TIGERTAIL LAGOON/SAND DOLLAR ISLAND ECOSYSTEM RESTORATION

Alternatives Analysis

August 2021

Abstract

This report is an addendum to the Tigertail Lagoon /Sand Dollar Island Engineering Management Plan to provide detailed analysis of alternatives and recommendations of proposed project design

Humiston & Moore Engineers

md@humistonandmoore.com

TABLE OF CONTENTS

Alternatives Analysis

INTRODUCTION

The goal of the Tigertail Lagoon / Sand Dollar Island (TLSDI) Ecosystem Restoration Project is to maintain Tigertail Lagoon as a wetland lagoon habitat with improved tidal exchange and flushing. The project has been developed in response to long term morphologic changes in the area. Analysis of the physical changes in the vicinity of the project is provided in the TLSDI Engineering Management Plan dated April 5, 2021 (H&M 2021). This report is an addendum to the TLSDI Engineering Management Plan to provide detailed analysis of alternatives and recommendations of proposed design.

Location and Background

The TLSDI system consists of a tidal lagoon that has formed behind Sand Dollar Island at the south attachment to Marco Island. The lagoon is connected to the Gulf of Mexico by a narrow flow channel that runs between Marco Island and Sand Dollar Island. At present time, Sand Dollar Island consists of an approximately 2-mile long sand spit having a narrow, low elevation section in the middle area which is subject to frequent overwash. The evolution of Sand Dollar Island is detailed in the Engineering Management Plan (H&M 2021), including the considerable growth over the past two decades, wrapping around Marco Island in front of the Hideaway Beach community. The north part of Sand Dollar Island is relatively sheltered from Gulf waves and more heavily influenced by the tidal hydrodynamics of Big Marco River. The combined effects of the tides and waves has resulted in a curved island wrapping nearly 2 miles around the northwest corner of Marco Island. These features are discussed in detail in the Engineering Management Plan (H&M 2021) and illustrated in **Figure 1**.

Over time the Gulf facing mid portion of Sand Dollar Island has been subject to frequent overwash and landward migration, shoaling and systematic reduction of the width of the mid-section of the lagoon, resulting in severe restriction to tidal flow. This has resulted in degradation of the lagoon ecosystem and loss of lagoon habitat caused by narrowing of the long flow channel due to landward migration of Sand Dollar Island. The migration of the island has smothered seagrass habitat and reduced tidal exchange within the lagoon. At the same time the north tip of Sand Dollar Island has grown extensively, progressing inland along the south bank of Capri Pass and encroaching on Big Marco River.

Design Goals

The design goals aim to improve the tidal exchange throughout Tigertail Lagoon and restore Sand Dollar Island as a more resilient sand spit. The proposed design would provide a nature based layered system of a stable sand spit, lagoon and mangrove areas providing diverse habitat for wildlife and natural storm risk mitigation for upland areas. This would require enhancing the flow channel from end to end, and at the same time, the beach berm would need to be elevated and relocated seaward toward the Gulf of Mexico. An enhanced profile of the reconstructed berm would reduce the rate of landward migration, making the overall project economically feasible and adding resiliency to the northwest area of Marco Island. The design goals are to restore ecosystem to conditions similar to or better than the 2017 pre-Hurricane Irma impacts.

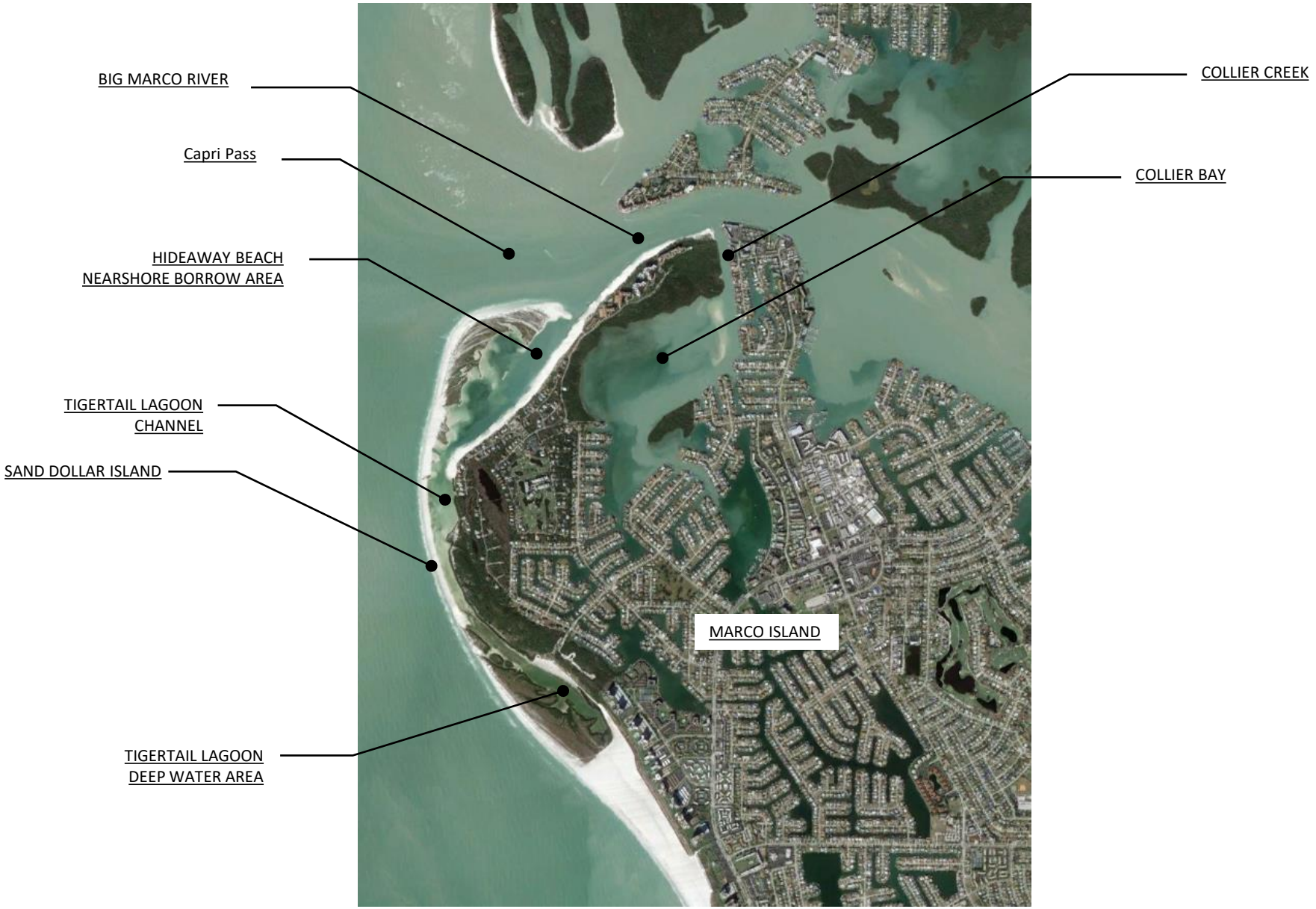


Figure 1. Tigertail Lagoon and Sand Dollar Island Location Plan

The TLSDI Ecosystem Restoration Project consists of three primary components that are necessary to the overall effectiveness of the plan but function essentially independent of one another. The three elements are:

1. Flow channel improvement,
2. Beach berm reconstruction, and
3. Renewable sediment source and sand trap.

In this report, each element is analyzed independently to determine the preferred design for that element. The preferred project design is the result of combining the preferred design elements.

1. TIDAL WETALND RESTOARTION: FLOW CHANNEL IMPROVEMENT

Sustainability of the system requires tidal flow supported by maintaining the lagoon entrance at the north end of the system. The entrance connects the lagoon to the gulf tide, and a continuous channel is required to maintain adequate flow throughout the 2-mile long lagoon. Design of an improved flow channel must balance the relative improvements from a given channel geometry with the presence of seagrasses in the vicinity. The improved flow channel should result in bathymetric conditions suitable for seagrass recruitment, but also be of sufficient size to be practical for construction and provide a reasonable design life between maintenance events.

For example, a channel that is small and narrow will have the advantage of avoiding seagrasses and minimize potential impacts during construction but may not provide adequate dimensions to improve tidal circulation and be sustainable. A channel that is too small and narrow would have a limited capacity to accumulate sediment over time and maintain effectiveness, leading to poor performance and/or increased frequency of maintenance events. On the other hand, an overly large channel might be economically unfavorable, deliver diminishing returns, and could potentially impact seagrass beds.

The location of the improved channel is a primary consideration. The project has been designed and will be constructed such that it will not directly impact existing seagrass beds. This is accomplished by locating the channel within overwashed areas as much as practical, while avoiding any mapped seagrasses when working in water. This will return the overwashed areas to wetlands and create an improved flow channel to improve flushing throughout the lagoon.

Alternatives Considered

The channel design elements evaluated are presented in **Figure 2.** To improve flushing to the deeper water at the south end of Tigertail Lagoon, it is necessary to connect the existing entrance and North Borrow Area (NBA) to the deeper water near Collier County's Tigertail Beach Park. This will require a channel through Zone 1 between the NBA and the shallow part of the lagoon at South Point near DEP monument R-128. This is proposed at -8' NAVD consistent with the NBA. The design channel south of R-128, passing through the shallow and narrow part of lagoon, will be created from the existing uplands along the overwash areas of the lagoon between R-128 and R-131.5. Several alternatives were considered for this area within Zones 2 & 3. Depths of -3' or -5' NAVD88 were considered, for a wide channel, as well as a narrow channel at -5' NAVD.

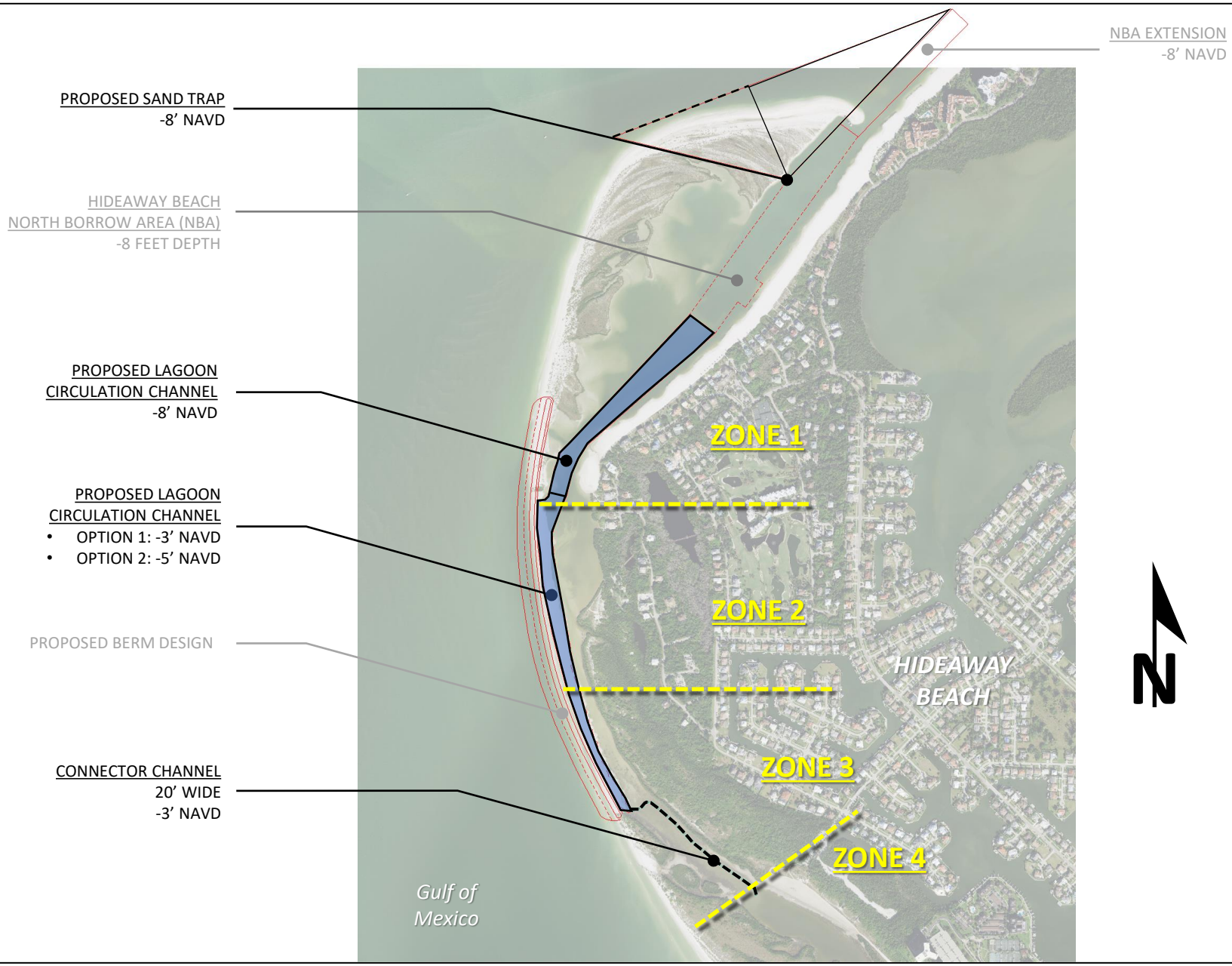


Figure 2. Tigertail Lagoon Circulation Channel Design Elements

In the southern portion of Zone 3 (R-131.5 to R-133), the proposed flow channel is optimized to avoid potential impacts to existing beach vegetation and existing seagrass beds. The existing flow channel in that area is behind vegetation that is broad and shallow, with complex braided flow channels at low water. The area also contains seagrass beds of varying density. As such, the south end of Zone 3 was evaluated with a small connector channel only 20' wide and 3' deep, or no new channel at all, to connect the deeper south area of Tigertail Lagoon to the improved tidal exchange. The overall flow channel alternatives, as modeled, are listed below:

- 2017 Condition: This alternative represents the initial simulation. This simulation is used for comparison in the analysis.
- 2020 Condition: This is the most recent condition at the time of analysis, it is used as a base to show the evolution of the system and for comparison purpose.
- -3' deep Channel: with lagoon circulation channel at -3' NAVD88 and connector channel.
- -5' deep Channel: with lagoon circulation channel at -5' NAVD88 and connector channel.
- -5' deep /Narrow No Connector: with lagoon circulation channel at -5' NAVD88 only.

In the absence of the proposed project, the channel will continue to shoal and narrow. Seagrass and lagoon aquatic habitat will be gradually reduced and eliminated, as has been documented since 2017. The beach berm will attach to Marco Island, creating a sandy beach in front of the existing mangroves. Further in the future, that sandy beach would be expected to erode, leaving the mangroves exposed to the open Gulf and also cutting off the supply of sediment to adjacent areas, transferring the erosion to adjacent beaches.

Model Set Up and Results

The Coastal Modeling System (CMS) Flow Model set up for Tigertail Lagoon as described in the Engineering Management Plan (H&M 2021) was used to evaluate several alternatives aimed at improving flushing of the Tigertail Lagoon. The model input water levels consisted of approximately 10 tide cycles including a low close to MLLW. A total of 5 simulations are considered in this alternatives analysis.

Results

CMS-Flow model results were extracted for each simulation at high tide and low tide. **Figures 3 & 4** present these results as color coded maps of the water levels for the model domain. In the figures, red indicates high water level and blue indicates low water level, a difference in color within the maps indicates a difference in water level within the system.

The maximum potential of tidal flushing that can be achieved by this system would occur if the water levels within all of Tigertail Lagoon reach the same elevation as Gulf water levels at high and low tide conditions. When water levels within the lagoon are limited to a narrower range than the Gulf, this results in a reduced tidal range within the lagoon, and therefore a reduced exchange of water and flushing. Reduced tidal exchange may occur for a number of reasons. At Tigertail lagoon it appears to be caused primarily by the constricted flow in the shallow and narrow areas that act as a dam, preventing the lagoon from reaching low water conditions.

High Tide

Figure 3 shows a comparison of the water levels during high tide. The model results indicate that for the 2017 conditions, Tigertail Lagoon's high water levels were lower than the Gulf of Mexico by approximately 0.36' on average, while in 2020 the difference in height increased to near 0.60' on average. The results for each alternative are also shown. The simulated alternatives showed improvements to the Lagoon with water levels, approaching the Gulf of Mexico elevation at high tide. All alternatives raised the elevation of

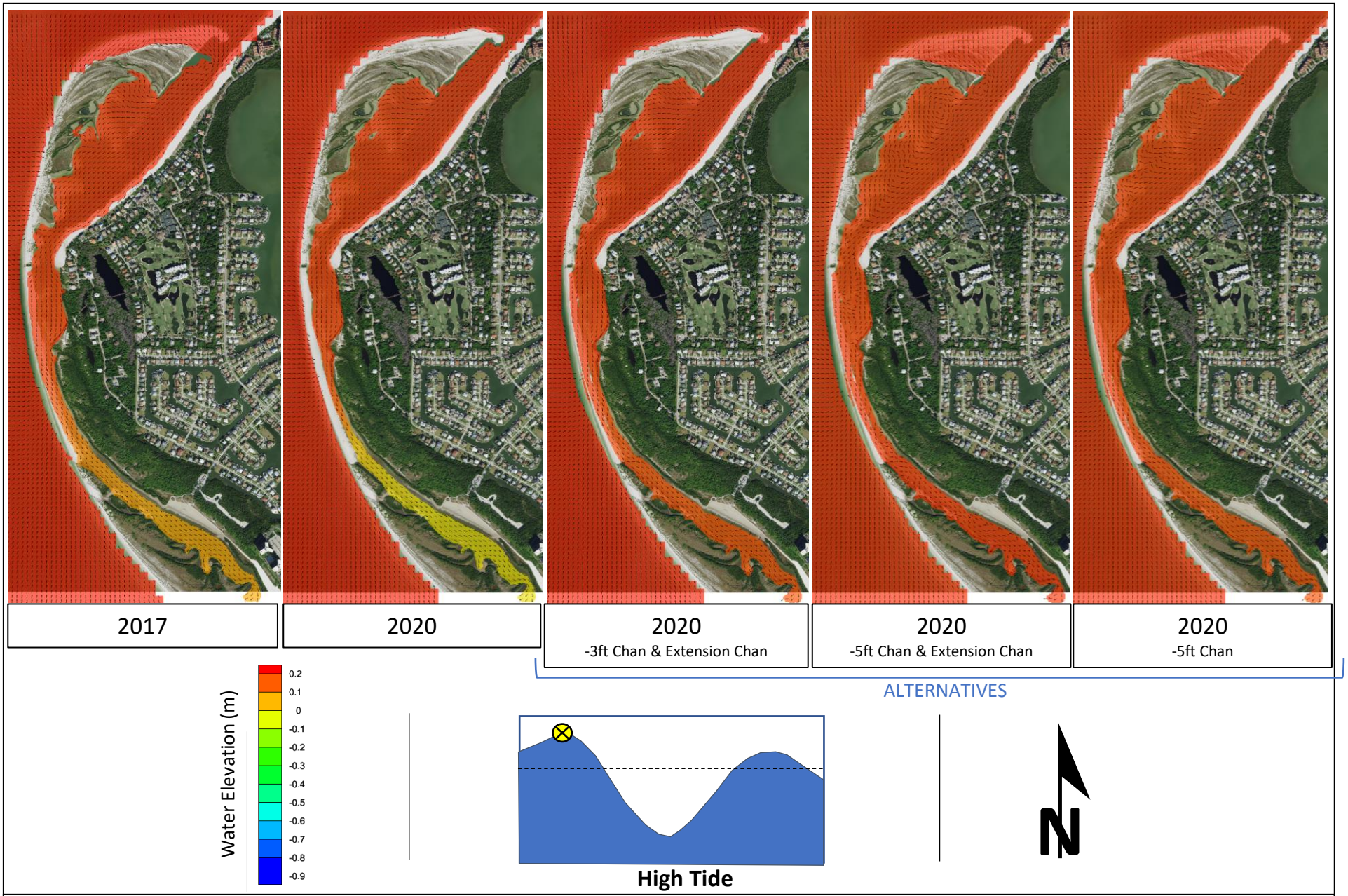


Figure 3. Sample CMS-Flow Model Results – High Tide

high water within the lagoon, which represents increased volume entering and leaving the lagoon around high tide compared to prior conditions.

Low Tide

Figure 4 shows a comparison of the water levels during a pronounced low tide. The model results indicate that for the 2017 conditions, Tigertail Lagoon's low water levels were higher than the Gulf of Mexico by over 2' on average. For the 2020 conditions the model has disconnected the lagoon from the Gulf of Mexico at low water. This indicates that essentially no water is leaving the lagoon during this time and the volume of water that could be exchanged is trapped in the lagoon.

All alternatives show a difference of approximately 1.5' between the Gulf and lagoon water elevation for the simulations that included the Connector Channel. The alternative without the connector channel shows that under these low water conditions the model disconnected the Lagoon from Gulf water. However, the constructed channel brings Gulf water much closer to the Tigertail Beach lagoon than was observed in the 2020 conditions. Although for alternatives without the connector channel the model disconnected the southernmost end of the lagoon at low water, the shallow area where the disconnection occurred has numerous small, braided channels that are not captured in the available data and model setup. It is possible that these channels would maintain a connection at low tide, though less effective than the connector channel.

Tide Range and Tide Range Ratios

The CMS-Flow model results were further analyzed by extracting the water levels at one location within the deeper water southernmost portion of Tigertail Lagoon (Zone 4) for the whole simulation duration and all 5 simulations. The resulting time series are presented in **Figure 5**. The water levels from the Gulf of Mexico are also shown in the figure as a black dashed line for comparison. The figure illustrates the differences in water levels between the input tide from the Gulf of Mexico and the simulations. Overall, the differences in water levels were more pronounced at low tide than high tide, due to the shallow area in Zone 3. At high tide, the flow increases as the channel widens and deepens from the rising water and allows more water to flow in through a larger channel cross section. At low tide, the channel becomes narrower and shallower from the receding water, and less water can evacuate through the smaller flow area. The model results indicate that areas where the bottom elevation is high, there is more resistance to the flow and eventually an obstruction develops between the Gulf and the south part of the lagoon. This is evident in the figure with water levels from the 2017 and 2020 conditions which tend to never go below a certain threshold elevation regardless of the water levels in the Gulf of Mexico.

Differences in water levels between Gulf and lagoon were quantified by computing the Tigertail Lagoon to Gulf of Mexico tidal range ratios. The range ratio compares the difference between high and low water elevations in Tigertail Lagoon and the Gulf of Mexico. The lagoon tidal range ratio relative to Gulf range can be determined for changes from low to high, or high to low. It is the fraction of Gulf of Mexico elevation change observed within the lagoon and can provide a direct measure to the percentage of tidal exchange.

The ratios were computed for each of the 10 tidal cycles simulated and then averaged for an overall ratio for each simulation. The ratios are presented at the bottom of **Figure 5**. The results indicate that between 2017 and 2020 the tidal range ratio decreased from 0.40 to 0.23, indicating that lagoon flushing was less than ½ of the maximum potential in 2017, and deteriorated to less than ¼ during that period. This is most likely the due to the progression of shoaling and narrowing of the lagoon resulting from frequent storm overwash at the mid-section of Sand Dollar Island.

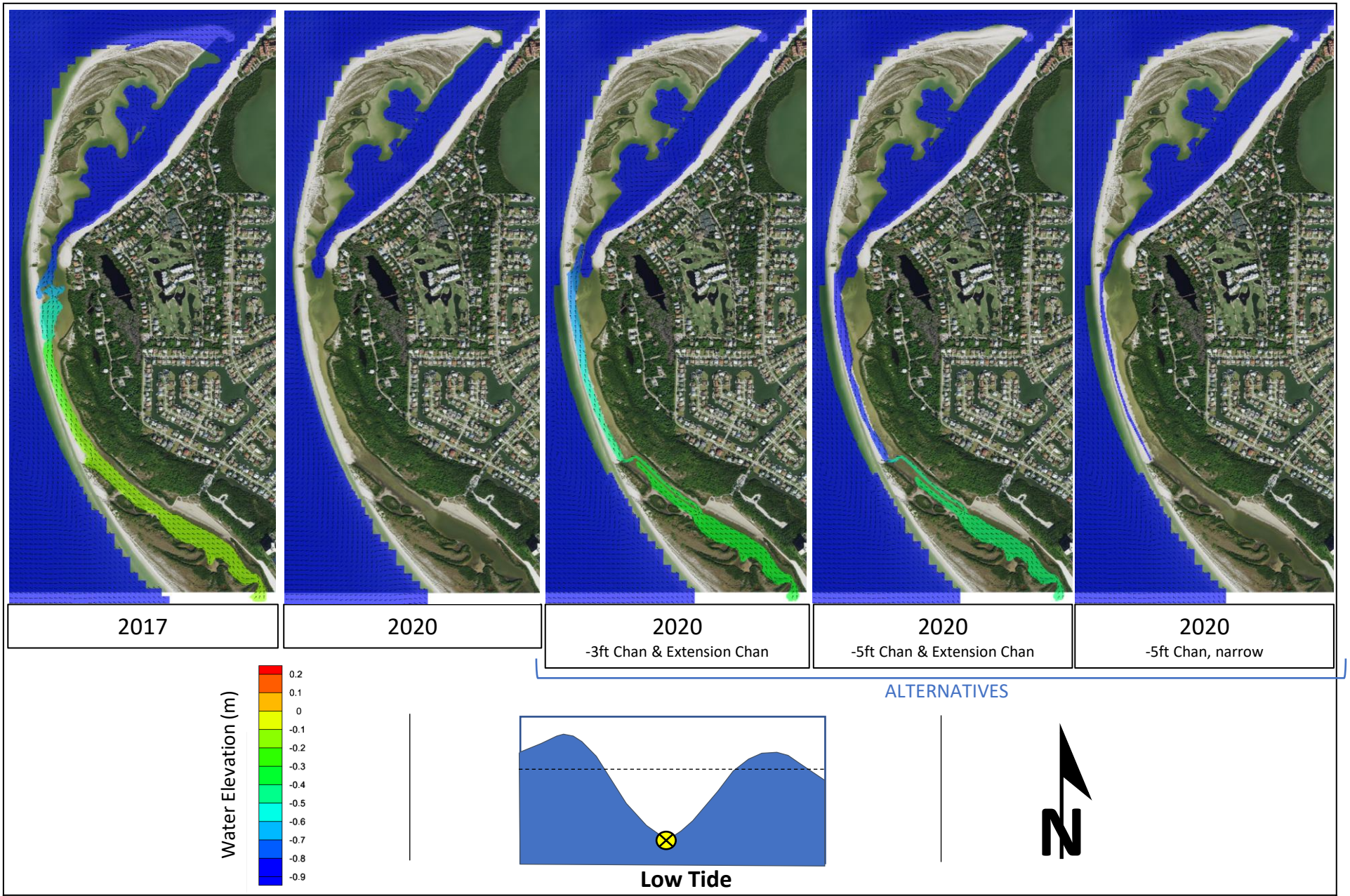
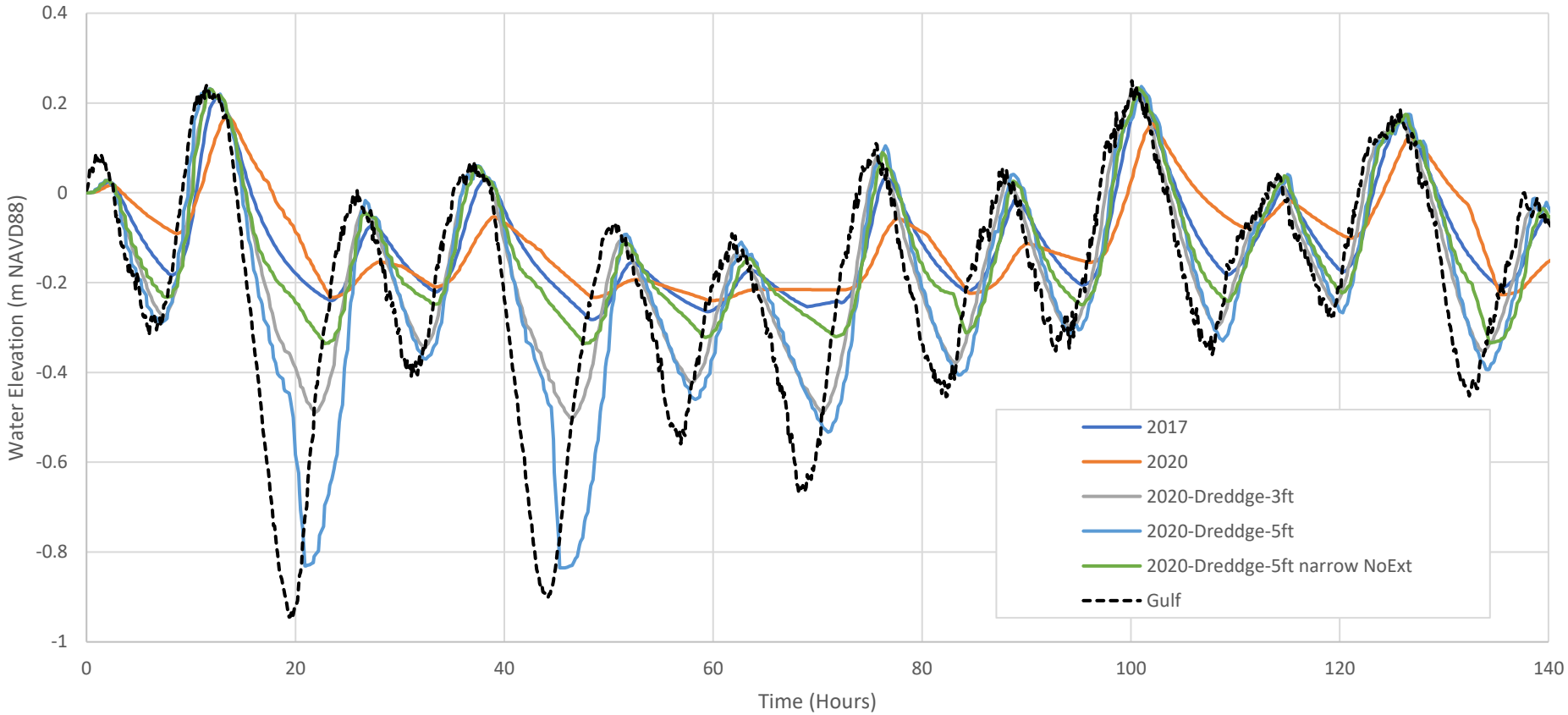


Figure 4. CMS-Flow Model Results – Low Tide



CMS-Flow Model Results
Tigertail Lagoon to Gulf Tidal Range Ratios

2017	2020	2020 -3ft & Extension	2020 -5ft & Extension	2020 -5ft
0.40	0.23	0.73	0.87	0.57

Figure 5. CMS-Flow Model – Lagoon Tidal Range

Overall, all the proposed alternatives simulated showed improvements to the system with Tidal Range ratios higher than the 2020 and 2017 conditions. The alternatives that included the connector channel provided the best results with ratios of 0.73 and 0.87. The alternative without the connector channel provided the least improvement with a ratio of 0.57 though this represents an improvement compared to the 2017 or 2020 conditions. With a ratio of 0.87, the -5' Channel alternative performed the best. The 0.87 tidal range ratio indicates that the water levels within the Lagoon would be nearly the same as those in the Gulf of Mexico, providing nearly the maximum potential flushing of Tigertail Lagoon. The modeled alternatives would be expected to provide approximately 60% to 90% of potential flushing, a significant improvement over the 2017 and 2020 conditions.

Preferred Alternative

All modeled alternatives would achieve the goal of improving tidal exchange within Tigertail Lagoon, restoring it to better than 2017 conditions. The greatest improvement would be achieved by the -5' NAVD scenario, including connector channel. The purpose of the proposed flow channel includes several factors. These include improved tidal exchange and water quality, re-establishing seagrass habitat, and providing a shoaling capacity over a number of years between maintenance events. As such, the -5' Deep Channel alternative with connector channel is preferred in order to provide the optimal benefit and longest duration.

In addition to the environmental and technical aspects, practicality and constructability need to be considered. A project design that allows for hydraulic or mechanical excavation will allow contractors to bid based upon a variety of methods, increasing competition and decreasing price. A design elevation of -3' NAVD is likely not practical for hydraulic dredging on this scale. Considering all factors, the -5' Channel with connector channel is the preferred alternative.

The connector channel could also be achieved through enhancement of existing channel meanders in the shallow area. This would need special considerations due to presence of seagrass beds in its vicinity. Dredging or maintenance dredging in such area needs field determination by professional environmental specialists to establish the minimum required flow channel necessary to support the health of surrounding seagrass beds. However, while the alternatives analysis indicates that the connector channel adds significant benefit to the tidal exchange and water quality improvements at the south part of lagoon, constructing the project without the connector channel may result in some improvement to tidal exchange within the deep-water area.

2. SAND DOLAR ISLAND RESLIENCY: BEACH BERM RECONSTRUCTION

The tidal lagoon system and seagrass habitats have evolved in the calm waters between Sand Dollar Island and Marco Island. The sandy beaches of Sand Dollar Island provide natural protection from incoming Gulf waves that break on the dynamic beach face, providing protection to the environmental resources and upland development. In addition to tidal flow enhancement needed to restore the lagoon, the viability of the system also requires maintaining the integrity of Sand Dollar Island as a coastal barrier sheltering the lagoon and maintaining the entrance open. This section addresses alternatives for stabilizing the mid-section of Sand Dollar Island where frequent overwash, since Hurricane Irma in 2017, is progressing towards closing the lagoon system. As such, restoration and resiliency of Sand Dollar Island is necessary to preserve the lagoon system.

In order to restore the lagoon area to 2017 (pre hurricane Irma conditions), the reconstructed section of Sand Dollar Island will need to be a more resilient sandy barrier located seaward of the current position, returning the Gulf Mean High Water line to its late 2016 position. Constructing the new beach berm provides an opportunity to reduce overwash and landward migration by elevating the berm to reduce the frequency of storm overtopping. Initial designs consisted of a conventional berm and dune profile which was modified after consultation with staff from Rookery Bay Aquatic Preserve. In response to their input, the beach berm is designed as a broad and relatively flat profile to provide the open spaces preferred by some shore bird species. The proposed beach slope is 1V:15H consistent with sea turtle protection standards. An innovative nearshore berm is also proposed at approximately the Mean Low Water elevation to provide an intertidal flat and minimize escarpment formation during beach profile initial adjustments.

The existing beach that is frequently overwashed has peak elevations ranging from about +3’ to +3.5’ NAVD. Two primary alternatives were evaluated, one with berm elevations of +4’ to +5’ NAVD, and another with elevations from +5’ to +6’ NAVD. The Marco Island Beach Restoration Project constructed about a mile to the south in the early 1990’s had a beach elevation of approximately +5’ NAVD and a dune elevation of approximately +8’ NAVD. Since that time, the naturally accreted beach at the Beach Restoration Project area ranges from +3’ to +5’ NAVD.

Alternatives Considered

The XBeach morphology numerical model presented and validated in the H&M April 2021, *“Tigertail Lagoon & Sand Dollar Island Ecosystem Restoration”* report was used to evaluate the design of the reconstructed beach berm. The alternatives considered in this study consisted in the following:

- 2020 Conditions: Model of existing conditions.
- +6’ Top of Berm: approximately 250’ wide berm at MHW with crest elevation at +5 to +6’ NAVD88 and a nearshore submerged berm at MLW for environmental enhancement.
- +4’ Top of Berm: approximately 100’ wide berm at MHW with crest elevation at +3’ to +4’ NAVD88.

Both berm designs would use a 1V:15H beach slope.

In the absence of the proposed project, the natural evolution of this sandy barrier will cause it to attach to Marco Island closing the mid part of the lagoon. The sandy beach would then continue to erode and then expose the existing mangroves to the Gulf of Mexico. Loss of the sandy beach at the northwest corner of Marco Island could then lead to erosion of adjacent beaches as the sand supply diminishes. This area would again be exposed to the open Gulf of Mexico as it was in the 1970’s, but this time without the vast submerged inlet shoals that formerly supported Big Marco Pass and the adjacent shoreline.

Resiliency Model Results

Each design alternative was evaluated under two different storm scenarios. The XBeach model was set up to simulate the waves and the rising and receding water from the storm surge of a high frequency storm (less than 10-year return storm) such as Tropical Storm Eta (2020, surge: approx. +3' NAVD88) and from a lower frequency major storm such as Hurricane Irma (2017 surge: approx. +4.5' NAVD88) which is comparable to a 10-year return storm identified in the 2019 FEMA Preliminary Flood Insurance Study. Modeled berm conditions post storm impact were evaluated to determine the level of resiliency provided by each alternative.

High Frequency Storm: Tropical Storm Eta

2020 Conditions

The first model test scenario examines the three alternatives under high frequency storm conditions such as Tropical Storm Eta. **Figure 6** presents the simulation results for 2020 Conditions. Three timesteps were extracted from the model at T1 (initial condition), T2 (conditions at peak surge) and T3 (conditions at end of simulation). Each timestep is presented in the figure as a regional contour map. The maps are color coded as described in the figure for elevations ranging from above 0 m to -2.5m (-8.2ft) NAVD88. The water surface is represented as a semitransparent blue overlay.

At peak surge (T2), the model shows the water level (including waves) overtopping most of Sand Dollar Island. By that point of time in the simulation, the existing beach berm in the mid-section of Sand Dollar Island has already started to shift landward (towards the east). At the end of the simulation (T3), the model results show the post storm overwash and shoreline landward migration. The simulated post storm conditions indicate that the lagoon becomes narrower than the initial conditions. The model also shows breaches through the berm connecting the Gulf of Mexico to the lagoon. Similar breaches were documented during tropical storm Eta. After the passage of Eta, these breaches rapidly shoaled and the beach berm recovered.

Figure 7 presents the same model results extracted at 4 profiles along the mid section of Sand Dollar Island. For each profile, the initial conditions are shown as a dashed line and the final profile is indicated in blue with areas of erosion and shoaling shaded in blue and orange respectively. Profiles 1 through 3 show a landward shift of the berm, shoreline recession, and narrowing of the lagoon width. Profile 4 align with one of the areas which experienced breaching during the simulated storm, resulting in an eroded profile along the breach area.

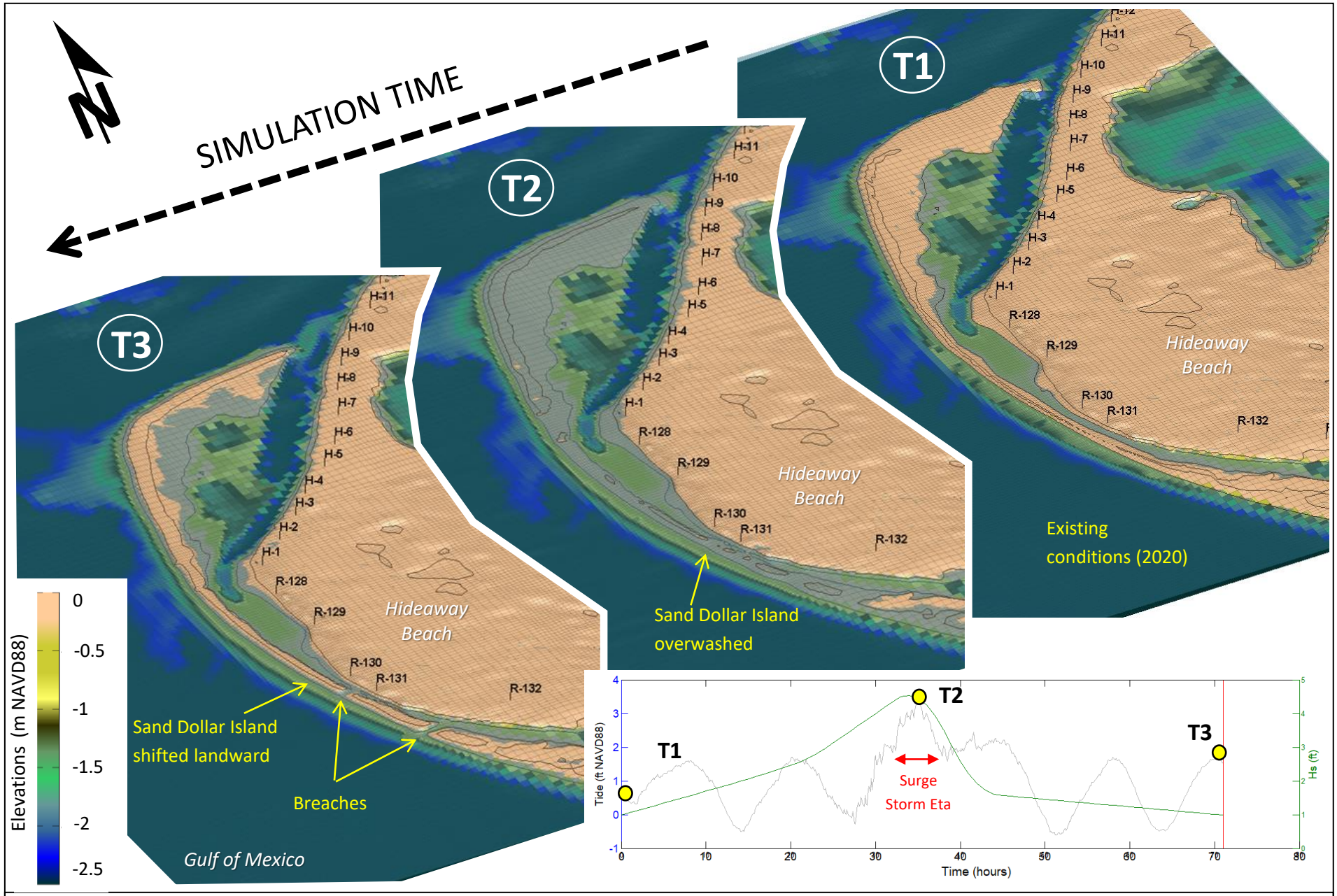


Figure 6. XBeach Model Results – ETA – EXISTING CONDITIONS (2020)

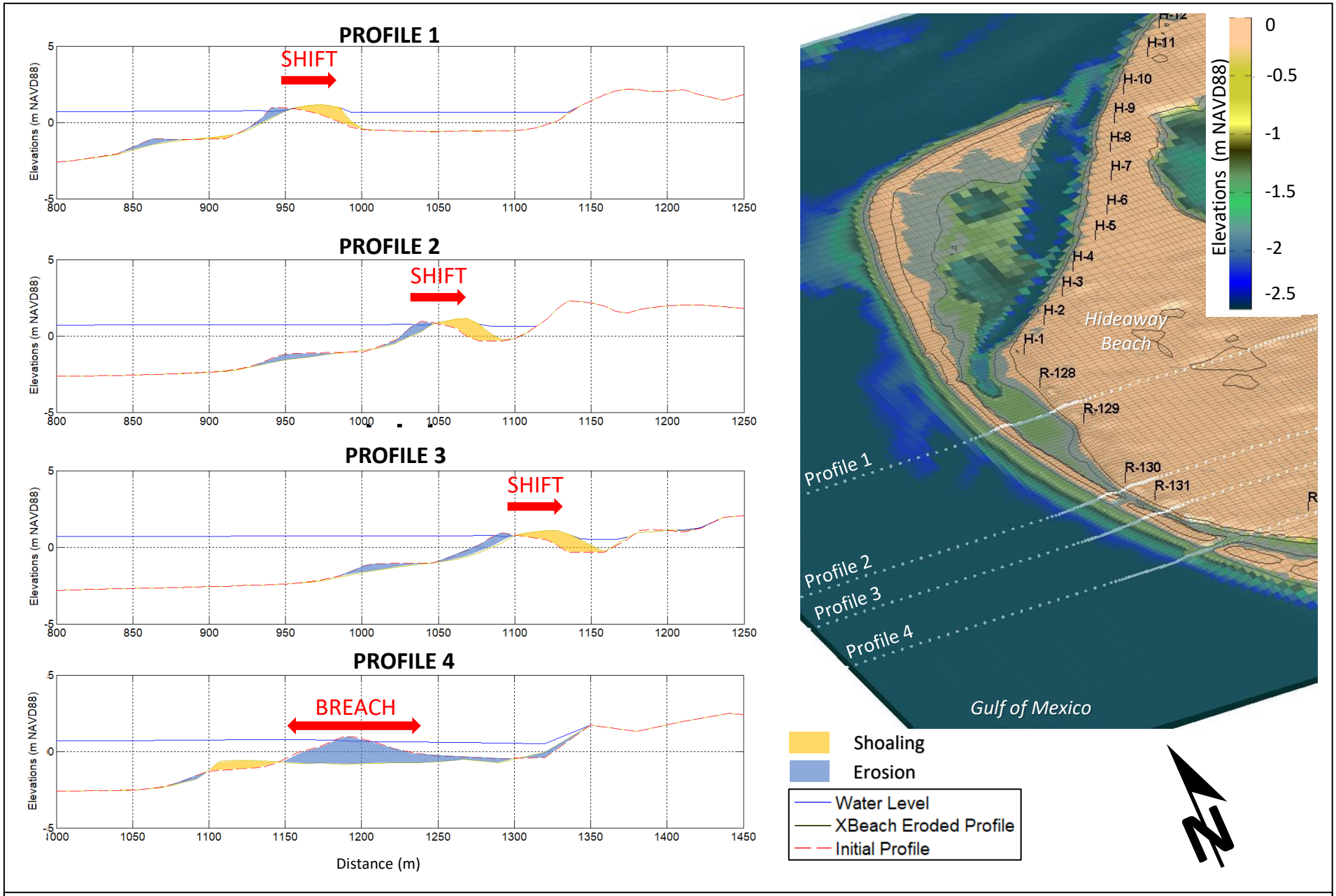


Figure 7. XBeach Model Results – ETA – 2020 Conditions - Profiles

+6' Top of Berm Alternative

Figure 8 presents the 2D model results for timesteps T1 through T3 as before. At peak surge (T2), the model results show that the +6' Berm prevented overwashing of Sand Dollar Island along the critical narrow section of beach. At the end of simulation (T3), the model results show that the +6' Berm would be resilient against high frequency storms such as the offshore passage of Tropical Storm Eta.

Figure 9 shows the model results for the +6' berm at the same 4 profiles along the mid section of Sand Dollar Island. The cross sections show typical profile adjustment on the nearshore without overwash or shoaling in the lagoon. The +6' Berm essentially eliminates shoaling within the lagoon from overwash and landward migration of Sand Dollar Island during storms with frequency greater than 10-year return intervals.

+4' Top of Berm Alternative

Figure 10 presents the 2D model results for timesteps T1 through T3 as before. At peak surge (T2), the results show that the +4' Berm would not prevent overwashing of Sand Dollar Island. At the end of simulation (T3), the model results show that the +4' Berm fares better than the 2020 Conditions but does not protect the lagoon from these relatively high frequency storm conditions.

Figure 11 shows the model results for the +4' berm for the same 4 profiles as before. The cross sections show minor profile adjustments for profiles 1 & 2, but profiles 3 & 4 show overwash of the berm and an overall migration of the berm towards Marco Island.

Figure 12 presents a comparison of the model results for Profile 3 in the middle of the project area for all the alternatives simulated using conditions from the passage of Tropical Storm Eta. Both berm designs show less overwash and landward migration than the 2020 Conditions. The comparison shows that the +6' berm design provides resiliency to high frequency storms such as Tropical Storm Eta, followed by the +4' berm design that provides improvement to existing conditions but insufficient resiliency to similar storms.

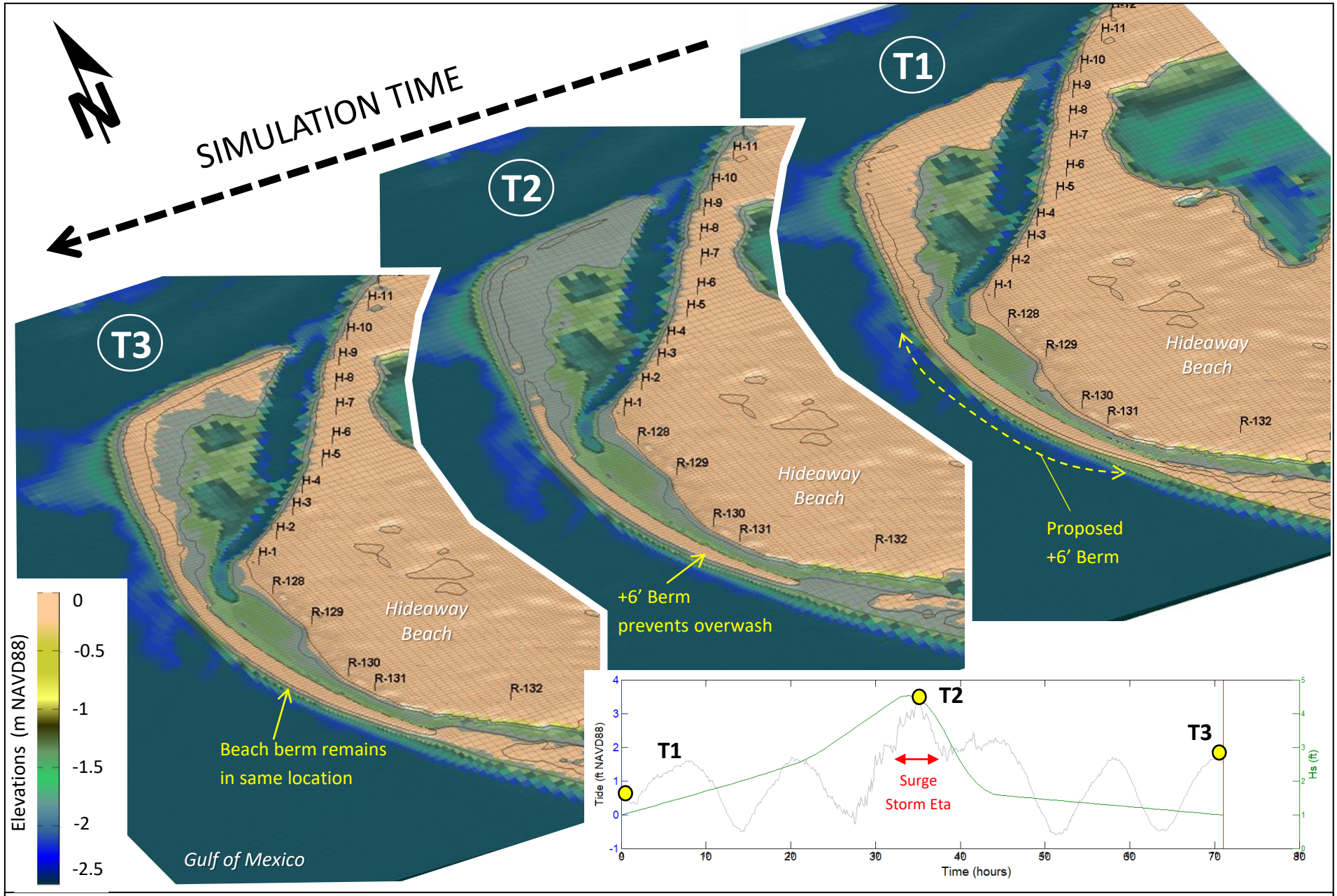


Figure 8. XBeach Model Results – ETA – +6' Berm

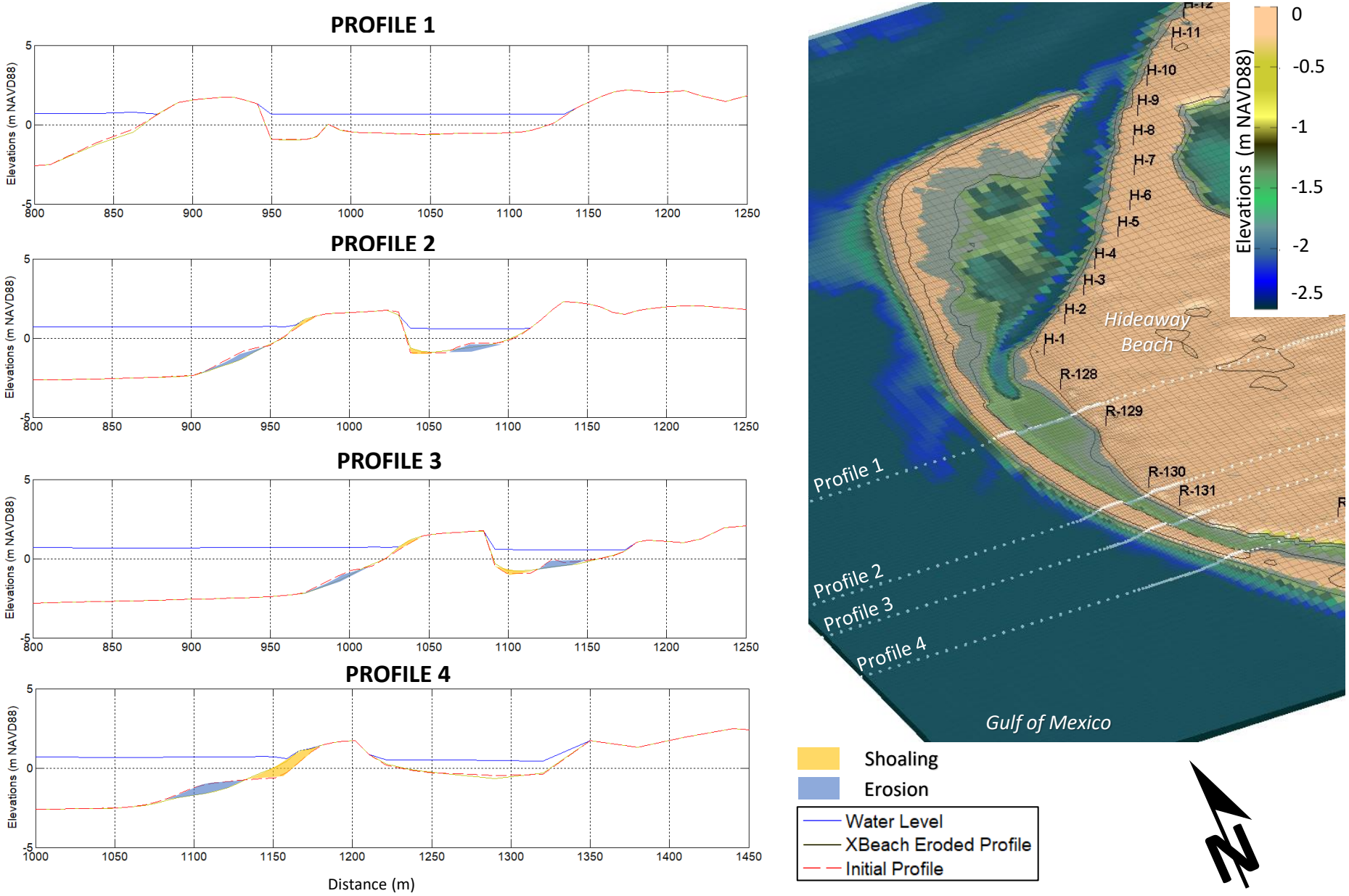


Figure 9. XBeach Model Results – ETA – +6' Berm - Profiles

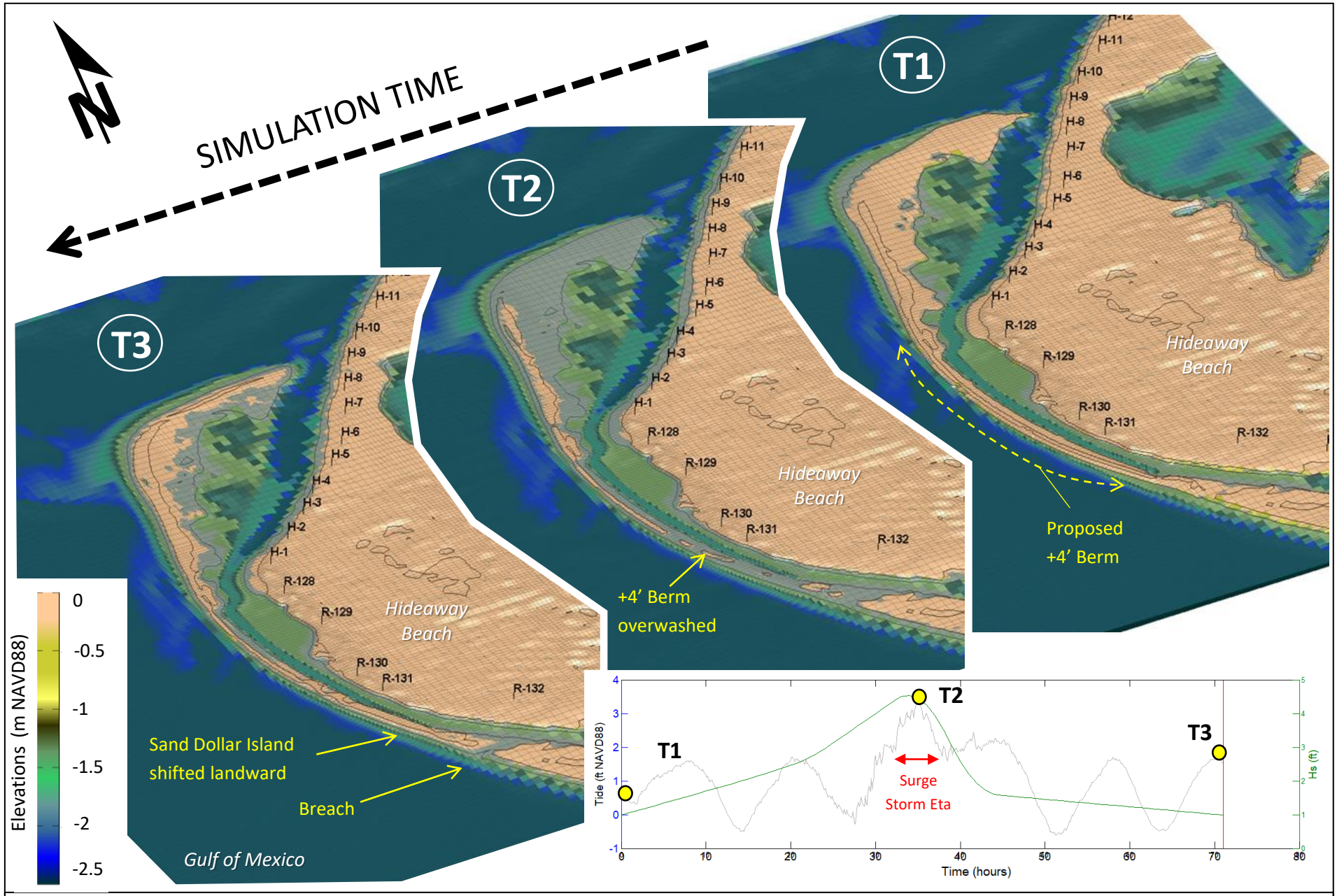


Figure 10. XBeach Model Results – ETA – +4' Berm

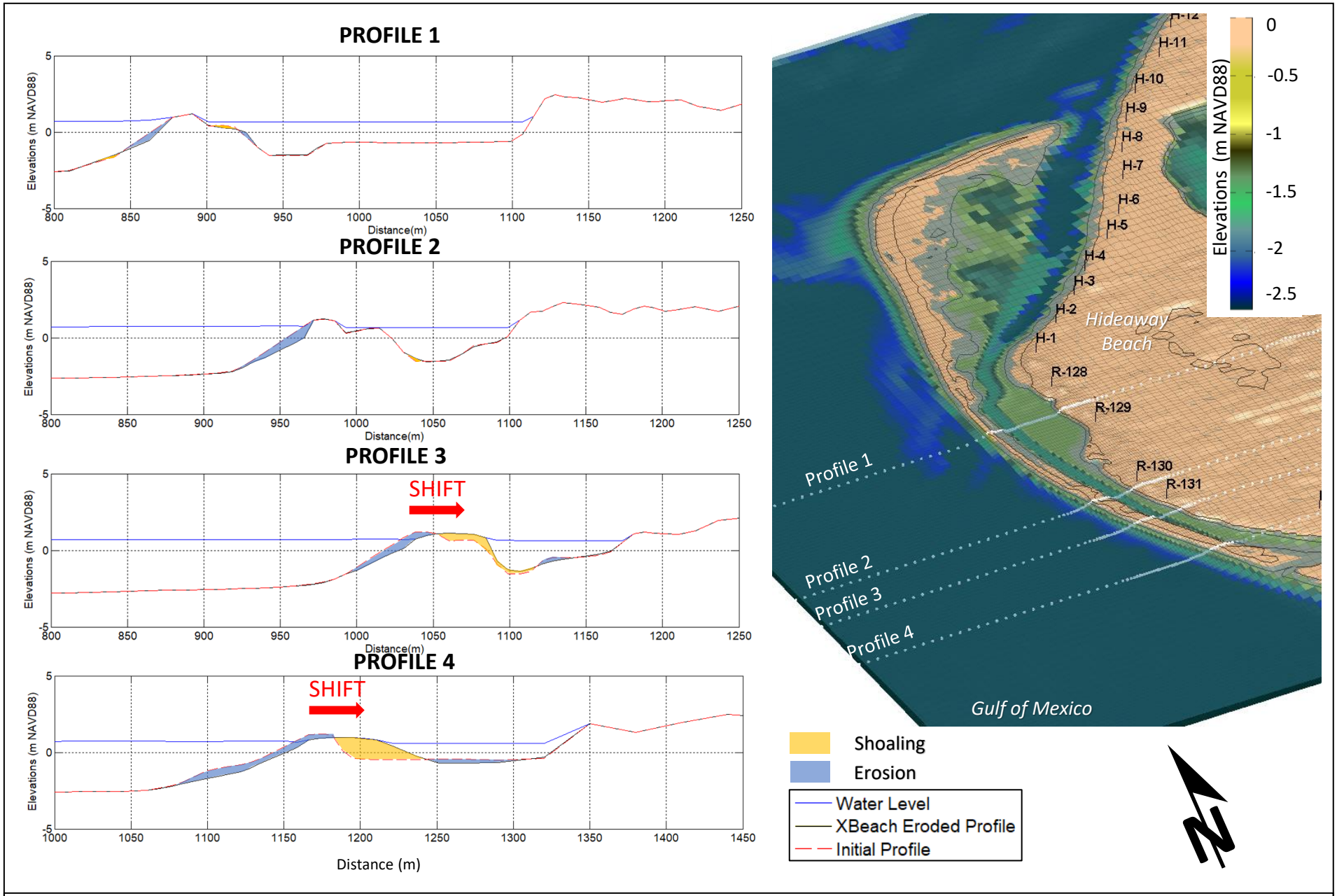
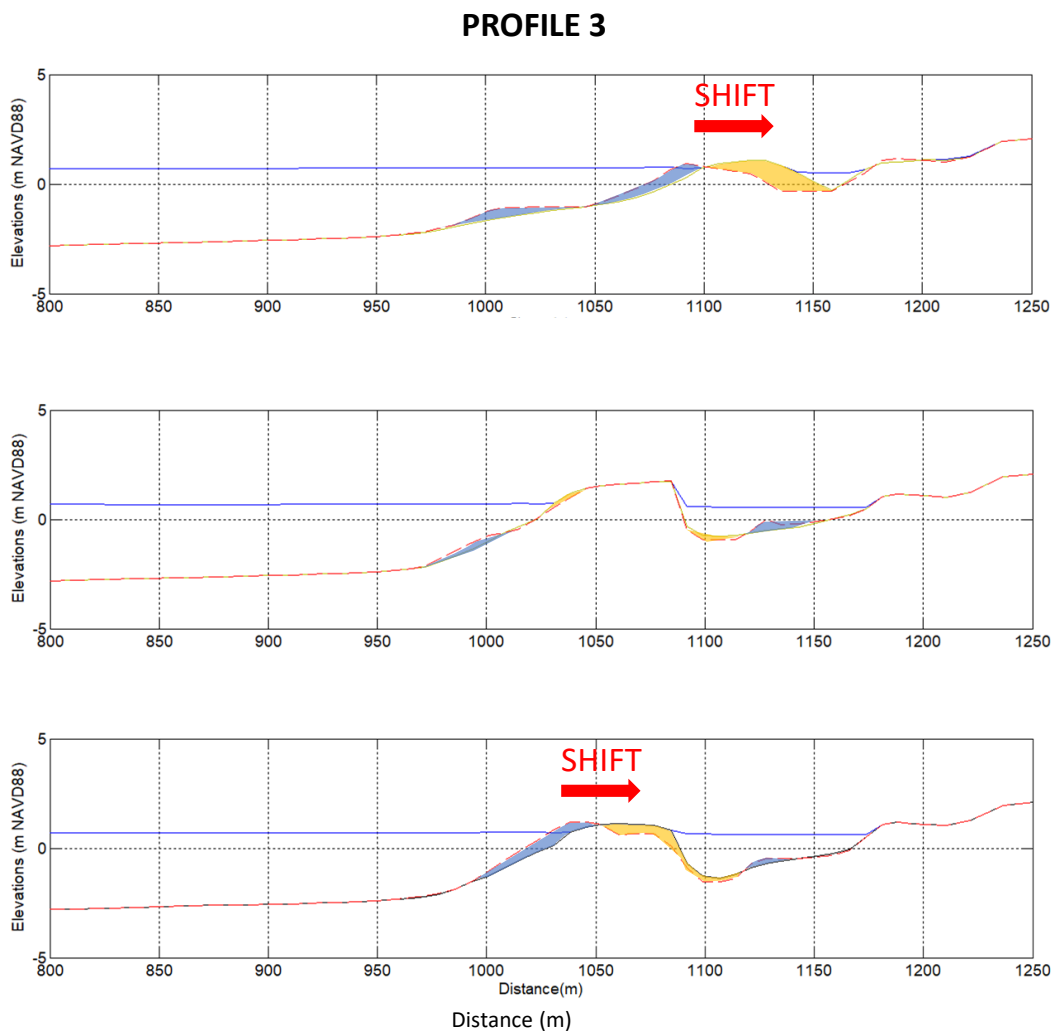


Figure 11. XBeach Model Results – ETA – +4' Berm - Profiles



2020 Conditions

+6' Berm

+4' Berm

Shoaling
Erosion
Water Level
XBeach Eroded Profile
Initial Profile

SIMULATION:
STORM ETA

Figure 12. XBeach Model Results – ETA – Alternatives – Profile 3

Major storm model test: 10-Year Return Storm Hurricane Irma

2020 Conditions

The second model test scenario examines the three alternatives under major storm conditions or a 10-year return storm such as 2017 Hurricane Irma. **Figure 13** presents simulation results for 2020 Conditions at Sand Dollar Island under Hurricane Irma storm conditions. At peak surge (T2), the model shows Sand Dollar Island is completely overtopped by the storm surge and waves and significant morphological changes have occurred. At the end of the simulation (T3), the model results show that the Sand Dollar Island shoreline has migrated east with overwash filling in the lagoon, resulting in the barrier beach welding onshore in the center (R-129 to R-131). The simulation also indicates a breach at the location where Big Marco Pass used to be.

Figure 14 presents the same model results extracted at 4 profiles along the mid-section of Sand Dollar Island. Profiles 1 through 3 highlight the shoreline and berm migration and attachment to Marco Island at the east, and the almost complete shoaling of parts of the lagoon. Model results at Profile 4 also show the migration of the shoreline and berm toward the east, but the lagoon channel is still apparent. Based on the Model simulation, a 10-year return storm impacting Sand Dollar Island in its present configuration would completely close the middle part of the lagoon and isolate the south part of the lagoon from tidal exchange.

+6' Top of Berm Alternative

Figure 15 presents the 2D model results for timesteps T1 through T3. At peak surge (T2), the results show that the +6' Berm would prevent overwashing of the berm into the lagoon along the proposed constructed berm covering the critical mid-section of Sand Dollar Island. The areas outside of the project area would still experience some level overtopping at peak surge. At the end of simulation (T3), the model results show that with the +6' Berm would be resilient to storms of approximately 10-year return interval. The model results show some shoaling in areas adjacent to the reconstructed berm, however, this area has established vegetation which adds a level of shore protection not represented in the model.

Figure 16 shows the model results for the +6' Berm 1 for 4 profiles along Sand Dollar Island. The cross sections for profiles 1 through 3 show minor profile adjustment in the nearshore without significant overwash or shoaling in the lagoon. At profile 4, the berm is still present, but some limited shoaling has occurred in the lagoon. The model results show that the enhanced profile effectively reduced shoaling within the lagoon channel from overwash and minimized potential for landward migration of Sand Dollar Island under 10-year return storm conditions.

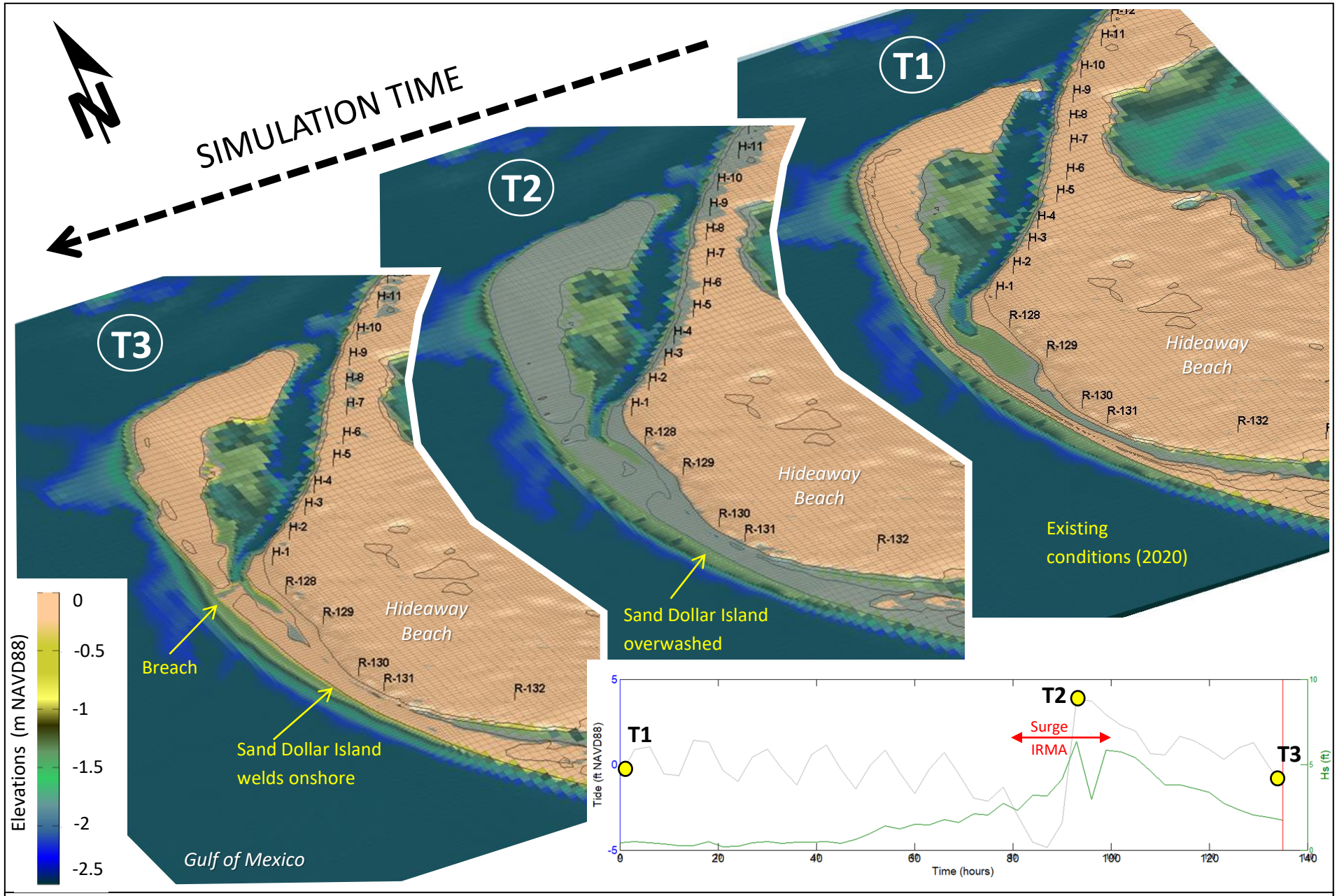


Figure 13. XBeach Model Results – IRMA – 2020 Conditions

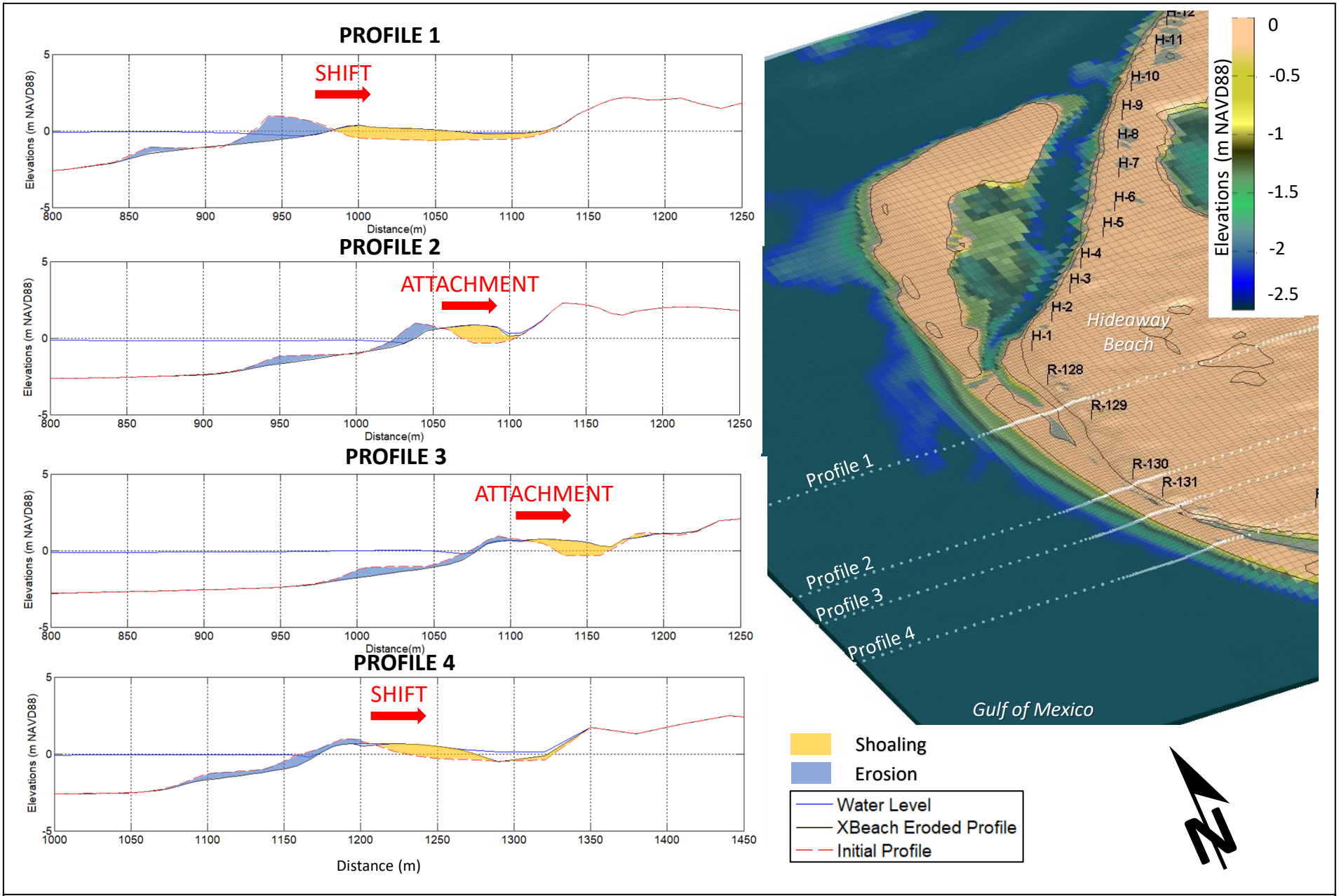


Figure 14. XBeach Model Results – IRMA – 2020 Conditions - Profiles

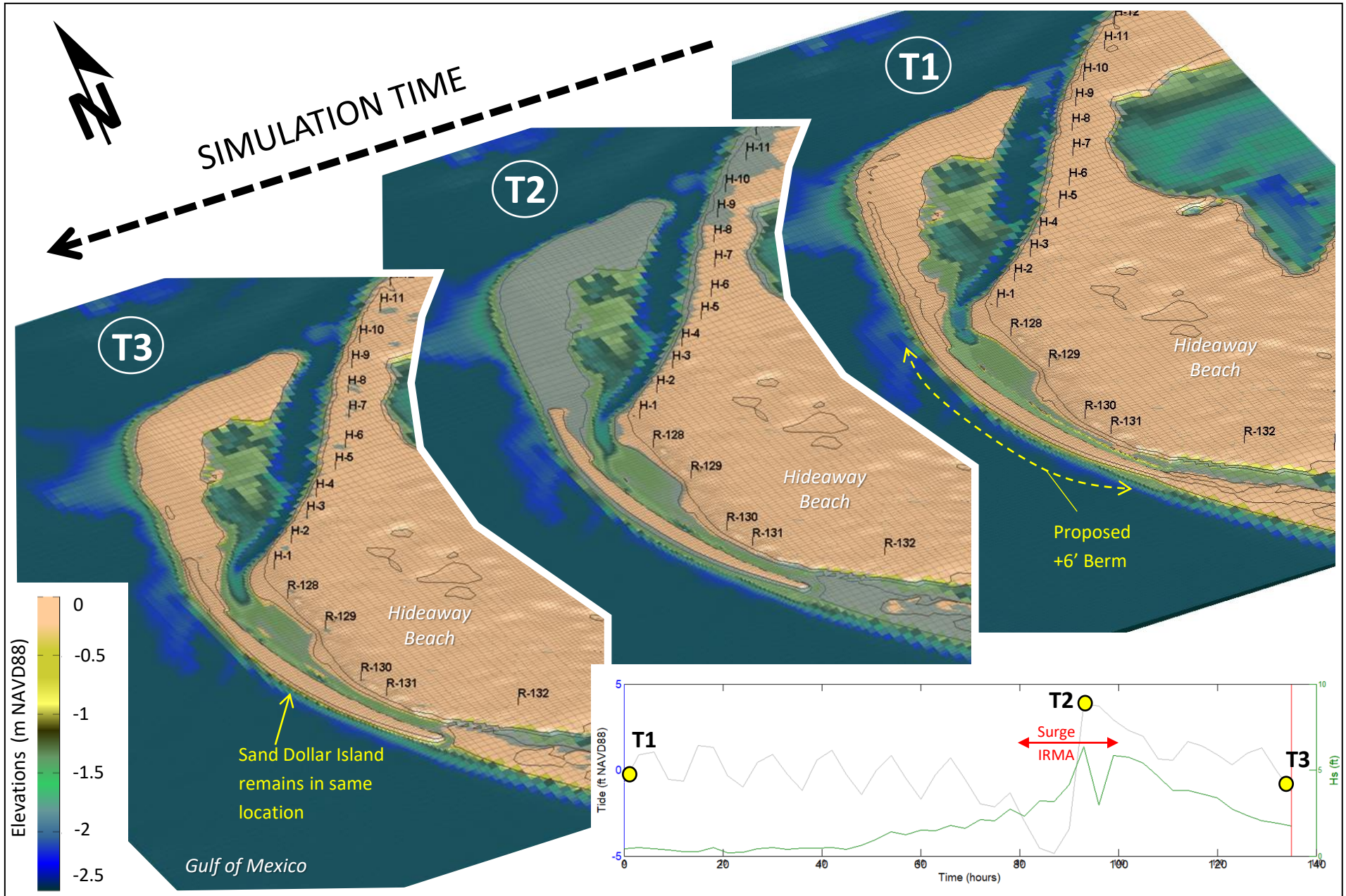


Figure 15. XBeach Model Results – IRMA - +6' Berm

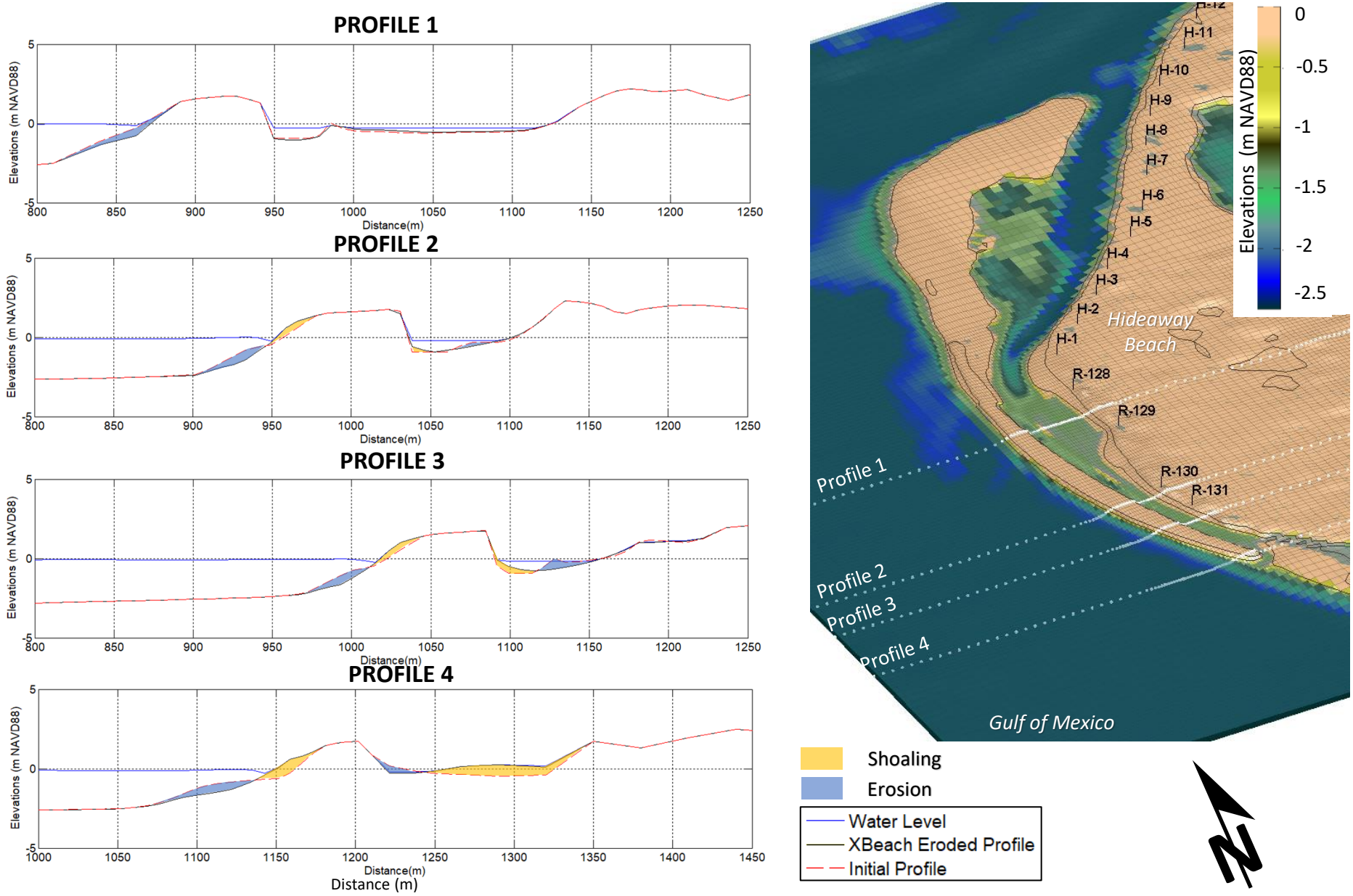


Figure 16. XBeach Model Results – IRMA – +6' Berm - Profiles

+4' Top of Berm Alternative

Figure 17 presents the 2D model results for timesteps T1 through T3. At peak surge (T2), the results show the +4' Berm completely overtopped and several breaches starting to form. At the end of simulation (T3), the model results show that some shoaling of the lagoon channel has occurred, and a portion of Sand Dollar Island has migrated east towards Marco Island. Additionally, 2 breaches are visible at the ends of the berm where established vegetation is present but not represented in the model.

Figure 18 shows the 1D model results along the same 4 profiles as previous. The cross sections confirm the significant migration of Sand Dollar Island towards the east and significant shoaling of the lagoon channel. Profile 1 also shows the breach of Sand Dollar Island and shoaling of the lagoon impacts of the storm.

Figure 19 presents a comparison of the model results for Profile 3 in the middle of the project area for all the alternatives simulated during a 10-year return storm such as Hurricane Irma. The comparison clearly shows that with the 2020 Conditions would result in Sand Dollar Island welding onto Marco Island, closing the major section of the lagoon and severing the south part of the lagoon from tidal exchange. The post storm conditions with the +6' Berm show minor morphologic change and the conditions with the +4' Berm show significant migration of Sand Dollar Island and shoaling of the lagoon channel.

Preferred Alternative

Based on the results of these simulations, the +6' Berm design provides significant protection to the integrity of Tigertail Lagoon and Sand Dollar Island for a 10-year return storm and more frequent storms. The +4' Berm provides significantly less improvement compared to the +6 Berm and is not resilient against a 10 year storm. A 10-year return design threshold is considered appropriate for the design life of this project, and represents a significant improvement over the existing conditions. The +6' Berm design alternative is the preferred design for the Sand Dollar Island restoration and enhancement component of the TLSDI Ecosystem Restoration Project. This selection is supported by the consideration that the model results represent initial conditions after construction and do not consider the compound effects of multiple storms and progressive longshore erosion over time. Those factors will reduce resiliency over time and an allowance for this must be included in the initial design.

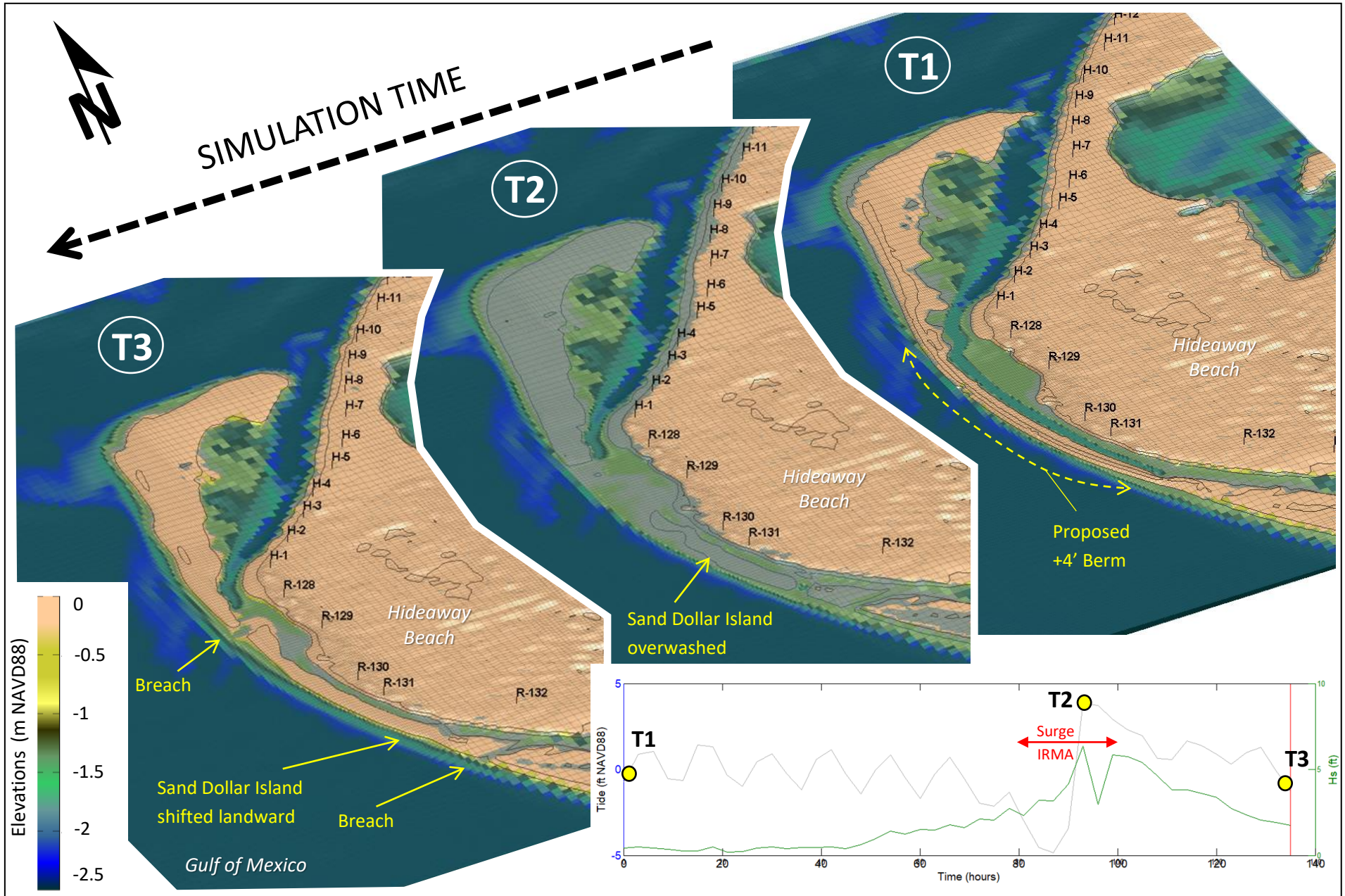


Figure 17. XBeach Model Results – IRMA - +4' Berm

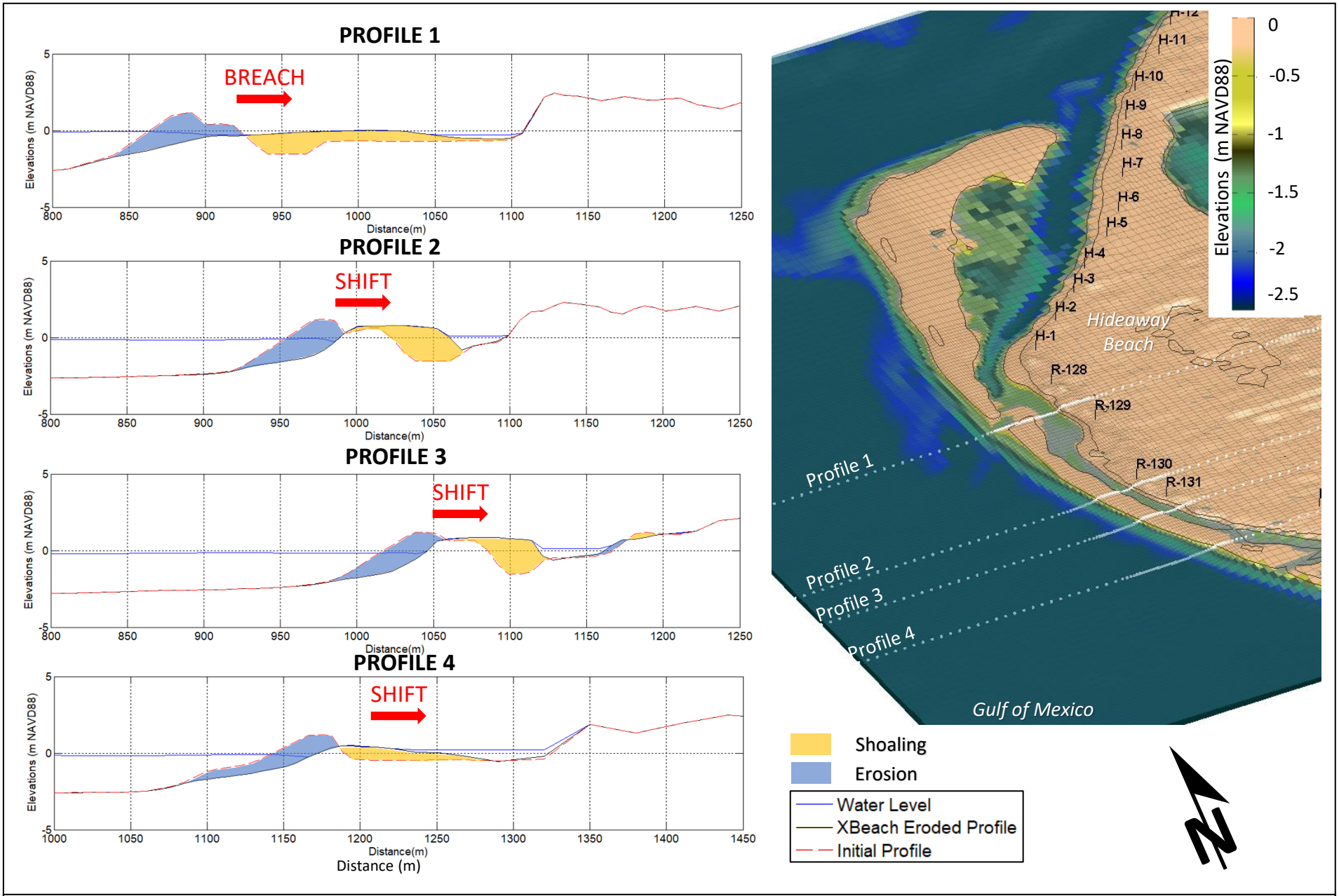
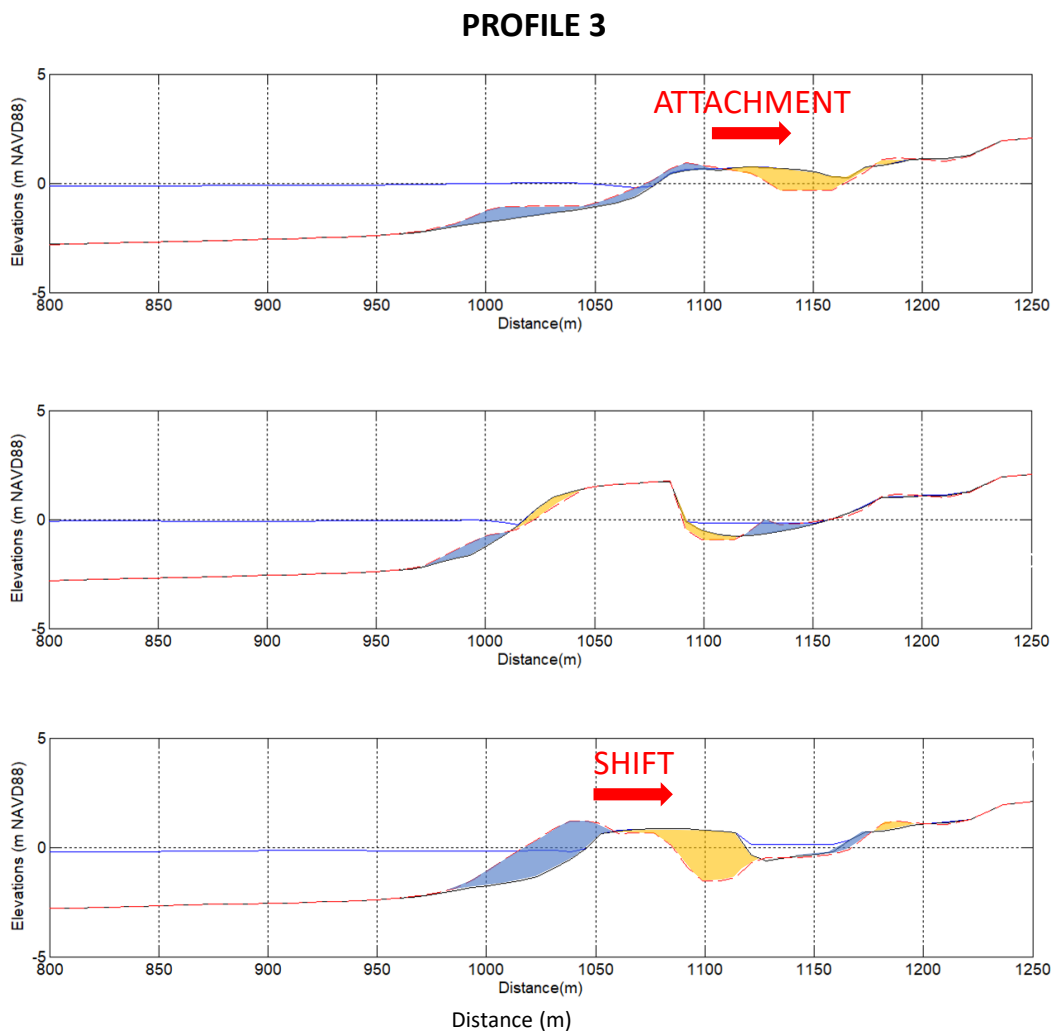


Figure 18. XBeach Model Results – Storm IRMA – PROPOSED ALTERNATIVE 2 - Profiles



Shoaling
Erosion
Water Level
XBeach Eroded Profile
Initial Profile

SIMULATION:
IRMA

Figure 19. XBeach Model Results – IRMA – Alternatives – Profile 3

3. LAGOON ENTRANCE ENHANCEMENT AND RENEWABLE SAND SOURCE: SAND TRAP DESIGN

The integrity and viability of the Tigertail lagoon as tidal lagoon is dependent on two main features, the sand barrier of Sand Dollar Island and tidal exchange with the Gulf through the maintained entrance at the north end of the system. The entrance at the north end has been maintained open through dredging in 2010, 2013, 2016, and 2019 to avoid closure and attachment of Sand Dollar Island north tip to Marco Island at Hideaway Beach, and will again be required soon. However, each dredging event occurred at a different location to keep up with the growth of the sand spit toward the northeast. At present time further extension of the entrance in the northeast direction to maintain the entrance open is becoming unsustainable. This is due to the physical and hydrodynamic restriction as the spit further encroaches on Big Marco River where flow confluence will force attachment and closure of the entrance. On the other hand, the lagoon area has been in decline over the past decade mainly due to shoaling and overwash of the midsection of Sand Dollar Island. The reduction of lagoon area and potential collapse of the mid part of the lagoon will further reduce the tidal flow at the entrance forcing closure at the northeast beyond the current dredging program.

To address both features necessary to restore the system, a resilient berm at the midsection of Sand Dollar Island is needed as well as stabilization of the entrance to earlier more stable conditions. Reconstruction of the beach berm at Sand Dollar Island will require a source of sediment in addition to sediment from the proposed flow channel. This source must also be available for future reconstruction events. Sand Dollar Island has grown significantly during the past two decades, from 21 acres north of R-131 in 2002 (including the former Coconut Island) to over 70 acres in 2019. The source of the sediment has been the ongoing collapse of the former Big Marco Pass ebb shoal and progressive erosion of Gulf-facing Sand Dollar Island.

Establishing a Sand Trap to remove sediment from this area will establish a renewable sand source that will also benefit the management of the entrance to the lagoon by intercepting the sediment before it accumulates at the entrance. A sediment source for the berm reconstruction in this area will also return the sediment to an up-drift position where it will erode back toward the end of the island, creating a renewable cycle. The renewable cycle will maintain the existing sediment cycle, which would otherwise deteriorate beginning with onshore attachment of Sand Dollar Island and accelerate when the erosion reaches the mangrove shoreline resulting in lack of sediment supply to the adjacent beaches.

Alternatives Considered

Two potential Sand Trap configuration are discussed below and contrasted with a scenario in which there is no Sand Trap in the area. The Sand Trap configurations considered consist of:

- <u>44 Acre Sand Trap Area</u>: Return to approximately 2013 island tip geometry
- <u>26 Acre Sand Trap Area</u>: Return to approximately 2016 island tip geometry

It is important to note that two proposed alternatives include upland areas to stabilize and reconfigure the entrance to the lagoon as well as providing sand supply to the Sand Dollar Island restoration. The Sand Trap is designed to accommodate both the immediate sediment needs and potential areas of future dredging in response to the growth dynamics of Sand Dollar Island. Limiting the Sand Trap configuration to submerged areas off the north end of Sand Dollar Island would not achieve the overall design and management goals to reduce the shoaling in the opening of the tidal bay areas and provide renewable sand source for berm reestablishment along the vulnerable mid-section of Sand Dollar Island. This is due to how the northern tip of the island has grown and essentially spilled into the inlet and Marco River channel. As evidenced by the profile sections on the attached permit drawings (**Appendix A**), the adjacent waters are relatively deep.

The sand trap designs presented are larger than the area with recoverable sediment in order to authorize removal of potential future shoaling and maintain the lagoon open to Gulf tides. The same design approach is used for the borrow area extension, which encompasses areas that do not currently require dredging to allow for adaptive management in the future.

In the absence of the Sand Trap, it is likely that the tip of the island will continue to grow then attach to Hideaway Beach and excess sand will continue to shoal or encroach on the Big Marco River and the entrance to Collier Bay. As this growth continues, the island will be progressively more constrained by the tidal currents of Big Marco River and the borrow area extension. This may initially necessitate more frequent dredging by Hideaway Beach/City of Marco to maintain the open waterway. However, the feasibility of dredging the entrance will not be sustainable as imminent closure will occur at higher frequency than the borrow area dredging program capacity. In addition, as the end of Sand Dollar Island continues to grow toward the east, without some form of intervention or stabilization, attachment and excess sand will also encroach on entrance to Collier Bay. This evolution process is similar to other sand spit evolution processes observed at other inlets in the Gulf of Mexico such as Big Carlos Pass and Longboat Pass. However, in this case at Marco Island, the Hideaway Beach NBA dredging over the last decade prolonged the lifecycle of this system to this point. A comprehensive management program as presented in this plan is necessary to maintain the integrity of the physical features of Tigertail Lagoon and Sand Dollar Island.

Sand Trap Analysis

The growth of Sand Dollar Island has been ongoing for two decades and was documented in the TLSDI Ecosystem Restoration Project Engineering Management Plan (H&M 2021). This analysis will summarize the ongoing changes and evaluate the Sand Trap configurations in the context of these changes. Key parameters consist of:

- Distance from North End of Hideaway Beach
- Total Area of Sand Dollar Island
- Volume Available in Sand Trap

Each of these plays a role in determining a suitable Sand Trap configuration.

Distance from North End of Hideaway Beach

The growth of Sand Dollar Island is related to the closure of Big Marco Pass as Capri pass evolved over half a century into the main inlet in this area. Big Marco Pass remained open until the early 2000's, separated from Capri Pass by Coconut Island. The growth of Sand Dollar Island is illustrated in **Figure 20**, showing aerial imagery between 2002 and 2021.The emergent Coconut Island is visible off Hideaway Beach in 2002 and as a submerged shoal in 2006. Establishment and continued growth are apparent from 2016 through 2021. Since 2002 the tip of Sand Dollar Island has moved from over 8,000 feet away from the entrance to Collier Bay at the north end of Hideaway Beach to approximately 3,100 feet in early 2021. This represents a trend of over 240 feet per year. Although the trend may be anticipated to change as the island interacts with Big Marco River, a substantial sand supply exists and will continue to be driven into the inlet by waves and tidal currents.

The sediment flux towards the northeast has been managed by repeated dredging events since approximately 2010. These have utilized the Nearshore Borrow Area (NBA) initially permitted as a sediment source for the previously eroding Hideaway Beach. Hideaway Beach has been nourished multiple times using sediment from the NBA to maintain the tidal lagoon open. In recent years it has been necessary to extend the NBA toward the northeast as the shoaling continues to progress toward Collier

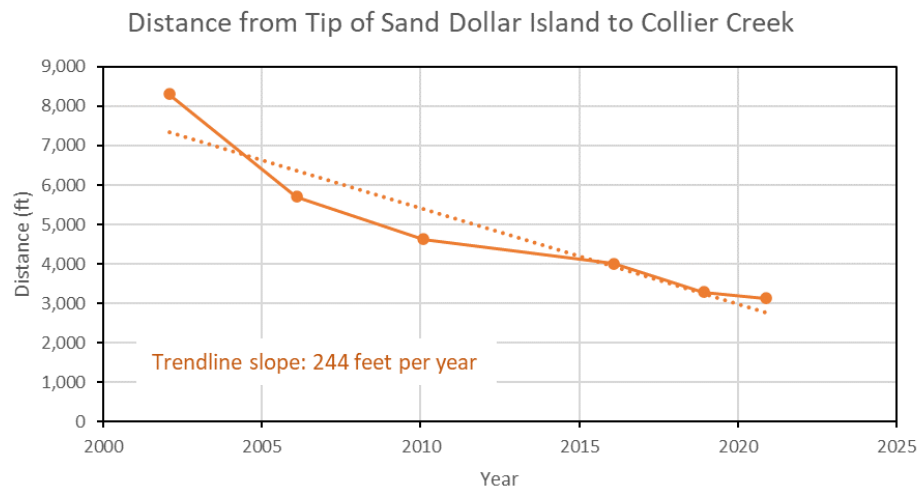


Figure 20. Growth of Sand Dollar Island - Distance to North End of Hideaway Beach

Creek. Another extension is currently in process to capture the new shoaling area and avoid closure of the lagoon entrance.

In the 2016 and 2019 dredging events, the volumes in the NBA exceeded the fill template on Hideaway Beach and additional sediment was placed at the Marco Central Regrade project to the south and in the offshore borrow area respectively. In the absence of the TLSDI Ecosystem Restoration Project, there is no disposal area available to maintain the sediment on the south side of the inlet system. The TLSDI project would provide beneficial re-use of dredged sediment from the NBA extension. Creation of the Sand Trap will provide enhanced management of the incoming sediment by capturing a large proportion and returning it to the updrift Gulf facing beach.

Total Area of Sand Dollar Island

The growth of the area of Sand Dollar Island between 2002 and 2019 was documented in the Engineering Management Plan (H&M 2021). That summary, updated to include recent data surveys in May 2021, is provided in **Figure 21**. The updated figure indicates a trendline average growth of 2.7 acres per year between 2002 and 2021, and a total acreage in excess of 70 acres. Total and unvegetated acreage updated to 2021 are presented in **Figure 22**. Post construction datapoints are provided to indicate the net result of the TLSDI project, not including the intertidal flats. Both total acreage and total unvegetated acreage will increase as a result of the project, as a result of the Sand Trap being deeper than the Berm Enhancement area.

After construction, the tip of Sand Dollar Island will be in a similar configuration to more stable historic shoreline conditions. The same forces of wave and tidal currents will continue to drive sediment into the inlet and toward the northeast tip of the island. The tip of the island will re-grow similar to its recent evolution in the same vicinity. The project will essentially wind back the clock to replay a geologic evolution similar to what was recently observed. In this manner the system is restored to maintain the integrity of Sand Dollar Island as a sandy barrier protecting the calm lagoon. The Sand Trap and NBA will maintain the entrance open and provide the renewable source of sand to maintain the sandy barrier in the future.

Volume

Another approach to understanding recent changes at the northeastern tip of Sand Dollar Island consists of tracking the volume available within the Sand Trap alternatives. Contours based on annual monitoring surveys are presented in **Figure 23**. Monitoring is generally conducted in May of the given year. The growth of Sand Dollar Island is apparent and summarized by the progressive 0’ NAVD contours shown on the image at bottom right. The 44 acre sand trap alternative would approximately mimic 2013 shoreline conditions, while the 26 acre alternative results in a slightly modified 2017 condition. Dredging of the NBA occurred in 2013 as part of a regular nourishment event, then in 2016 and 2019 to maintain the waterway open and is presently required again.

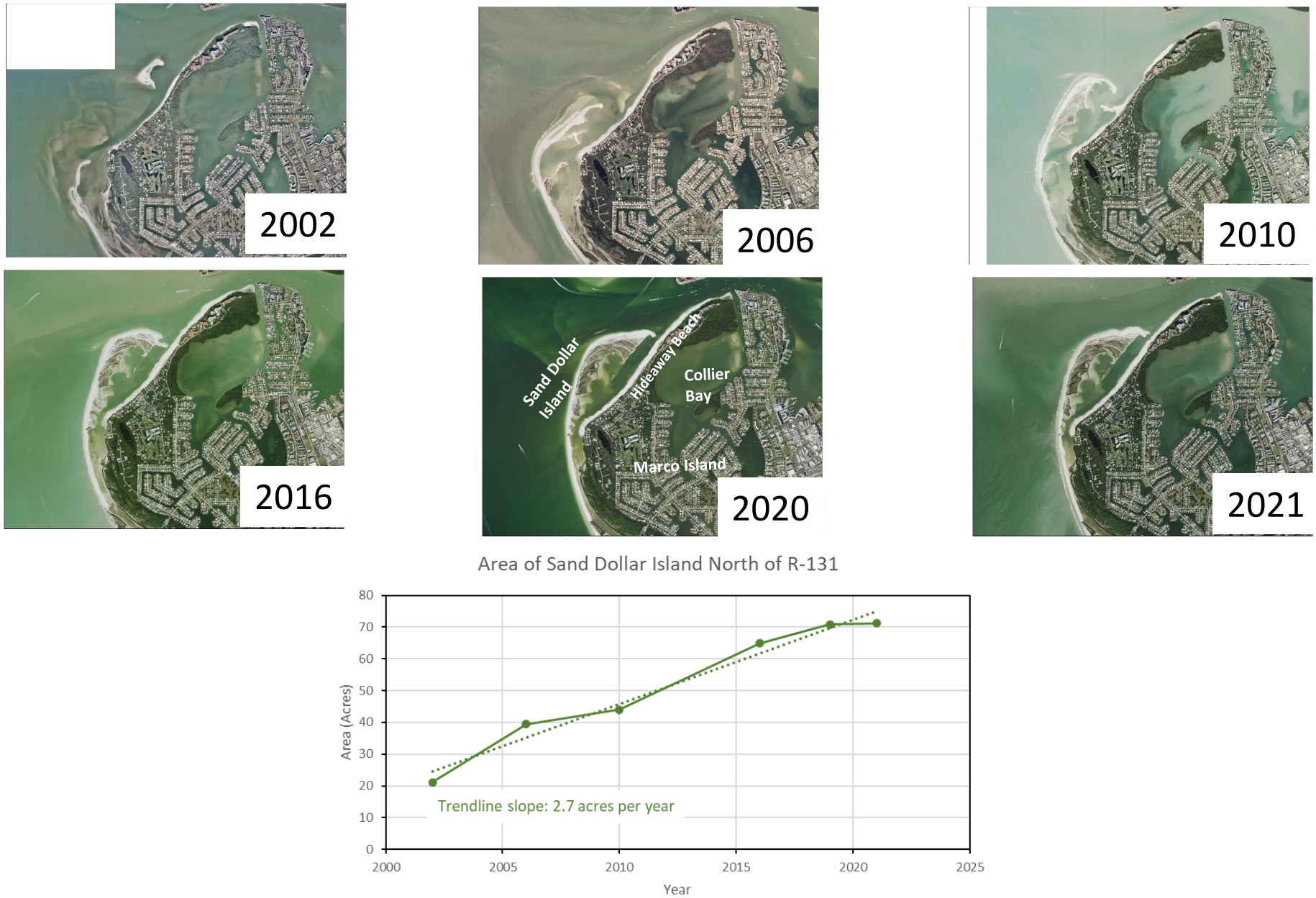


Figure 21. Growth of Sand Dollar Island - Acreage

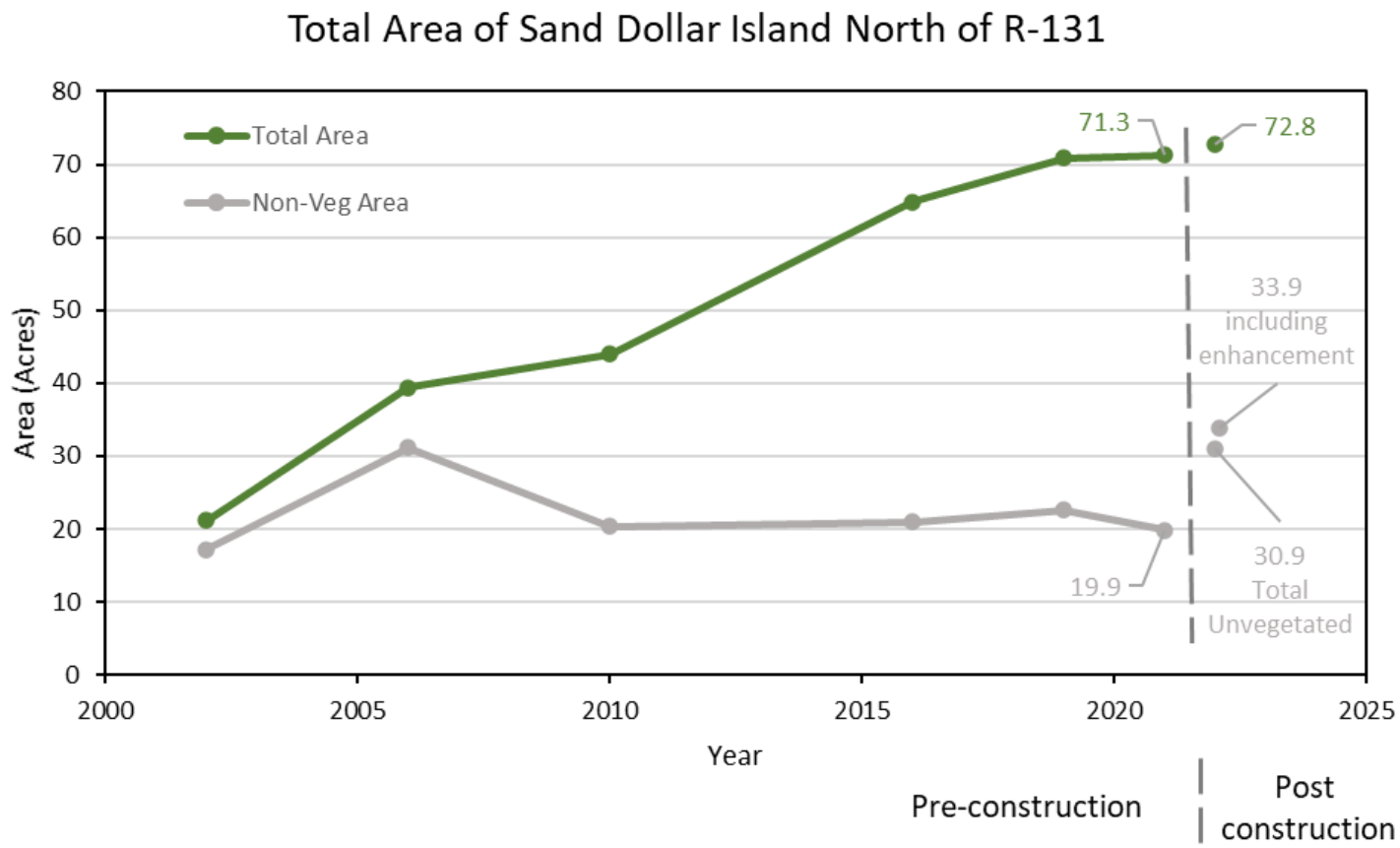


Figure 22. Sand Dollar Island – Acreage Over Time and Post Construction Conditions

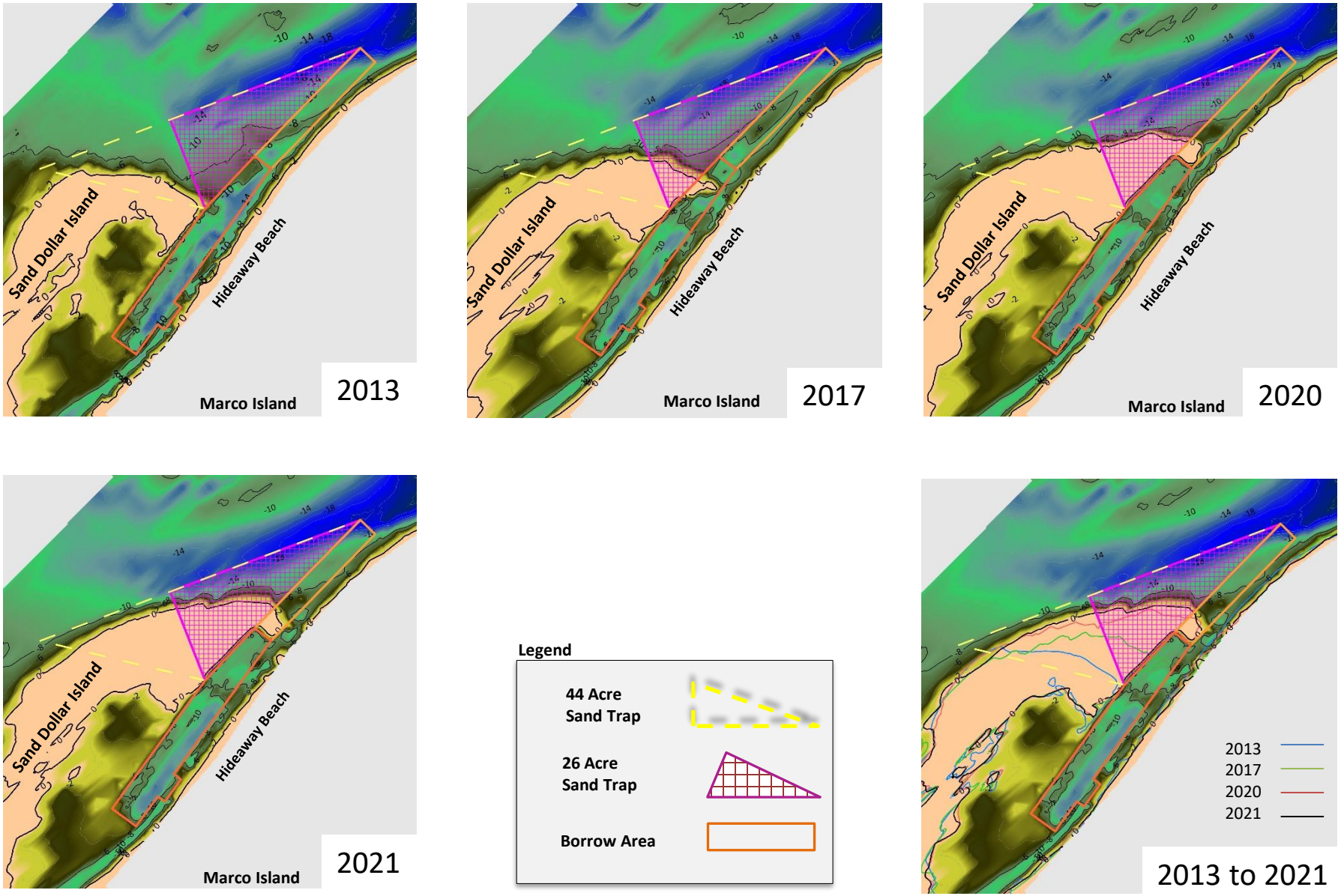


Figure 23. Northeastern Tip of Sand Dollar Island – Monitoring Surveys

Taking a design bottom elevation of (-8' NAVD), consistent with the adjacent NBA, which was also the approximate natural bottom elevation in that location prior to shoaling, the volume within each alternative is presented in **Figure 24**, along with rates of growth over time. When comparing the two curves, the 44 acre alternative consists of a larger area of active shoaling, and consequently contains more volume and shoals at a higher rate in total. When comparing rates over time, slow initial growth rates are indicative of the early stages when shoaling is only beginning to enter the control volume. Higher growth rates indicate active shoaling within the control volume. In theory, these would again decrease into the future as the control volume reaches its maximum capacity and no more sediment can be added within the control volume by natural processes.

As of May 2021, the 44 acre alternative contained approximately 415,000 cy of sediment, whereas the 26 acre alternative contained 185,000 cy. *Sediment quantity is only one consideration in the design of the Sand Trap. Improving management of the entrance to Tigertail Lagoon and establishing a backpassing pattern to feed the eroding Gulf facing beach are essential to overall management of the system*. A deficit of sand at the Gulf side is best addressed by cycling back sediment from the excess at the tip. If the enhanced berm is constructed by adding sand from outside of the immediate system, it will compound the excess of sediment at the tip. Using the tip as the source of sediment addresses both needs.

Preferred Alternative

A Sand Trap at the northeastern tip of Sand Dollar Island will serve multiple functions by:

- Providing sediment for Gulf beach berm enhancement.
- Improving management of the entrance to Tigertail Lagoon.
- Establishing a backpassing program instead of providing additional sediment loading.
- Preventing further migration of the tip and reducing sediment transport toward Collier Creek.

The Sand Trap is a necessary component in the restoration of the TLSDI ecosystem. The 26 acre Sand Trap configuration will serve the purposes of the Trap while minimizing the disturbance of Sandy Beach. The island will continue to grow due to ongoing shoaling regardless of any future activities in the area. There will be recovery of the island in the Sand Trap during interim years, similar to the geologic processes that have occurred in the recent past.

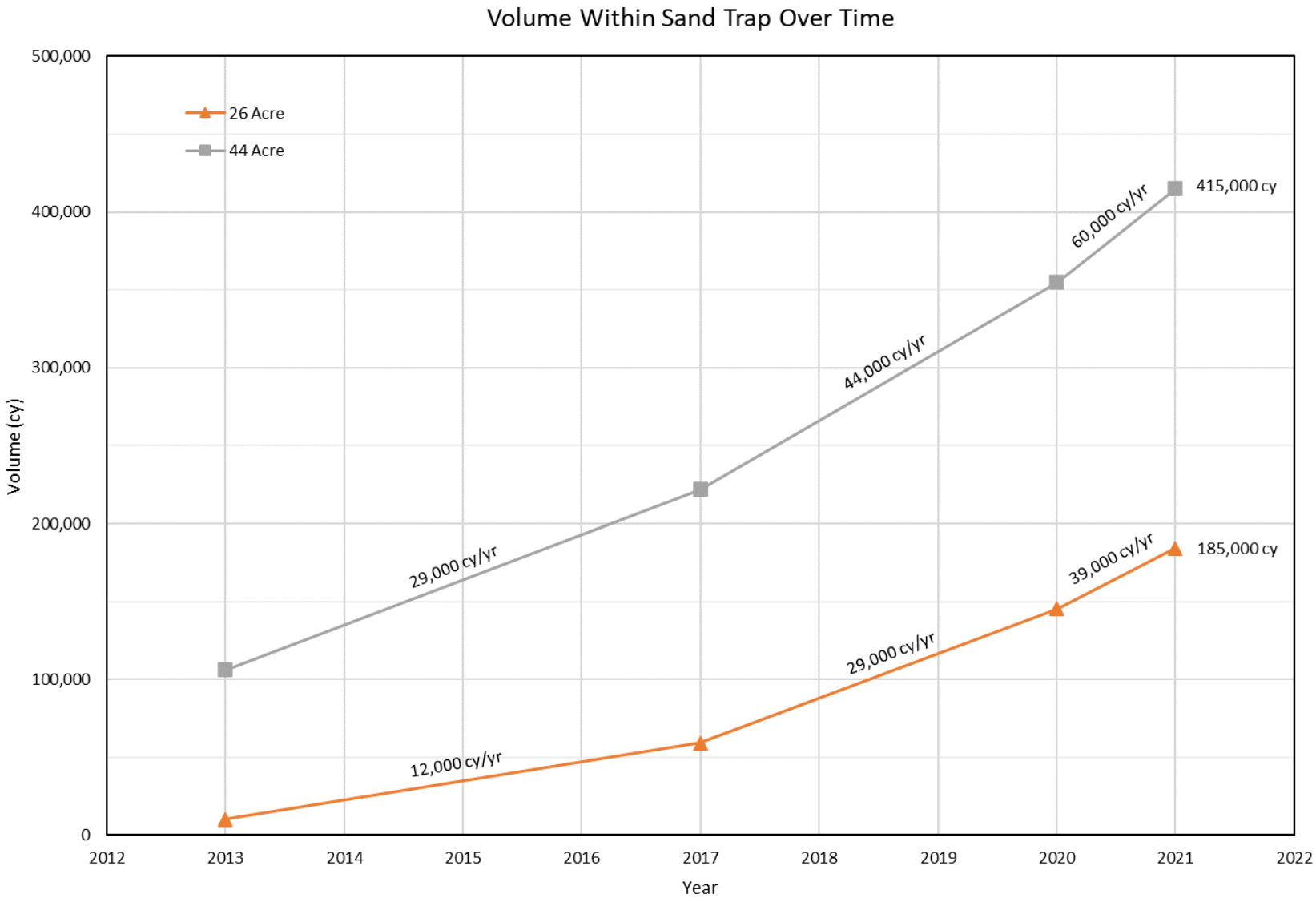


Figure 24. Volume Within Sand Trap Alternatives - -8' NAVD

OVERALL PROJECT DESIGN

This Alternatives Analysis has identified preferred alternatives for each component of the Tigertail Lagoon Sand Dollar Island Ecosystem Restoration Project. A summary of the alternatives and scenarios modeled and assessed is provided in **Figure 25**. Consideration of the preferred alternative must include both the existing and future conditions without the project. If the project is not constructed, the result will not be stable existing conditions, but instead a progressive deterioration and loss of the existing environmental resources.

The preferred project design is shown on the permit plans (**Appendix A**) and would consist of an improved channel with bottom elevations of -8' to -5' NAVD and a narrow connector at -3' to the deep water area at the south part of the lagoon. This would be sheltered from Gulf waves by an enhanced beach berm with maximum elevation at +6' NAVD and no dune. The berm will be constructed from sediment removed to create the improved channel and a Sand Trap at the northeastern tip of Sand Dollar Island. The Sand Trap is the optimal sediment source because it will improve management at the NBA and establish backpassing instead of adding sediment loading to the system.

The TLSDI Ecosystem Restoration Project has been holistically designed to incorporate improvements to aquatic and upland habitat while preserving and enhancing the resiliency of the natural system. This project provides a clear example of working with the natural environment and coastal processes to preserve and enhance existing habitat in a naturally evolving system The project also provides nature based coastal resiliency to the environmentally sensitive area fronting upland communities. Establishing resiliency through nature based solutions such sandy barriers, coastal lagoons and mangrove shorelines sets an example to monitor and study in the years to come. Such examples are valuable for future planning as coastal cities and developed coastal areas are assessing future vulnerabilities to sea level rise and developing adaptation plans for improved resiliency.

REFERENCES

H&M 2018 Tigertail Lagoon & Sand Dollar Island, Ecosystem Restoration and Engineering Management Plan. prepared for Hideaway Tax District. March 2018

H&M 2021 Tigertail Lagoon/ Sand Dollar Island Ecosystem Restoration, Engineering Management Plan prepared for Hideaway Beach Tax District, City of Marco Island.

Alternatives Analysis Matrix

Preferred Alternative identified in bold

Project	Element	Scenario	Description
Tigertail Lagoon / Sand Dollar Island Ecosystem Restoration Project	Flow Channel	2017 Conditions	Tidal Range Ratio of 0.40 indicates less than 1/2 of potential tidal exchange is occurring.
		2020 Conditions	Tidal Range Ratio of 0.23 indicates less than 1/4 of potential tidal exchange is occurring.
		-3' NAVD	Tidal Range Ratio of 0.73 indicates greater tidal exchange compared to 2020 & 2017.
		-5' NAVD	**Tidal Range Ratio of 0.87 is the greatest improvement in tidal exchange. Ratio approaching 90% indicates that nearly all potential tidal exchange occurs.**
		-5' NAVD Narrow No Connector	Tidal Range Ratio of 0.57 is the smallest improvement in tidal exchange. This alternative provides improvement, but limited widening for seagrass habitat and limited future overwash capacity.
		No Restoration	All alternatives represent improvement in tidal exchange. Without the TLSDI Ecosystem Restoration Project Sand Dollar Island will attach to the existing mangrove shoreline, eliminate seagrass habitat between R-128 & R-131 and sever connection of the deep water area and Gulf.
	Beach Berm	2020 Conditions	Existing Gulf facing beach berm is overwashed by both a 10 year return storm (Hurricane Irma) and a less than 10 year return storm (Tropical Storm Eta). If impacted by a 10 year return storm at 2020 conditions the beach berm would weld onto Marco Island and isolate the deep water lagoon area.
		+6' Berm	**Provides resilient protection against 10 year return storm and more frequent storms. Model water levels suggest that storms with greater than 10 year return periods would overwash the berm.**
		+4' Berm	Provides resilient protection against less than 10 year return storms. 10 year return storm conditions overwashed the berm and resulted in landward migration.
		No Restoration	Overwash and landward migration continue on a fequent basis. Beach berm will weld onto Marco Island, isolating deep water lagoon and eliminating existing seagrass habitat behind the beach. In future, beach erosion will continue and spread to adjacent areas as supply is depleted.
	Sand Trap	44 Acre	Provides over 400,000 cy of sediment available as of May 2021. Re-establishes approximate 2013 tip geometry. Sand Dollar Island will continue to grow at the tip due to sediment supply.
		26 Acre	**Provides approximately 185,000 cy of sediment available as of May 2021. Re-establishes approximate 2016 tip geometry. Sand Dollar Island will continue to grow at the tip due to sediment supply.**
		No Restoration	Tip of Sand Dollar Island will contine to extend toward the end of Hideaway Beach. Management challenges as the opening will persist. Addition of sand supply from other sources to beach berm will add supply to the system and compound tip growth management challenges.

Figure 25. Alternatives Analysis Matrix

APPENDIX A: PERMIT PLANS