LCA TERREBONNE BASIN BARRIER SHORELINE RESTORATION STUDY

ANNEX L-3 SUPPLEMENTAL MODELING REPORTS

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This Annex to the Terrebonne Basin Barrier Shoreline Restoration's Engineering Investigations and Cost Estimates report (Appendix L) describes procedures and results of shoreline change analysis using the GENESIS model and storm-induced cross-shore sediment transport analysis using the SBEACH model.

GENESIS is a widely accepted longshore sediment transport model utilized for predicting long-term platform evolution of a beach in response to imposed wave conditions as well as simulating beach fill diffusion and response to coastal structures. The model's use is considered standard practice both in the United States and internationally as evidenced by the many documented applications in professional journals and conference proceedings. The assumptions utilized in the modeling program along with verification of use of the model are presented herein.

SBEACH is a widely accepted cross-shore sediment transport model utilized for predicting storm-induced beach and dune erosion. The model's use is considered standard practice both in the United States and internationally as evidenced by the many documented applications in professional journals and conference proceedings. The assumptions utilized in the modeling program along with verification of use of the model are presented herein.

1. GENESIS MODELING REPORT

1.1 EXECUTIVE SUMMARY

Raccoon Island and Whiskey Island, located in Terrebonne Parish, Louisiana, form the western extent of the Isles Dernieres barrier island arc. These islands experience severe shoreline erosion and retreat rates as a result of barrier island roll-over in response to relative sea level rise, overwash during severe storm activity, wave-induced erosion, inadequate sediment supply and anthropogenic influences. The performance of eight detached segmented breakwaters constructed in 1997 at the eastern end of Raccoon Island to mitigate erosion has generated interest in the potential usage of such coastal protection measures in the restoration efforts currently being considered for other barrier islands in the Terrebonne Basin.

Of immediate interest is an assessment of the impact specific shore protection measures placed off of Raccoon and Whiskey Islands may have on the islands' long-term erosion problems. This report details shoreline change modeling based on a coupled wave/shoreline change model undertaken to evaluate these specific management measures. The Steady State Spectral Wave (STWAVE) model was used to transform wave data from offshore locations to locations near the surf zone. The Generalized Model for Simulating Shoreline Change (GENESIS) uses this information to simulate shoreline change due to wave-driven longshore sediment transport. The model assumes that the cross shore profile is in equilibrium, so that morphological change can be represented by the change in shoreline position alone. The background shoreline change option in GENESIS was utilized to simulate the long-term net aggregate effects of all cross-shore processes which dominate the erosional processes experienced by the islands compared to the longshore processes.

It was shown that GENESIS reasonably reproduced the medium to long-term erosion trends observed on Raccoon and Whiskey Islands, and the response of the shoreline of Raccoon Island after the placement of the system of breakwaters. The potential shoreline responses to the placement of additional structural measures on Raccoon Island and Whiskey Island in the future were evaluated. These structural measures included: a terminal groin at the western end of Raccoon Island, and 19 detached segmented breakwaters placed off of Whiskey Island. Both measures reduced the rate of shoreline recession. The model results were utilized to assess the performance of the structures on the evolution of habitat acres over time.

The complexity of the erosional and depositional processes at play in this environment naturally dictates that numerical model results should be used with caution and in conjunction with other empirical evidence. Additionally, the design of any engineering project aimed at mitigating shoreline retreat on Whiskey Island and the other Terrebonne Basin barrier islands will greatly benefit from the formation of a detailed sediment budget. Lastly, due to the highly variable nature of the coastal processes within the Terrebonne Basin and the limitations of modeling barrier island restoration performance and response to structures with the GENESIS model as noted herein, it is recommended that combined wave and current modeling be conducted in the Planning, Engineering, and Design Phase (PED) on a system-wide level to support the National Ecosystem Restoration (NER) Plan.

1.2 INTRODUCTION

The Terrebonne Basin Barrier Island system is a 40 mile long barrier island chain made up of two island arcs: Isles Dernieres (Raccoon Island, Whiskey Island, Trinity/East Island and Wine Island) and the Timbalier Islands (Timbalier Island and East Timbalier Island) located in Terrebonne and Lafourche parishes. These islands have historically experienced extensive shoreline retreat as a result of landward barrier migration in response to relative sea level rise, episodic damage from tropical cyclones, sediment starvation and anthropogenic influences. As part of the Raccoon Island Breakwaters Demonstration project (TE-29; Armbruster, 1999), eight detached segmented breakwaters were constructed in 1997 at the eastern end of Raccoon Island to reduce shoreline erosion and promote accretion. These breakwaters are widely regarded as having fulfilled their intended function due to rapid salient development behind most of the breakwaters and a measurable decrease in the rate of shoreline retreat.

In 2005, a terminal groin was added to the eastern end of the island, and eight additional breakwaters were constructed immediately west of the original eight structures (TE-48). As a result of the performance of the 1997 breakwaters, there is interest in the potential for using detached segmented breakwaters to assist in the restoration efforts currently being considered for the six other Terrebonne Basin barrier islands. Of immediate interest is an assessment of the impact segmented breakwaters placed offshore of Whiskey Island may have on the Island's long-term erosion problems and an assessment of the impact a terminal groin placed at the western end of Raccoon Island may have on the continued shoreline recession experienced west of the system of breakwaters.

This report details shoreline change modeling based on a coupled STWAVE/GENESIS model undertaken to evaluate these specific management measures. The STWAVE model transforms wave data from offshore locations to the surf zone. An initial effort was made to evaluate the ability of GENESIS to reproduce the medium to long-term shoreline change trends observed on Raccoon and Whiskey Islands, as well as to reproduce the response of the shoreline of Raccoon Island to the placement of the initial set of offshore breakwaters. Upon successful calibration and validation of GENESIS for these Islands, the model was used to evaluate the potential shoreline response to: (1) the placement of 19 detached breakwaters in the nearshore region of Whiskey Island based on the design parameters of the Raccoon Island breakwaters, and, (2) the placement of a terminal groin at the western end of Raccoon Island.

1.3 GEOMORPHIC SETTING

Rosati and Stone (2009) provide an excellent review of the literature pertaining to the formation and geomorphic evolution of barrier islands along the shoreline of the northern Gulf of Mexico. A summary of that work is outlined below. The Terrebonne Basin Barrier Island chain represents the erosional remnants of the abandoned Teche and Lafourche deltas of the Mississippi River system. The formation of these barrier islands occurs in four stages: (1) flow is redirected to a more efficient distributary, resulting in the in-filling of the old delta with fine sediment, (2) the abandoned delta lobe undergoes erosion and feeds flanking barrier islands, (3) this sediment source is depleted by wave-induced erosion and subsidence due to sediment compaction, (4) the barrier islands retreat as they are reworked by inner shelf processes and their underlying substrate consolidates and subsides.

There are three primary causes for the barrier islands to have experienced rapid erosion and disintegration. The first cause is that the islands are not connected to any outside sediment source and hence are starved of sediments. The second cause is the compaction and subsidence of the underlying deltaic material, which results in a relative lowering of the island profile due to the relative sea level rise. A final cause for the rapid land loss in these islands is the impact of catastrophic storm activity which removes material from both the Gulf-side and bay-side of the island chain, causes landward migration and also exposes the underlying deltaic material to wave attack.

Cross-shore profiles on these shorelines exhibit a break in slope around the 2 to 3 meter isobaths. Above this point, the profile is of the approximate form $y = ax^{2/3}$, and the material is made up of sand with median grain size in the range 0.1-0.14 mm. Below this point, the profile is distinctly flat and composed mostly of silts and clays. The islands typically have low elevations and are washed-over during major storms; the morphologic responses to the two major storm systems – cold fronts and hurricanes – are distinctly different.

Campbell (2005) developed a conceptual morphodynamic model for the shoreline retreat observed west of the Plaquemine-modern delta of the Mississippi River based on the analysis of historical beach profiles. The underlying substrate of the island chain is made up of mixed deltaic sediment (sand, silt, and clay); this material is covered by a thin veneer of sand which is eroded during storms, exposing the underlying marsh sediment. In the aftermath of major storms, this exposed material is subsequently eroded by wave action. Fine sediment is suspended and lost from the littoral system. Coarser material is either transported offshore or alongshore, ending up in tidal inlets to be transported into the bays behind the islands. Inlet formation plays a major role in the landward migration of the islands, for example, inlets facilitate cross-shore movement of sediment through ebb/flood shoal formation.

1.4 DESCRIPTION OF NUMERICAL MODELS

1.4.1 Steady State Spectral Wave (STWAVE) Model

Wave information immediately outside of the surf zone is required as input for the longshore sediment transport and shoreline change estimates. Typically, wave information is only available at offshore locations and this information must be transformed to the edge of the surf zone for use by GENESIS. STWAVE was used in this study to perform this wave transformation.

STWAVE is a steady-state, phase-averaged spectral wave model for the simulation of wind-wave growth and propagation in arbitrary depths. The model simulates wind-wave growth, refraction and shoaling due to both bathymetric features and currents, depth- or steepness-limited wave breaking, wave diffraction, wave-wave interactions and white-capping by solving the spectral action balance equation along backward traced rays (Smith et al., 2001).

The spectral action balance equation is of the form (Smith et al., 2001):

$$\left(C_{ga}\right)_x \frac{\partial}{\partial x}\frac{C_a C_{ga}\cos\left(\mu-\alpha\right)E\left(f,\alpha\right)}{\omega_r}+\left(C_{ga}\right)_y \frac{\partial}{\partial y}\frac{C_a C_{ga}\cos\left(\mu-\alpha\right)E\left(f,\alpha\right)}{\omega_r}=\sum\left[\frac{S}{\omega_r}\right] \quad [1]$$

where C_{ga} is absolute wave group celerity; $[x,y]$ denote x and y components respectively; C_a is absolute wave celerity; μ is the current direction; α is the propagation direction of a spectral component; E is the spectral energy density; f is the frequency of spectral component; ω_r is the relative angular frequency; and S represents energy sources and sinks (i.e. momentum from winds, losses from whitecapping or breaking, etc.). Numerical solution of the spectral action balance equation is achieved using a finite difference scheme formulated on a Cartesian grid system.

In the surf zone, the maximum wave height is limited by water depth and wave steepness based on the Miche criterion (Smith et al., 2001):

$$(H_{mo})_{max} = 0.1L \tanh kd \qquad [2]$$

where H_{mo} is the zero-moment wave height, L is wavelength, k is wave number, and d is the total water depth. The STWAVE model assumes: mild slope and limited wave reflection; steady-state waves, currents, and winds; linear refraction and shoaling; depth-uniform current; negligible bottom-friction; and linear radiation stress. Model input required for the shoreline change application are bathymetry, model grid and offshore directional wave spectrum at the open ocean boundary (Smith et al., 2001). The transformed wave conditions are stored at nearshore locations for use by GENESIS.

1.4.2 Generalized Model for Simulating Shoreline Change (GENESIS)

GENESIS belongs to the class of shoreline change models known as one-line models. The underlining assumption is that the cross-shore beach profile does not change with time, so that the active profile only moves parallel to itself. Assuming that the cross-shore profile is in long-term equilibrium (i.e. cross-shore movement of sediment averages out over time), the rate of shoreline change ($\partial y/\partial t$) is simply a function of the variation in longshore sediment transport ($\partial Q/\partial x$). It follows from the principle of mass conservation (Hanson, 1989) that:

$$\frac{\partial y}{\partial t} + \frac{1}{D_B + D_C}\left(\frac{\partial Q}{\partial x} - q\right) = 0 \qquad [3]$$

where D_C is the depth of closure, D_B is the berm height, and q accounts for sediment sources and sinks.

In GENESIS, the longshore transport rate (Q) is parameterized on breaking wave conditions as follows (Hanson, 1989):

$$Q = \left\{H^2 C_g\left(a_1 \sin 2\theta - a_2 \cos\theta \frac{\partial H}{\partial x}\right)\right\}_b \qquad [4]$$

where H is the breaking wave height; C_g is the wave celerity; b denotes breaking wave conditions, θ is the dominant wave direction, and a_1 and a_2 are dimensionless coefficients given by:

$$a_1 = \frac{K_1}{16\left(\rho_s/\rho\right)(1-p)(1.416)^{5/2}}$$

$$a_2 = \frac{K_2}{8\left(\rho_s/\rho\right)(1-p)\tan\beta\,(1.416)^{7/2}}$$

where K_1 and K_2 are empirical constants, ρ_s is the density of sand, ρ is the density of water, p is the porosity of sand and $\tan\beta$ is the average slope of the active beach profile. In a coupled STWAVE/GENESIS application, GENESIS receives wave height and wave direction information at the edge of the surf zone. This wave information is transformed by internal wave transformation routines in GENESIS to the point of breaking using Snell's law. Since the model assumes an equilibrium profile, the basic inputs required for running GENESIS are an initial shoreline position, the average height of the beach berm, the depth of closure and the effective grain diameter which are used to define an equilibrium profile.

1.5 DATA

1.5.1 Historical Shorelines

The Barrier Island Comprehensive Monitoring (BICM, Martinez, 2004) project provides a comprehensive dataset of shoreline change data covering the period 1855 to 2005 based on the analysis of historical maps, aerial photography and satellite imagery. Quantification of shoreline change patterns and rates of change were conducted based on shore perpendicular transects spaced at 50 meter intervals using the high-water line as the official shoreline. The average historical (1855-2005) shoreline change rate for the Louisiana Coastal Zone was -2.7 m/yr. Over the past decade this rate has accelerated to -8.2 m/yr; the impacts of Hurricanes Katrina and Rita accelerated the rate of retreat to -57.8 m/yr between 2004 and 2005 (BICM Task Order 3). The BICM dataset is primarily based on four time periods: 1855-2005, 1920-2005, 1996-2005 and 2004-2005. Because of the inadequate temporal resolution of this dataset pre-1996, additional historical shoreline data for 1978, and 1989 was taken from Thompson et al. (2004).

1.5.2 Wave Climate

Wave data was sourced from the Wave Information Studies (WIS) conducted by the Coastal Hydraulics Laboratory (CHL) and Engineer Research and Development Center (ERDC), Vicksburg, Mississippi. WIS data provides directional wave climate information for shorelines of the Gulf of Mexico based on a 20 year hindcast using the 2nd generation wave model WISWAVE. The current hindcast covers the period 1980 to 1999, and provides hourly hindcasts of the significant wave height, peak spectral period and the dominant wave direction. No collocated wave buoys were found in the vicinity of the Study area for estimation of the model skill of the WISWAVE hindcasts. Several WIS stations were located in the vicinity of the Isles Dernieres. Figure 1-1 shows wave rose diagrams of the directional distribution of wave heights at six WIS stations offshore of the Raccoon and Whiskey Islands. Figure 1-2 shows the locations of the WIS stations.

A visual inspection of the wave roses shows very little difference in wave climate, especially with respect to the angles of incidence of the large wave energy bands. Sensitivity tests using each of these data confirmed that using different WIS stations from the area resulted in similar estimates of longshore transport rates. WIS Station 125 was chosen to provide offshore wave data for this work because it sits in a location which is closest to the center of the study area.

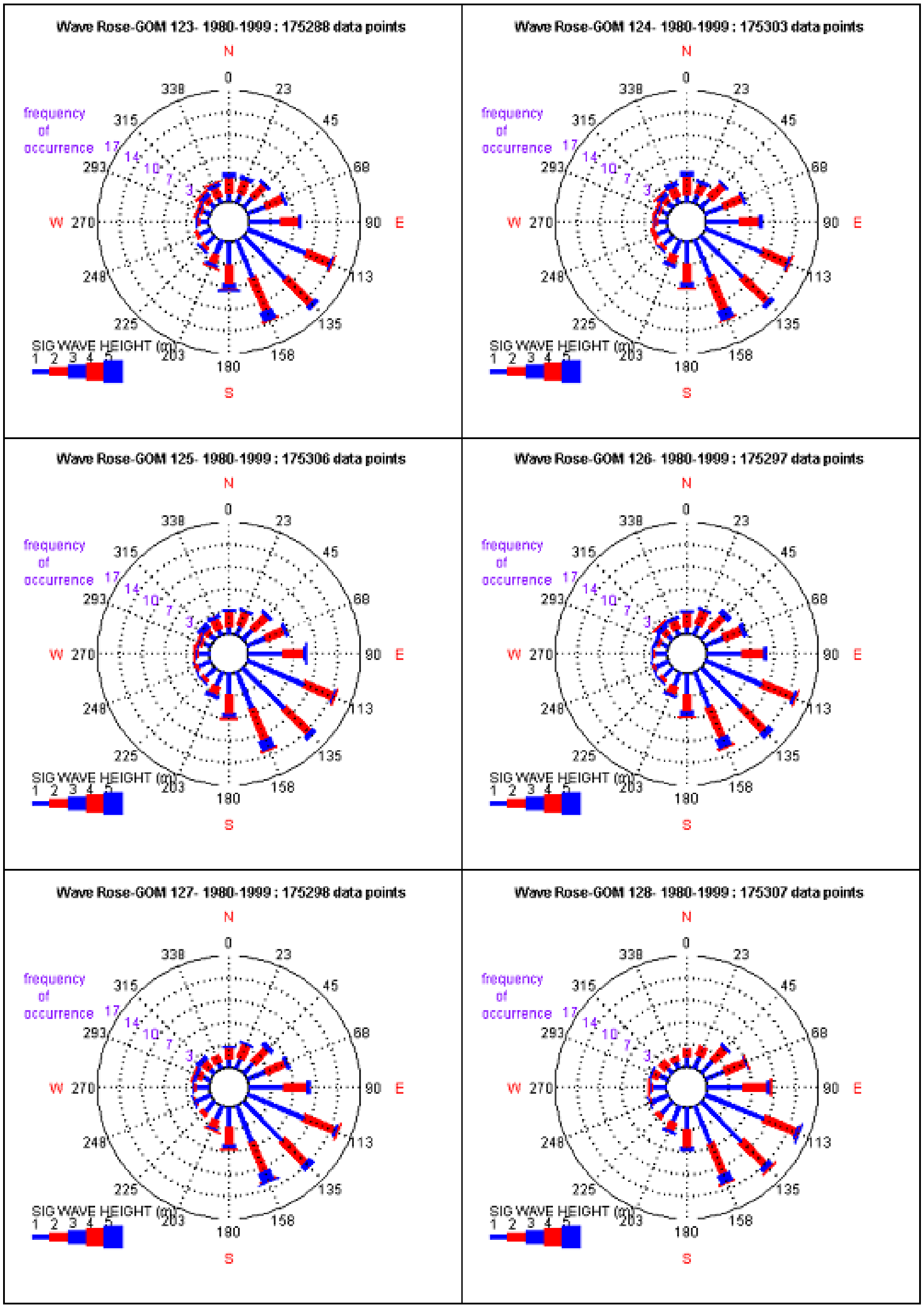

Figure 1-1. Wave rose diagrams showing the directional distribution of significant wave heights at WIS hindcast stations immediately offshore of Isles Dernieres. The distributions of wave heights in the various directional bins are similar. Each of the six WIS datasets predicts similar longshore sediment transport rates (source: http://frf.usace.army.mil/cgi-bin/wis/atl/atl_main.html).

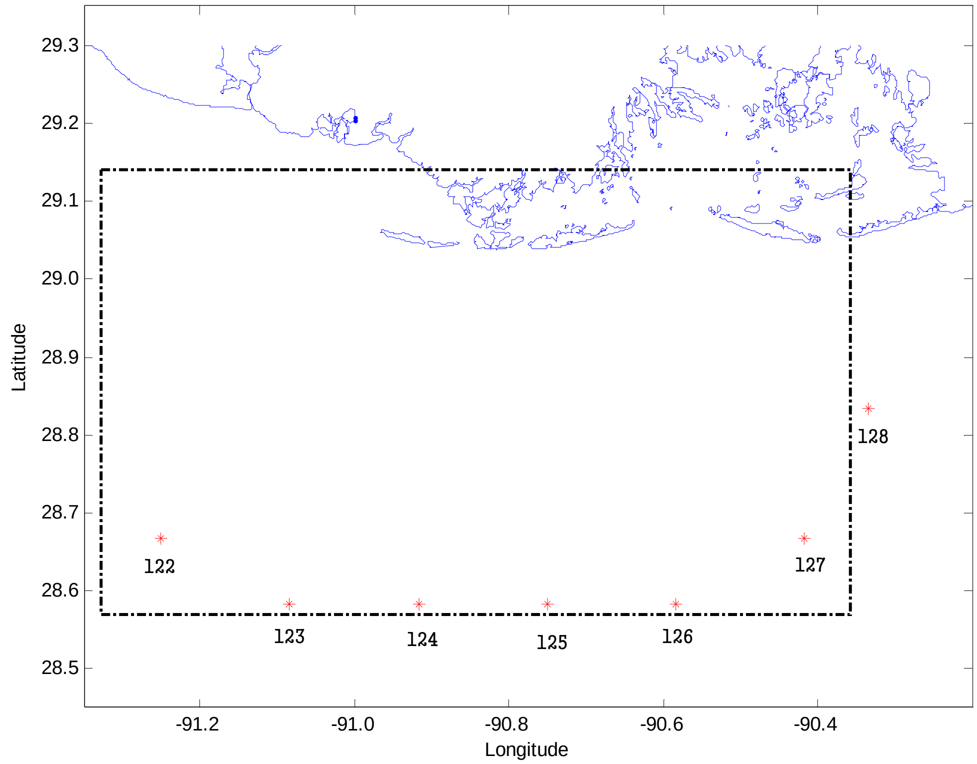

Figure 1-2. STWAVE model domain (dashed lines) showing the location of WIS stations. Station 125 was used to provide offshore wave boundary conditions for STWAVE model runs.

1.5.3 Bathymetry

Bathymetric information for the areas surrounding Raccoon and Whiskey Islands was taken from the 2006 BICM survey data. These data provide dense nearshore profiles in addition to survey information which extends 4 to 5 miles offshore of the islands in some instances. Despite this coverage, bathymetric data even further offshore was needed for use in the wave transformation calculations between WIS Station 125 and the nearshore area.

Bathymetric data further offshore was sourced from depth soundings available in electronic format from the Geophysical Data System (GEODAS). The GEODAS database is maintained by the National Geophysical Data Center (NGDC) of the National Ocean Survey (NOS). The data available offshore of the study area comes from two data sets, both of which are dated from the late 1930’s. Despite the age of the data, in the absence of another source these represent the only option available. A majority of this data falls in depth of 40 feet or more which is well outside of the typical sediment transport zone. As a result the primary difference in elevation between the data from the 1930’s and 2006 is expected to be due primarily to changes in relative sea level described in Section L2.7 of Appendix L. Based on the sea level change rates, the GEODAS bathymetry was lowered by 2.2 feet. Merging this adjusted offshore bathymetry with the BICM nearshore data resulted in a single seamless 2006 bathymetry set which was used for all simulations discussed below.

1.5.4 Beach and Sediment Transport Characteristics

Stone and Zhang (2001) made empirical estimates of longshore transport rates based on nearshore wave information obtained through numerical wave modeling. A detailed sediment budget study for Raccoon Island was conducted by Thompson et al. (2004) using an analytical morphologic model. In this study, volumetric changes at closely spaced transects on the island were estimated using the observed cross-shore changes in beach profile and estimates of shoreline retreat due to relative sea level rise, and the active profile height. Based on conservation of sand principles, the net longshore transport was estimated by summing volumetric changes in the direction of the net littoral drift, starting at a nodal point. Georgiou et al. (2005) also developed longshore sediment transport estimates in coastal Louisiana.

Although the other two referenced studies (Stone and Zhang, 2001 Georgiou et al., 2005) provided qualitative estimates of longshore transport, estimates of the depth of closure, berm height, and the effective grain size for this modeling report were taken from Thompson et al. (2004). These values were 1.8 m, 1.2 m and 0.14 mm respectively.

1.6 MODEL SETUP

1.6.1 STWAVE Model Setup

The coupled STWAVE/GENESIS model was setup in NEMOS (Nearshore Evolution Modeling System). NEMOS provides a GIS-based user interface which allows for the efficient generation of both STWAVE and GENESIS model grids and the preparation of model input files. The merged BICM-GEODAS bathymetric dataset was imported and triangulated in NEMOS, after which a uniform computational grid was generated. The open ocean boundary of the STWAVE grid was located in proximity to the WIS stations, eliminating the need for 1D wave transformations from WIS station locations to the wave model's open ocean boundaries.

Figures 1-2 and 1-3 show the extent of the STWAVE model grid and the model bathymetry, respectively. No direct wave measurements coincident with the period of record of the WIS data could be located in the model domain for model calibration and validation. Instead, a sensitivity analysis for grid convergence was performed to ensure that the numerical solution was independent of the grid resolution.

A sensitivity analysis was conducted using grid resolutions of 400x400 m, 200x200 m, 100x100 m, and 50x50 m. The 200x200 m grid provided the optimum balance between numerical convergence and computational cost. The final STWAVE grid has 71,176 cells (328 cells in the shore normal direction and 217 cells in the shore perpendicular direction). Because it is impractical to run STWAVE at each shoreline simulation time step, the typical STWAVE/GENESIS application utilizes a time saving procedure in which offshore wave conditions are binned into wave height, wave period and wave direction bands. Combinations of these wave conditions are transformed to nearshore locations at which refraction coefficients are determined for each height-period-direction combination. For every time step in the shoreline simulation, GENESIS applies a unique refraction coefficient for each offshore wave event, which is determined as the ratio of the offshore wave height to the transformed wave height. The WIS data used in this study was binned into wave height, wave period, direction bands with widths of 2 meters, 3 seconds, 15 degrees, respectively, resulting in a total number of 300 combinations. Figures 1-4 and 1-5 show the frequency distributions of the significant wave heights, and peak wave periods, respectively.

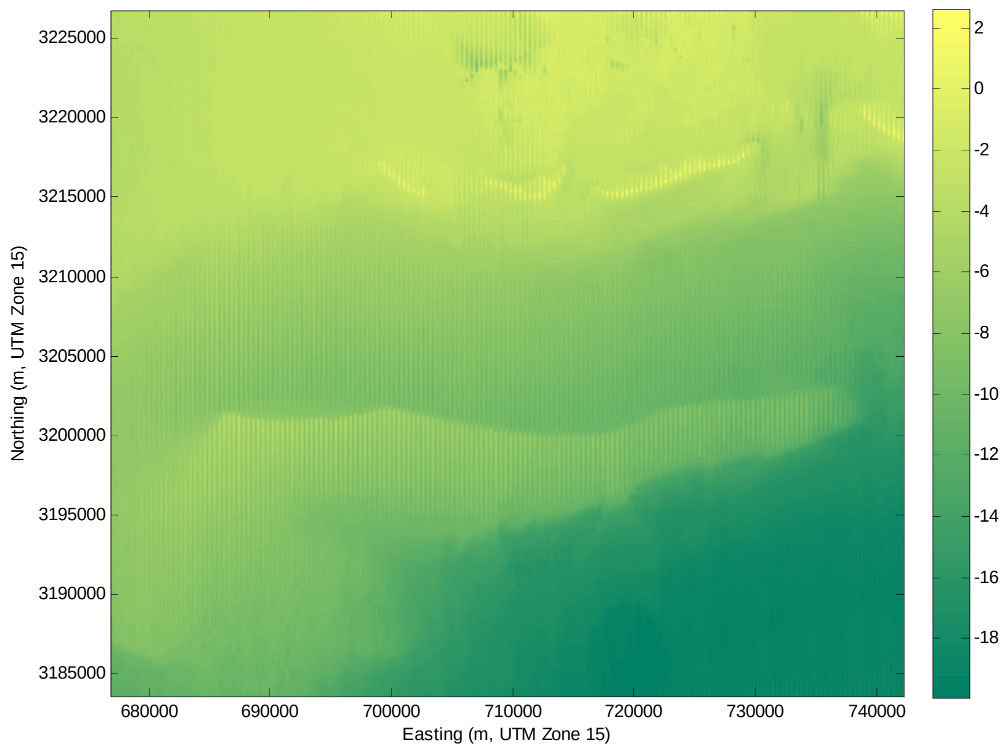

Figure 1-3. STWAVE model bathymetry (meters) obtained by triangulation of the merged BICM-GEODAS datasets onto a uniform grid.

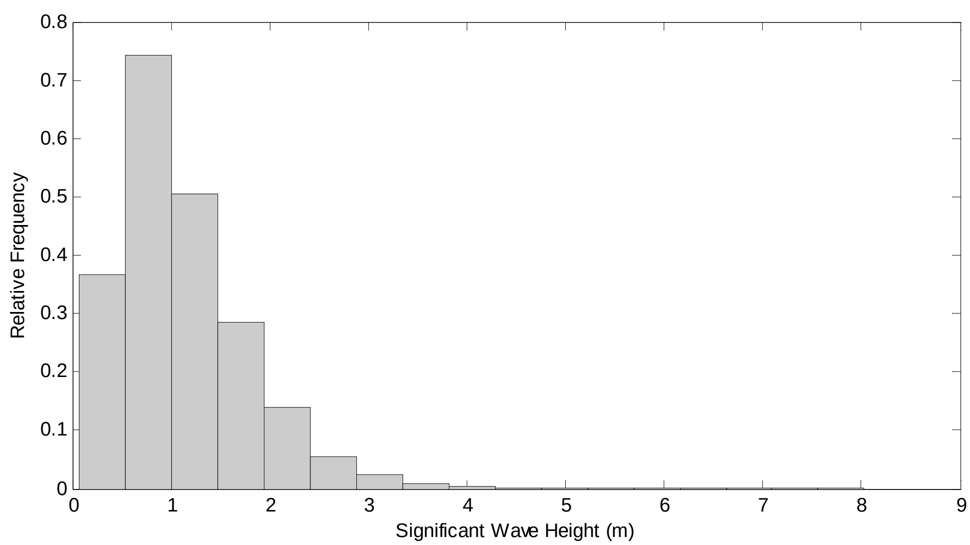

Figure 1-4. Relative frequency of significant wave heights offshore of Raccoon Island and Whiskey Island based on the 20-yr WIS hindcast at station 125. The wave height has a mean value of 0.81 m, with a standard deviation of 0.41 m. The 50-yr (2% annual exceedance probability) wave height is 8.1 m based on a Weibull distribution fit.

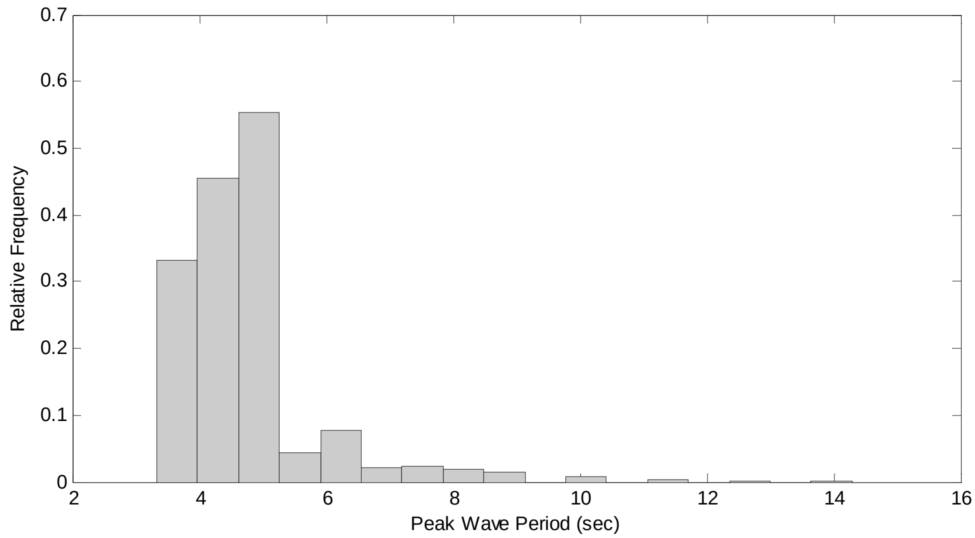

Figure 1-5. Relative frequency of peak wave periods offshore of Raccoon Island and Whiskey Island based on the 20-yr WIS hindcast at station 125.

1.6.2 GENESIS Model setup

The one-dimensional grid required by GENESIS was setup in NEMOS. The GENESIS grid consists of a one-dimensional array of cells along the shoreline; the shoreline is represented as distances from a straight baseline. At each cell and for each simulation time step, the model requires breaking wave height and wave angle information to compute a spatially and temporally varying longshore transport rate. In NEMOS, STWAVE output stations corresponding to GENESIS grid cells can be automatically generated based on some user specified water depth. These stations were typically located on the 2 meter isobath. The average berm height was specified as 1.2 m and the depth of closure was specified as 1.8 m. These values are based on beach profile survey data contained in Thompson et al. (2004).

There is general consensus in the literature (Rosati and Stone, 2009) that the depth of active sand transport on the Louisiana barrier islands to the west of the modern delta lies in the ~2 to 3 m range. Beyond this point lies a passive depositional zone which is typically very flat and composed of silts and clays separated from material eroded from the islands when they had been stripped of sand cover in the aftermath of major storm activity. This range of values is smaller than the ~5 m depth of closure predicted by empirical equations (e.g. Birkemeier, 1985) given the wave climate at the study site. The 1.8 m value was used in this study because it is the actual measured depth of closure at the site. Additionally, the net longshore flux computed by Thompson et al. (2004), against which the current shoreline model has been calibrated, is based on this value. The effective grain diameter was specified as 0.14 mm based on sieve analysis of grab samples taken on Raccoon Island.

1.7 MODEL CALIBRATION AND VALIDATION

In order to quantify the potential shoreline response to the structural measures proposed for Raccoon Island and Whiskey Island, a three-stage calibration and validation process was undertaken. The approach is outlined below as follows:

- a coupled STWAVE/GENESIS model was setup and calibrated for Raccoon Island for a period preceding the initial construction of breakwaters (1978-1989);
- a coupled STWAVE/GENESIS model was setup for Raccoon Island for a period post-construction of the first eight demonstration breakwaters (1996-2004). The sediment transport parameters were carried over from the initial calibration period without adjustment;
- finally, a coupled STWAVE/GENESIS model was setup for Whiskey Island using the model setup and sediment transport parameters carried over from the Raccoon Island simulations.

In the initial calibration runs (1978-1989), the sediment transport parameters (K_1 and K_2) were adjusted till the model reproduced: the net longshore transport rate ($\sim 40{,}000\ m^3/yr$); the average shoreline retreat rate due to longshore sediment loss ($\sim 4\ m/yr$) – based on the littoral budget computed by Thompson et al. (2004); and, the correct direction of net littoral drift (westward). Since GENESIS only explicitly simulates shoreline change due to longshore transport, which according to the sediment budget accounts for about 34% of the shoreline change observed on Raccoon, the background shoreline change option in GENESIS was utilized to simulate the remainder of the shoreline change (66%) not explicitly accounted for in the model. The background change rate represents the long-term net aggregate effects of all cross-shore processes. The background change option moves the shoreline backwards (or forwards if desired) at a user specified rate (meters/day). The WIS data used for this simulation covered the period 1980 to 1990.

For the model validation period for Raccoon Island (1996-2004), the simulation runs were made using the initial shoreline (1996) and the initial set of TE-29 breakwaters. The sediment transport parameters and basic GENESIS model setup was carried over from the calibration runs. Since the shoreline at the eastern end of Raccoon is curved, the easternmost two breakwaters could not be represented in the model. Additionally, the curved portion of the island acts as a headland, producing diffracted waves; this conflicts with GENESIS' structure placement rules, which do not allow for the placement of overlapping diffracting structures. For this reason the next two breakwaters could also not be represented in the model. A workaround this problem would have been be to artificially foldout the eastern portion of the island, this option was ruled out because a straightened shoreline would misrepresent incident wave angles – and hence sediment transport rates would not be accurately predicted.

The coordinates of the start and end points of the breakwaters were digitized from rectified aerials and directly imported into GENESIS. The remaining breakwaters on Raccoon Island were placed 91.44 m from the shoreline, they were 91.44 m long, and had

91.44 m wide gaps in between breakwaters. As reported by several authors (e.g. Stone and Liu, 2006; Armbruster, 1999), the accretion observed leeward of the demonstration set of breakwaters was largely due to the impoundment of cross-shore sediment drift from nearby shoals (see Figures 1-6 and 1-7). Since GENESIS does not explicitly allow for the specification of sediment sources or sinks, this effect was simulated by introducing sediment into the model via the beach fill option as recommended by Hanson and Kraus (1989). The volume of sand impounded behind the breakwaters was computed as the product of the active profile height and the berm width added per day over the simulation period. In the absence of this impoundment of sand, the model shows very little accretion landward of the breakwaters.

Figure 1-8 shows plots for simulated versus observed shoreline positions for the end position of the initial calibration period. Figure 1-9 shows plots for simulated versus observed shoreline positions for the end shoreline position for the first validation period. Finally, the validation procedure was repeated for Whiskey Island for the period 1996-2004. Figure 1-10 shows plots for simulated versus observed shoreline positions for the end shoreline position for the second validation period. In Figure 1-11, the validation runs were repeated with the regional offshore contour option in GENESIS. This option assumes that the depth contours in the surf zone are similar to the initial shoreline orientation. This option however resulted in sediment transport rate predictions that were unreasonably low. Table 1-1 shows a compilation of model setup parameters for all three calibration/validation periods. A quantitative assessment of model skill based on cell by cell comparisons between simulated and observed shorelines is provided in Table 1-2.

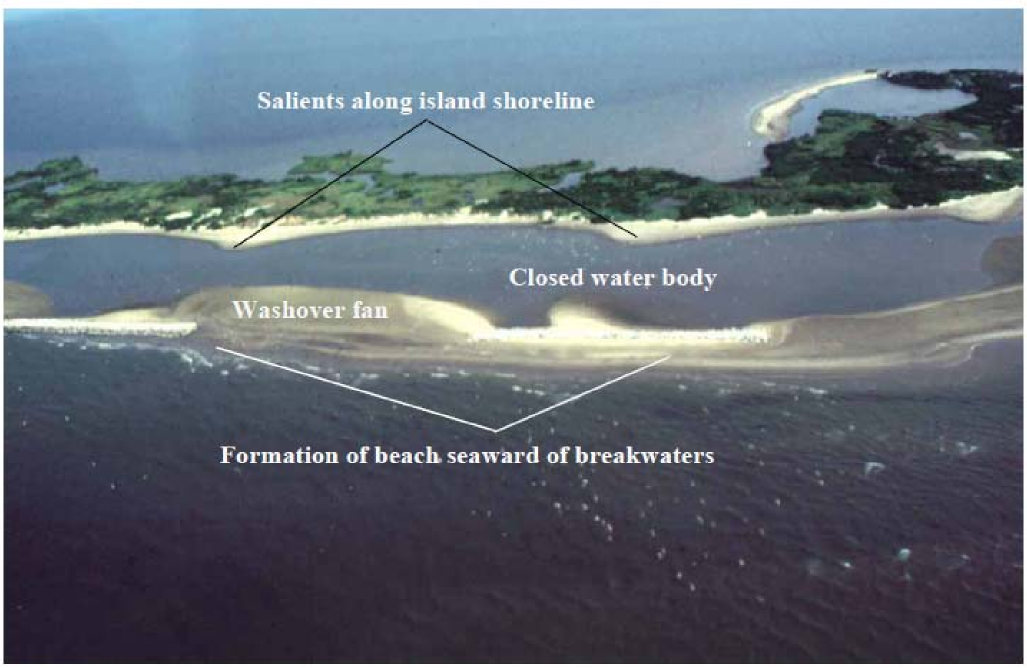

Figure 1-6. August 1999 photograph showing the response of the demonstration breakwater field to breakwater construction. Note the width of the salients after two years compared with the width of the beach formed in the vicinity of the breakwaters (Armbruster, 1999).

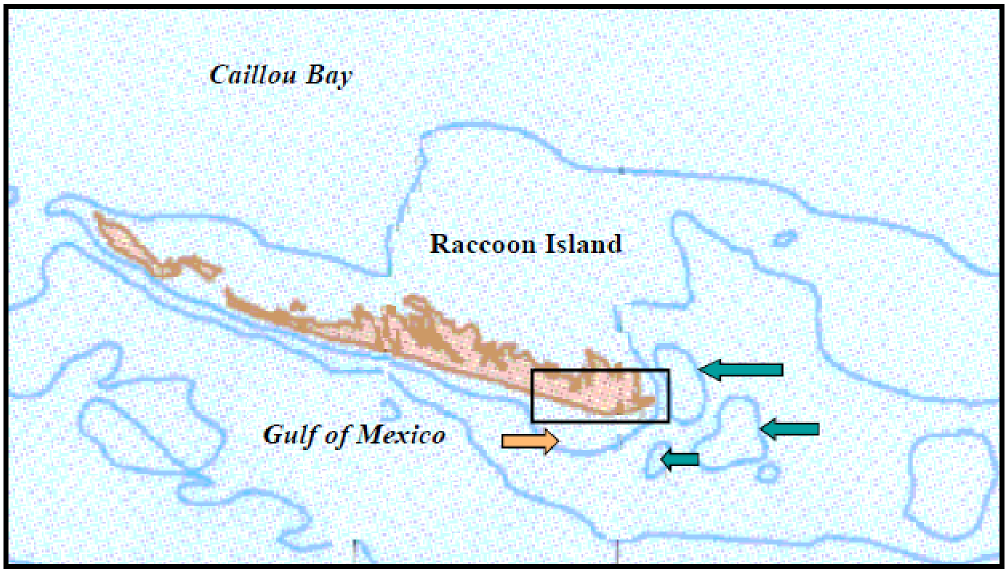

Figure 1-7. Nearshore bathymetry around Raccoon Island showing offshore shoals around the eastern tip of the island (Armbruster, 1999).

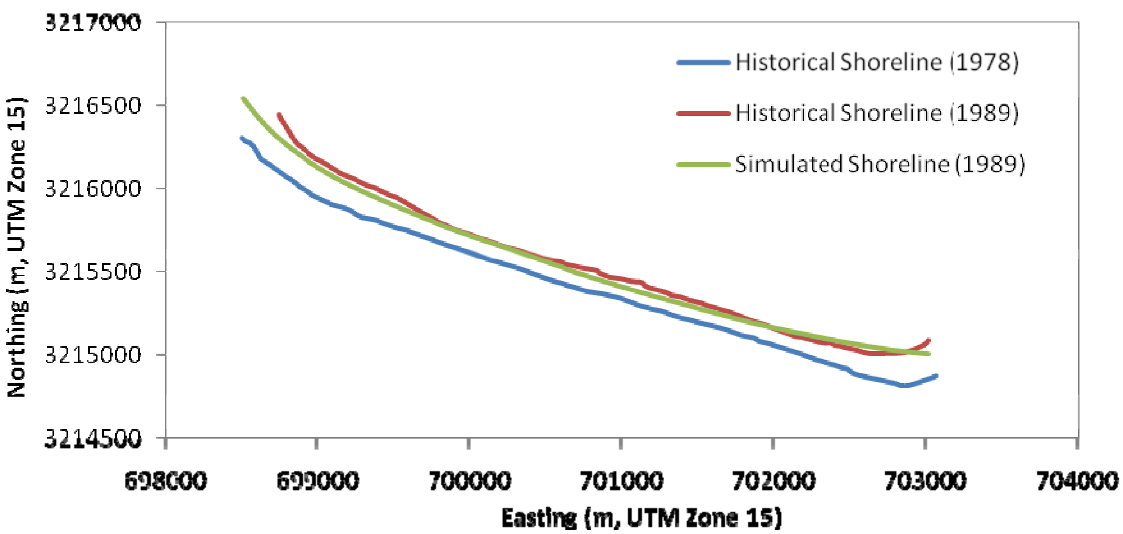

Figure 1-8. GENESIS model results for the initial calibration period 1978-1989 showing observed and simulated shorelines for Raccoon Island.

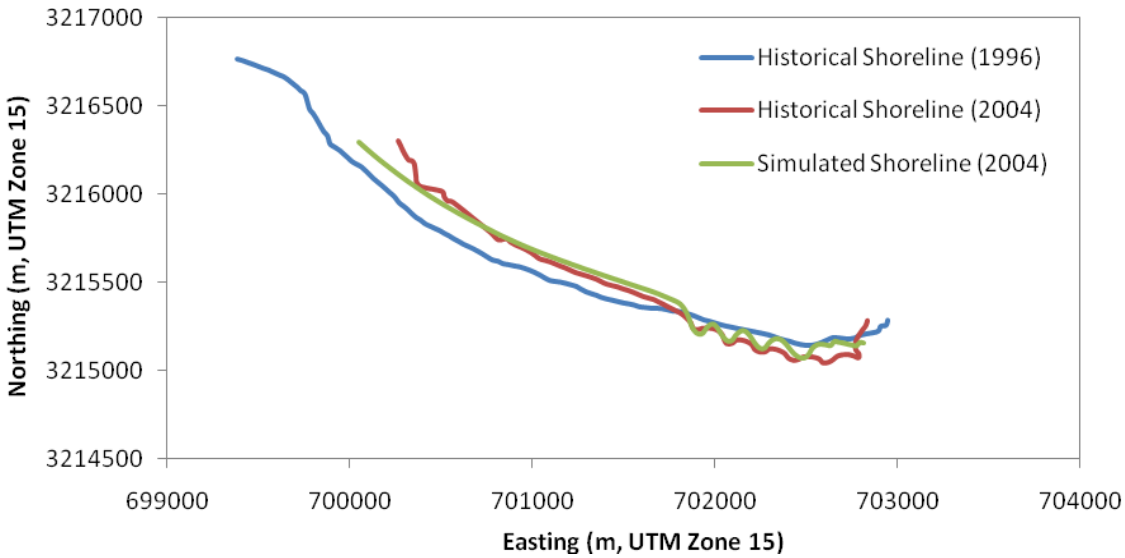

Figure 1-9. Validation of the Raccoon model for the period 1996-2004 illustrating the model's ability to capture the response of the shoreline after the placement of the initial set of eight demonstration breakwaters. The eastern end shows erosion instead of the observed accretion because the breakwaters could not be represented in the model due to the orientation of the shoreline at that end.

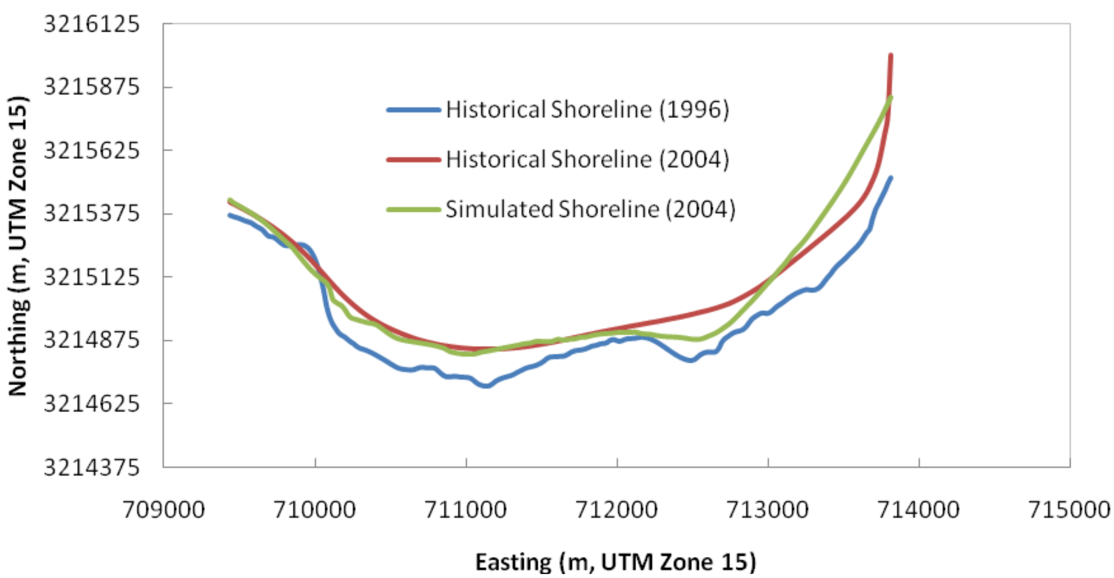

Figure 1-10. Validation of the GENESIS model setup for Whiskey Island. The simulated shoreline is smooth because of the hand-off of STWAVE information to GENESIS outside of the surf zone where the depth contours are almost straight and parallel.

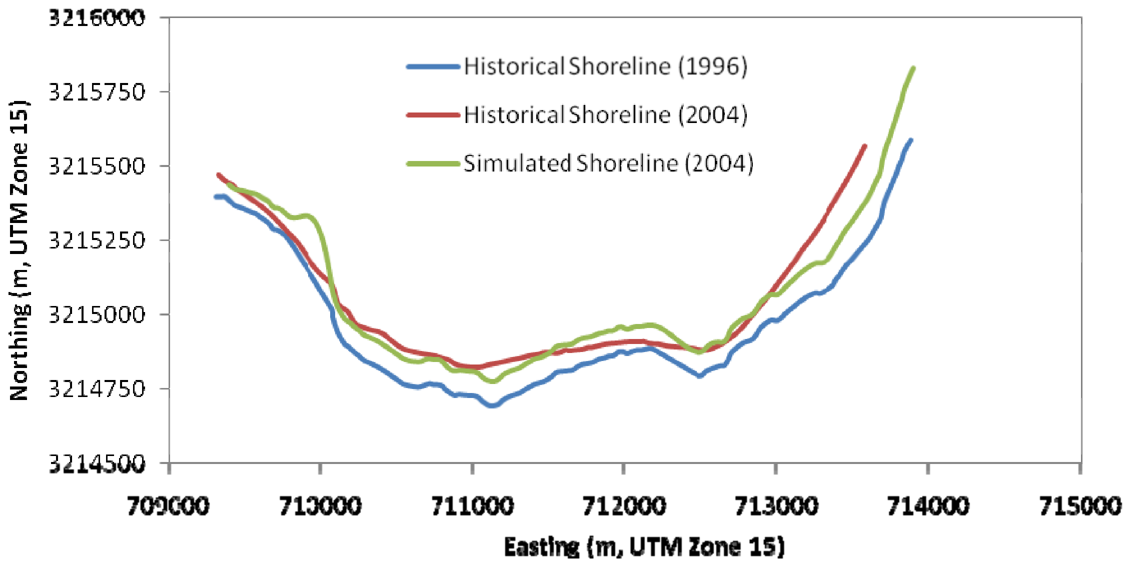

Figure 1-11. Repeat of the Whiskey Island validation runs assuming that the orientation of the initial shoreline is representative of offshore contour lines in the surf zone. This option in GENESIS resulted in erroneous transport rates and hence was not used.

Table 1-1. GENESIS Model Setup Parameters

Parameter	Raccoon Island 1978 – 1989	Raccoon Island 1996 – 2004	Whiskey Island 1996 – 2004
Number of cells	225	170	225
Cell width	30 m	30 m	20 m
Simulation time step	1 hr	1 hr	¼ hr
Left lateral boundary condition	-0.037 m/day	-0.037 m/day	-0.037 m/day
Right lateral boundary condition	-0.062 m/day	-0.062 m/day	-0.013 m/day
Background retreat rate	-7 m/yr	-9 m/yr	-9 m/yr
Median grain size	0.14 mm	0.14 mm	0.14 mm

Parameter	Raccoon Island 1978 – 1989	Raccoon Island 1996 – 2004	Whiskey Island 1996 – 2004
Berm height	1.2 m	1.2 m	1.2 m
Depth of closure	1.8 m	1.8 m	1.8 m
K_1	0.02	0.02	0.02
K_2	0.02	0.02	0.02
Number of breakwaters	0	4	0

Table 1-2. Summary of Model Skill Indicators.

	Raccoon Island Model 1978 – 1989	Raccoon Island Model 1996 – 2004	Whiskey Island Model 1996 – 2004
Average Error	1.20 m/yr	2.12	0.81 m/yr
Maximum Error (+)	2.05 m/yr	7.03	20.54 m/yr
Minimum Error (-)	-4.29 m/yr	-6.82	-24.04 m/yr
Root Mean Squared Error	1.94 m/yr	3.89	7.78 m/yr

1.8 PERFORMANCE OF STRUCTURAL MEASURES

1.8.1 Detached Breakwaters off of Whiskey Island

In order to assess the potential response of the shoreline to the future placement of breakwaters off of Whiskey Island, nineteen breakwaters were inserted into the 2005 shoreline and a shoreline change simulation was run for an eight year period terminating in 2012. The design parameters for the breakwaters on Whiskey Island were based on the structural configuration of the TE-29 breakwaters on Raccoon Island. Since GENESIS only accounts for longshore sediment transport, there was a need to apply a background shoreline change rate reflecting the long-term average effects of overwash, aeolian and other cross-shore transport processes that do not average-out long-term as assumed in the formulation of the GENESIS model. Following Thompson et al. (2004), this residual retreat was estimated to be 50% of the original long-term cross-shore transport related shoreline change rate in Table 1-1. Figure 1-12 shows the initial and final positions of the Whiskey Island shoreline for the simulation period. Tables 1-2 and 1-3 provide summaries of error estimates and shoreline change rates, respectively.

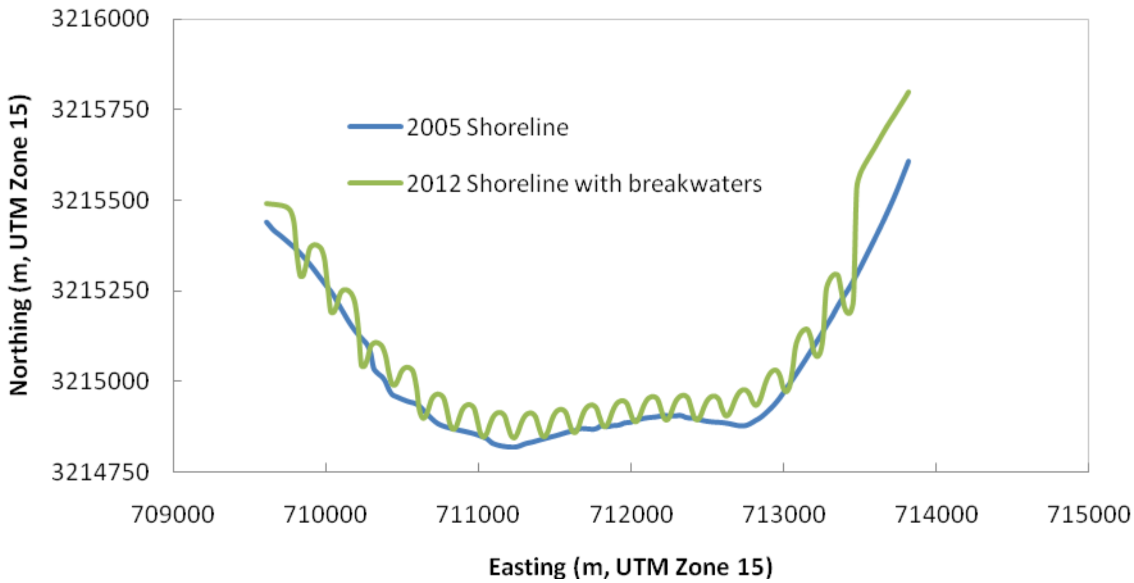

Figure 1-12. Simulated shoreline change on Whiskey Island assuming the placement of detached segmented breakwaters (lengths, gap widths, and distance from shore all approximately 92 m).

Table 1-3. Summary of shoreline change rates. Note that the rates for Raccoon Island do not include any background (cross-shore transport-related) shoreline change rates.

	Shoreline Change Rate (m/yr)	
	Whiskey Island	Raccoon Island
Without structure	-13.82	-2.45
With structure	-8.2	-1.65

1.8.2 Terminal Groin at Western End of Raccoon Island

The potential response of the shoreline to the placement of a terminal structure at the western end of Raccoon Island was also evaluated. The terminal groin is aimed at intersecting the net longshore sediment flux, thereby retaining sediment on the beach updrift of the groin. The length of the groin from the beach to the seaward tip was set to approximately 365 meters. This structural measure was evaluated by running an eight year shoreline change simulation starting in 2005 and terminating in 2012. The shoreline responses in the absence and presence of a terminal groin on Raccoon Island are depicted in Figures 1-13 and 1-14, respectively. Tables 1-2 and 1-3 provide summaries of error estimates and shoreline change rates, respectively.

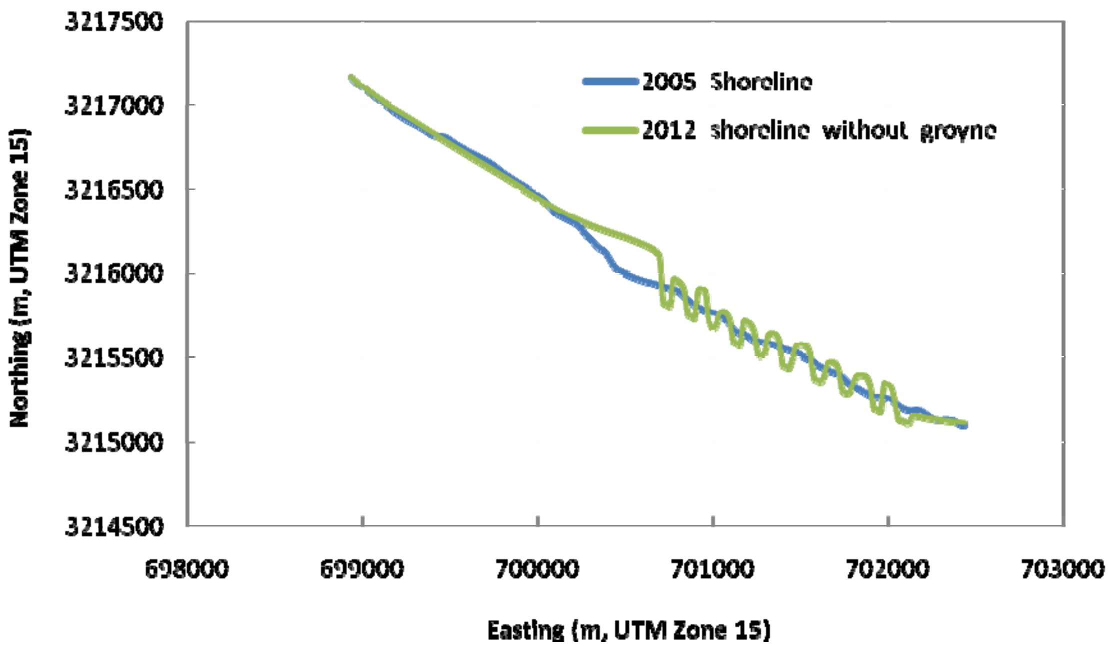

Figure 1-13. Raccoon Island simulation (2005-2012) without any background shoreline change imposed. Model setup includes all TE-48 breakwaters and two TE-29 breakwaters.

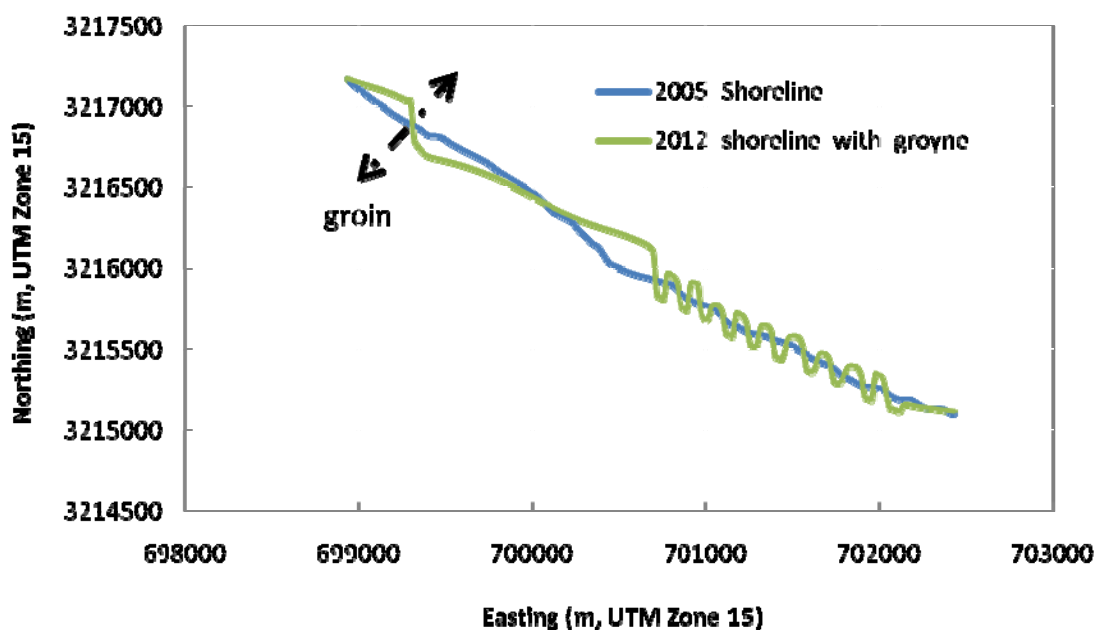

Figure 1-14. Same as Figure 1-14 with the exception of a terminal groin placed near the western end of Raccoon Island.

1.9 CONCLUSIONS

GENESIS reasonably reproduced shoreline change trends observed on the Isles Dernieres for the years 1978 to 1989 and 1996 to 2004 on Raccoon Island, and for the years 1996 to 2004 on Whiskey Island. The calibrated model results were used to evaluate the potential performance of proposed structural measures aimed at mitigating sediment loss and shoreline recession on Raccoon and Whiskey Islands. These measures included a terminal groin at the western end of Raccoon Island and a system of detached breakwaters off of Whiskey Island. The model results showed that shoreline erosion and retreat will be mitigated with the proposed structural measures.

GENESIS only explicitly accounts for longshore sediment transport, which is only of secondary importance (Rosati and Stone, 2009, Thompson et al., 2004) as far as sediment transport mechanisms responsible for shoreline erosion and retreat on the islands are concerned. Other sediment transport mechanisms are only treated in the model in terms of long-term average background change rates. Additionally, the erosional and depositional processes at play on these barrier islands are complex, and no single process controls or explains the geomorphologic response of the islands to external forcing. Therefore the model results, when applied to engineering design and the evaluation of alternative shore protection measures, should be treated with care. For example, it will be beneficial to evaluate the historical response of breakwater protected shorelines to episodic but catastrophic events such as the passage of severe tropical cyclones. Further, it is recommended that combined wave and current modeling be conducted in PED on a system-wide level to support the NER Plan.

Due to the small net longshore flux on these islands (an average of 40,000 cubic meters per year; Rosati and Stone, 2009) and the possibility of adverse downdrift impacts, optimum project designs should include beach nourishment.

2. SBEACH MODELING REPORT

2.1 SBEACH MODEL DESCRIPTION

SBEACH (Storm-induced BEAch CHange) was developed at the U.S. Army Engineer Waterways Experiment Station, Coastal and Hydraulics Laboratory (CHL), to calculate beach and dune erosion under storm water levels and wave action (Larson and Kraus 1989; Larson, Kraus, and Bymes 1990; Rosati et al. 1993). Model development was based on extensive analysis of beach profile change produced in large wave tanks and in the field. It is a two-dimensional model meaning that longshore wave, current, and sediment transport processes are omitted. Breaking waves and changing water level are the major driving agents in SBEACH that produce sediment transport and beach profile change.

SBEACH has significant capabilities that make it useful for quantitative and qualitative study of beach profile response to storms. It accepts as input varying water levels as produced by storm surge and tide, varying wave heights and periods, and an arbitrary grain size in the fine-to-medium sand range. Either a user-specified schematic dune and berm configuration or a surveyed profile configuration can comprise the initial profile.

2.2 SBEACH INPUT

SBEACH requires several inputs: profile configuration, time series of wave parameters (wave height, period and direction), and time series of water elevation. The user must also specify sediment size, grid spacing, time step, and other parameters.

Because Hurricanes Katrina and Rita occurred in August-September of 2005 within 25 days they were combined in one storm event. Similarly, because Hurricanes Gustav and Ike occurred in September 2008 within 11 days of each other, they were also combined in one storm event.

For the Katrina-Rita and Gustav-Ike SBEACH simulations, water elevation time series were obtained from verified historical records at NOAA/NOS CO-OPS Station 8761724 located at the Coast Guard Station on Grand Isle. Wave and wind data were acquired from the NOAA/NWS/NCEP operational ocean wave predictions based on the output from the WAVEWATCH III model (http://polar.ncep.noaa.gov/waves/index2.shtml). The wave and wind data were obtained at the WIS-125 location (LAT=28.58N, LON=90.75W) in approximately 60-foot deep water.

The STWAVE model was used to propagate the wave conditions at WIS-125 to the offshore SBEACH boundary located approximately 8,000 feet seaward of the barrier shoreline in approximately 14-foot deep water. Figures 2-1 and 2-2 present wave height, wave period, and water elevation used in the SBEACH simulations of Katrina-Rita and Gustav-Ike, respectively.

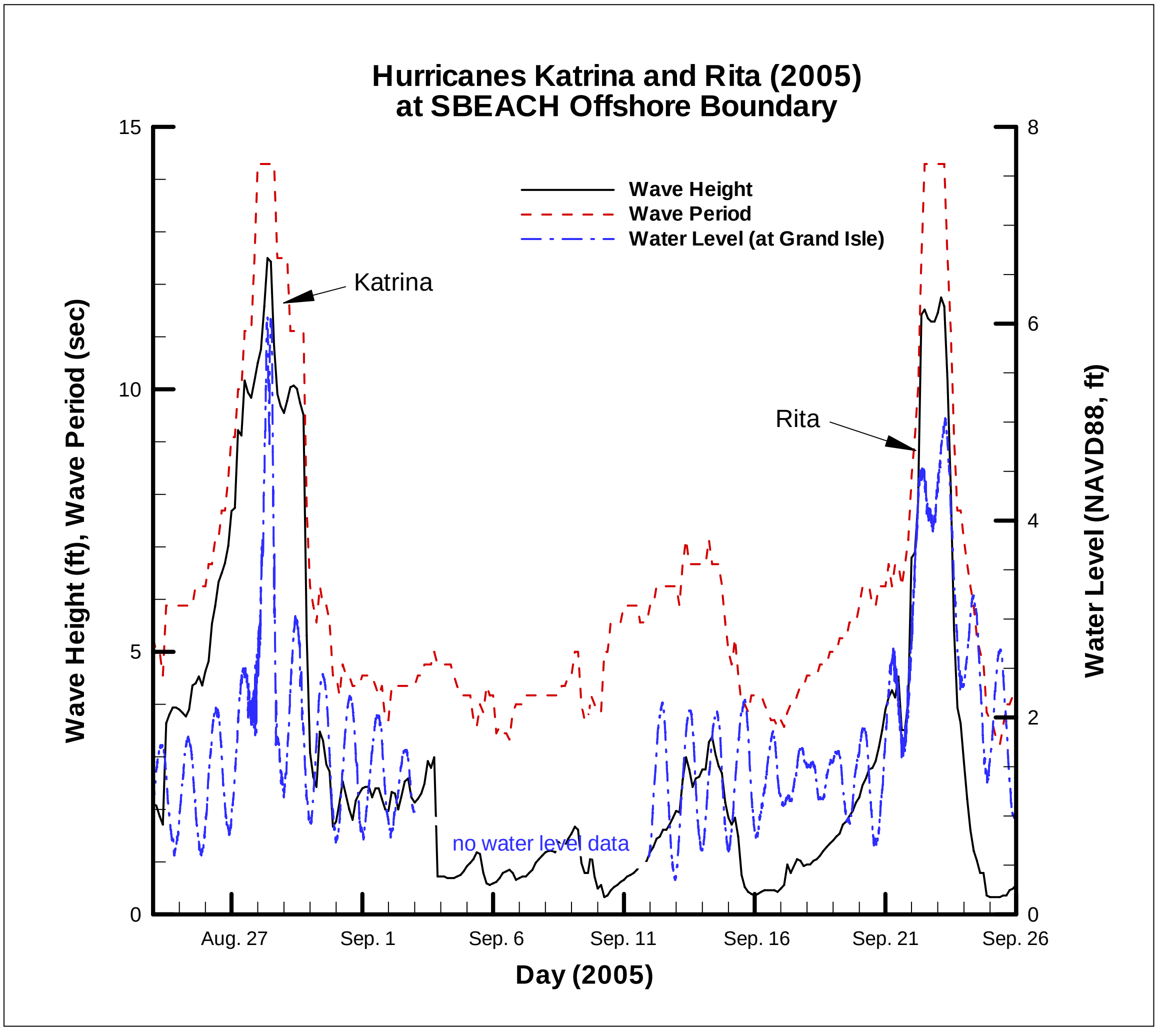

Figure 2-1. Hurricanes Katrina-Rita wave/water level input information used in SBEACH.

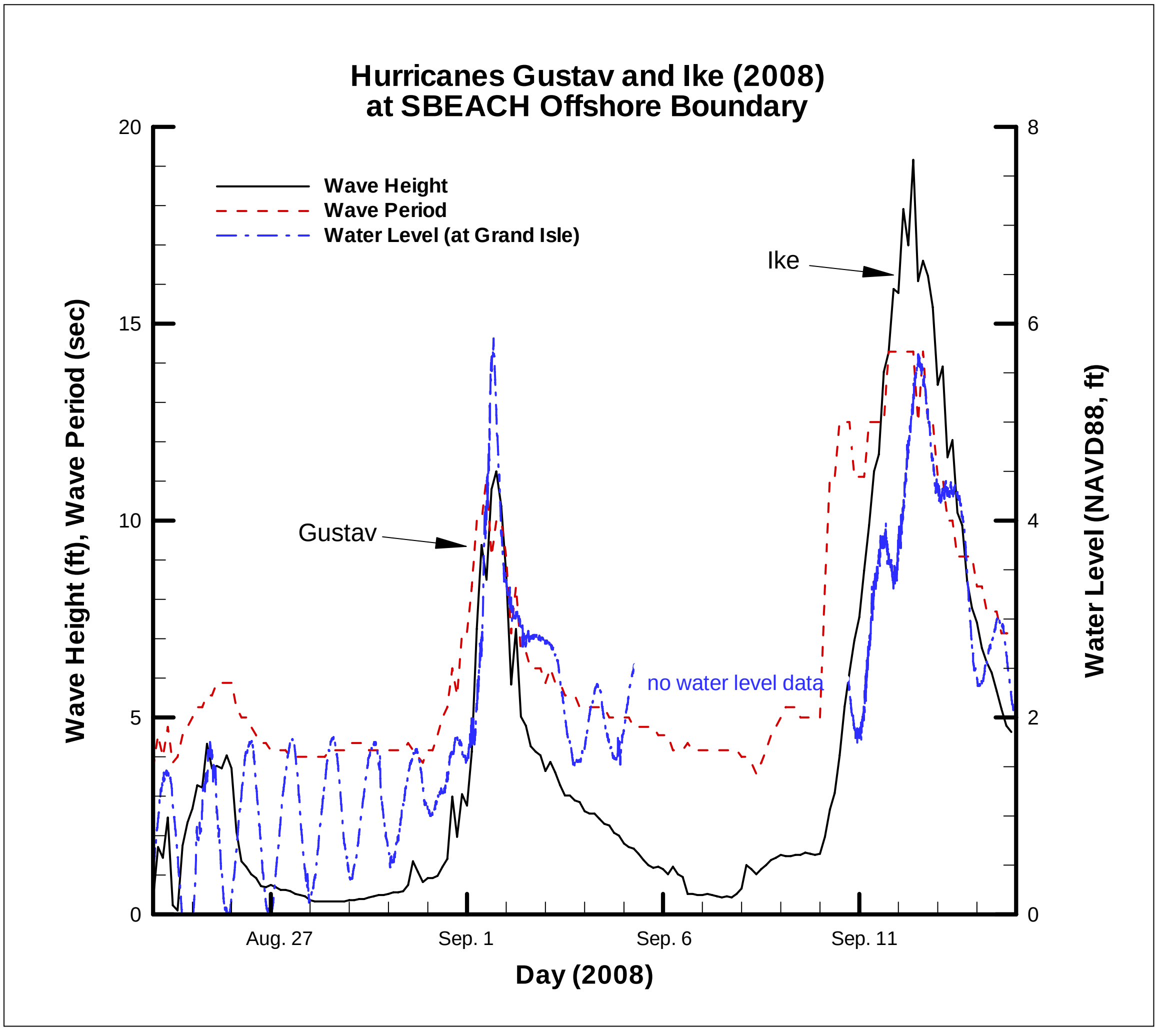

Figure 2-2. Hurricanes Gustav-Ike wave/water level input information used in SBEACH.

Figures 2-3 and 2-4 present wind speed used in the SBEACH simulations of Katrina-Rita and Gustav-Ike, respectively.

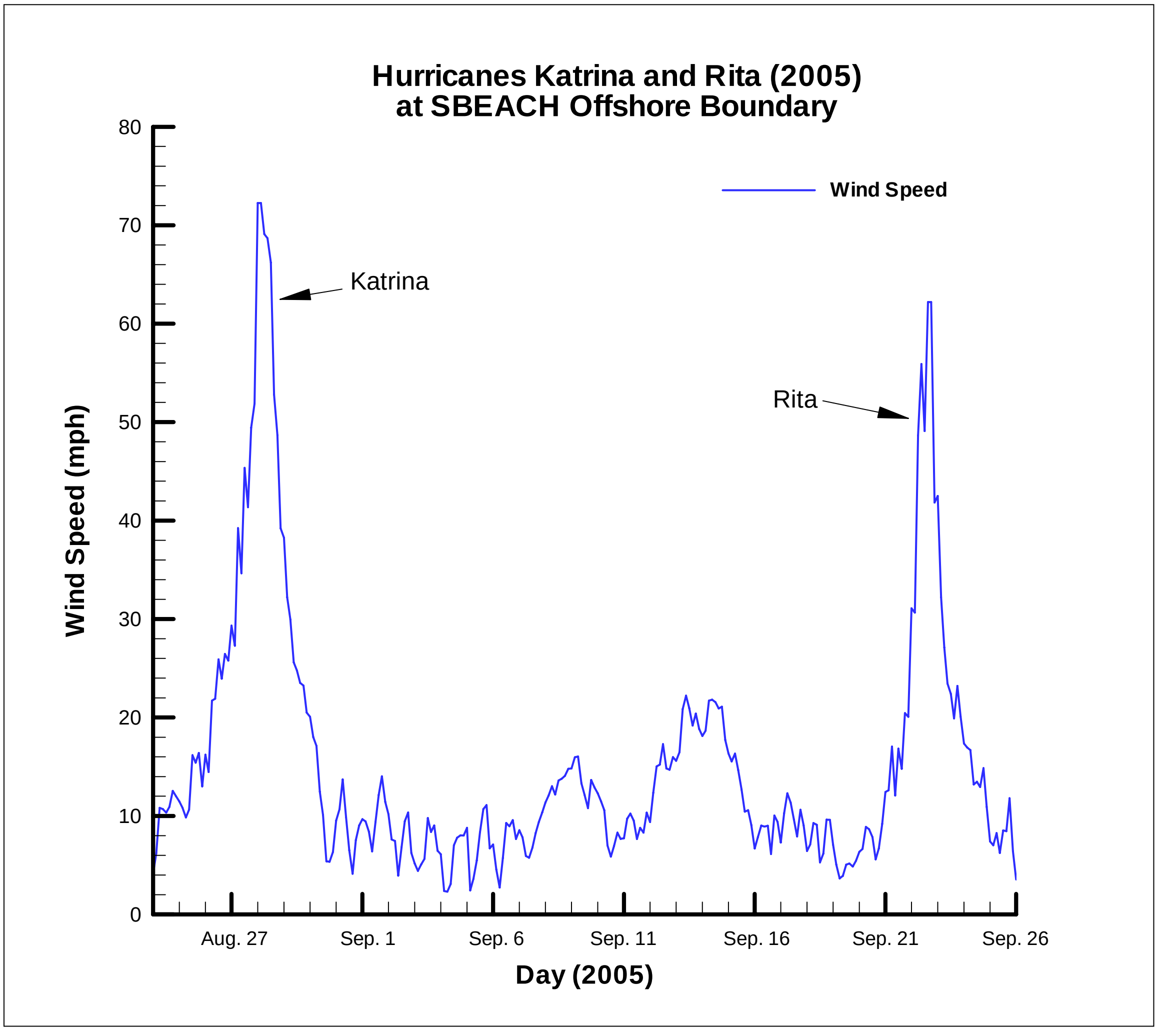

Figure 2-3. Hurricanes Katrina-Rita wind speed used in SBEACH.

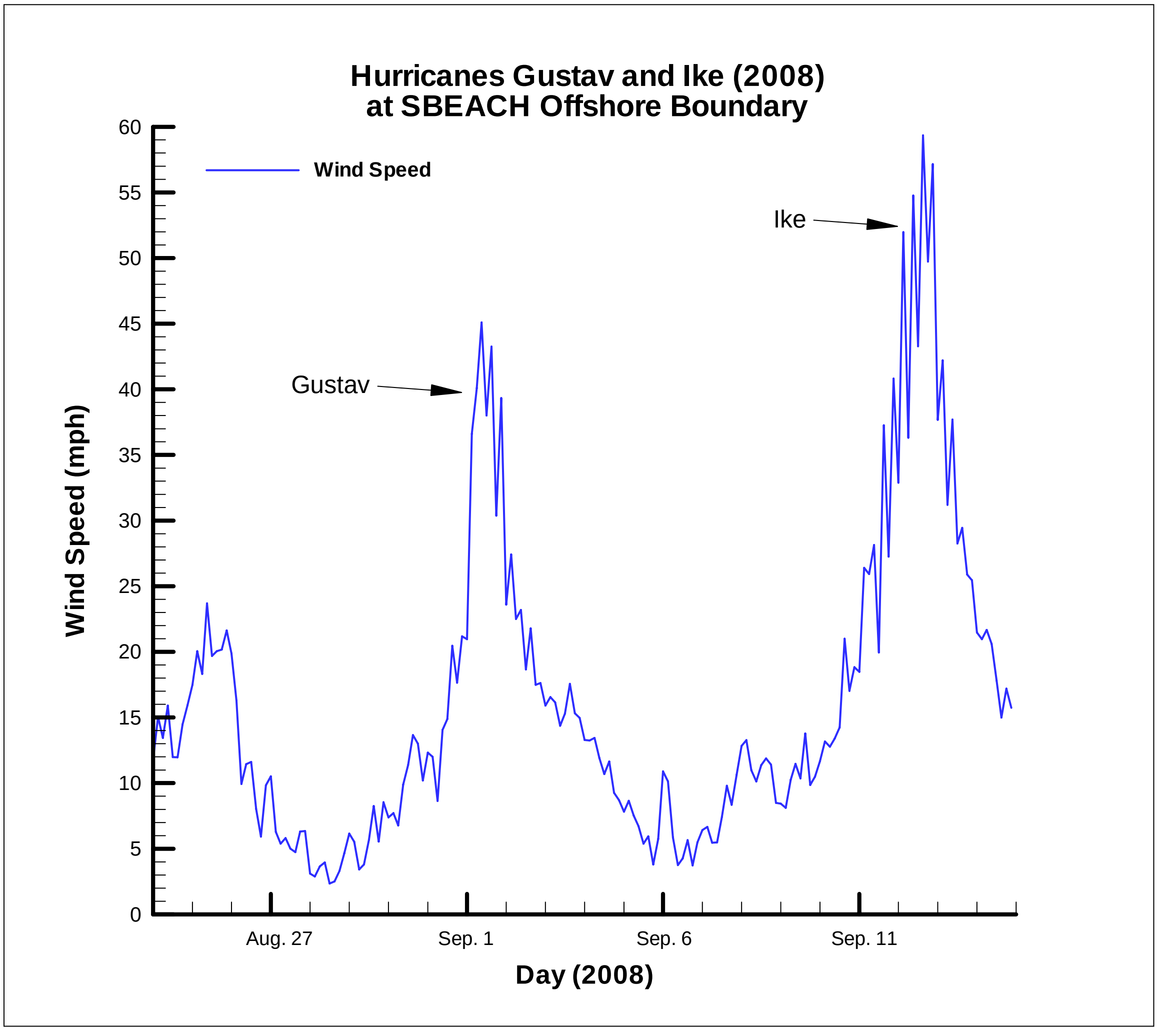

Figure 2-4. Hurricanes Gustav-Ike wind speed used in SBEACH.

The 50-year hypothetical storm was created based on the analysis of extreme wave conditions obtained at WIS-125 station and extreme storm surge statistics at Grand Isle. Based on the extreme wave analysis, a 50-year storm at the WIS-125 location would produce 27-foot high waves at the peak of the storm with a period of 13.2 seconds. According to USACE (1979), a surge elevation at Grand Isle that corresponds to the 50-year return interval is 8.5 feet. Because this is a hypothetical storm, a time series of wave height and water elevation that occurred during Hurricane Katrina (2005) was used to create a time series of wave height and water elevation for the 50-year storm. The Hurricane Katrina wave height and water elevation time series were proportionally adjusted to match the peak 50-year storm wave height and water elevation. Figure 2-5 presents the wave height, wave period, and water elevation used in the STWAVE model to propagate the 50-year storm from the WIS-125 location to the SBEACH offshore boundary. Figure 2-6 presents the wave height, wave period, and water elevation used in the SBEACH simulation of the 50-year storm.

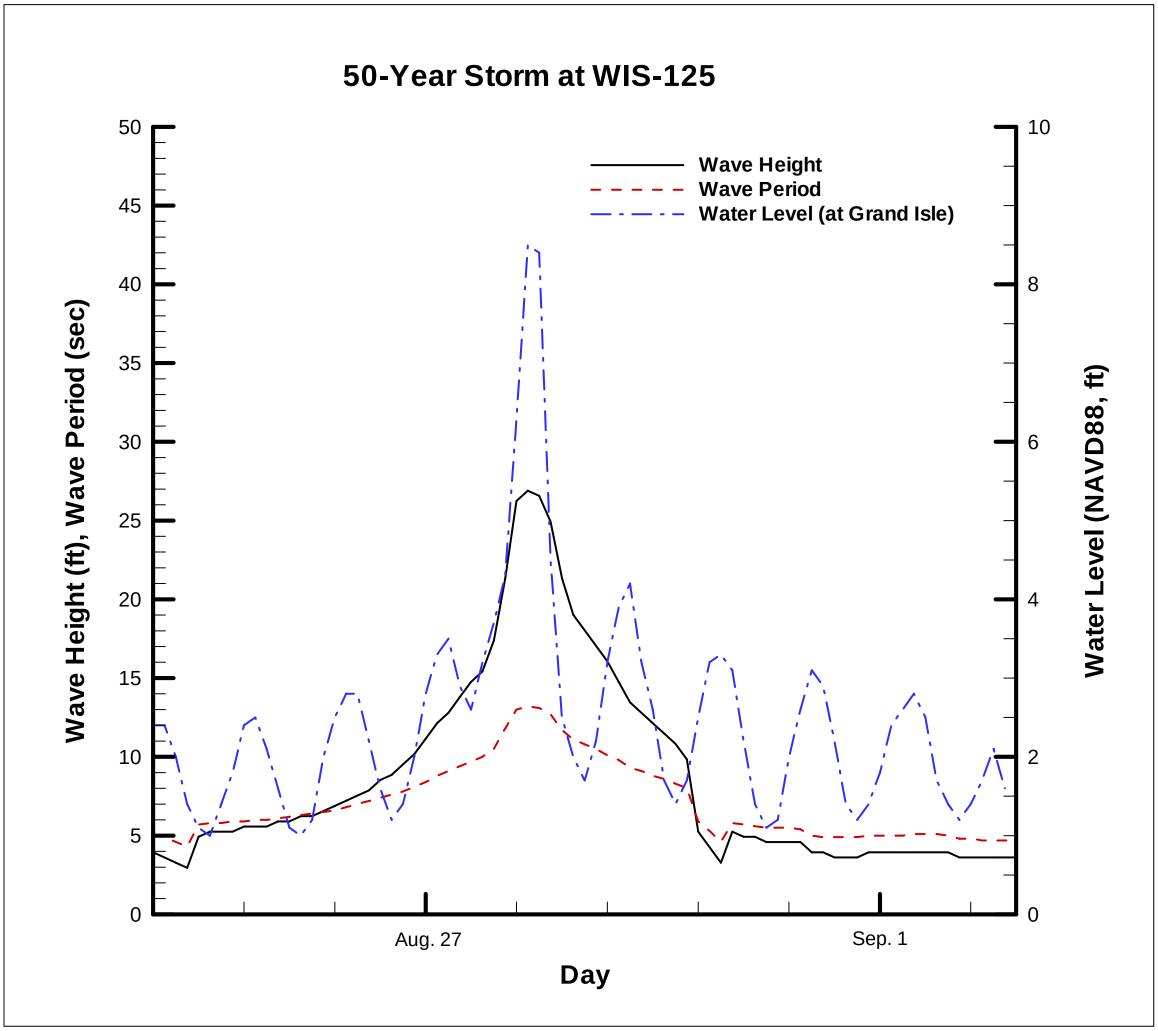

Figure 2-5. 50-year storm wave/water level input information at WIS-125.

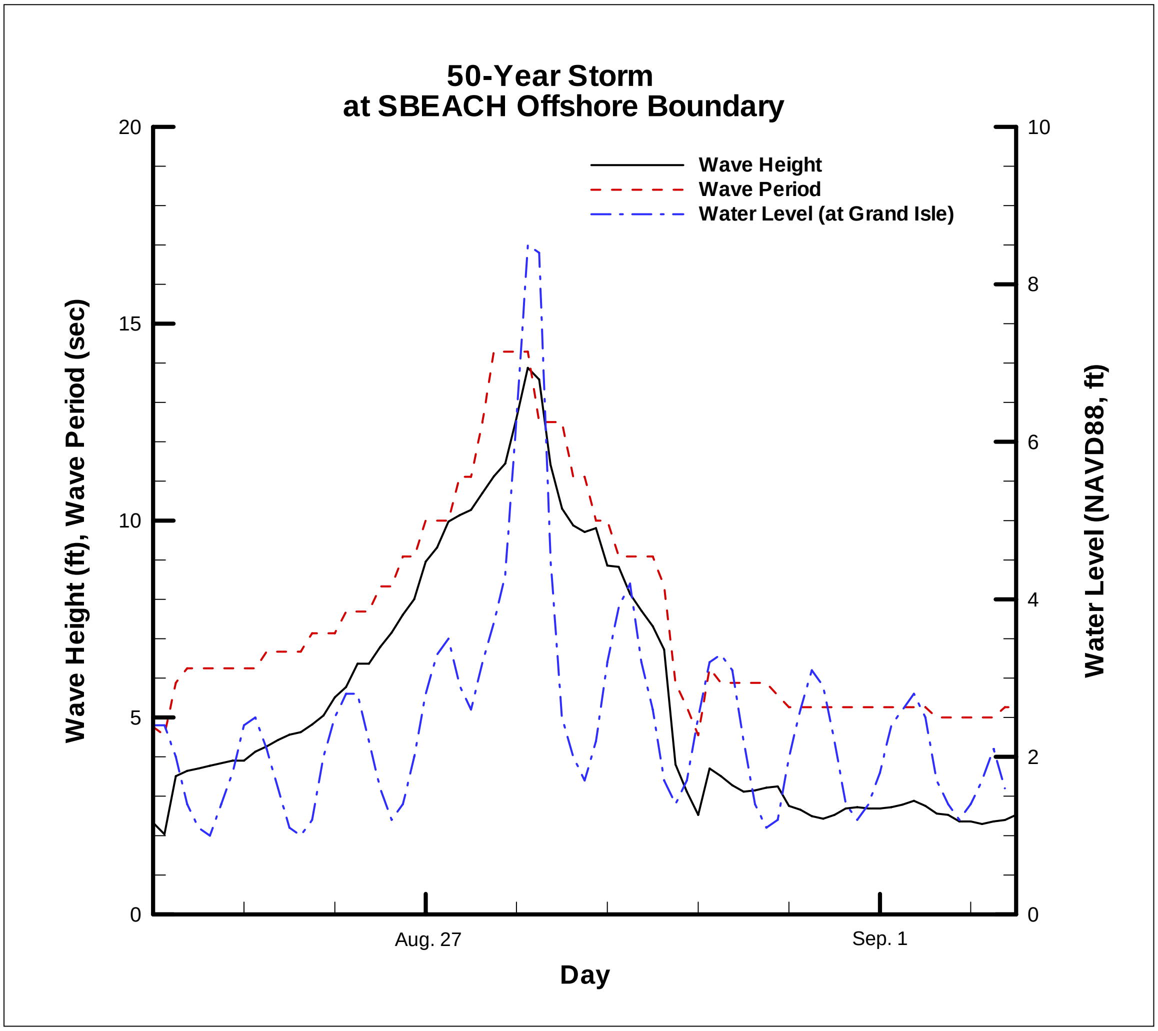

Figure 2-6. 50-year storm wave/water level input information used in SBEACH.

2.3 SBEACH RESULTS

SBEACH simulations were performed in order to determine the minimal barrier island design parameters that retain barrier island's geomorphic form and ecologic function after being subjected to design storm including a combined storm event of Hurricanes Katrina and Rita, a combined storm event of Hurricanes Gustav and Ike, and a hypothetical 50-year storm.

Thirteen (13) dune/beach/marsh templates were designed in an iterative process to yield the minimized restoration design template. Table 2-1 presents the design template parameters which include dune/beach/marsh width and elevation. A typical profile based on the 2006 BICM survey data of Whiskey Island was used to complete the template seaward and landward of the restoration design template.

Table 2-1. Summary of Design Template Parameters Used in SBEACH Modeling

Template	Dune Width, ft	Dune Elev., ft NAVD	Gulfside Beach Width, ft	Bayside Beach Width, ft	Beach Elev., ft NAVD	Marsh Width, ft	Marsh Elev., ft NAVD
01	100	6	300	100	4	1000	1.6
02	100	6	400	100	4	1000	1.6
03	200	6	400	100	4	1000	1.6
04	100	6	250	100	4	1000	1.6
05	100	6	200	100	4	1000	1.6
06	100	6	150	100	4	1000	1.6
07	100	6	100	100	4	1000	1.6
08	100	6	50	100	4	1000	1.6
09	100	5.5	200	100	4	1000	1.6
10	100	6	250	100	3.8	1000	1.6
11	100	6	250	75	3.8	1000	1.6
12	100	6	250	100	3.5	1000	1.6
13	75	6	250	100	4	1000	1.6

Initially, each of the design templates was modeled using the 50-year storm parameters and 0.16 mm grain size. Based on the results of these simulations, a decision was made whether to continue to model the template applying the hurricane event conditions or to screen out the template from future consideration.

For the screened templates, three grain sizes, 0.12 mm, 0.16 mm, and 0.20 mm, were used in SBEACH simulations to account for variability in sediment sizes of potential borrow sources.

Table 2-2 presents the SBEACH results of 50-year storm simulations expressed in terms of shoreline recession at Mean High Water (MHW), maximum post-storm dune elevation, dune overwash and, beach overwash. Based on the outcome of these simulations, Templates 02, 03, 05, 06, and 08 were screened out and removed from further analysis because the performance of comparable templates of smaller dimensions met the required criteria to retain barrier island’s geomorphic form and ecologic function.

Table 2-2. Summary of 50-year Storm Simulations

	Template	Dune Elevation, ft NAVD88	Erosion at MHW, ft	Dune Overwash, ft	Beach Overwash, ft
Sediment Size = 0.12mm	01	5.1	123	123	19
	02	N/M*	N/M	N/M	N/M
	03	N/M	N/M	N/M	N/M
	04	5.3	123	120	25
	05	N/M	N/M	N/M	N/M
	06	N/M	N/M	N/M	N/M
	07	4.8	120	118	33
	08	N/M	N/M	N/M	N/M
	09	4.6	122	115	28
	10	5.1	126	123	29
	11	5.2	125	97	29
	12	5.0	131	118	33
	13	5.2	123	126	35
Sediment Size = 0.16 mm	01	5.3	84	126	20
	02	5.3	85	121	23
	03	5.6	85	114	2
	04	5.3	84	116	25
	05	5.1	85	125	28
	06	5.0	85	119	26
	07	5.0	85	116	32
	08	4.9	83	117	38
	09	4.5	84	116	33
	10	5.2	86	116	29
	11	5.2	86	98	36
	12	5.1	89	120	28
	13	4.9	84	111	25
Sediment Size = 0.20 mm	01	5.3	51	121	21
	02	N/M	N/M	N/M	N/M
	03	N/M	N/M	N/M	N/M
	04	5.2	51	123	22
	05	N/M	N/M	N/M	N/M
	06	N/M	N/M	N/M	N/M
	07	5.0	51	118	34
	08	N/M	N/M	N/M	N/M
	09	4.5	51	125	41
	10	5.1	53	121	28
	11	5.2	53	105	34
	12	5.1	54	117	28
	13	5.0	51	120	28

*N/M denotes not modeled after template was screened out

All of the templates that passed the 50-year storm screening were further analyzed and modeled using two combined storm events: 1) Hurricanes Katrina and Rita, and 2) Hurricanes Gustav and Ike. Tables 2-3 and 2-4 present the SBEACH results expressed in terms of shoreline recession at Mean High Water (MHW), maximum post-storm dune elevation, dune overwash and, beach overwash, that occurred during the simulations of Katina and Rita, and Gustav and Ike, respectively.

Table 2-3. Summary of Hurricanes Katrina and Rita Simulations.

	Template	Dune Elevation, ft NAVD88	Erosion at MHW, ft	Dune Overwash, ft	Beach Overwash, ft
Sediment Size = 0.12mm	01	4.2	150	297	188
	04	4.0	150	343	239
	07	3.6	144	Dune Gone	271
	09	3.7	149	Dune Gone	303
	10	4.2	156	335	218
	11	4.1	157	333	249
	12	4.0	161	320	216
	13	4.0	148	362	261
Sediment Size = 0.16 mm	01	4.7	106	301	190
	04	4.0	104	345	235
	07	3.7	102	Dune Gone	290
	09	4.1	105	402	292
	10	4.1	104	329	232
	11	4.0	106	334	251
	12	3.9	107	322	218
	13	4.1	101	362	263
Sediment Size = 0.20 mm	01	4.3	68	297	185
	04	4.0	67	349	235
	07	3.7	64	Dune Gone	307
	09	3.7	65	Dune Gone	284
	10	4.0	67	332	223
	11	3.9	66	327	246
	12	3.8	66	321	217
	13	3.9	64	Dune Gone	268

Table 2-4. Summary of Hurricanes Gustav and Ike Simulations.

	Template	Dune Elevation, ft NAVD88	Erosion at MHW, ft	Dune Overwash, ft	Beach Overwash, ft
Sediment Size = 0.12mm	01	4.1	116	294	188
	04	4.0	116	344	236
	07	3.6	116	Dune Gone	288
	09	3.6	118	Dune Gone	282
	10	4.0	118	333	219
	11	3.9	118	336	243
	12	3.8	126	322	218
	13	4.0	116	364	260
Sediment Size = 0.16 mm	01	4.1	80	322	208
	04	4.0	80	341	235
	07	3.7	80	Dune Gone	251
	09	3.8	81	Dune Gone	287
	10	4.0	82	333	229
	11	3.9	82	318	245
	12	3.9	85	322	217
	13	4.0	80	365	249
Sediment Size = 0.20 mm	01	4.0	44	324	213
	04	4.0	44	343	227
	07	3.7	44	Dune Gone	270
	09	3.7	44	Dune Gone	283
	10	4.0	44	333	226
	11	3.9	45	325	248
	12	3.8	45	317	215
	13	3.9	44	Dune Gone	252

Based on the results of these simulations, Templates 07, 09, 11, and 12 did not meet the required criteria to retain the barrier island's geomorphic form and ecologic function. Of the remaining four templates that passed the screening criteria, Template 10 was determined to be minimal and thus was selected as the design template.

2.4 Minimal Design Template Performance

Figures 2-7 through 2-9 present comparisons between the pre-storm and post-storm Template 10 (minimal design template) beach profiles computed for Hurricanes Katrina and Rita, Gustav and Ike, and the 50-year design storm, using grain sizes of 0.12 mm, 0.16 mm, and 0.20 mm, respectively.

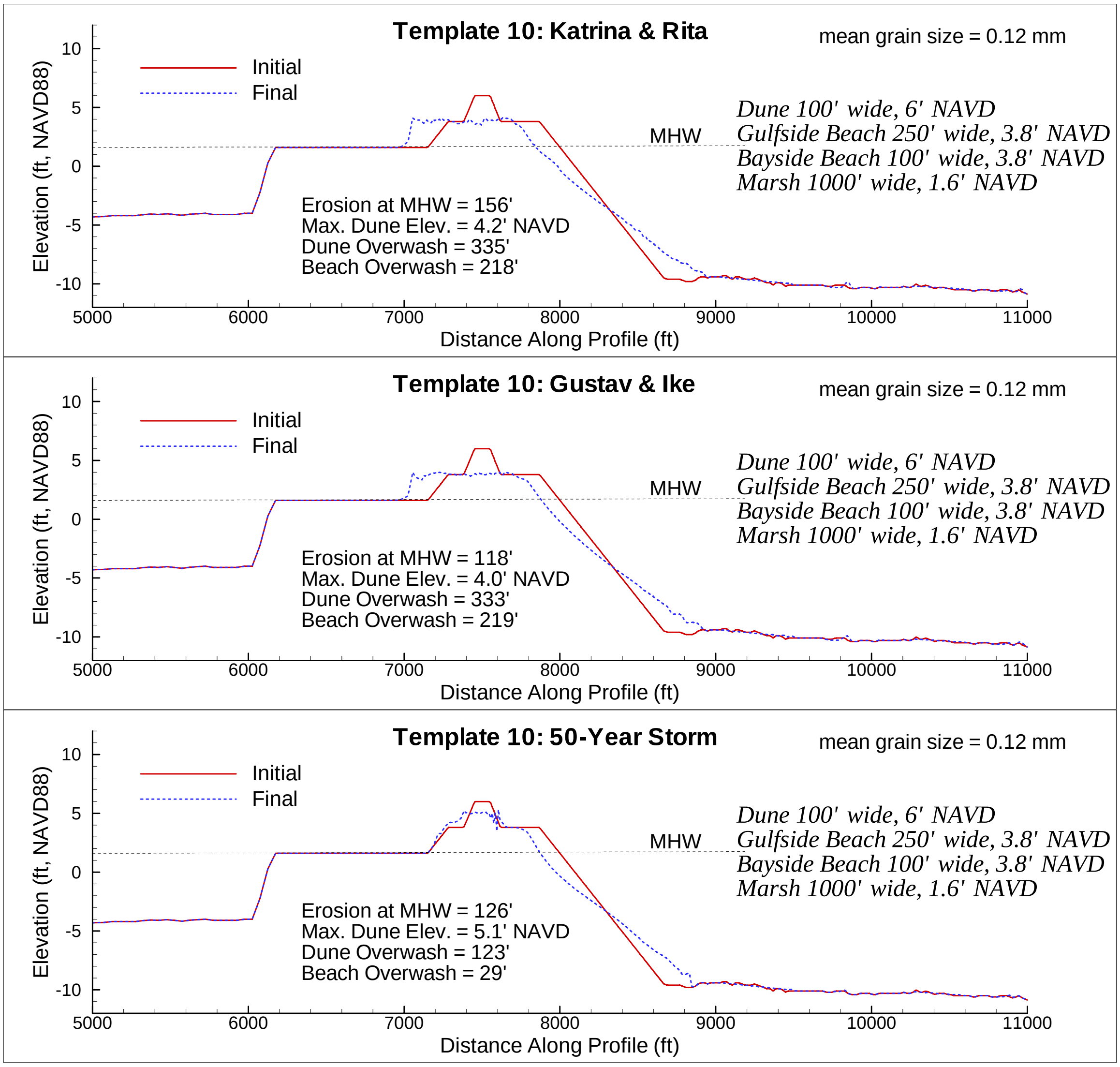

Figure 2-7. Pre-storm (Initial) and Post-storm (Final) Template 10 Profiles using 0.12-mm Grain Size.

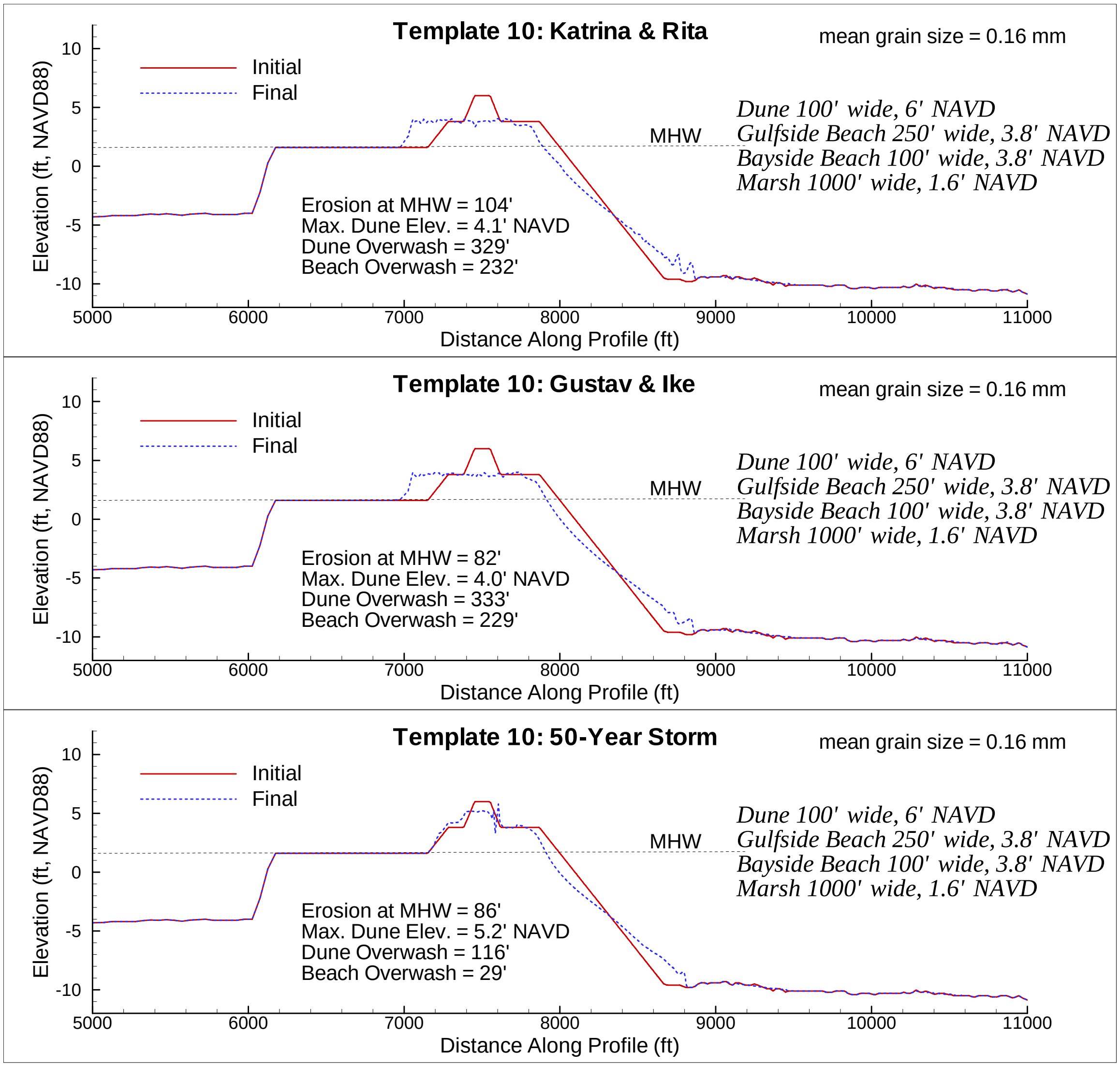

Figure 2-8. Pre-storm (Initial) and Post-storm (Final) Template 10 Profiles using 0.16-mm Grain Size.

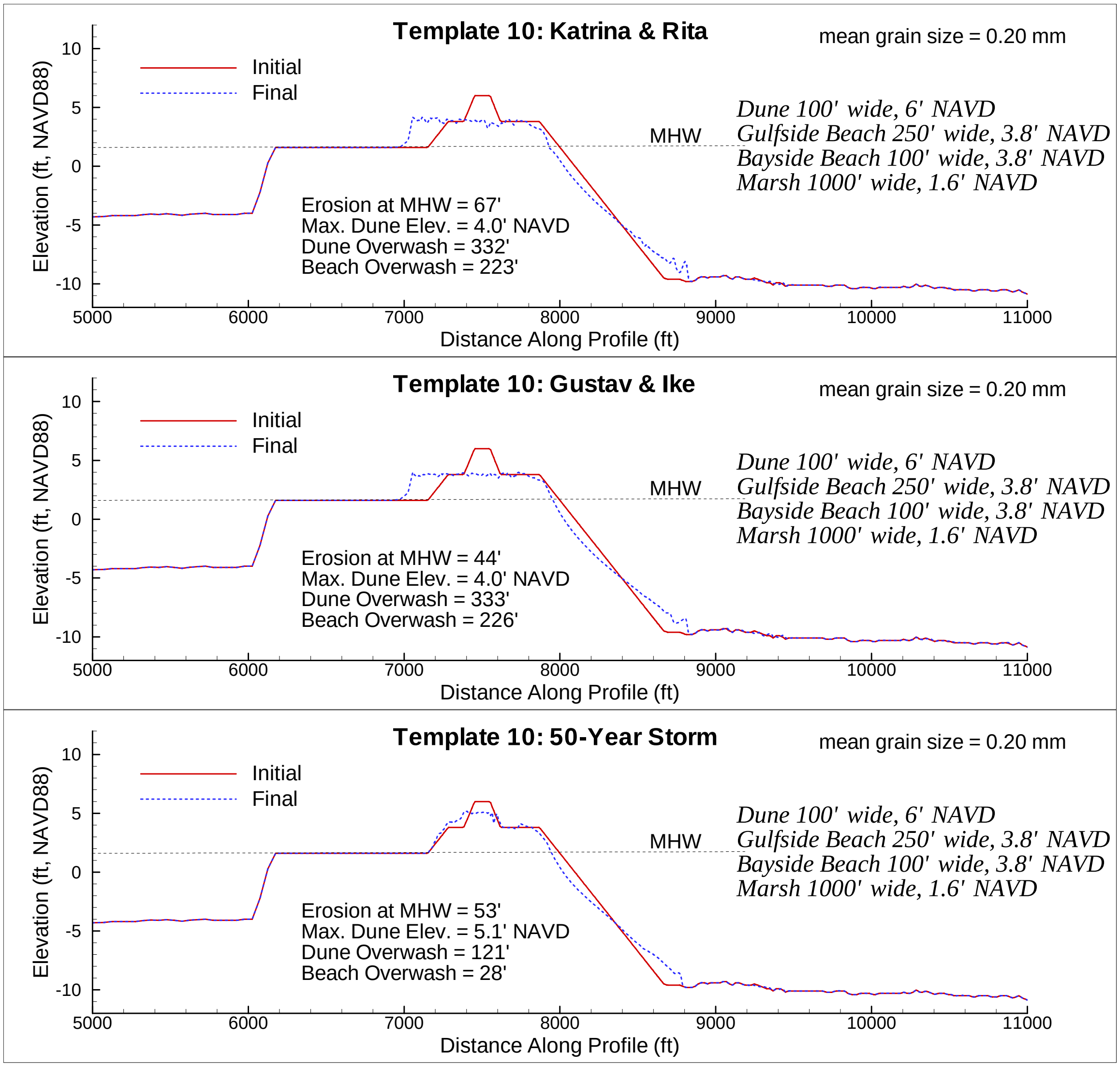

Figure 2-9. Pre-storm (Initial) and Post-storm (Final) Template 10 Profiles using 0.20-mm Grain Size.

Because pre- and post-storm survey data for the Terrebonne Islands were not available the SBEACH model was not calibrated and default sediment transport model parameters were used including:

- Transport rate coefficient = 1.75×10^{-6} m^4/N
- Overwash transport parameter = 0.005
- Coefficient for slope-dependent term = 0.002 m^2/S
- Transport rate decay coefficient multiplier = 0.5

However, model results were verified using shoreline erosion rates estimated based on aerial photographs taken in 2004 and 2005 during which Hurricanes Katrina and Rita occurred. OCPR (2008) reported 181.4 feet of erosion and 124.3 feet of erosion on Whiskey Island and on the Isles Dernieres island chain, respectively. Taking into account historic erosion rates presented in Appendix L, Section L3.2, 42.7 feet per year for Whiskey Island and 37 feet per year for the Isles Dernieres island chain, the magnitude of erosion resulting from the two hurricanes was 138.7 feet and 87.3 feet for Whiskey Island and the Isles Dernieres island chain, respectively. The range of erosion caused by the combined Katrina and Rita event computed by SBEACH was between 67 feet (upper grain size limit = 0.20 mm) and 156 feet (lower grain size = 0.12 mm). Therefore, the estimated magnitude of erosion falls within the erosion range computed by SBEACH and thus verifies model results and justifies using the SBEACH model.

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