where the waves were strongly depth-limited (see Tolman, 1997, 1999), such as shallow or intermediate depth areas.

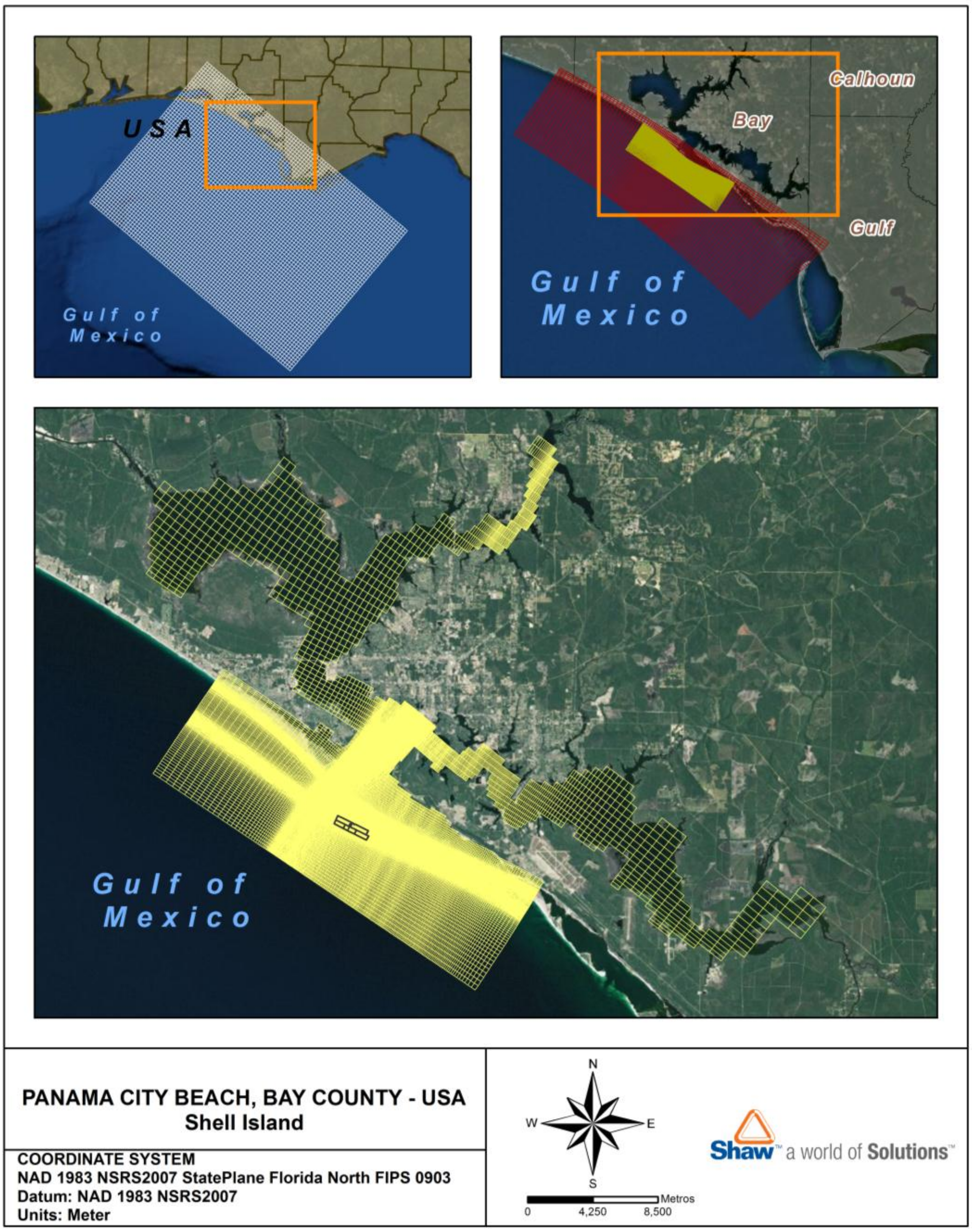

Figure 3. Numerical wave and hydrodynamic/morphologic meshes used on the study.

CALIBRATION

The calibration process utilized wave, water level, wind, and current measurements collected by Acoustic Doppler Current Profilers (ADCPs), an offshore wave buoy maintained by the National Oceanographic and Atmospheric Administration (NOAA), and the NOAA tide gage located on the Panama City Beach pier.

Wave Model Calibration

The SWAN model was calibrated in terms of bottom friction using deep-water, moderate depth, and nearshore wave measurements. The nearshore waves calibration is shown below:

The period where the highest waves were measured by the nearshore ADCPs was selected to calibrate nearshore wave transformation using SWAN. The model used wave information input measured in 23 meters of water (deep water ADCP) and was calibrated against ADCP measurements conducted landward of a nearshore borrow area, in 9.1 meters of water (Figure 4). The wave event used in the calibration extended from June 2 to June 4 of 2007, and corresponded to the waves associated with the passage of Tropical Storm Barry near Tampa.

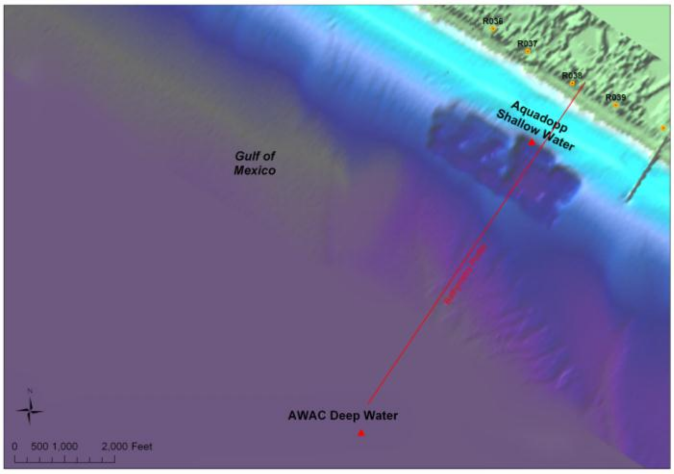

Figure 4. Bathymetry, offshore ADCP, nearshore ADCP

It was noticed that nearshore waves measured by the Aquadopp were slightly larger than offshore input waves. We hypothesize that this is due to shoaling and focusing since the Aquadopp is located on the corner of an existent borrow area cut (Figure 4). Wave direction was from the south-southwest. Peak wave periods, although not shown, ranged from 8s to 5s.

Comparisons between predicted and measured nearshore wave heights and direction are shown in Figure 5 and Figure 6. Predicted wave heights were well matched with the nearshore measurements when waves were higher than 1.0 m. During smaller wave occurrences the agreement between predicted and measured was less satisfactory. A similar effect was observed for wave direction. Predicted and observed wave directions matched well during the second half of the wave event, when wave heights were above 1.0 m. Comparisons did not match so well when wave heights were very small (first half of wave event). When waves are higher, the model was able to reproduce the increase in wave height occurring at the nearshore location (Figure 6, 6/4/07 6:00 am to 12:00 am). Because the model predictions were well matched with the nearshore measurements, especially for the most important higher waves, we conclude that SWAN is doing a decent job in transforming waves across the nearshore borrow area.

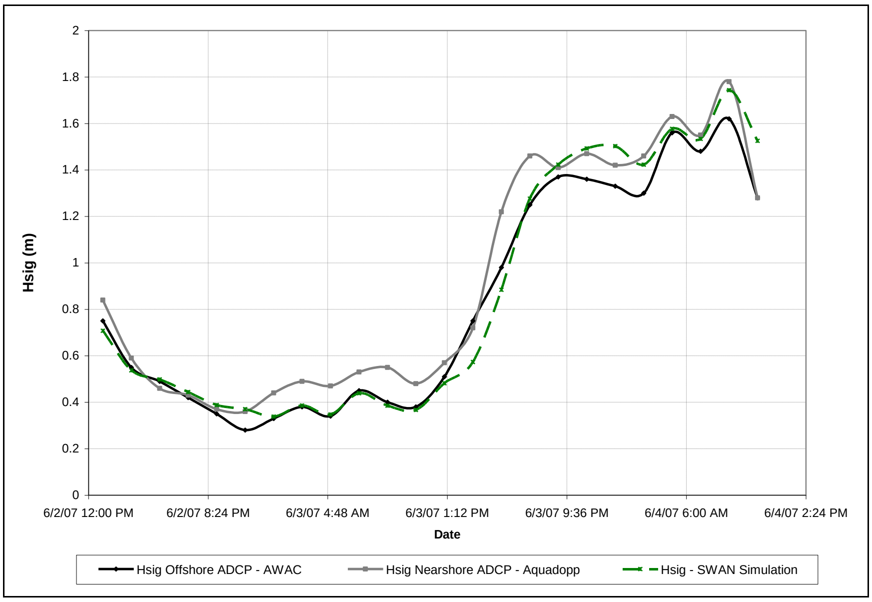

Figure 5. Comparison of predicted and measured nearshore wave heights

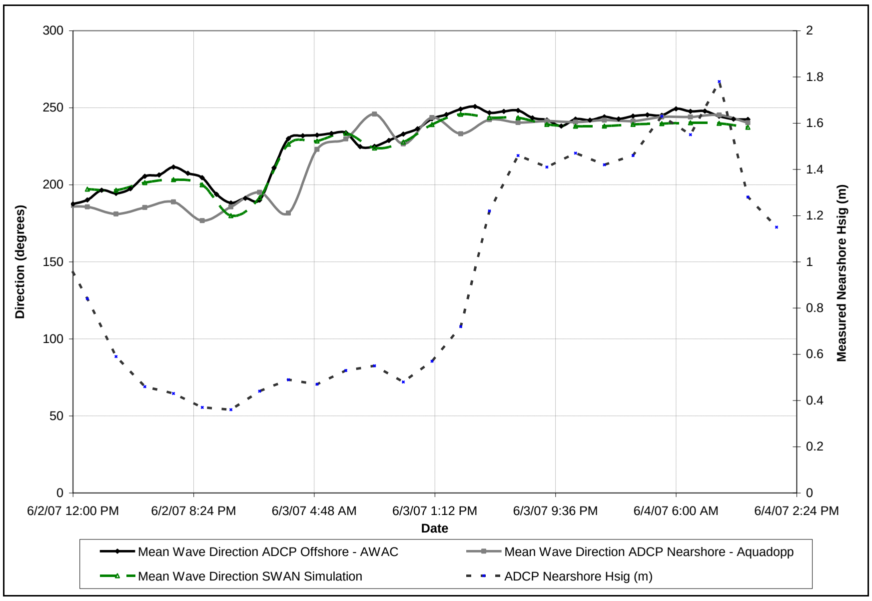

Figure 6. Comparison of predicted and measured nearshore wave direction

Flow Model Calibration

The flow parameters within Delft3D-Flow were calibrated using water level measurements at the Panama City Beach pier and current measurements in St. Andrews Inlet.

For calibration purposes Inlet tidal currents were simulated for most of the month of May and for a two-day period during high waves in April (April 26 to April 27 of 2007). The simulations for the month of May were forced by water level time-series at the ocean boundary, and winds distributed over the entire model domain (both parameters were measured at the city pier). The simulations for the two day period in April were forced by water levels, winds measured at the city pier, and waves measured at the deepwater ADCP.

The good agreement between measured and predicted currents (Figure 8) demonstrates the capabilities of Delft3D to simulate tidal flows in large barriers. With measured water levels on the open ocean boundary, and model domains built to cover all the back-barrier water bodies, the model is able to replicate well the magnitude and phase of observed tidal currents.

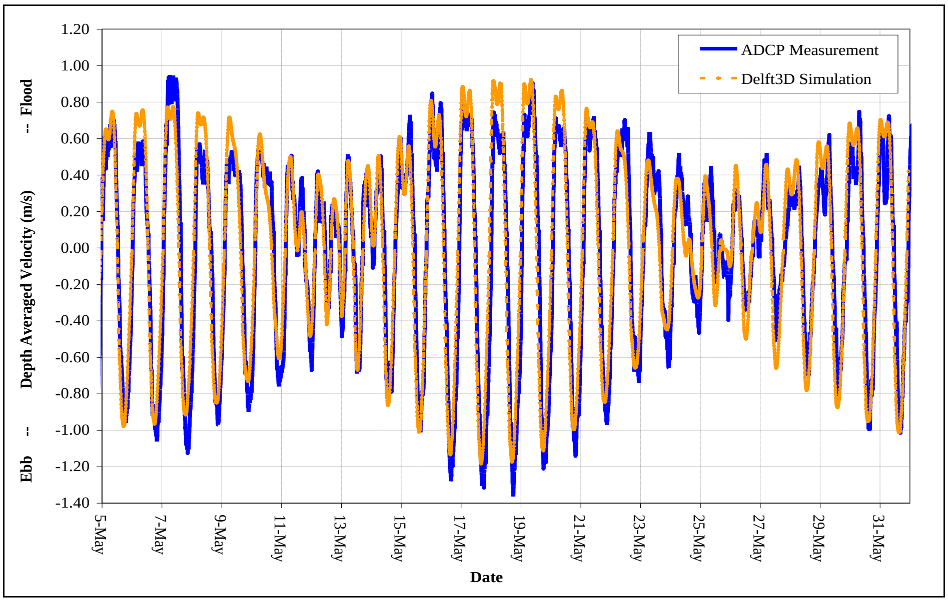

Figure 7. Predicted versus observed tidal currents, St. Andrews Inlet, May 5 to May 31.

BORROW AREA DESIGN REFINEMENT

The original Borrow Area S1 design limits of excavation appear in Figure 2. Dredging the entire area to the original depths shown would supply a total volume of approximately 6,260,000 m³. However, the minimum volume needed from Borrow Area S1 is in order of 2,675,000 m³. Given this consideration, reductions in the size of the borrow area can be made, if needed to reduce its impact on the adjacent beaches.

According to Benedet & List (2008b), the depth of cut and cross-shore width of a borrow area both have a great influence on the magnitudes of its impacts on the adjacent beaches. A borrow area that contains the same volume, but is longer in the longshore direction, narrower in the cross-shore direction, and shallower relative to the existing bathymetry will usually have a reduced impact. As the Borrow Area S1 was relatively close to the beach, different designs were tested to reduce its impact on the adjacent beaches. The alternatives that were examined were the following (see Figure 8):

0. The No Action Scenario
1. Original design
2. Original borrow area limits with a shallower and uniform depth of cut (-15 m NAVD) and less volume (5,380,000 m³)
3. A narrower borrow area with a cut depth of -15.7 m NAVD and a volume of 3,555,000 m³.
4. A narrower borrow area with fewer sharp corners in its cut boundaries, the original cut depths, and a volume on the order of 3,060,000 m³ (**Erro! Fonte de referência não encontrada.**).
5. Alternative 4, with a uniform cut depth of -15 m NAVD and a volume of 2,755,000 m³.

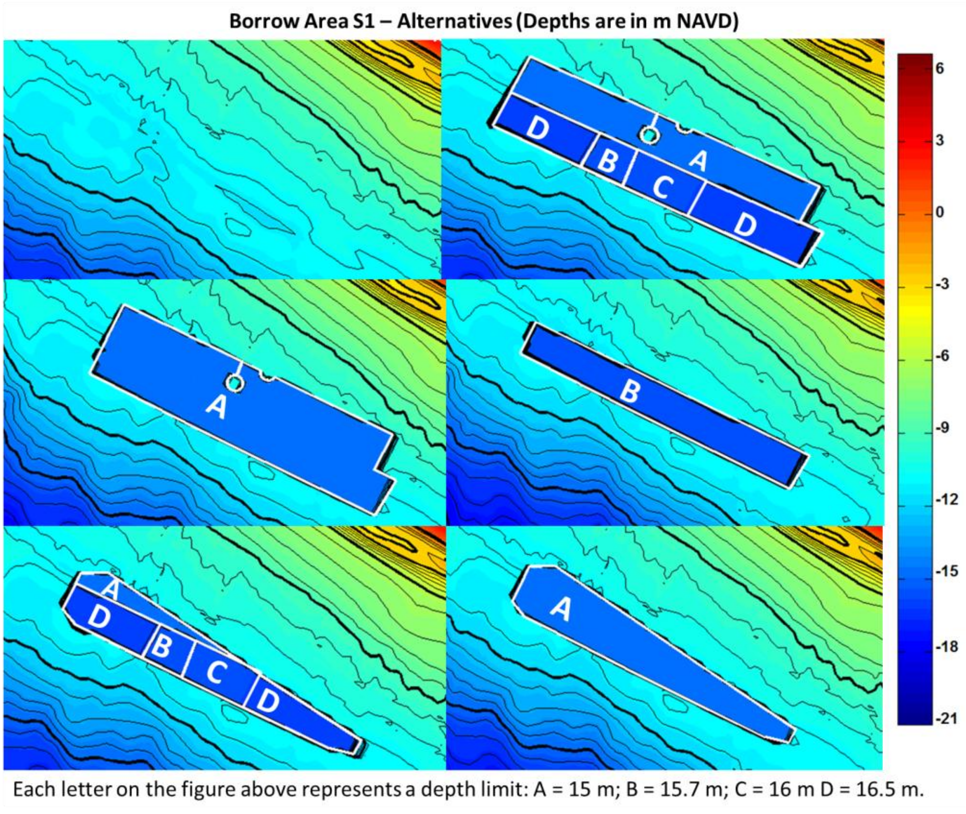

Figure 8: Borrow Area S1 Modeling Alternatives.

MORPHOLOGICAL MODEL SETUP

To evaluate the potential impacts associated with the excavation of Borrow Area S1, the Delft3D modeling package was applied to simulate 13 years of changes given a no-action scenario and various dredging alternatives. The 13 year simulation period was roughly equal to the period of time between Hurricane Opal (1995) and the most recent beach profile surveys compiled by FDEP (1996-2009). In the recent inlet management study for Destin, FL (CPE, 2010), Hurricane Opal was a significant event that marked the beginning of the present erosional patterns along that area.

Because long term (years) simulation with brute-force (i.e. time-series) input would result in high computationally and time demanding simualtions the *Morfac* approach was herein used as described in Lesser et al (2004) and Benedet and List (2008). Within this technique, the Delft3D model is typically run for a shorter period of time, and the corresponding changes in bed elevation are scaled using "morphological acceleration factors" (*morfacs*) that corresponds to the ratio between the shorter time period used in the model and the longer time period being analyzed. For this reason, a schematization of the input boundary conditions (waves and tides) is needed in order to simulate 13 years of morphological change (1996 to 2009).

For example, a wave case that occurs 14 days over the study period can be simulated over 24 hours with a *Morfac* (M) value of 14. With the Delft3D modeling community, it is common practice to use lower M values for high wave cases, when the most significant morphological changes occur, and higher M values for smaller wave cases, where little change takes place.

Schematized Tides

The purpose of creating schematized tide series is to simplify the complex pattern of the real tides and reduce computational demand. While each wave case could be simulated over a full, 14-day, spring-neap tidal cycle, this would inflate the model's run time to unacceptable levels (i.e. 1 month). Simulating each wave cases for a portion of the spring-neap tidal cycle introduces biases that negatively affect the model results, since the tidal component of the sediment transport would not be the same for each wave case. As an alternative, the tide can be approximated as a simple sine wave with characteristic period and amplitude. The simplified tide should be representative for the study area and reproduce the same residual sediment transport and morphologic change patterns as the full, 14-day tide (Lesser, 2009).

Based on water level measurements at the Panama City tide gage (Station 8729108) by NOAA, the tides are diurnal, with a period on the order of 25 hours. The amplitude of the simplified tide (0.63 feet) was based on the Mean High Water and Mean Low Water elevations at the gage, which were +0.74 feet NAVD and -0.51 feet NAVD, respectively

Annual Wave Climate

To simulate future scenarios and evaluate borrow area impacts on the study area, a schematic annual wave climate needed to be generated. The wave cases were selected from the 1996 to 2009 wave hindcast based on the mean wave energy flux. On the mean energy flux technique all the wave cases on the time-series are separated in direction and height bins in a manner that each bin has equal amount of mean wave energy flux (see Figure 9). A representative case for each of those is selected, and a morfac is stipulated based on their frequency of occurrence

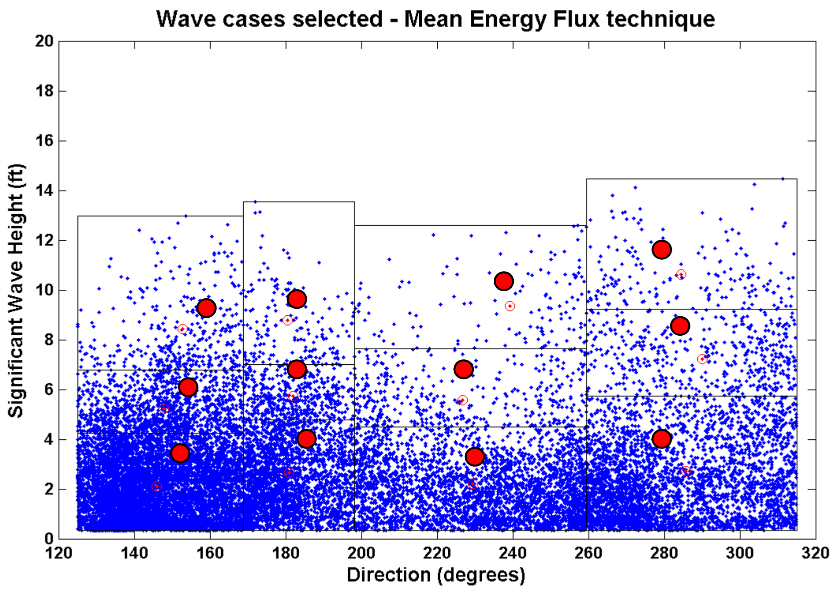

Figure 9. Wave cases selected using the mean energy flux technique. Wave cases on the record are in blue, and selected cases, in red.

The problem of generating a schematized annual wave for Panama City Beach lies on the fact that the wave climate is event driven, and years with unusual storm activity (hurricanes) can skew the wave record significantly. Even though hurricanes are very common for that region, they are inconsistent on the time series (Figure 10) and do not always have similar properties such as magnitude, period or direction (Figure 11). Simply annualizing the wave data record might result in a wave climate that would not be representative for the study area.

Therefore, all the major hurricanes were removed from the time series, and a regular annual wave climate was analyzed. It is worth to mention that the purpose of this first study was to evaluate the performance of five different borrow area designs in a comparative basis, where all alternatives were submitted to same energy condition. After a better performance alternative is selected, that one will be further evaluated. Impact assessment due to hurricanes will be performed on a next study.

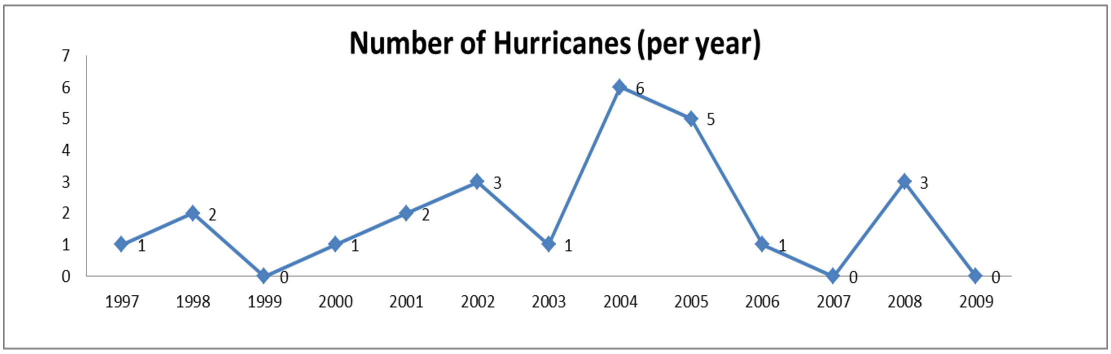

Figure 10: Number of hurricanes registered per year from 1997 to 2009.

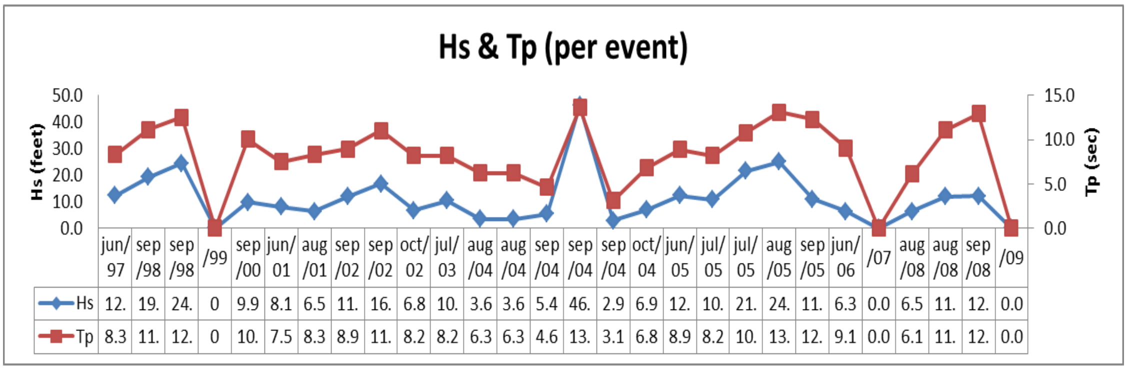

Figure 11: Distribution of hurricane properties (H – significant height and Tp – Peak period) over the registered events

RESULTS AND FINAL CONSIDERATIONS

The results are shown on Figure 12 and table 1. On the Figure 12, the middle panel show erosion and accretion volumes over the beach profiles (up to the depth of closure) for each of the alternatives while the lower panel show the difference between the alternatives and the baseline simulation (No action scenario). Table 1 show the net volumes shown on figure 12, in between the beach profile monuments shown on upper Figure 12.

The magnitude of the borrow area's impact can be compared to the natural alongshore variability. The Panama City Beach area has natural cuspate features that evolve over time. Based on the current bathymetry and topography at Shell Island, the nearshore varies between approximately +10 to -22.6 m^3/m-year as illustrated on upper Figure 12. This is the volume shoreward of the borrow area and depth of closure. These alternating bands of erosion and accretion will migrate under this influence. In addition, legacy bathymetric highs from earlier features, such as the mid-1800 location of East Pass in the R-15 to R-20 sector influence matters. This is the location of recent overwashes. FWS (U.S Fish and Wildlife Service) considers these types of processes essential to certain types of habitats. If impacts are kept below these natural and mobile variations, they will become part of the coastal processes and natural change will occur to adjust to the situation.

For Panama City Beach, the average and standard deviation of volumetric change between 1999 and 2010 was -6.8 m³/m-yr and 8.5 m³/m-yr respectively. The results from modeling are well within the magnitude of these parameters. The magnitude of the borrow area's impact can also be assessed in relationship to its ability to be measured using beach surveys. The Florida Department of Environmental Protection (FDEP, 2004) requires a vertical survey accuracy of ±0.15 m below the water line. The highest level of accuracy possible for a hydrographic survey is ±0.06 m. Over a beach profile that is 800 km long, the volumetric uncertainty is ±50 to ±123 m³/m given vertical uncertainties of ±0.06 to ±0.12 m. Over the 13 year modeling period, the equivalent rates would be ±3.9 to 9.5 m³/m-yr.

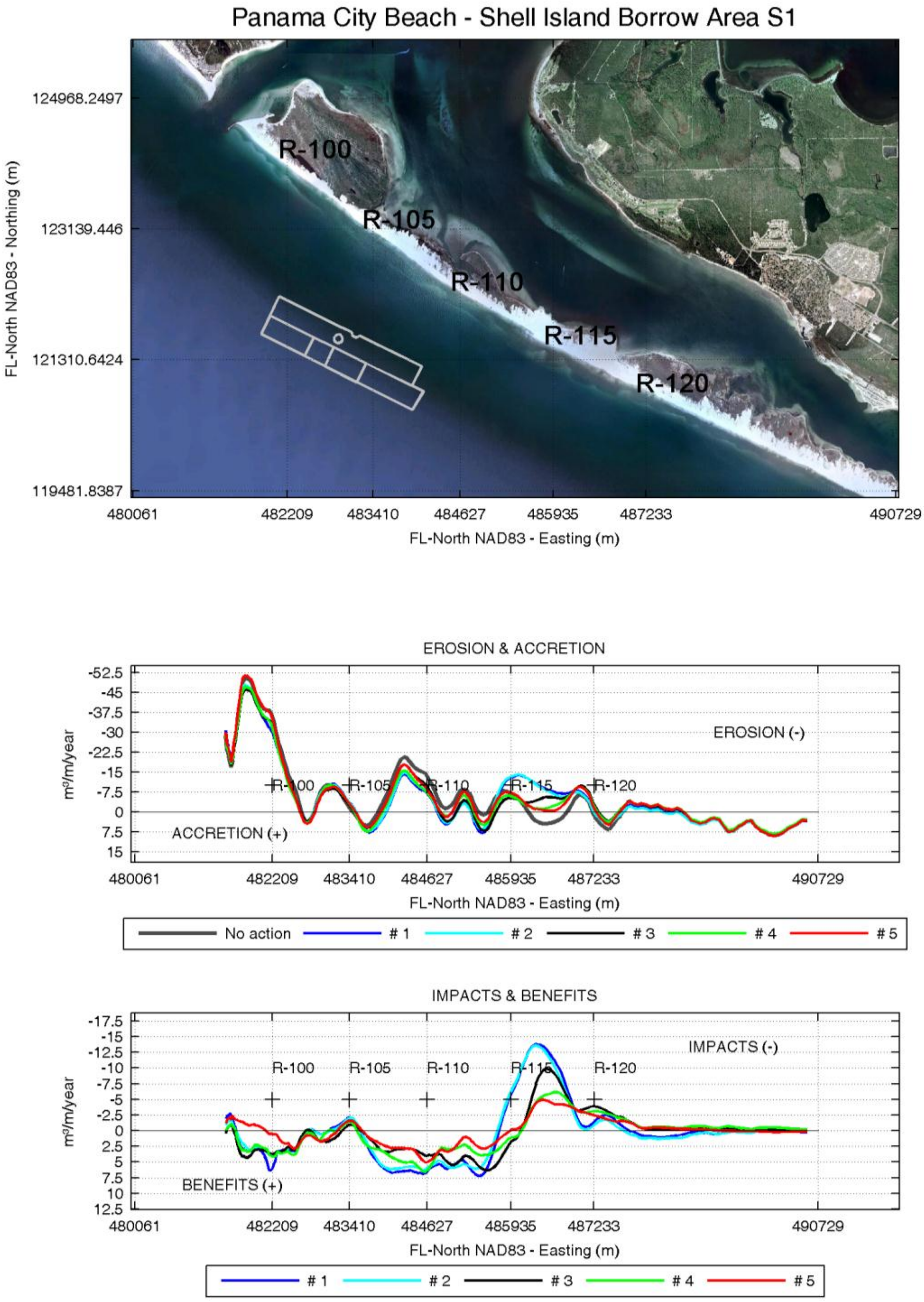

Figure 12: Predicted Volume Changes. On the middle panel, absolute changes, on the lower panel, differences between the modeled alternative and the no action scenario.

Table 1: Thirteen Year, Predicted Volume Changes by Reach.

Alter-native	Average Volume Changes (m³/m-year)				
	R-100 to R-105	R-105 to R-110	R-110 to R-115	R-115 to R-120	R-100 to R-120
No Action	-9.5	-7.8	-5.3	-1.0	-6.0
1	-8.5	-3.5	-1.3	-9.0	-5.5
2	-8.5	-3.8	-1.8	-8.5	-5.5
3	-8.0	-5.8	-0.5	-5.8	-5.0
4	-8.3	-4.5	-2.0	-4.5	-4.8
5	-8.5	-6.0	-3.0	-4.0	-5.3
Alter-native	Erosional Impact (-) or Benefit (+) (m³/m-year)				
	R-100 to R-105	R-105 to R-110	R-110 to R-115	R-115 to R-120	R-100 to R-120
1	1.0	**4.5**	4.0	**-8.0**	0.5
2	1.0	**4.0**	3.5	**-7.8**	0.3
3	1.5	2.0	**4.5**	**-5.0**	0.8
4	1.5	3.5	3.3	-3.5	1.0
5	1.0	2.0	2.3	-3.3	0.5

NOTE: Measureable impacts (> 3.9 m^3/m-yr) are indicated in **bold**.

As shown in Figure 12 and Table 1, the original borrow area design (Alternative 1) has the potential to generate a measurable impact between profiles R-115 and R-120. While the model predicts stability along this area given the No Action Scenario, Alternative 1 could make this area erosional or increase the rates of erosion that would occur in the future. It should be noted that under Alternative 1 features deep cut depths (~4.5 m) relative to the existing bathymetry over a broad area. Given these considerations, modifications to the original borrow area design are warranted.

Switching to a uniform cut depth under Alternative 2 does not result in a substantial reduction of the borrow area's projected impact. Since the cut depth is still deep, and the surface area is unchanged, Alternative 2 can only achieve minor reductions in the borrow area's potential impact.

Alternative 3 is able to provide more substantial reductions in the borrow area's impact. By reducing the acreage of the borrow area and switching to a uniform cut depth, the projected impact of the borrow area decreases 39% between profiles R-115 and R-120. In addition, the beach length subject to increased erosion rates is shorter (see Figure 22, bottom graph). Nevertheless, the potential impacts are still above the measureable range (3.9 m^3/m-yr).

Under Alternatives 4 and 5, the impacts of the borrow area are projected to be less than 3.9 m^3/m-yr. While both alternatives are viable, Alternative 5 has the smaller potential impact, a uniform cut depth, and a volume that still satisfies the project's requirements. Given these considerations, Alternative 5 is the preferred alternative. The revised design under Alternative 5 was renamed as "Borrow Area S1-A". Note that all the alternatives increase the net-accretion between R-100 and R-120 between 0.3 to 1 m^3/m-yr, a valuable side effect in a region with high net erosion of 800,000 m^3 since 1996. A detailed discussion of Borrow Area S1-A's impact will be performed in further details on a next study.

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