2023 COASTAL MASTER PLAN

BARRIER ISLAND MODEL IMPROVEMENTS

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COASTAL PROTECTION AND RESTORATION AUTHORITY

This document was developed in support of the 2023 Coastal Master Plan being prepared by the Coastal Protection and Restoration Authority (CPRA). CPRA was established by the Louisiana Legislature in response to Hurricanes Katrina and Rita through Act 8 of the First Extraordinary Session of 2005. Act 8 of the First Extraordinary Session of 2005 expanded the membership, duties, and responsibilities of CPRA and charged the new authority to develop and implement a comprehensive coastal protection plan, consisting of a master plan (revised every six years) and annual plans. CPRA's mandate is to develop, implement, and enforce a comprehensive coastal protection and restoration master plan.

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EXECUTIVE SUMMARY

The 2023 Coastal Master Plan Barrier Island Model Improvements team was tasked with evaluating the 2017 Coastal Master Plan barrier island models and providing recommendations for improvements and updates to predictive models that will inform the 2023 Coastal Master Plan. The Barrier Island Model Development (BIMODE), a barrier island modeling workflow, was developed for the 2017 Coastal Master Plan. Its purpose was to predict barrier shoreline evolution over 50-year time scales as a component of the regional-scale Integrated Compartment Model (ICM). One of the goals of BIMODE was to improve upon models developed to support the 2012 Coastal Master Plan by incorporating physical processes, such as barrier overwash during storms, to drive barrier evolution. This report is intended to provide a summary of the 2023 Coastal Master Plan Barrier Island Model Improvements Team assessment of BIMODE, to identify options for improving and advancing predictive modeling capabilities for barrier islands and their integration into the ICM, and to provide recommendations of methods for advancing prediction of realistic future barrier shoreline configurations for master plan modeling efforts.

An effective master plan barrier island model should: 1) simulate coastal barrier island hydraulics that inform ICM basin hydraulics with feedback between the two, and 2) predict barrier island evolution to provide future (e.g., at least 50 years) morphology configurations (in the form of digital elevation models [DEMs]) to support storm surge inundation modeling. The team determined that these two objectives should be developed separately due to the simplified nature of the ICM versus the complexities involved in simulating island morphologic evolution to produce a DEM. BIMODE attempted to accomplish these goals under a single modeling effort, some of which was physics-based. While this effort produced a model framework that captured certain processes relevant to barrier island evolution, the development was complicated, and BIMODE does not attempt to simulate two important drivers of Louisiana barrier evolution: 1) tidal inlet processes and evolution and 2) lower shoreface (deeper than 2m) processes and evolution.

The barrier island models for 2012 and 2017 Coastal Master Plans are the first attempt to develop and apply barrier island models for regional-scale management applications in Louisiana. Model development is an iterative process. Some of the assumptions and simplifications in BIMODE limited its ability to reflect shoreline dynamics and these can be improved; including long-shore transport and inlet-sand bypassing. This effort in support of the 2023 Coastal Master Plan provides an opportunity to continue model advancement, build on efforts that started in support of the 2012 Coastal Master Plan and advanced in support of 2017 Coastal Master Plan, and provide a foundation for continued model improvement to support future master plans.

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LIST OF ABBREVIATIONS

BARSIM .... BARRIER ISLAND SIMULATION
BIMODE..BARRIER ISLAND MODEL DEVELOPMENT
BICM...........................BARRIER ISLAND COMPREHENSIVE MONITORING PROGRAM
BISM.. BARRIER ISLAND SYSTEM MANAGEMENT
BRIE ....BARRIER INLET ENVIRONMENT
CERC .... COASTAL ENGINEERING RESEARCH CENTER
CPRA.................................COASTAL PROTECTION AND RESTORATION AUTHORITY
DEM..DIGITAL ELEVATION MODEL
ICM..INTEGRATED COMPARTMENT MODEL
LSCB...LARGE-SCALE COASTAL BEHAVIORAL
RSLR...RELATIVE SEA LEVEL RISE RATE
SBEACH...STORM INDUCED BEACH CHANGE
SLR..SEA LEVEL RISE
SWAN .... SIMULATING WAVES NEARSHORE MODEL

1.0 BIMODE REVIEW AND EVALUATION

1.1 OVERVIEW OF THE BIMODE WORKFLOW

A practical workflow was developed for BIMODE (Poff et al., 2017) to evolve barrier islands through a model process (Figure 1) that includes shoreline evolution due to long-shore transport during quiescent conditions, sea level rise (SLR), land subsidence, storm impacts of cross-shore profile evolution, and breach formation.

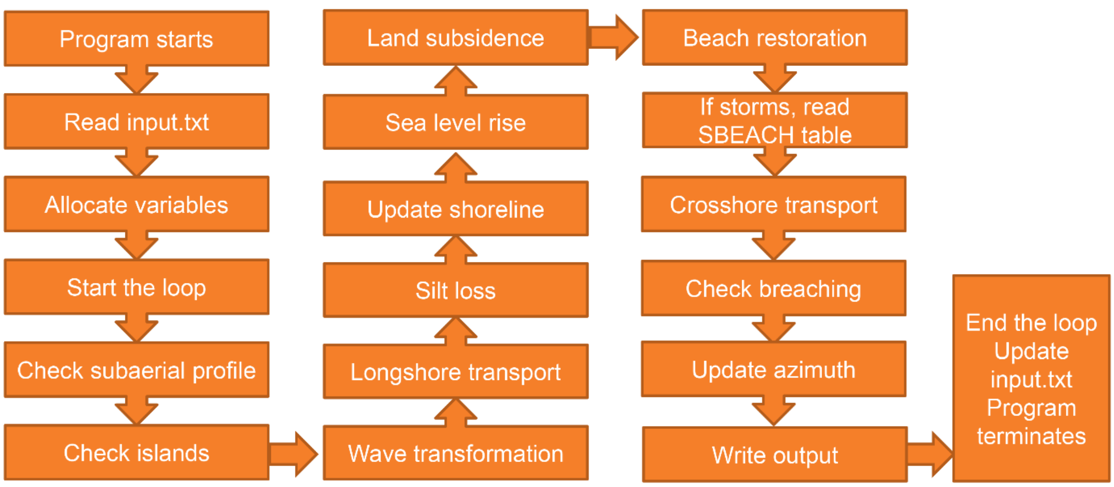

Figure 1. Flow chart illustrating BIMODE operation for 2017 Coastal Master Plan. Image from BIMODE Modeling Overview presentation, 2019-April-16.

The model workflow starts by reading all input data including barrier cross-shore profile information (initial morphology in x,y,z format; DEM) and establishing littoral cells (typically every 100 m along the coast). The model then cycles through a series of modules (loops) to identify the appropriate wave climate to force each of four BIMODE regions (see Figures 14-19 in Poff et al., 2017). Subsequently, the model checks for cross-shore profiles that cross subaerial barrier islands or associated submerged features (i.e., along spit platforms and inlets). The submerged profiles (i.e., profiles that do not intersect a subaerial barrier) are flagged to determine if long-shore transport is active. Transformed near-shore waves are stored in memory and used as needed to drive long-shore transport calculations. After determination of long-shore sediment flux corrected for silt loss, shoreline position is adjusted in a cross-shore direction (landward or seaward) to reflect either a sediment deficit or a surplus (erosional or progradational response). Profiles are then adjusted for SLR and subsidence (vertical adjustment). Because barrier island management actions were explicitly modeled for the 2017 Coastal Master Plan, the model also checks if restoration is to be implemented at each profile location. If so, profiles along the coast receiving restoration are adjusted based on the design template.

The Storm Induced BEAch CHange (SBEACH) model (Larson & Kraus, 1989) is used within BIMODE to assess storm impacts. SBEACH is a cross-shore, one-dimensional model that simulates morphologic response to a storm event based on empirically derived equations. Within each SBEACH cross-shore profile, volume is conserved. It is a widely used model applied extensively to calculate beach and dune erosion/lowering and overwash under storm wave action (Larson & Kraus 1989; Larson, Kraus & Bymes, 1990). SBEACH is used to simulate storm-induced change for idealized profiles, thereby populating a database of profile response. BIMODE uses a lookup table to predict real-world profile response by matching each actual profile and storm to be modeled against this prepopulated storm response database. After each real-world profile has been matched to an idealized profile, the cross-shore erosion (or deposition) predicted for the storm by SBEACH at each point along the profile is used to decrease (or increase) the elevation of the corresponding point in the real-world profile. This process is performed on all profiles for the entire coast. In implementing this approach, the developers of BIMODE found that certain portions of the real profiles tended to incur repeated erosion over the course of multiple storms, resulting in an unrealistic profile shape. To address this issue, they introduced small, randomized lateral shifts in aligning the real-world profiles to the idealized profiles so that the same cross-shore sections of the profile were not repeatedly eroded.

BIMODE then checks for barrier breaching based on criteria developed for CPRA's Breach Management Program (Coastal Engineering Consultants, 2015) and adjusts the shoreline angle based on results from the profile transformation routine. If a barrier meets breaching criteria, the profiles coinciding with the breach are flagged as submerged and assigned a minimum depth of 2 m. After this operation BIMODE reached the end of the workflow loop (1-month timestep), results were written in output files, and the loop was restarted for the next month. Additional information on the operation of BIMODE may be found in Poff et al. (2017).

1.1 BIMODE LIMITATIONS

A detailed investigation into the individual components of the workflow, source code, mechanics of BIMODE, and the exchange of information between BIMODE and the 2017 Coastal Master Plan ICM, resulted in identification of some important areas where the model framework should be improved. With respect to meeting the needs of the ICM, BIMODE did not have an active tidal inlet module to facilitate an increase in the cross-sectional area of inlets in response to an increase in the tidal prism. As discussed in more detail below (see Background section), increasing tidal prism at the tidal inlets is a dominant driver of barrier island evolution and sediment dynamics, primarily along the south-central coast. Likewise, it is important that inlet hydraulics and geometry are accurately represented and incorporated in the ICM due to the controls inlet hydraulics have on interior basin hydraulics and vice-versa. Another concern identified by the team is that BIMODE does not consider sediment transport processes along the middle and lower shoreface that are important to capture, especially over multi-decadal timescales. More details are provided below about how sediment transport is treated in BIMODE and attendant limitations that could be improved to achieve more realistic simulation capability.

1.2 LONG-SHORE SEDIMENT TRANSPORT IN BIMODE

The long-shore transport algorithm within BIMODE adequately simulates long-shore transport trends along coastal Louisiana. The Simulating Waves Nearshore (SWAN) model, used to transform offshore waves to breaking for use in the long-shore transport formula, was applied along four regions encompassing all barriers along the coast. One issue identified was the assumption of zero sediment bypassing between these regions. For instance, within each of those regions transport is calculated every 100 m (profile spacing) in the alongshore direction; however, at the edges of the regions, regardless of the rate, sand transport is zeroed and no bypassing was allowed. The assumption of zero bypassing at certain locations does not match observations or the current understanding of Louisiana barrier system dynamics (e.g., Jaffe et al., 1997; Miner et al., 2009a; 2009c; Georgiou et al., 2019; & Beasley et al., 2019).

Additionally, BIMODE did not permit long-shore transport to occur at depths greater or equal to 2 m. This treatment prevents bypassing across even small tidal inlets or breaches that are more than 2 m deep. Because this was the minimum depth set when the breaching criterion is reached, long-shore transport is prevented from occurring at these locations, and breaches cannot heal via infilling from long-shore transport. In reality, if sufficient sediment is available and there is an active littoral zone supplying long-shore drift, most barrier island breaches heal (Kahn, 1986; Fearnley et al., 2009).

1.3 CROSS-SHORE SEDIMENT TRANSPORT IN BIMODE

As summarized above, storm-induced cross-shore transport in BIMODE is accomplished in part through the use of SBEACH. While mass-conservative in the cross-shore dimension, SBEACH does not account for long-shore transport input, and thus sediment exchange cannot occur with nearby or adjacent profiles. If adjacent profiles have variable relief (e.g., at the terminus of barriers and spit platforms), they may be matched to different idealized profiles resulting in different patterns of erosion and deposition for the same storm. The end result is a loss of long-shore continuity. The modeled shoreline may become unrealistically jagged, requiring an alongshore smoothing filter to attain a more natural configuration. Long-shore transport occurs concurrently with cross-shore transport during storm events in natural systems, and the end result of the combination of forcing is a natural "smoothing filter".

Another potential issue with storm prediction in BIMODE is the limited number of profiles and storms used to populate the lookup table. The fewer profiles and storms in the database, the more likely it is that a given real-world profile will be repetitively matched to the same idealized profile and storm. The result is repeated erosion at the same cross-shore location. Randomly shifting (seaward/landward) the erosion/deposition did not eliminate this problem. This problem may have been exacerbated by the framework not including post-storm profile recovery, which would naturally build back portions of the shoreface and subaerial beach over time.

2.0 RECOMMENDATIONS FOR MODEL IMPROVEMENTS

Based on the team's evaluation of BIMODE, it was determined that the overall existing framework, workflow, and attendant operational code was well organized, providing a good framework to improve upon. Many of the suggested improvements herein involve better integration with the ICM and building on and adapting from previous and ongoing efforts from the barrier island/coastal morphodynamics global modeling community (Figure 2).

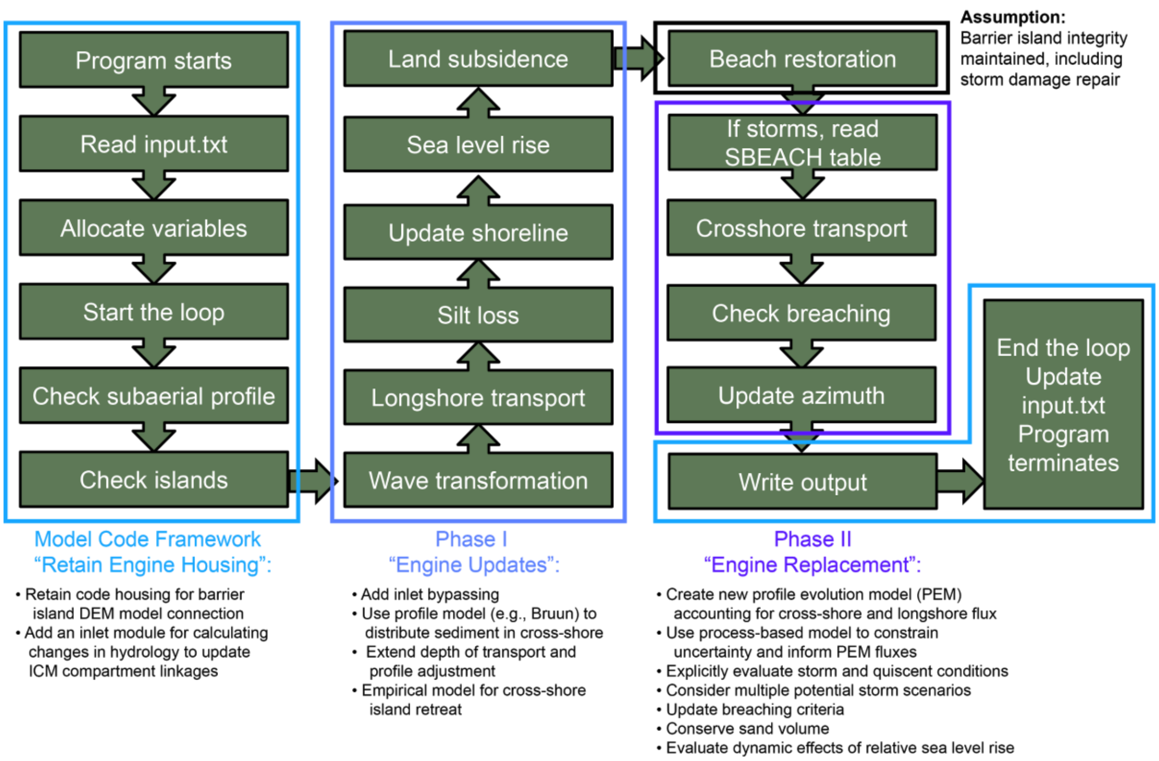

Figure 2. Suggested modifications to the BIMODE flow diagram.

The final recommendations include two parts:

1) Development of a tidal inlet module that is either fully integrated within the ICM (e.g., specialized "links") or a separate module that communicates seamlessly with the ICM and updates the ICM as inlet geometry (and hydraulic links) evolves. This simple approach will be developed on a timeline that allows for integration with the ICM (with the same timesteps). It will be fully calibrated prior to master plan future without action model runs. Throughout the

development of this inlet module, close coordination with the ICM-Hydro team will be crucial. (Note: This approach assumes dynamic equilibrium inlet morphology as a function of tidal prism; hence, if the ICM is calibrated to reproduce water levels from 2006-2018, the resulting tidal prism would be sufficiently accurate and calculation of inlet cross-sectional area response (increase or decrease), which is a derivative of the tidal prism, will be accurate. The team is not suggesting calibration of inlet morphology.)

2) Development of a morphologic evolution model that employs a modified version of the existing BIMODE workflow to update morphology-based DEMs and integrates them into a regional topobathy DEM output used for surge inundation modeling. This will be accomplished in two phases. In Phase I, a module for evolving the position of the barrier island profiles will be developed that utilizes and advances the long-shore flux, SLR, and land subsidence components of BIMODE by adding widespread inlet bypassing and extending the depth of profile evolution. Cross-shore island migration in Phase I would be predicted using an empirical approach with simple cross-shore flux (overwash and shoreface) calculations supplemented by historical trends extrapolated into the future to determine shoreface position/retreat rates. This module would replace the explicit modeling of storm events in BIMODE currently using SBEACH and lookup tables. In Phase I, the shape of the cross-shore profile will not change over time. During Phase II, which is recommended to begin concurrently with Phase I, the empirical cross-shore migration component of Phase I will be replaced with a process-based module. The Phase I profile evolution module (accounting for long-shore flux, SLR, and land subsidence) will be retained in Phase II for predicting the evolution of the barriers during quiescent conditions. The advantage of the process-based approach is that altered conditions (e.g., wave climate, storminess, sediment availability, SLR rates) can be incorporated to improve barrier response predictions. The empirical approach in Phase I is less applicable for evaluating specific responses to altered conditions, but will provide a reliable fallback in the case that development of a process-driven shoreface and shoreline evolution approach in Phase II cannot be fully accomplished in a time frame necessary to inform 2023 Coastal Master Plan planning. This will, however, continue toward meeting the long-term goal (i.e., 2023 and beyond) of a process-driven barrier evolution model to inform coastal management in Louisiana.

The reference to Phase I and Phase II above might be interpreted as two separate options. However, the model improvement team recommends that the efforts be pursued together as they are complementary. For instance, both the simplified and process-based approaches for profile evolution will utilize offshore waves (transformed to a desired location) to evaluate cross-shore fluxes, and both will require development of an alongshore/cross-shore mass balance approach. The main difference between Phases I and II is that in Phase II the shape of the cross-shore profile will change over time depending on storm forcing and the cross-shore migration rate of barrier islands can be affected by changes in relative sea level rise rate (RSLR) and storm frequency or intensity. In Phase I, profiles will only be affected by quiescent wave conditions and will migrate inshore based on historic rates, limiting the ability to predict the influence of changes in, or uncertainty associated with, RSLR rate predictions and the frequency and intensity of storms.

2.1 INLET MODULE

The most immediate need that can be addressed with a somewhat simple approach is ensuring the ICM has realistic tidal inlet processes, evolution, and feedbacks with basin hydraulics. The team proposes to implement this either within the ICM, or as an independent module that communicates directly with the ICM, given that it would rely on information from the ICM to accurately calculate tidal prism. During the 2017 Coastal Master Plan model development efforts, there was not sufficient time to incorporate the tidal inlet module previously used in the 2012 Coastal Master Plan, which computed the potential increase in tidal inlet cross-sectional area resulting from an increase in the tidal prism in the backbarrier basins. As a result, BIMODE was not able to provide the ICM with updated cross-sectional area for the inlet links. The team proposes to re-activate and further develop this routine for the 2023 Coastal Master Plan, as well as incorporate some modifications and improvements.

When the tidal prism is known, as is the case with the ICM, then the inlet can be adjusted using equilibrium relationships aimed at predicting the minimum (equilibrium) cross-sectional area of the inlet (e.g., Jarret, 1976; O'Brien, 1969), the modified form known as the O'Brien–Jarrett–Marchi law (D'Alpaos et al., 2009), or a method proposed by Larson et al. (2011). The simple O'Brien relationships implemented in the 2012 Coastal Master Plan Barrier Shoreline Morphology Model (Hughes et al., 2012) with corresponding exponents representing un-jettied Gulf coast inlets is recommended for testing and use in 2023 Coastal Master Plan, which includes the general form of the equation (shown in equation 1). For the 2023 Coastal Master Plan the team proposes to re-implement this relationship and also evaluate for adoption, a more sophisticated version of the Gulf coast version of the Jarrett-O'Brien-Marchi relationship (D'Alpaos et al., 2009):

$$A = kP^a$$

Where

$A =$ inlet cross-sectional area

$k =$ Gulf coast coefficient

$P =$ maximum tidal prism

$a =$ exponent for the Gulf coast inlets

The total tidal prism for a basin is defined as:

$$P = A_1T_1 + .. + A_nT_n$$

Where

$P =$ tidal prism for the basin (estuary)

$T =$ tidal range (m) for the n^{th} hydrodynamic cell in the basin

$A =$ area (open water) of the cell

$n =$ the number of cells which make up a given bay or estuary

This approach does neglect complex processes occurring at inlets, such as inlet migration (Miner et al., 2009a; 2009c) or the effects of antecedent geology on inlet position and geometry (e.g., Kulp et al., 2007). Regardless, the methodology proposed above, although simple, is quite powerful, can be implemented easily, and aligns with the regional-scale and computationally efficient ICM approach. Adding complexity and process-based approaches to inlet morphology is premature at this stage where the goal is to have realistic hydraulics and inlet-basin feedbacks functional in the ICM. Process-based inlet morphologic modeling requires a more holistic barrier system approach primarily because of the role of wave-associated sediment dynamics and is discussed below in the Barrier Island Digital Elevation Model (DEM) section.

In order to best represent basin hydraulic influence on tidal inlets, each inlet link in the ICM will be assigned a portion of the basin (known as the effective tidal prism for each inlet), and only those compartments will be partitioned to infer the change in the tidal prism at the inlets over the 50-year simulation period. Additional improvements would include asymmetric partitioning. For instance, as a result of marsh submergence, a backbarrier basin's open water area may become asymmetric (spatially) and more submergence may take place away from a fluvial source compared to an area close to a fluvial source. Asymmetric partitioning will allow for the re-distribution of the tidal prism increases, such that it is not distributed equally among all inlets (or links) in the ICM, which reflects a more realistic scenario at the affected inlet(s). While simple, this adjustment would be particularly beneficial for screening projects targeted to reduce or offset tidal prism and for evaluation of how different projects affect tidal prism.

Inlet stability can be assessed using a measure of velocity by using Escoffier (1940; 1977) or van de Kreeke (1990) and methods therein. Furthermore, other data such as knowledge of the ebb-jet size and structure (if known, or proxies can be developed to inform this approach), can help better establish sediment bypassing around inlets and elucidate on bypassing volumes (Kraus, 2000) for use in the barrier island DEM.

2.2 BARRIER ISLAND DIGITAL ELEVATION MODEL

PHASE I

The evolution of barrier island profiles in response to gradients in long-shore flux, SLR, and land subsidence will follow a similar approach to the one developed in BIMODE (Figure 2 – Figure 4; Poff et al., 2017). Long-shore flux along each barrier island will be calculated by applying the Coastal Engineering Research Center (CERC) equation to a derived set of average wave conditions (see Introduction). The method used in BIMODE to calculate long-shore flux will be modified to account for sediment transport across inlets (i.e., inlet bypassing) based on data and interpretations in Jaffe et al. (2007), Miner et al. (2009a; 2009 c), and Berlinghoff et al. (2019) and methods in Krauss (2002), Hughes et al. (2012), and Beck and Wang (2019). The long-shore flux into and out of each cross-shore profile of the island will then be used to calculate a sediment deficit (or surplus), which will be subtracted (or added) to the volume of sediment within the shoreface. The new volume of sediment will then be distributed across the active shoreface following the methods developed for BIMODE. However, the extent of the active shoreface will be extended to a more realistic depth of closure (~10-15 m depending on location), consistent with studies illustrating that sediment transport and resultant profile adjustment occur to these depths for the Louisiana barriers (Penland et al., 1988; List et al., 1994; 1997; Miner et al., 2009a-c; & Beasley et al., 2019).

One underlying difference in the 2023 Coastal Master Plan compared to the 2017 Coastal Master Plan is the assumption that barrier island integrity will be maintained through maintenance and restoration projects evaluated and undertaken outside of the master plan process as part of the Barrier Island System Management (BISM) program. A key implication of this decision for barrier island modeling in the 2023 Coastal Master Plan is that it can be assumed that storm damage to barrier islands will be repaired if it is substantial enough to degrade island integrity, therefore on the time-scale of the master plan, storm impacts such as breaching do not need to be explicitly modeled.

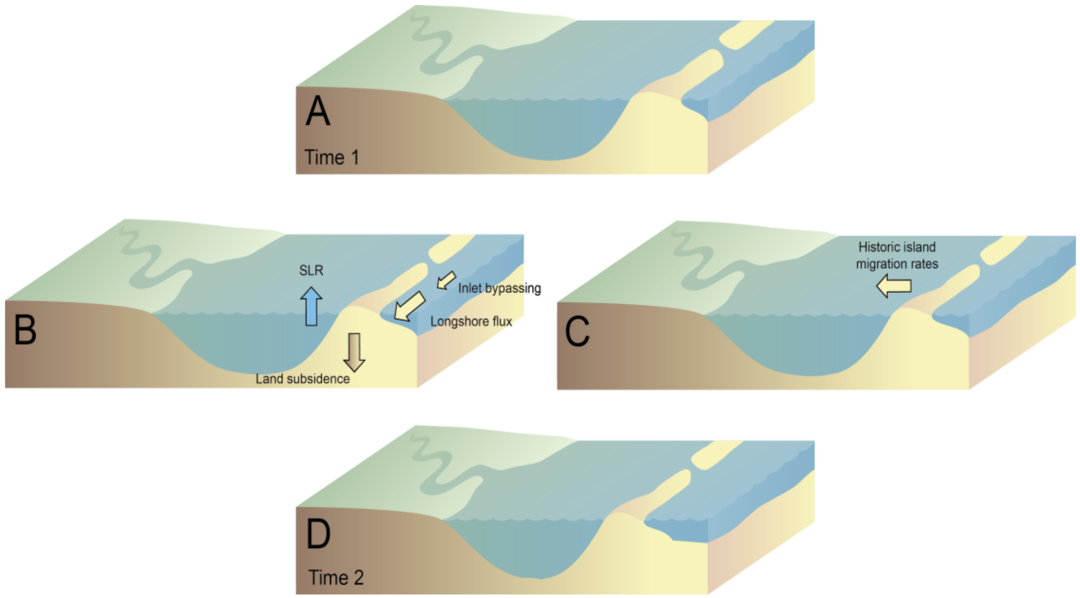

Figure 3. Conceptual diagram of barrier island evolution in Phase I. (A) DEM for a section of the coast with two barrier islands and an inlet. (B) Gradients in long-shore transport are used to calculate the sediment volume surplus or deficit for each cross-shore profile. The sediment volume surplus or deficit is used to adjust each cross-shore profile, which is then vertically adjusted in response to SLR and land subsidence. For example, the island would narrow in response to SLR and subsidence in the absence of a sediment surplus. This approach follows methods used in BIMODE for calculating island evolution during quiescent conditions, with the addition of inlet bypassing to the long-shore flux calculation. (C) Historic migration rates for each barrier island would be used to move each cross-shore profile inshore. This simplified approach removes the effects of individual storms, modeled in BIMODE using SBEACH, and is consistent with the assumption that barrier island integrity will be restored if lost during a storm event (e.g., breaches will be repaired). (D) DEM after the model timestep. Island profiles have been modified in response to long-shore flux gradients and RSLR, and moved inshore based on historic cross-shore island migration rates. Base diagram modified from symbols acquired from the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

The mechanics of the barrier island DEM model can be significantly simplified under this assumption (and Figure 4), given that the primary requirement of the modeling framework is to predict the landward island migration that would occur as a result of the combined influence of multiple storm events over time. In Phase I of model development, it is recommended that this cross-shore migration rate be derived by extending historic island migration rates into the future. Data for calibrating this empirical migration rate model would come from the Barrier Island Comprehensive Monitoring Program (BICM) and recent analysis conducted by Beasley et al. (2019). For Phase I, an empirical model calibrated to reproduce observed shoreface and shoreline response over decadal time-scales using BICM datasets is recommended. Capturing historic barrier island migration rates validated through a similar observation window (~25-50 years) will implicitly predict cross-shore response (for shoreline and shoreface), and thus the modeled barrier will respond to the combined effect of storms and RSLR. This simplified model would not predict the inland sediment flux associated with individual storm events, the effect of which would instead be averaged over the decadal scales of relevance. An advantage of this approach for Louisiana barrier systems is the availability of data assembled under BICM, List et al. (1994), and McBride et al. (1992) that capture barrier shoreface and shoreline evolution dating to the late 1800s. Because the Louisiana barriers evolve so rapidly, this dataset covering 140 years captures large magnitude of coastal change (that would be barely detectable on most stable coasts for the same time period) from which regional trends have been identified and quantified (List et al., 1994; Miner et al., 2009 a, b; Beasley, 2018; & Beasley et al., 2019) and can be incorporated to develop empirically-based predictive models for shoreface retreat (e.g., Hughes et al., 2012).

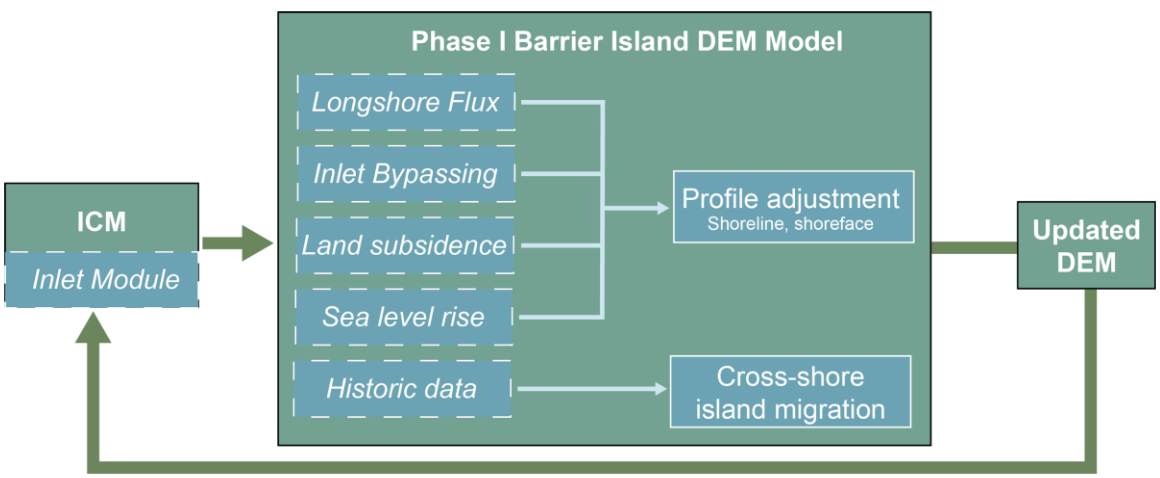

Figure 4. Flow diagram of Phase I Barrier Island DEM model.

It is recommended that the cross-shore migration model be assessed and calibrated against observations in Louisiana (e.g., BICM) using one or more cross-shore flux models that explicitly account for RSLR (e.g., those described below). Application of these models will assess the validity of the cross-shore migration model and ensure that migration rates are realistic and consistent with predicted rates of RLSR.

This hybrid approach (empirical cross-shore migration model calibrated and assessed with a cross-shore flux model accounting for RSLR) is computationally inexpensive and consistent with the assumption that barrier island integrity (i.e., subaerial footprint) will be maintained even as shoreline and shoreface retreat continues at realistic rates. For example, the new position of the barrier can be determined using the following relationship:

$$x_{new} = x_{old} + \left(\frac{dx}{dt}\right) * t$$

where, x_{old} is the old barrier position; x_{new} is the new barrier position; dx/dt is the cross-shore migration rate; and t is time.

The term dx/dt can be subdivided into an actual rate $(dx/dt)_H$ informed by historic rates, and a fluctuating $(dx/dt)'$. Recognizing that historical rates may exhibit unrealistic response to SLR except those experienced over the record of change the team proposes to improve these predictions by using a cross-shore sediment flux model to independently calculate $(dx/dt)'$, including conditions of higher SLR to provide a framework for determining uncertainty resulting from SRL such that:

$dx/dt = \alpha(dx/dt)_H + \beta(dx/dt)'$

The α and β terms in the above equation are weighting coefficients (i.e., sum to a total of one) to control the relative contribution of the historic and modeled rates of cross-shore island migration to the overall rate used in predicting barrier island evolution. These factors cannot be known with certainty for future conditions. Therefore, they will need to be selected during model development based on, for example, evaluation of the skill of the predictive model in simulating Louisiana barrier island evolution (e.g., hindcast application and assessment at one or more test sites, if time allows). Alternately, the uncertainty associated with calibration of these parameters may be quantified using sensitivity testing, noting that the modeled rates may ultimately be found to be similar to historic rates during model development.

Examples of cross-shore models that might be modified for the Louisiana barriers and incorporated as part of Phase I can be found in Lorenzo-Trueba and Ashton (2014), Nienhuis and Lorenzo-Trueba (2019), and/or an improved version of Hughes et al. (2012).

Lorenzo-Trueba and Ashton (2014) present a cross-shore model that includes shoreface flux and overwash with variable boundary conditions (e.g., SLR). The barrier is divided into three segments bounded by the shoreface toe, shoreline, and backbarrier face. Each dividing point changes position at an independent rate, allowing the segments to prograde or transgress with time. Under dynamic equilibrium, the dividing points all move at the same rate, remaining static relative to each other. The shoreface flux is driven by the difference between the shoreface slope and the equilibrium shoreface slope; this difference is scaled by a site-specific shoreface response rate constant (which for their study was informed by the New England coast). The overwash flux is calculated from the deficit volumes in the top- and backbarrier and is scaled by the maximum volume of overwash determined for the site. Overwash only occurs when the barrier width and height are below a set critical value. In its current state, individual storms are not modeled, and storm impacts are only considered through maximum volume of overwash. Long-shore transport is not considered, but this can be addressed by running this model for multiple cross-shore profiles and linking them via long-shore transport, as done by Komar (2002), Palermo et al. (2019), and Nienhuis and Lorenzo-Trueba (2019). *Model Inputs:* Initial profile elevations (shape), location of sea level, sediment characteristics (spatially constant), maximum expected overwash volume (derived from dune height and wave climate), SLR rate, subsidence, wave climate. *Model Outputs:* final profile shape and cross-shore sediment flux.

Nienhuisand and Lorenzo-Trueba (2019) present the BarrieR Inlet Environment (BRIE) model, which they describe as a "Large-Scale Coastal Behavioral (LSCB)" model (de Vriend et al., 1993). BRIE models long-shore and cross-shore sediment fluxes. The cross-shore fluxes are calculated at separate profiles along the barrier using the cross-shore model presented in Lorenzo-Trueba and Ashton (2014) with a slight modification. This version allows for fine sediment deposition in the backbarrier. Similar to the approach employed for 2012 and 2017 Coastal Master Plan barrier models (Hughes et al., 2012; Poff et al., 2017), the CERC formula (USACE, 1984) is used to calculate sediment transport alongshore and into tidal inlets; this formula is a function of shoreline orientation, as well as wave height, period, and direction. Simplified inlet dynamics and cross-shore fluxes are coupled through long-shore transport using a non-linear diffusion equation (Ashton & Murray, 2006; Crank & Nicolson, 1947), which depends on wave energy and direction. It should be noted that in the south-central Louisiana barrier setting the rapidly expanding tidal prism and inlet dynamic response would be treated separately as described above. *Model Inputs:* Initial shoreline position, barrier width and height, shoreface slope, location of inlets. *Model Outputs:* final shoreline position, barrier width and height, shoreface slope, location of inlets, cross-shore sediment flux.

The proposed Phase I approach is easy to implement and would retain the existing ICM housing and model linkages (Figure 2 and), with targeted improvements focused on addressing key areas of BIMODE including: 1) adding inlet bypassing; 2) adjusting the cross-shore profile to be more realistic by accounting for profile adjustments at lower shoreface depths; and 3) developing a method for predicting the average cross-shore retreat rate of barriers on the 50-year time scale of master plan modeling independent of the influence of individual storm events.

The Phase I modeling approach does have several important limitations, however, including:

- Sand volume nourishment needs due to storm impacts or island evolution resulting from longer time-scale processes cannot be predicted or evaluated.
- Short-term impacts of storm damage cannot be holistically assessed (e.g., potential feedback mechanisms between direct marsh impacts during storms and

simultaneous loss of barrier island integrity).

- Dynamic effects of SLR on barrier islands cannot be assessed. For example, an increase in SLR may shift the cross-shore sediment transport direction for some storms from offshore (due to berm and dune erosion) to onshore (due to overwash and inundation). The cumulative effect of these types of changes on multiple storm events may alter the cross-shore migration rate from its historic value, which cannot be captured with the Phase I empirical framework.
- Island/inlet/nourishment interactions cannot be evaluated (e.g., increased long-shore transport of a restored island changing inlet dynamics and/or bypassing rates).
- System sand volume is only loosely conserved (i.e., the model will be evaluated for realistic island response, while not strictly enforcing conservation).
- If the assumption of barrier island integrity maintenance does not hold (e.g., due to insufficient funds) and/or the time-scale of maintenance is insufficient to prevent negative impacts to the marsh prior to restoration, the impacts cannot be reasonably modeled.

PHASE II

Several of the limitations of the Phase I model development will be addressed through the development of a more comprehensive, process-based model of island evolution developed in Phase II, which can be started concurrently with Phase I. In the Phase II barrier island DEM model, long-shore and cross-shore fluxes under quiescent and storm conditions will be used simultaneously to evolve the island profile, evaluate the potential for breaching, and holistically evolve the islands and inlets (Figure 5and Figure 6). This approach allows for the impacts of a wider range of barrier island responses to be resolved, such as the impact on the DEM and associated hydrodynamics if factors such as cost inhibit the ability of restoration efforts to preserve the integrity of the islands (Figure 7

For Phase II, the cross-shore migration of barrier islands will be predicted by incorporating barrier island response to storms, refining the approach taken in the 2017 Coastal Master Plan with BIMODE.

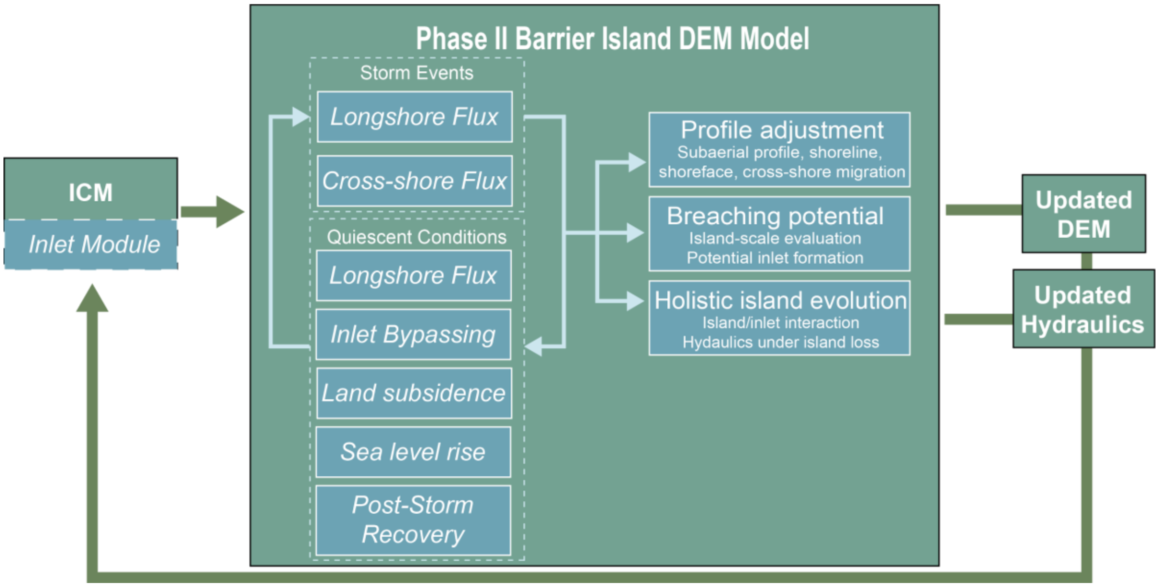

Figure 5. Flow diagram of Phase II Barrier Island DEM model. This model methodology predicts the impacts of individual storm events and allows for the barrier island and associated inlets to be holistically evolved. In this manner, both the DEM and the associated hydraulics can be simultaneously updated, including for cases where the barrier island is not or cannot be maintained due to timing or budget constraints (i.e., barrier island loss).

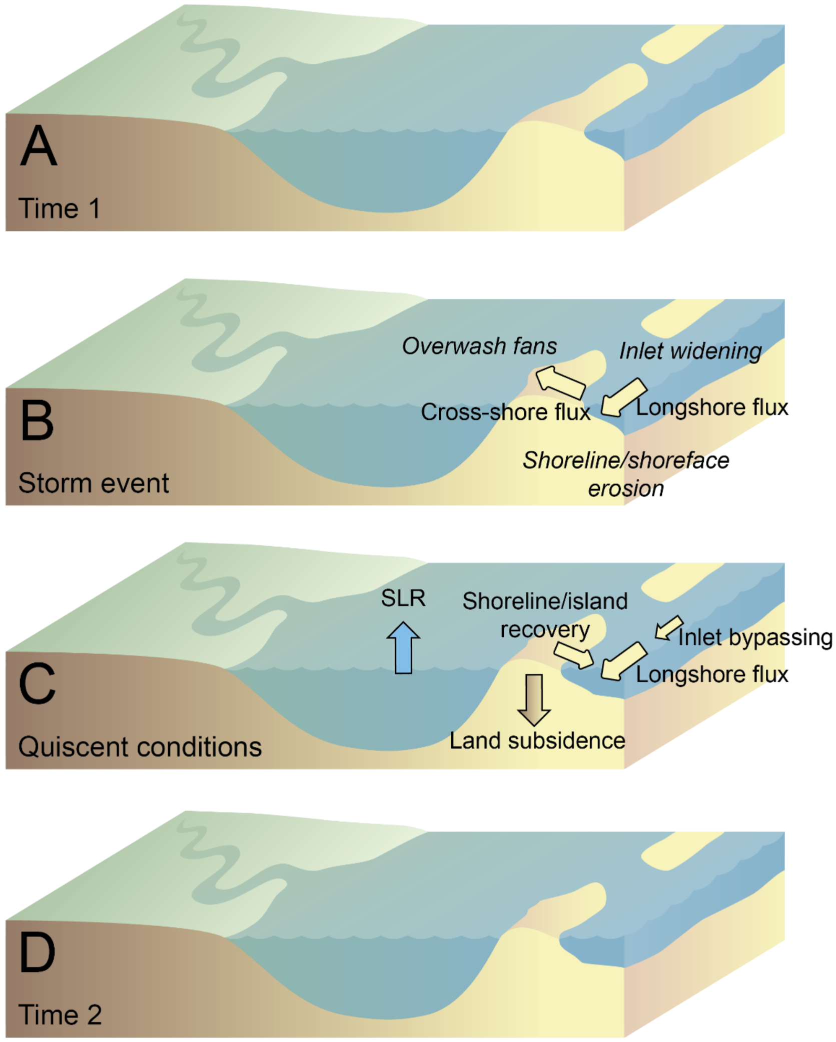

Figure 6. Conceptual diagram of barrier island evolution in Phase II. (A) DEM for a section of the coast with two barrier islands and an inlet. (B) Long-shore and cross-shore sediment flux during storm events is explicitly modeled leading to, for example, overwash fans, shoreline and shoreface erosion, and widening of inlets. The resultant changes in inlet configuration are captured and provided to the inlet module. (C) During quiescent conditions, gradients in long-shore transport along with SLR and land subsidence are used to evolve the cross-shore profiles, similar to Phase I. In addition, post-storm recovery processes are empirically modeled. (D) DEM after a storm/recovery cycle. Island profile shape has been modified in accordance to long-shore flux gradients and RSLR, in addition to the impacts of storms. Inshore island migration is captured through cross-shore transport during storm events, which also accounts for SLR (included in modeling of quiescent conditions). Base diagram modified from symbols acquired from the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

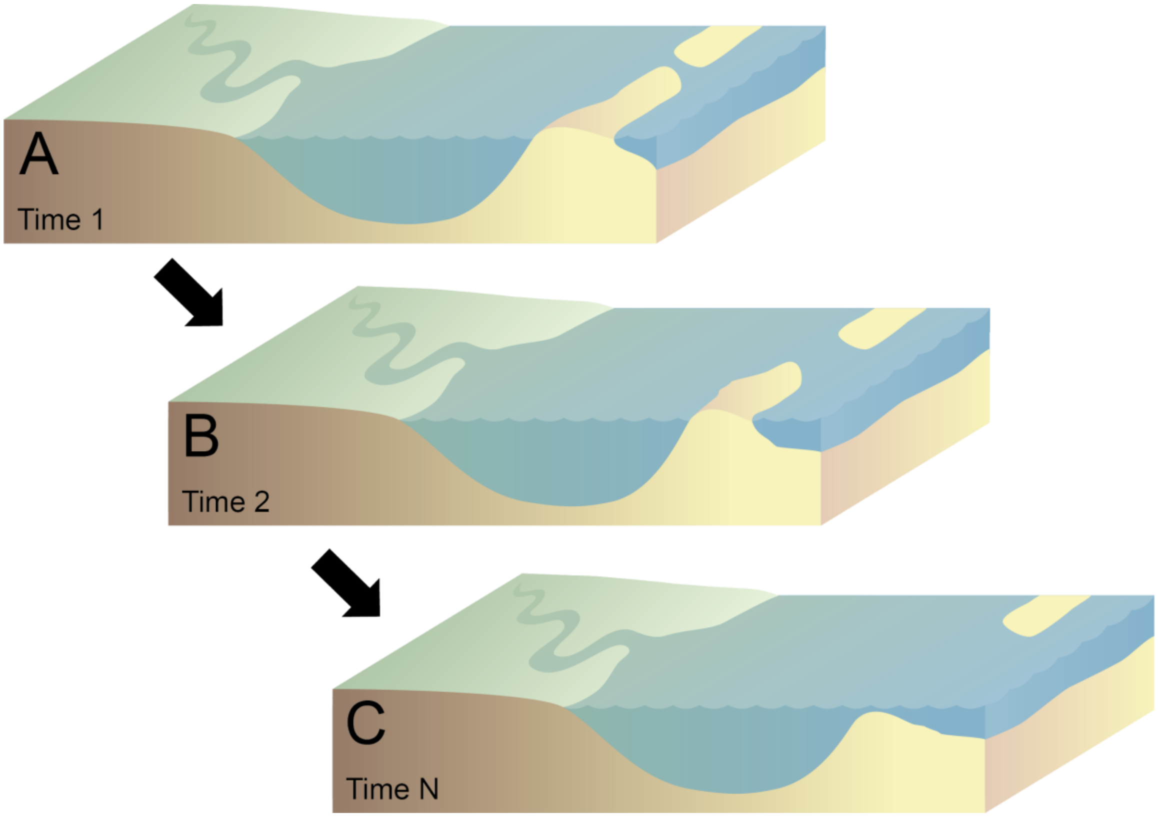

Figure 7. Conceptual diagram of barrier island evolution in Phase II after multiple moderate to extreme storm events, removing the assumption that barrier island integrity will be maintained. (A) DEM for a section of the coast with two barrier islands and an inlet. (B) Modeled island state after the single storm event shown in Figures 5-6. (C) Modeled submerged shoal after multiple storm events if there is insufficient natural sediment supply or restoration action to maintain barrier island integrity. The changes in hydrodynamics associated with the loss of the barrier island can be captured through the link to the inlet module. Base diagram modified from symbols acquired from the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

BARRIER ISLAND EVOLUTION DURING STORM EVENTS

Long-shore and cross-shore sediment transport during storm events will be modeled using a framework developed from existing deterministic numerical models. The Phase II modeling approach would resolve several of the aforementioned limitations of the Phase I approach and allow for a much wider range of future scenarios to be considered, including variation in storm forcing and missed or deferred maintenance of island integrity. Examples of process-based models that might be modified and adapted under Phase II to address profile adjustment include Cowell and Kinsella (2018), Ortiz and Ashton (2016), and Storms et al. (2002; 2003).

Analysis from energetics-based approach to shoreface sediment transport reveals that the sediment grain-size influences the slope of the equilibrium profile, as Dean (1993) suggested, and not the depth of closure; the depth of closure depends on the wave height and period among others (Ortiz & Ashton, 2016; Hallermeier et al., 1981). Ortiz and Ashton (2016) showed that with this approach, storm events can be weighted by their impact on sediment transport in addition to their frequency of occurrence. Their results emphasize the influence of infrequent but large storms on shoreface dynamics. *Model Inputs:* Initial profile elevations (profile shape), sediment characteristics, position of sea level along the profile, wave height, wave period, fall velocity for sediment size. *Model Outputs:* final profile elevations defining the shape of the profile.

Storms et al. (2002) studied the specific impacts of sediment supply, grain size distribution, and substrate slope on the morphodynamic evolution of barriers to develop the Barrier Island Simulation (BARSIM) model. BARSIM was designed to predict response of barrier systems to longer-term geologic time-scales, taking into consideration the long-shore transport gradients (as a proxy for updrift sediment supply), SLR, subsidence, wave climate and variable grain size sediment transport. Some adjustments to BARSIM are needed for applications to shorter time-scales (e.g., 50 years). The team has been working with BARSIM developers and practitioners to update the model for application to the Louisiana barriers. At the centennial to millennial scale of interest in Storms et al. (2002), the model predicted reasonable migration rates for barrier islands, after it was validated for the Dutch coast. Furthermore, the ability to include multiple sediment classes in the simulation is a positive attribute, which helps elucidate subsequent controls on shoreface evolution. *Model Inputs:* Initial profile elevations, initial distribution of sediment characteristics along the profile - if variable, position of sea level along the profile, depth of wave base and slope of the substrate (from lower shoreface toe to backbarrier). *Model Outputs:* final profile elevations defining the shape of the profile, distribution of grain-sizes along the profile.

Cowell and Kinsella (2018) applied a modified version of BARSIM (Storms et al., 2002) to investigate the influence of SLR rates and substrate slope on shoreface evolution. They reported that the middle and lower shoreface exhibited greater sensitivity to changes in SLR and substrate slope, often of the order of several meters of change in the vertical, than did the upper shoreface. Lower shoreface behavior forced upper shoreface and shoreline response. These findings are important because, as previously discussed, mid-to-lower shoreface processes and evolution had previously been ignored in BIMODE, and historical data for Louisiana's barriers demonstrate significant changes along the lower shoreface over decadal timescales. This also has significant implications of the volume of sand released from the lower shoreface during transgression, the quantity available to benefit the barrier, and the impact of the lower shoreface on inducing shoaling for storm waves.

For Phase II, it is recommended (following testing) to use either BARSIM, a modified Ortiz and Ashton

(2016) model, or equivalent to serve as the cross-shore engine. The adopted model, would utilize input from the long-shore transport engine currently available in BIMODE, compute cross-shore fluxes, and adjust the cross-shore profile accordingly. Abundant grain size data are available for the shoreface (e.g., Dreher et al., 2008; Kulp et al., 2017; Georgiou et al., 2018) that will be utilized. A mass-balance approach should be implemented to ensure that all cross-shore profiles interact with their neighbors and utilize long-shore transport gradients in the mass balance (e.g., Palermo et al., 2019). Using mass-balance (locally) and sweeping through the entire domain (entire coast) in this phase, both long-shore and cross-shore fluxes will be utilized to calculate the retreat rate. This approach allows inclusion of explicit or probabilistic storms. Lastly, this approach may be efficient enough to be tested and included at a daily timestep, which would then allow for semi-empirical recovery from storms to be included.

The modeling approaches that are recommended for the 2023 Coastal Master Plan do not explicitly include the impacts of storms on the subaerial barrier island (e.g., upper beach, berms, and dunes); however, consideration of these impacts is beyond the reasonable scope of effort for Phase II of 2023 Coastal Master Plan modeling. The framework being recommended for the 2023 Coastal Master Plan would build on the BIMODE approach and allow incorporation of these processes in future efforts (e.g., under the BISM program). For example, the look-up table approach used by BIMODE could be replaced with a probabilistic model framework that predicts storm response based on idealized model simulations that incorporate cross-shore and long-shore transport during storm events using a deterministic model such as XBeach (Roelvink, 2009). This approach would allow consideration of the combined direct and indirect impacts of storms on interior marsh areas and for the sand volumes needed to preserve island integrity under different combinations of storms and RSLR to be calculated. While explicitly modeling the response of the subaerial barrier island to individual storm events is important for predicting the evolution of individual restoration projects in particular, including these processes is not as relevant when predicting the evolution of the barriers on 50-year time scales. It is therefore recommended to focus on the shoreline and shoreface evolution (Phase II model development) in response to storms and quiescent conditions for the 2023 Coastal Master Plan.

BARRIER ISLAND EVOLUTION UNDER QUIESCENT CONDITIONS

The module developed under Phase I to predict the profile evolution due to gradients in long-shore flux, SLR, and land subsidence will be incorporated into Phase II to predict the evolution of the barrier islands during quiescent conditions, with one modification. Because storm effects are being modeled in Phase II, the recovery of the barrier island (e.g., relaxation of the profile from the post-storm state) must also be captured. The models recommended for Phase II of the modeling framework for evolving the shoreface (e.g., Ortiz & Ashton, 2016) focus on the decadal scale evolution of the barriers and should, therefore, implicitly include the impacts of post-storm recovery. However, the validity of this assumption should be assessed and refined as needed during model development and calibration (i.e., with evaluation against historic barrier island shoreface evolution).

As previously discussed, one potential future modification of the barrier island modeling approach beyond Phases I and II of the 2023 Coastal Master Plan would be the explicit modeling of individual storm events. If and when this approach is pursued (i.e., advancement of the storm-response modeling used in BIMODE), post-storm recovery would also need to be explicitly accounted for. An example of a methodology that could be considered is using a process-based model that predicts coastal evolution including recovery processes (e.g., Cohn et al., 2019) to develop a database of idealized profile responses. This database could then be used with either a look-up table or a probabilistic model framework (e.g., Gutierrez et al., 2011; Plant et al., 2014; Plant et al., 2016) to predict the recovery of barrier island profiles over the decadal time-scales of interest to the master plan.

3.0 BACKGROUND

LOUISIANA BARRIER ISLAND SYSTEMS

Coastal Louisiana barrier systems are a product of the delta cycle, which involves a regressive stage of delta building and a transgressive component where marine processes rework abandoned delta lobes (Figure 8; Penland et al., 1988; Roberts et al., 1997; Coleman et al., 1998). Marine reworking of the relict delta lobes drives large scale coastal behavior manifested by processes such as coastal straightening (sensu Swift 1975; Figure 8). This is unique relative to more stable, straighter coasts and must be considered when attempting to model and manage these barrier systems (Miner et al., 2009a).

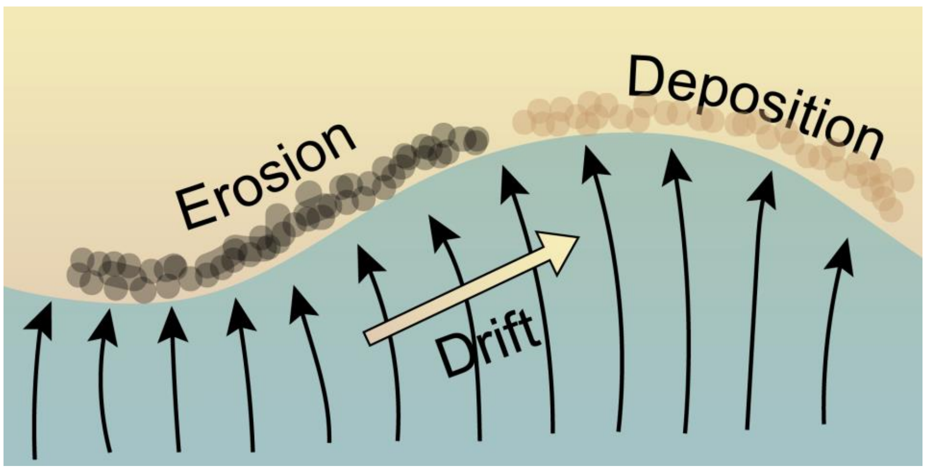

Figure 8. Conceptual representation of coastal straightening. Wave-refraction pattern with wave approach normal to the coast. Modified from Swift (1975).

The transgressive reworking of delta lobes and development of barrier systems is summarized in a three-stage conceptual model proposed by Penland et al. (1988; Figure 9). After fluvial abandonment of a major distributary, wave and tidal currents rework and laterally distribute sands originally deposited proximal to the distributary, forming erosional headlands with flanking barrier islands (Stage 1; Penland et al., 1988). The Caminada Headland and flanking barrier islands (Grand Isle to the east and the Timbalier Islands to the west) represent a Stage 1 system. Increasing wave and tidal scour in the backbarrier forces mainland detachment and development of transgressive barrier islands (Stage 2). Shoreface ravinement and lateral sand transport away from the original fluvial depocenter with redeposition as spit platforms at the flanks of the barrier chain forces coastal straightening and depletes sand available for the system. Ultimately, shedding barrier sand to deepwater sinks makes it difficult for the barrier island to maintain exposure in a regime of rapid RSLR, forcing transgressive submergence (conversion to a Stage 3 inner shelf shoal; Penland et al., 1988).

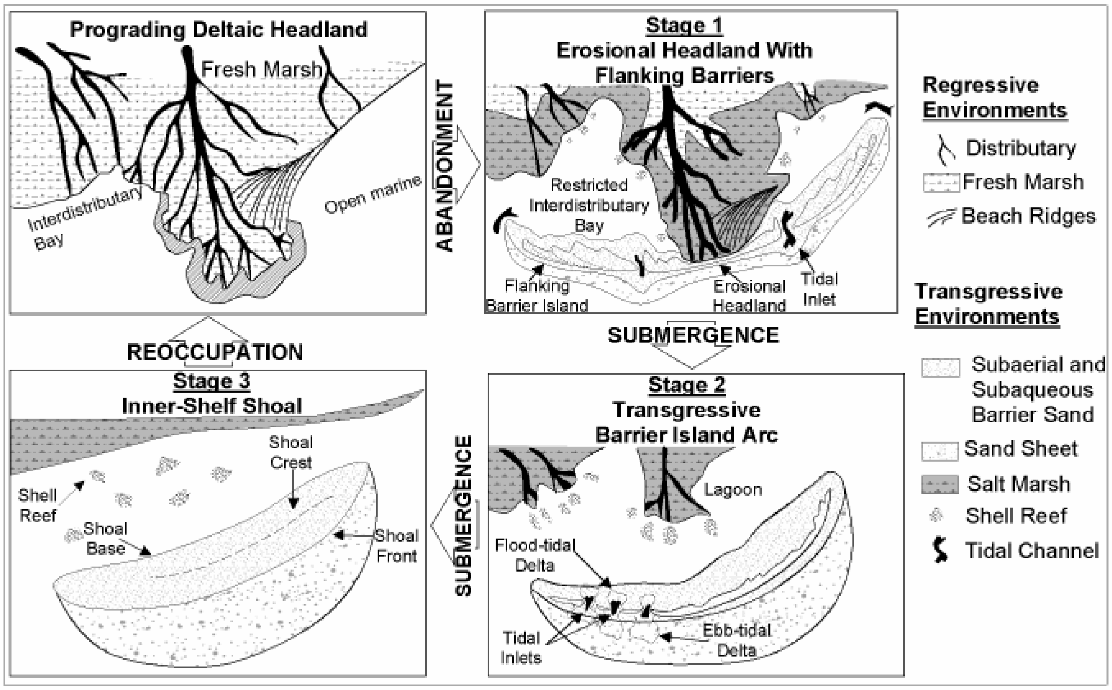

Figure 9. Three-stage model conceived by Penland et al. (1988) for the formation and evolution of transgressive Mississippi River delta barrier islands. Deltaic abandonment results in the formation of a Stage 1 erosional headland with flanking barriers separated by tidal inlets, followed by mainland detachment and the formation of a Stage 2 transgressive barrier island arc. Sand loss and RLSR results in transgressive submergence and the formation of an inner-shelf shoal. From Kulp et al. (2005) modified from Penland et al. (1988).

Tidal inlets comprise an important component of the barrier and overall estuarine system by facilitating water, sediment and nutrient exchange between the backbarrier environment and coastal ocean (e.g., Ranasinghe et al., 2013). The inlet size is maintained by tidal currents by removing wave-deposited sand, leading to the development of ebb- and flood- deltas seaward and landward of the inlet throat, respectively (Hayes, 1980 & FitzGerald et al., 1984). This volume of water that moves through the inlet over a tidal cycle is called the tidal prism. O'Brien (1969) reported that inlet cross-sectional area positively correlates to the tidal prism, a statement also supported by Jarret (1976) and D'Alpaos et al. (2007). Walton and Adams (1976) reported that the volume of sand comprising the ebb tidal delta also correlates with the tidal prism. Therefore, loss of interior wetlands increases tidal prism and facilitates enlargement of the ebb delta and the inlet throat (FitzGerald et al., 2007; Miner et al., 2009a). The increasing water levels in the basin reduce frictional damping of the tidal wave, thus increasing the backbarrier tidal range, which further augments the tidal prism (Gehrels et al., 1995; Howes, 2009). Simultaneously, the expansion of the ebb-tidal delta may hinder the amount of sand bypassing the inlet through long-shore transport, decreasing local sediment supply to the downdrift barrier and hastening the transition to a transgressive island chain (FitzGerald et al., 1984 & FitzGerald et al., 2007). The inference here is that as the tidal prism increases, ebb-delta sediment trapping efficiency increases, reducing inlet-sediment bypassing because more is retained in the ebb tidal delta.

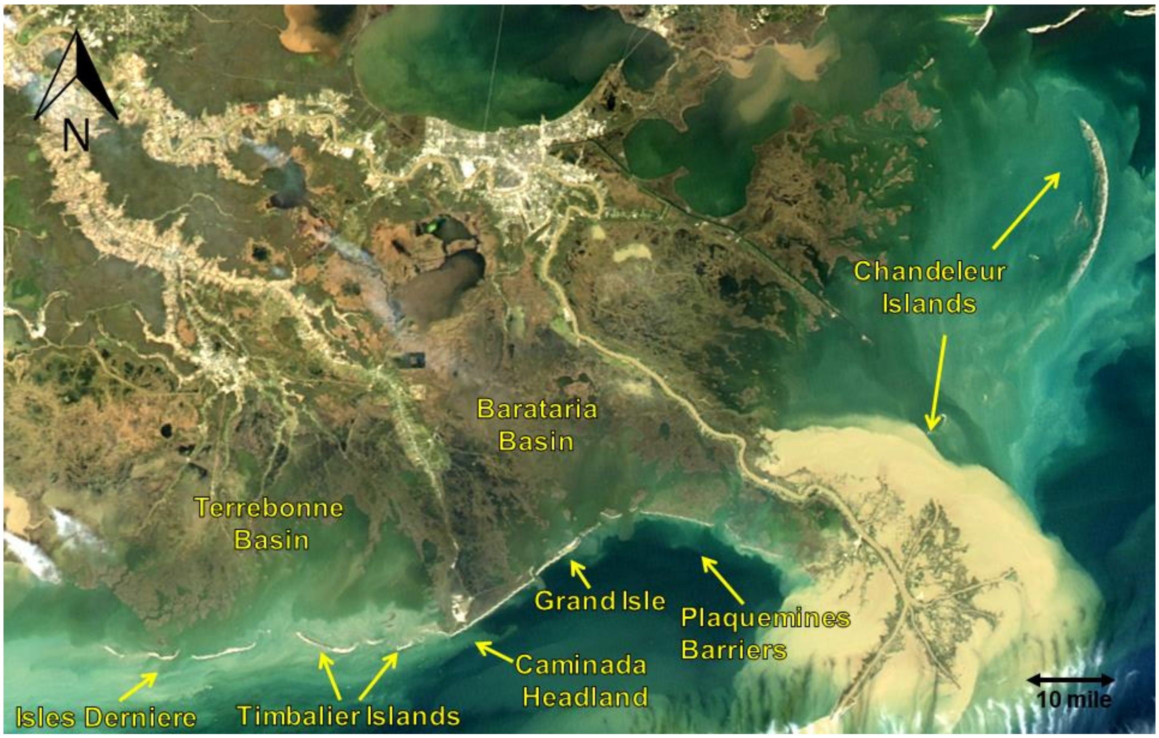

Figure 10. Louisiana barrier island systems. Image source: NASA 2002.

Louisiana barrier systems in different evolutionary stages (see Penland model Figure 9) have different governing parameters. The south-central Louisiana barrier coast fronting Terrebonne and Barataria Basins (Figure 10) is primarily in the erosional headland/flanking barrier islands stage. It is controlled by processes related to marine reworking of abandoned deltas: 1) tidal inlet response to expanding tidal prism associated with interior wetland loss and 2) coastal straightening as headlands are reworked by shoreface retreat with sand being distributed laterally to the flanks (List et al., 1997; Miner et al., 2009a; Beasley et al., 2019). These processes result in sand being removed from the subaerial barrier island system and stored at ebb tidal deltas and coastal bights or transported out of the system (e.g., offshore, downdrift deepwater sinks, or inshore). The resulting deficit in coastal sand supply controls barrier evolution along this sector of coast (instead of RSLR alone; List et al., 1997; Miner et al., 2009a). This large scale reworking of an abandoned headland represents a far more complex scenario than is contemplated in many existing coastal sediment transport and morphological evolution models (e.g., Larson & Kraus, 1989; CERC, 1984; Moore et al., 2010). For example, cross-shore models either do not consider long-shore sediment flux or accept constant sediment flux as input. However, long-shore sediment flux along a headland varies due to curvature, requiring a non-constant sediment input for a cross-shore model, which presents a challenge unless multiple transects are considered (e.g., Beasley et al., 2019). Further complexities arise because sediment sourced from shoreface erosion (to depths >15 m) is dominantly fine-grained relict deltaic deposits (~15% sand) and is exported from the barrier-shoreface system to distal ebb tidal deltas, the shelf, and inshore to the marsh surface resulting in a net sediment deficit of >1 billion m3 of sediment per century (Miner et al., 2009a).

The southeastern Louisiana coastal zone includes the Chandeleur Islands barrier chain, representing remnants of the St. Bernard delta complex (fluvial abandonment ~1,800 yrs BP; Frazier, 1967), that are separated from the mainland marsh by the ~40 km wide Chandeleur-Breton Sound. In this Stage 2 barrier island system (sensu Penland et al., 1988, Figure 8), the island chain is not segmented by large tidal inlets typical of the younger south-central coast barrier systems. Instead, tidal currents primarily flow through deep, broad troughs around the flanks of the island chain. The Chandeleur Islands are also suffering from a large sand deficit; however, it is due to sand being lost to deepwater sinks at the flanks of the island chain instead of being sequestered at ebb tidal deltas (Miner et al., 2009b; Georgiou & Schindler, 2009). Because these islands are removed (temporally) from the headland-detachment process, they no longer effectively scour relict deltaic sands. Instead, they scour existing barrier deposits that are encountered during shoreface retreat; essentially, the only sand available must be recycled from within the barrier system. Sand loss via long-shore transport to deepwater sinks has led to a long-term reduction in island area. The majority of the southern Chandeleur Islands have already converted to shoals and are characterized by wave-generated sediment transport processes associated with shoal behavior (where cross-shore transport dominates) instead of barrier shoreline processes (where long-shore transport dominates; Miner et al., 2009b; Figure 11).

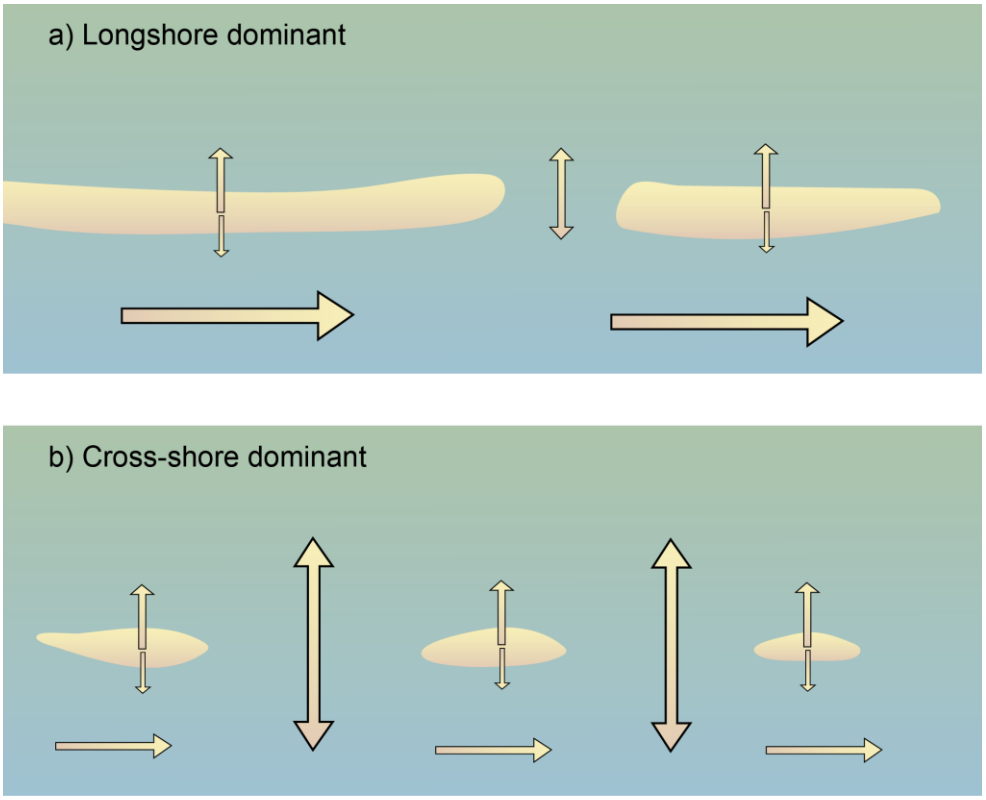

Figure 11. Conceptual representation of long-shore dominant (a) and cross-shore dominant (b) coastal systems; arrows indicate the relative magnitude of sediment transport.

IMPLICATIONS FOR MODELING BARRIER ISLAND EVOLUTION

Considering the drivers of barrier island geomorphic evolution along the Louisiana coast described above, three important factors should be considered on a system-wide scale for predictive models developed to inform management decisions: 1) expanding inlet tidal prism; 2) shoreface erosional processes and products; and 3) barrier island system sand budgets. The dominance of tidal prism dynamics on barrier evolution is related to the magnitude and patterns of interior wetland loss requiring communication between the barrier island system (tidal inlets) and interior wetland components of a regional model. Shoreline retreat and attendant shoreface erosion that occurs to depths >15 m offshore must also be considered due to implications on sediment flux, wave behavior, and barrier position/coastline configuration.

Modeling barrier island evolution for management timescales (e.g., 50 years) is difficult, partially because of variable response to short-term events (storms) that might dominate the long-term evolution. In Louisiana, because barrier system evolution is related to disintegration of abandoned delta lobes, the coast is out of equilibrium relative to the regional wave climate which drives coastal straightening over time (Figure 12). Therefore, a regional perspective that considers large-scale landscape responses is important in developing 50-year predictions of the evolution of these systems. Empirically-based predictive tools that were developed and tested on more stable, straighter, and sandier coasts are often not directly applicable for modeling Louisiana barrier systems. An important path forward is to improve the ability to simulate and predict cross-shore dynamics (through both overwash and shoreface evolution processes), especially along the mid to lower shoreface where infrequent events drive change that affects the entire profile. On more stable "mature" coasts a challenge arises due to limited observational data available because of timescales necessary to document change that is extremely infrequent. This is due to a simple relationship between depth and wave energy: waves interact less with bed sediment in deeper conditions, such as the lower shoreface, as compared to shallower conditions on the upper shoreface (Cowell & Kinsella, 2018). With less interaction, there is a slower response time to changing conditions, such as SLR. If the timescale of interest is shorter (i.e., decades), changes in the lower (i.e., deeper) segments of the shoreface may not be apparent. However, the timescales over which Louisiana barriers evolve are much faster, and lower shoreface evolution over multi-decadal to century timescales has been well documented and quantified (e.g., List et al., 1994; 1997; Miner et al., 2009 a, b; and Beasley et al., 2019).

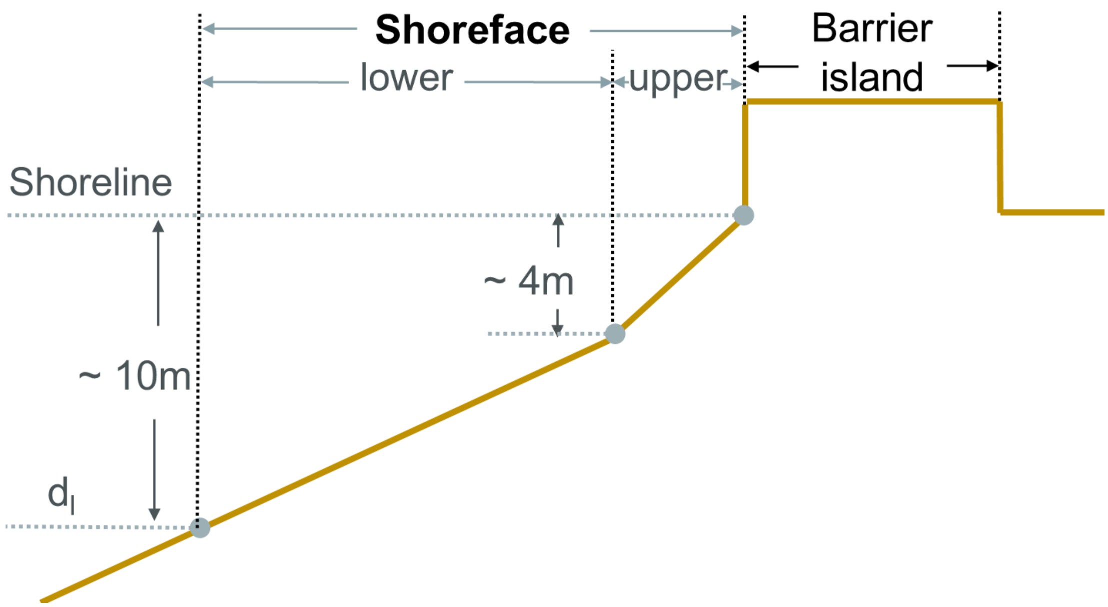

Figure 12. Idealized cross-shore profile for barrier islands and shoreface showing upper/lower shoreface slopes (from Beasley et al., 2019).

Shoreface evolution can be thought of in terms of a balance between sediment supply and volume available for sediment deposition (i.e., accommodation space or deficit volume). Understanding forcings and magnitudes of creation or filling of accommodation space along the lower shoreface is important to predict shoreface evolution and overall shoreline change (Cowell & Kinsela, 2018). Energetics-based, empirical, and lumped-parameter models have been developed to study shoreface dynamics and progress the ability to predict barrier island response to SLR, alterations in sediment supply, and storm frequency and magnitude. Recommendations provided earlier in this document involve adapting approaches such as these to improve master plan modeling capabilities.

4.0 SUMMARY

As previously mentioned, all modeling approaches require simplifications based on computational feasibility, time constraints on model development and implementation, state-of-the-science in understanding of natural processes, and current best practice in model application. A comparison of the BIMODE approach used in the 2017 Coastal Master Plan with the two-phase approach recommended for the 2023 Coastal Master Plan and beyond is shown in Table 1.

Table 1. Summary of the different processes captured in the proposed Phase I and Phase II components of barrier island modeling for the 2023 Coastal Master Plan (and beyond), along with the 2017 Coastal Master Plan BIMODE approach.

QUIESCENT CONDITIONS	*INCLUDES SLR*	*INCLUDES SUBSIDENCE*	*EVOLVES UPPER SHORELINE DUE TO LONG-SHORE PROCESSES*	*EVOLVES UPPER SHOREFACE DUE TO LONG-SHORE PROCESSES*	*EVOLVES LOWER SHOREFACE DUE TO LONG-SHORE PROCESSES*	*ACCOUNTS FOR INLET BYPASSING*	*MIGRATES ISLANDS INSHORE*
BIMODE							IMPLICIT: VIA STORMS
PHASE I							
PHASE II							
STORM CONDITIONS	*RESOLVES STORM IMPACTS*	*INCLUDES STORM LONGSHORE TRANSPORT*	*ACCOUNTS FOR STORM RECOVERY*	*ALLOWS ASSESSMENT OF THE IMPACT OF VARIATION IN STORMS, SLR*	*COMPLEXITY OF DEVELOPMENT*		
BIMODE					RELATIVELY HIGH		
PHASE I					RELATIVELY LOW		
PHASE II					RELATIVELY HIGH		

The key aspects of the Phase I modeling approach are that it adds inlet bypassing and evolution of the lower shoreface; capitalizes on existing components of BIMODE (effective linkage to ICM; inclusion of SLR and land subsidence, and evolution of the upper shoreface and shoreline); and is relatively straightforward to implement. The Phase I approach has several limitations that will be resolved in Phase II, however, namely that it (a) cannot explicitly account for variability in SLR or storm frequency/intensity in altering the inshore island migration rate and (b) cannot consider what the evolution of the barrier islands might be if integrity cannot be maintained as planned. Phase II builds upon both the Phase I approach (addition of inlet bypassing, evolution of the lower shoreface) and the storm-inclusive modeling approach of BIMODE, while advancing several aspects of the 2017 Coastal

Master Plan framework that constrained its ability to robustly evolve the barrier islands on decadal time-scales (e.g., inclusion of storm-driven long-shore transport and recovery impacts).

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