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Alternatives to Reduce Shoaling in the Gulf Intracoastal Waterway and Prevent Erosion of Bay Islands along the North Shoreline of West Galveston Bay

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PURPOSE: The purpose of this Coastal and Hydraulics Engineering Technical Note (CHETN) is to document development of a regional sediment budget and assessment of coastal sediment processes for a Regional Sediment Management (RSM) study along the Gulf Intracoastal Waterway (GIWW) of West Galveston Bay from just north of Greens Lake to Chocolate Bay, TX. The loss of bay barrier islands is reducing the available placement options and may be leading to increased channel shoaling rates. Several design alternatives were investigated to reduce dredging requirements and prevent erosion of the bay islands that act as a barrier protecting the GIWW.

INTRODUCTION: The area of study encompasses Sta. 40+000 to Sta. 120+000 (old stationing), with the primary focus on Placement Areas (PAs) 62 through 65 shown in Figure 1. PAs 62 and 63 serve as barriers along the GIWW and are experiencing the most significant erosion in this area at 8,000 cubic yards (yd^3)/ 5,000 linear feet per year (lin ft/yr). Sediment is being lost along the shallow embankments on both sides of the navigation channel and the adjacent bay shoreline due to a combination of currents, wind-generated waves, and ship wakes. PAs 62 and 63 are semiconfined, and as they erode and the frontage levees are breached, sand and silt pass through and are deposited in the channel. If the placement areas are allowed to further erode, they will eventually become unavailable for placement of future dredged sediment. To address this problem, the U.S. Army Corps of Engineers (USACE), District, Galveston (SWG), has identified several sediment management options to prevent erosion of these placement areas, to stabilize the inlets, and to reduce channel shoaling.

Figure 1. Placement Areas 62–65 along GIWW of West Galveston Bay, TX.

HISTORICAL DREDGING DATA: Existing data were used to improve understanding of regional sediment transport in the area. Information and data from previous field surveys, investigations, and dredged sediment placements events were gathered in addition to discussions with SWG operations managers and engineers.

To estimate annual shoaling rates in the GIWW, historical dredging quantities from 1943 to 2012 were obtained from the SWG Dredging Histories Database. An annual shoaling rate was calculated for each 5,000 lin ft increment of shoreline from Sta. 50+000 to Sta. 100+000, which correspond to PAs 62–65, based on the amount of time that had passed since that increment was last dredged. The shoaling rates were then used to calculate 25 yr and 50 yr averages. The 25 yr averages were used in the sediment budget analysis since much of the older dredging data is incomplete and recent numbers are more relevant. Shoaling near the north end of the area of interest (Sta. 50+000 to 55+000) was the greatest at approximately 21,200 yd^3/yr. From Sta. 55+000 to 100+000, the average shoaling rate ranged from 11,900 to 19,500 yd^3/yr with the mean being approximately 15,100 yd^3/yr/5,000 lin ft. A table of the annual shoaling rates in the GIWW from Sta. 50+000 to Sta. 100+000 is available in Townsend (2014).

SHORELINE CHANGE DATA: One potential common correlation to estuarine channel shoaling is the erosion of the adjacent beaches. Erosion rates along the shoreline were obtained through comparison of shoreline positions from historical imagery from 1995, 2004, 2006, 2010, and 2012. Shoreline positions from each year were traced and then overlaid to calculate the area in square yards of shoreline lost or gained during that time period.

Stations were grouped together according to what placement area they are adjacent to, and an average annual erosion rate (square yards per year) for each stretch was calculated. An average depth of 9 ft was assumed, and a constant equilibrium profile was assumed to estimate the annual volume of sediment lost. This is an appropriate approach because the sediments in this area tend to maintain a relatively constant profile through time, even with continual erosion, as long as the forces remain unchanged (Dean 2002). Because the erosion of cohesive sediments is irreversible once the cohesive bonds are broken, the eroded material can be easily carried long distances in suspension and can become resuspended relatively easily (USACE 2002).

Results revealed that shoreline erosion rates along the portion of the GIWW that has bay barrier islands (Sta. 54+000 to Sta. 85+000) range between 40% to 60% less than the estimated annual shoaling rates in that area, using a constant equilibrium profile approach and without considering bulking or the eroded sediment as no data were available to quantify this anticipated phenomenon (USACE 2002). This suggests that a majority of the shoaling in that portion of the channel is due to erosion of the adjacent shorelines. However, from Sta. 85+000 to Sta. 98+000 where there are no bay barrier islands and the channel is open to West Galveston Bay, the erosion rate is significantly lower compared to the annual shoaling rate (Figure 2). This portion of the shoreline has been armored with articulating concrete blocks since 2000, which explains the much lower erosion rates. This implies that most of the sedimentation within this portion of the channel is from other sources, particularly West Galveston Bay and nearby Chocolate Bay via a combination of currents and wind-driven waves. The table providing calculated average annual shoreline erosion rates along the GIWW is available as a technical reference in Townsend (2014).

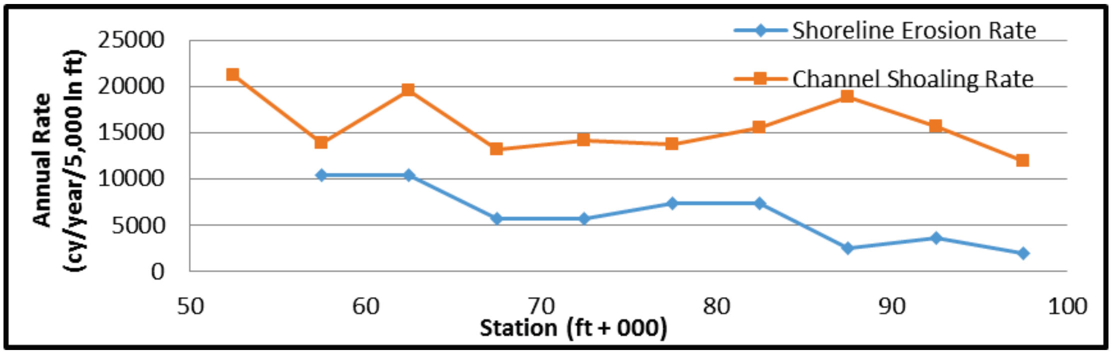

Figure 2. Channel shoaling rate vs. shoreline erosion rate from PA 62 to PA 65.

Erosion rates inside the GIWW were then compared to shoreline change rates on the bay side of the bay barrier islands. The mainland and bay side of the bay barrier islands are eroding the fastest, with several large reaches losing 4–8 ft/yr between 1995 and 2012.

Erosion along the channel side of the bay barrier islands is more modest, with most areas eroding at roughly 1–3 ft/yr (Figure 3).

NUMERICAL MODELING: The U.S. Army Engineer Research and Development Center (ERDC) Coastal Modeling System (CMS) was selected to simulate physical processes near inlets, ports, harbors, and coastal structures. The CMS uses an integrated numerical modeling system to model waves, currents, sediment transport, and morphology change at coastal inlets and entrances (Demirbilek and Rosati 2011).

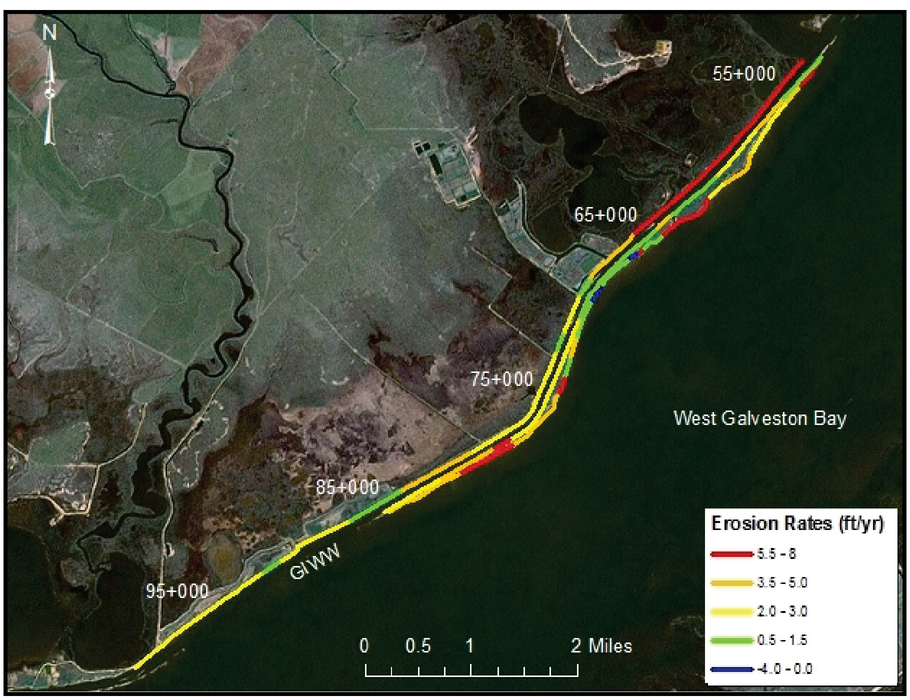

Figure 3. Erosion and accretion along West Galveston Bay and the GIWW.

For this study, the CMS was used to calculate sediment transport and qualitatively identify areas of erosion and accretion in Galveston Bay. The model domain covers the entire Galveston Bay with navigation channels connecting the GIWW to the Gulf of Mexico. The CMS grid extends approximately 60 miles alongshore and 40 miles cross-shore, with the southern offshore boundary reaching to the 60 ft isobaths. The CMS was calibrated with water level, current, and wave data collected around the Bay entrance inlet over a period of 11 days, 19–30 June 2010.

Sediment in Galveston Bay is mixed, with increased percentages of sand near the Bay entrance and inlets, along the coast, and surrounding the bay barrier islands. More silt and clay are found in the landward side of the Bay and in the GIWW and ship channels. The CMS was set up to calculate sediment transport using a mixed sediment model (Lambert et al. 2013). There were no existing measurements of sediment transport or of shoreline erosion and channel infilling for calibrating the 11-day simulation, and therefore, morphologic change is qualitatively assessed here to identify where erosion and accretion occurred.

The simulations verified that PAs 62 and 63 experience significant channel side erosion. There is evidence of sediment deposition within the GIWW, farther north at PAs 55–60, potentially sediment transporting through the Galveston Entrance Channel (Figure 4). It is assumed that there is minimal longshore and wind-generated wave transport where the barrier island features are still present. Therefore, the majority of erosion is likely coming from another source, presumably ship-wake-induced sediment suspension and redistribution through tidal flow.

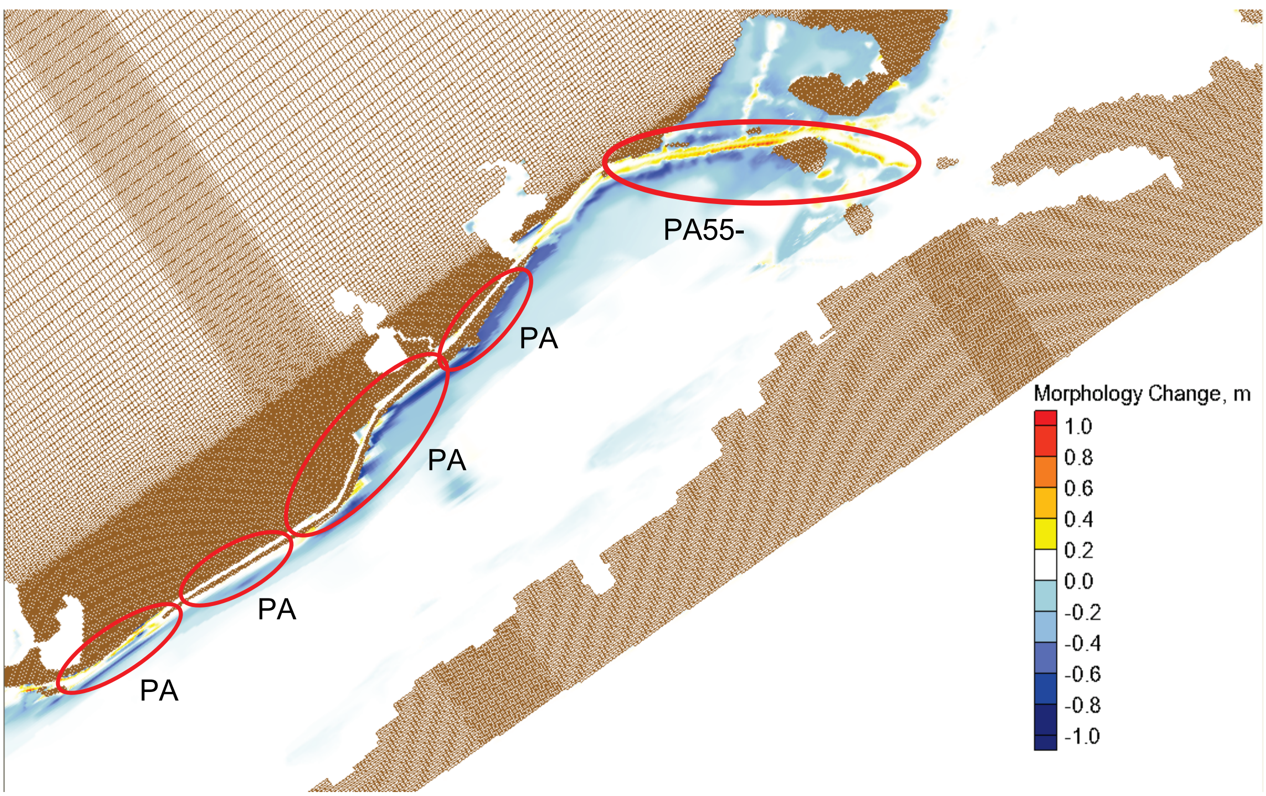

Figure 4. Shoreline change along the West Bay, 19–30 June 2010.

Simulations show strong tidal flow in the GIWW from the Gulf of Mexico via the Galveston Entrance Channel and San Luis Pass. This is a potential source of shoreline erosion and sediment deposition and redistribution along the navigation channel.

SEDIMENT BUDGET ANALYSIS: The Sediment Budget Analysis System (SBAS) (Rosati and Kraus 2001 [rev. 2003]; Dopsovic et al. 2002 [rev. 2003]) was applied to compile existing sediment erosion and shoaling information along the GIWW from the Galveston Causeway to Bastrop Bayou into a single budget to gain greater knowledge of the relationship between sediment sinks and sources within the project area (Figure 5). There was no bulking factor applied to relate the shoreline-eroded sediment to the volume deposited in the channel. The difference due to consolidation could be significant, but no applicable information was available. Thus, bulking was assumed not to be a factor for this analysis.

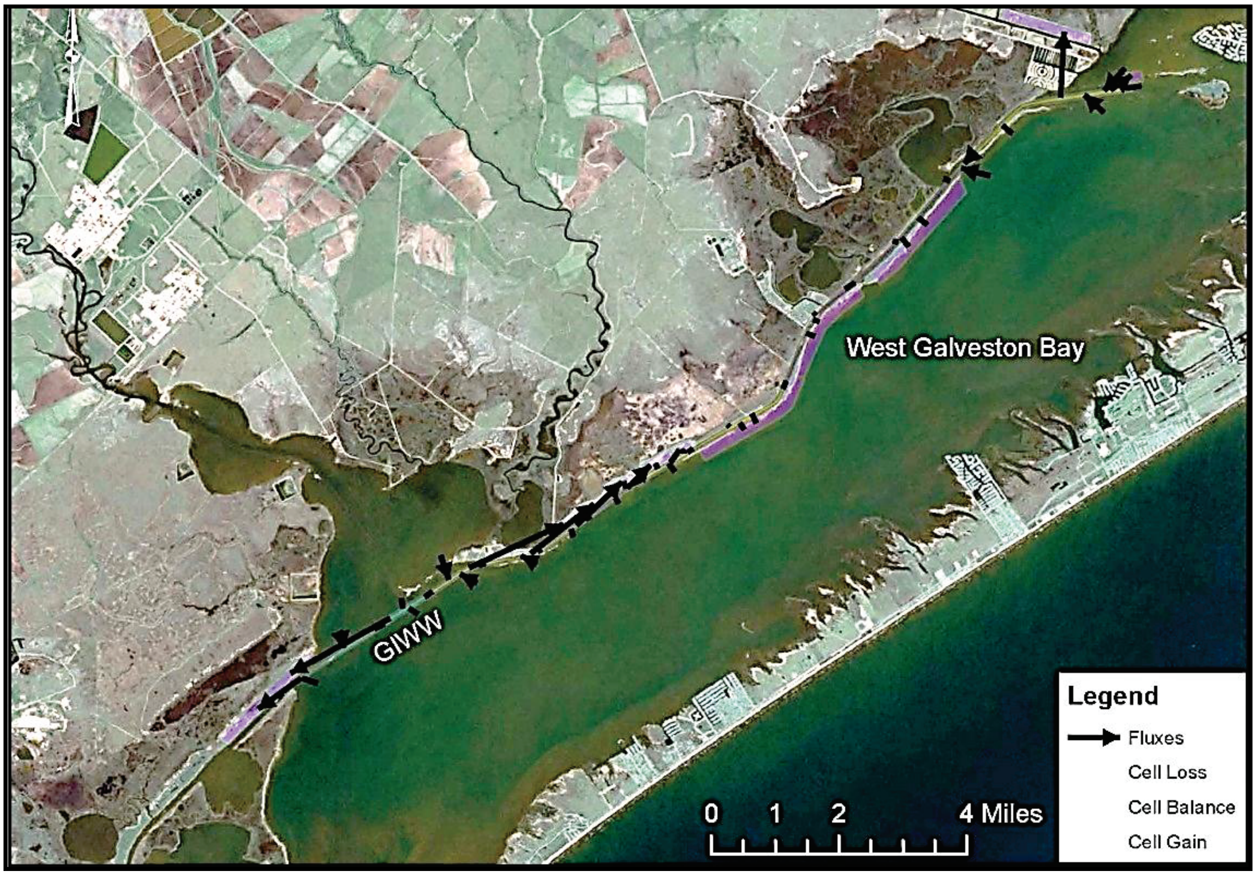

Figure 5. Sediment budget cells from Galveston Causeway to Bastrop Bayou.

Several assumptions were made to create the sediment budget:

- Sediment is transporting from channel reach to channel reach due to currents within the GIWW and vessel traffic.
- There is some recirculation from bayside placement areas back into the GIWW.
- Reaches were created based on the PA allotment of dredged sediment that was taken from the most recent dredging contract (2010). An extensive background check of historical sediment placement was not performed.

- Averages of dredging data over the most recent 25 yr were used, since they depict current conditions more accurately.
- Shoreline erosion rates were calculated using a 9 ft active depth based on historical cross sections of the channel, and no bulking factor was applied.
- Thirty percent uncertainty was used in the sediment budget, which is the standard practice for this type of analysis.

The final product is a sediment budget with cells and fluxes derived from the regional sediment budget analysis. The sediment budget cells are color coded to represent erosion, accretion, or a sediment balance within the cell. Arrows indicate sediment fluxes, in units of cubic yards per year, or direction of net transport at cell boundaries. The along-shore length of each cell marks the approximate limits of cell boundaries. Placement or removal of sediment is included within the cells where needed, typically to account for beach nourishment or dredging.

The Galveston Causeway to Bastrop Bayou sediment budget indicates that sediment is transported along the channel from reach to reach due to vessel traffic and tidal currents, adding to shoaling in the channel. The area experiencing the more significant shoaling is around PA 62 (Sta. 50+000 to Sta. 65+000) where shoaling quantities cannot be accounted for simply with near-shore erosion. It is therefore assumed that some sediment originates from West Galveston Bay and Greens Lake in this reach, and possibly Jones Bay farther east as well.

The following general conclusions are accepted based on the sediment budget analysis of historical data:

1. From Sta. 50+000 to Sta. 65+000, approximately 60% of sediment dredged originates from erosion of adjacent GIWW shorelines. The remaining 40% of sediment is assumed to originate from the bay, Greens Lake, or other unknown sources or is from reach-to-reach, tidal-induced sediment transport. (An exception is that shoaling is locally higher at Carancahua Cut and Greens Cut, where more sediment likely originates from the adjacent upland bays.)
2. From Sta 65+000 to Sta. 85+000, 40%–50% of dredged sediment originates from erosion of adjacent shorelines. The remainder is due to reach-to-reach transport and inflow from the bay through Carancahua Cut.
3. From Sta. 85+000 to Sta. 100+000, 75%–85% of dredged sediment is from near-shore erosion in West Galveston Bay, erosion of relic bay barrier islands, and from Chocolate Bay. The remaining 15%–25% is from shoreline erosion or other unknown sources.
4. From Sta. 100+000 to Sta. 120+000, 90% of the dredged sediment is coming from near-shore erosion in West Galveston Bay and from a combination of wave action and currents from Chocolate Bay. The remaining 10% is presumably from shoreline erosion or other unknown sources.
5. Substantially higher shoaling rates from Sta. 50+000 to Sta. 55+000, Sta. 60+000 to Sta. 65+000, and Sta. 85+000 to Sta. 90+000 where the bay barrier islands have already eroded, suggest that the bay barrier islands may reduce shoaling rate by as much as 5,000 yd^3/yr/5,000 lin ft section (1 yd^3/yr/lin ft).
6. Comparison of shoreline erosion and dredging requirements suggests that halting shoreline erosion within the GIWW may reduce shoaling by up to 8,000 yd^3/yr/5,000 lin ft section (1.6 yd^3/yr/lin ft).

INITIAL ALTERNATIVES: The primary metric for selecting one or more of the suggested alternatives below is quantifiable shoaling reduction. The alternative(s) must stabilize the inlets and reduce near-shore erosion. The alternative(s) must also be economically feasible and have the potential to be approved by resource agencies. Beneficial use of dredged sediment from the navigation channel is a preference. The following alternatives were posed for consideration:

- breakwaters: articulated concrete block (ACB), rip rap, reef balls, oyster castles
- sacrificial berms
- revetments: rip rap, reef balls.

COST ESTIMATE AND FINAL SELECTION OF ALTERNATIVES: A detailed design was completed for each of the aforementioned alternatives, and a cost comparison per linear foot was performed. Based on the cost comparison, a rip rap revetment was selected as the lowest cost alternative for structures adjacent to channels, costing $501/lin ft (Figure 6). Prefabricated breakwater concrete units, although cheaper at $402/lin ft, were not selected for these locations due to the potential for damage from barges, which would compromise their functionality and require significant repair to the revetment after each impact event.

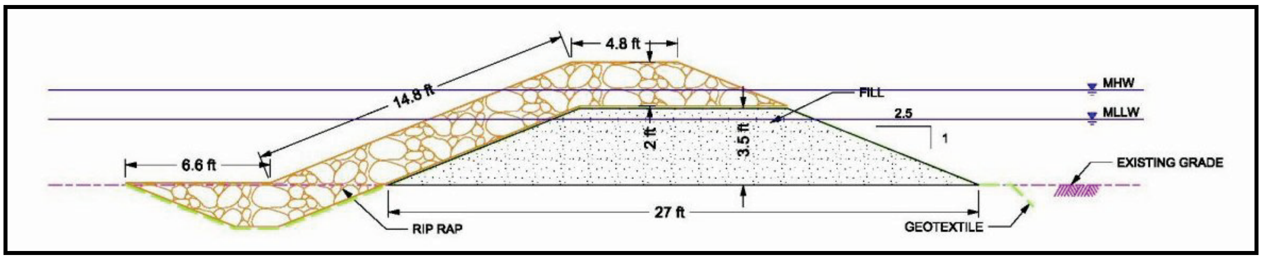

Figure 6. Typical cross section for rip rap revetment.

The lowest-cost alternative for bay-side structures is oyster castles, at $352/lin ft (Figure 7). This is also the most constructible alternative for these areas, as this material can be delivered to the construction location on small, shallow-draft boats and can be hand assembled, requiring no heavy equipment. However, because SWG has no previous experience implementing oyster castles, it may prove wiser to implement mostly rip rap revetment during Phase 1, initially placing oyster castles only where erosion is mild so that SWG can observe performance.

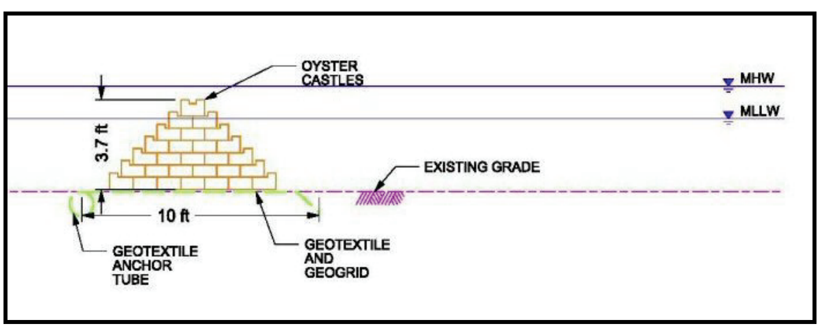

Figure 7. Typical cross section for oyster castle breakwater.

In addition to these hard structures, *sacrificial berms* were chosen for the bay side of the bay barrier islands to serve as training dikes and allow for the continued placement of dredged sediment (Figure 8). The sacrificial berms also function as renourishment sediment to maintain the island features. The berms are economical as well, costing under $52/lin ft.

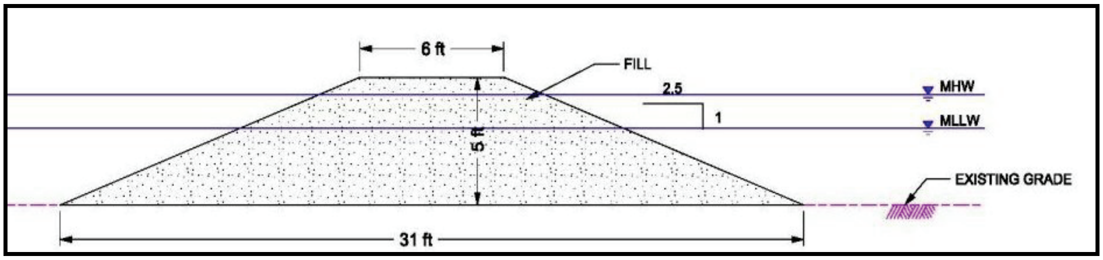

Figure 8. Typical cross section for sacrificial berm.

PROPOSED DESIGN LAYOUT: The final layout of protection was divided into two phases to ensure that structures in the most critical areas will be implemented first. Phase 1 encompasses PAs 62 through 64, with the regions to the north and south of these PAs designated as Phase 2. Within each phase, each structure was labeled with a certain priority based on the severity of erosion and on channel shoaling along that particular reach of shoreline. SWG chose to categorize the proposed designs this way to make very clear where the most critical areas are located in case resources are limited and only certain priority reaches can be addressed.

North of Greens Lake near PAs 60 and 61, a revetment is proposed along both sides of the GIWW. Along the bay side of these bay barrier islands, a sacrificial berm wraps all the way around to the channel side to provide continued storage of dredged sediment. A bayside offshore structure of either oyster castles or rip rap revetment serves as a means of erosion protection and as a physical barrier for the beneficial placement of dredged sediment bayside of existing identified resource areas (Figure 9).

Along PA 62, channel shoaling and shoreline erosion are major issues, particularly toward the north end. To alleviate the persistent shoaling in the GIWW, both sides of the channel along PA 62 should be protected by revetments. A sacrificial berm placed on the bayside of PA 62 could help expand the placement areas and prevent them from losing sediment to the bay. In addition, placement of a hard structure offshore beyond the sea grasses along the north end of the bay side of PA 62 will help protect the barrier island from further erosion. Erosion is not as severe farther south along PA 62, so the sacrificial berm in this area can be designated *beneficial*, and the offshore hard structure does not continue farther south.

The northern half of PA 63 is also experiencing significant erosion, and the GIWW shoals steadily in this area, as well. A revetment on both sides of the channel (Priorities 1 and 2) and a sacrificial berm along the bay side of the channel (Priority 1) (Figure 9) are proposed here to address the erosion issues. The revetment continues on both sides of the GIWW along the southern half of PA 63, as does the sacrificial berm on the bay side. Additionally, a hard structure is placed offshore beyond the seagrasses as a beneficial structure to prevent further erosion (Figure 10).

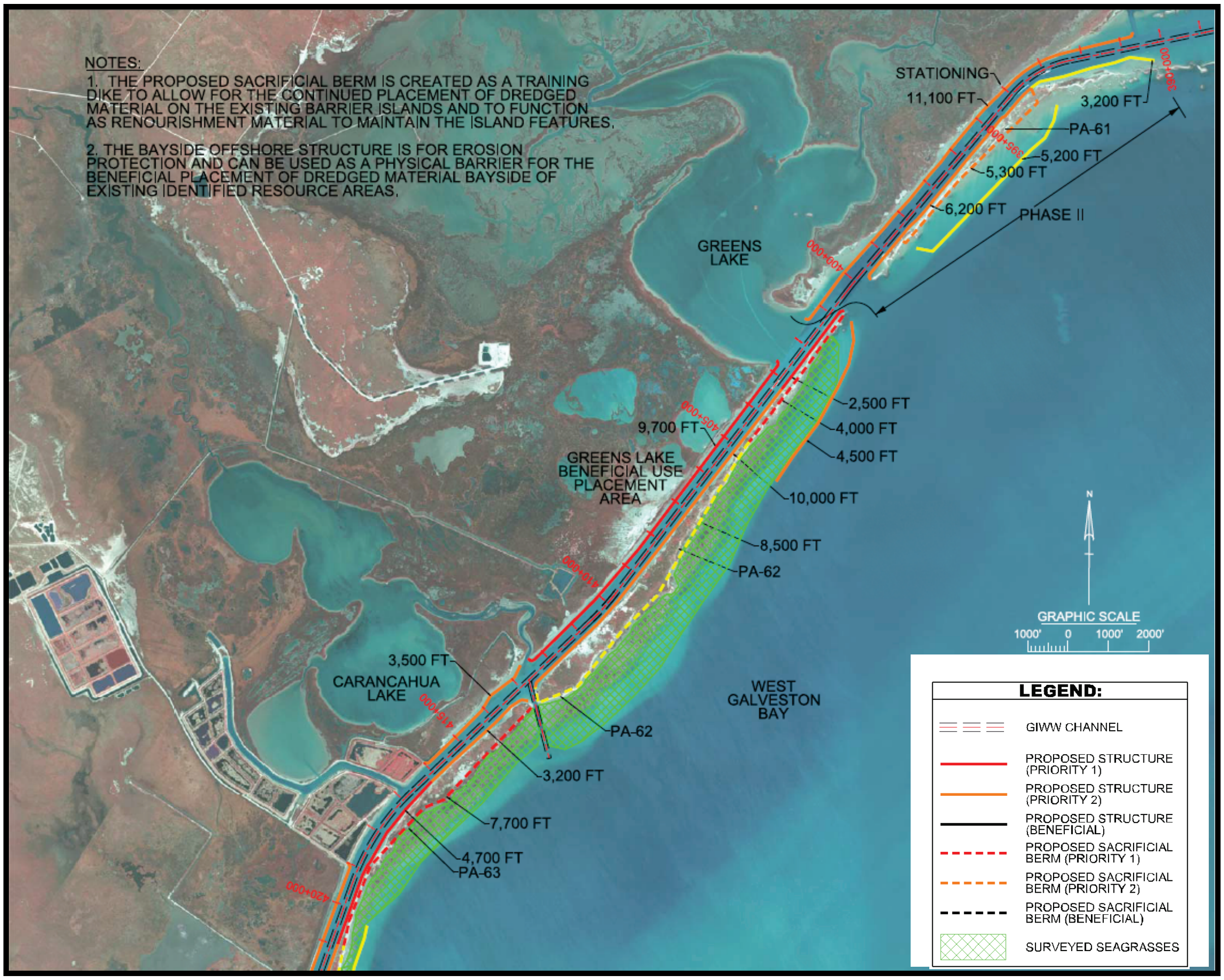

Figure 9. Proposed design layout northern portion of project area.

The proposed revetment along the mainland ends at PA 64 because PAs 64 and 65 are currently armored with ACB. The hard structure around PA 63 extends southwest all the way toward the west end of PA 64. Another hard structure is proposed offshore adjacent to PA 65 (Figure 10). These new dikes will provide capacity to store a sizable amount of additional dredged sediment, rebuilding the bay-side barrier islands that protected the GIWW.

West of PA 65, the revetment continues along the mainland side of the GIWW to Chocolate Bay. The offshore dike previously mentioned extends to the West Bay Mooring Beneficial Use Site (Figure 10).

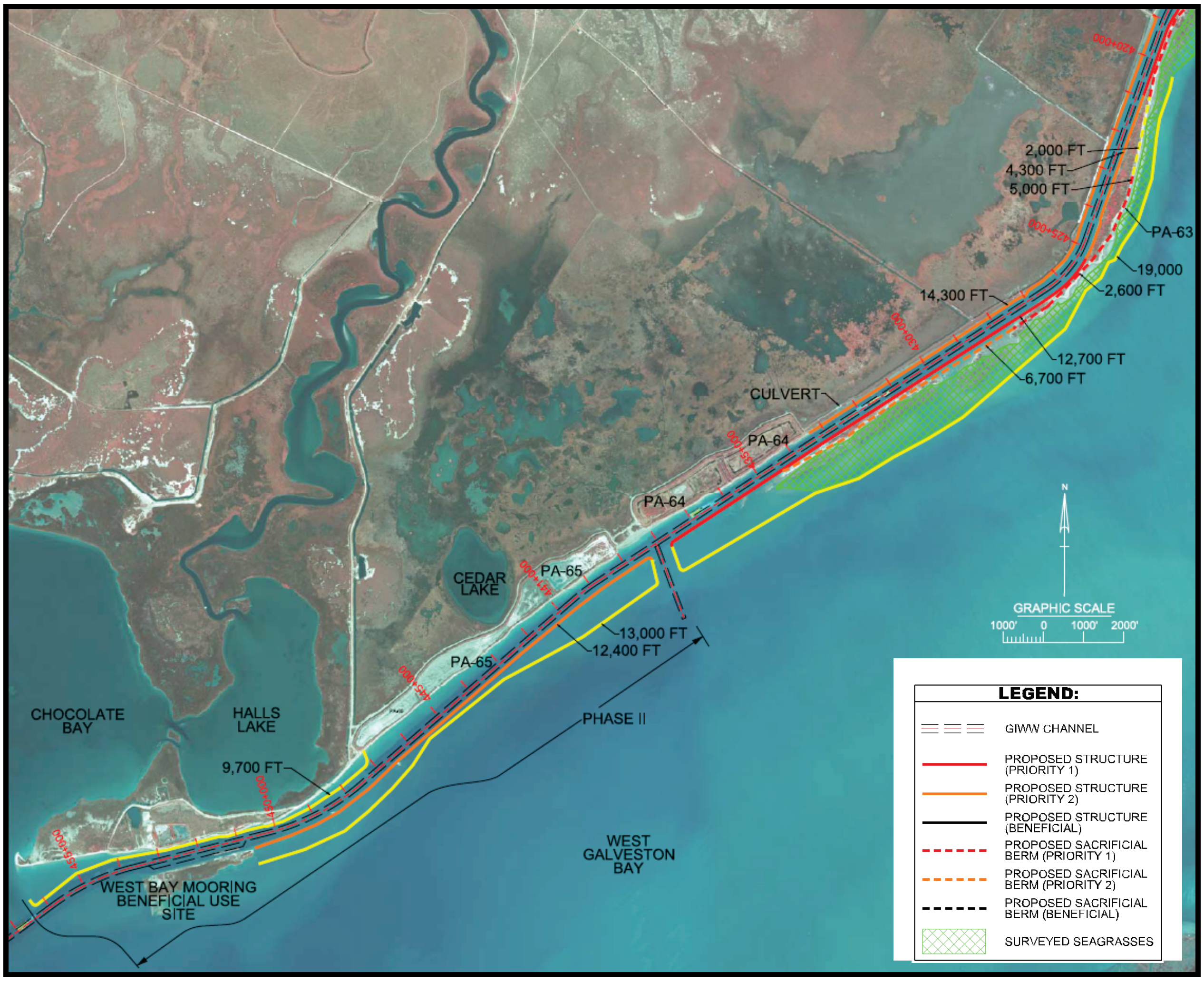

Figure 10. Proposed design layout southern portion of project area.

MODELING PROPOSED STRUCTURES IN CMS: The proposed structures and sacrificial berms were added into the CMS, and the model was run to qualitatively identify the impact of these designs on morphologic change in the study area. The model was run for the entire year of 2010 with (1) existing channel conditions and configuration, (2) Priority 1 structures and sacrificial berms implemented, and (3) structures and berms of Priorities 1 and 2 implemented. The calculated morphology changes for 2010 in the GIWW are qualitatively compared in six channel sections, from PAs 60 and 61 (Section 1) at the north end to Chocolate Bay at the south end (Section 6) (Figure 11).

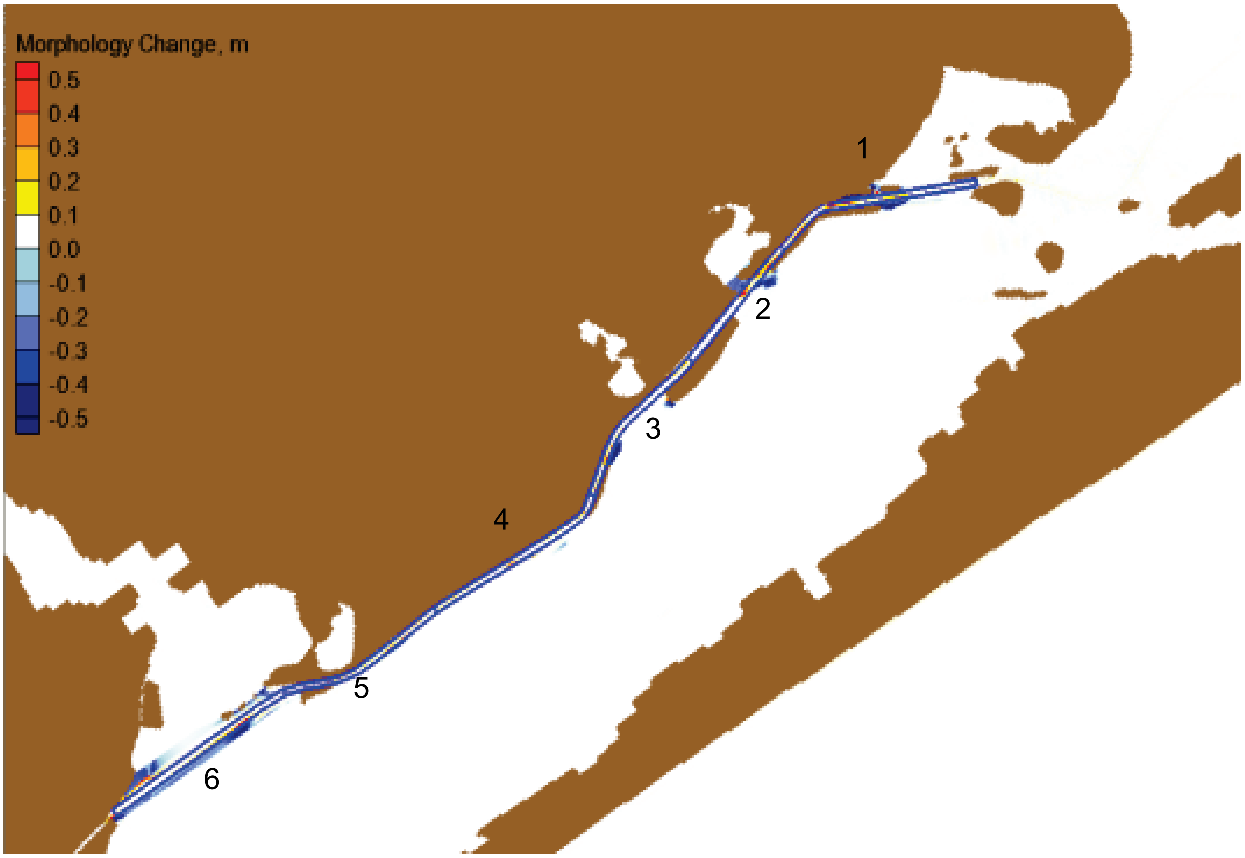

Figure 11. Channel sections in CMS.

The model shows a significant reduction of shoaling rates in the GIWW over the entire project area as a result of the proposed design layout. The reduction is particularly substantial around Sections 2 and 3, which roughly correspond to PAs 62 and 63. Shoaling in Section 2 of the channel is reduced by 60% when Priority 1 and 2 structures are added. In Section 3, shoaling is reduced by 67% when Priority 1 and 2 structures are added. While there are a few areas that experience an increase in shoaling as a result of the proposed designs, the entire study area shoaling was found to be reduced by 23% when Priority 1 designs are implemented and 34% when designs of Priorities 1 and 2 are implemented (Table 1).

Table 1. Calculated sediment volume change (yd^3), Jan–Dec 2010.

Channel Sections	Existing Channel	Priority 1 Structures	All Priorities
1	156,140	155,440	148,920
2	89,530	74,030	35,680
3	125,630	48,840	41,150
4	550	2,750	3,130
5	3,360	2,770	8,880
6	21,530	21,640	25,990
Total (Sec1-6)	396,750	305,470	263,750

CONCLUSIONS: Based on this study's findings, and with a qualitative analysis using the CMS, it is apparent that protecting the bay barrier islands with a combination of hard structures and sacrificial berms will reduce shoaling in the region and ensure the continued availability of placement areas for dredged sediment. Several design alternatives are suggested to protect the bay barrier islands and reduce shoaling in the GIWW. It is recommended that the order of implementation of these structures be determined according to phase and priority so that the most critical locations are protected first.

This CHETN is intended to improve RSM communication both within SWG and between the SWG and its partnering organizations. This work follows a standard procedure for RSM of first identifying a problem, understanding physical processes, and then ultimately working to find a regionally based solution to sediment management.

ADDITIONAL INFORMATION: This study was funded by the USACE Regional Sediment Management (RSM) Program, and was conducted by Kimberly Townsend, Eric Wood, Derek Thornton, Jantzen Miller, Tricia Campbell, and Robert Thomas, U.S. Army Engineer District, Galveston (SWG); Sheridan Willey, U.S. Army Engineer District, Fort Worth (SWF); and Lihwa Lin and Coraggio Maglio, U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory, Vicksburg, MS. Questions pertaining to this CHETN and study can be addressed to Kimberly Townsend (*Kimberly.E.Townsend@usace.army.mil*) or to the USACE RSM Program Manager, Linda Lillycrop (*Linda.S.Lillycrop@usace.army.mil*). Additional information regarding RSM can be found at the Regional Sediment Management website *http://rsm.usace.army.mil*.

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REFERENCES

Dean, R. G., and R. A. Dalrymple. 2002. *Coastal processes with engineering applications.* Cambridge, UK: Cambridge University Press, 163.

Demirbilek, Z., and J. D. Rosati. 2011. *Verification and validation of the Coastal Modeling System: Summary report.* ERDC/CHL TR-11-10. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Dopsovic, R., L. Hardegree, and J. D. Rosati. 2002 (rev. 2003). *Sediment Budget Analysis System-A: SBAS-A for ArcView© application.* ERDC/CHL CHETN-XIV-7. Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://chl.erdc.usace.army.mil/library/publications/chetn/pdf/chetn-xiv-7.pdf*

Lambert, S. S., S. S. Willey, T. C. Campbell, R. C. Thomas, H. Li, and T. L. Welp. 2013. *Regional Sediment Management studies of Matagorda Ship Channel and Matagorda Bay system, Texas*. ERDC/CHL TR-13-10. Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://acwc.sdp.sirsi.net/client/search/asset/1029180*

Rosati, J., and N. Kraus. 2001 (rev. 2003). *Sediment Budget Analysis System (SBAS): Upgrade for regional application.* ERDC/CHL CHETN-XIV-3. Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://chl.erdc.usace.army.mil/library/publications/chent/pdf/chetn-xiv-3.pdf*

Townsend, K., E. Wood, D. Thornton, J. Miller, T. Campbell, S. Willey, L. Lin, C. Maglio, and R. Thomas. 2014. Reducing shoaling in the GIWW and erosion of barrier islands along West Galveston Bay. *Terra et Aqua* 136. http://www.iadc-dredging.com/227/terra-et-aqua/issue?id=149?id=149

U.S. Army Corps of Engineers (USACE). 2002. Erosion, transport and deposition of cohesive sediments. In *Coastal Engineering Manual*, Part III, Coastal Sediment Processes. Engineer Manual 1110-2-1100. Washington, DC: U.S. Army Corps of Engineers.