

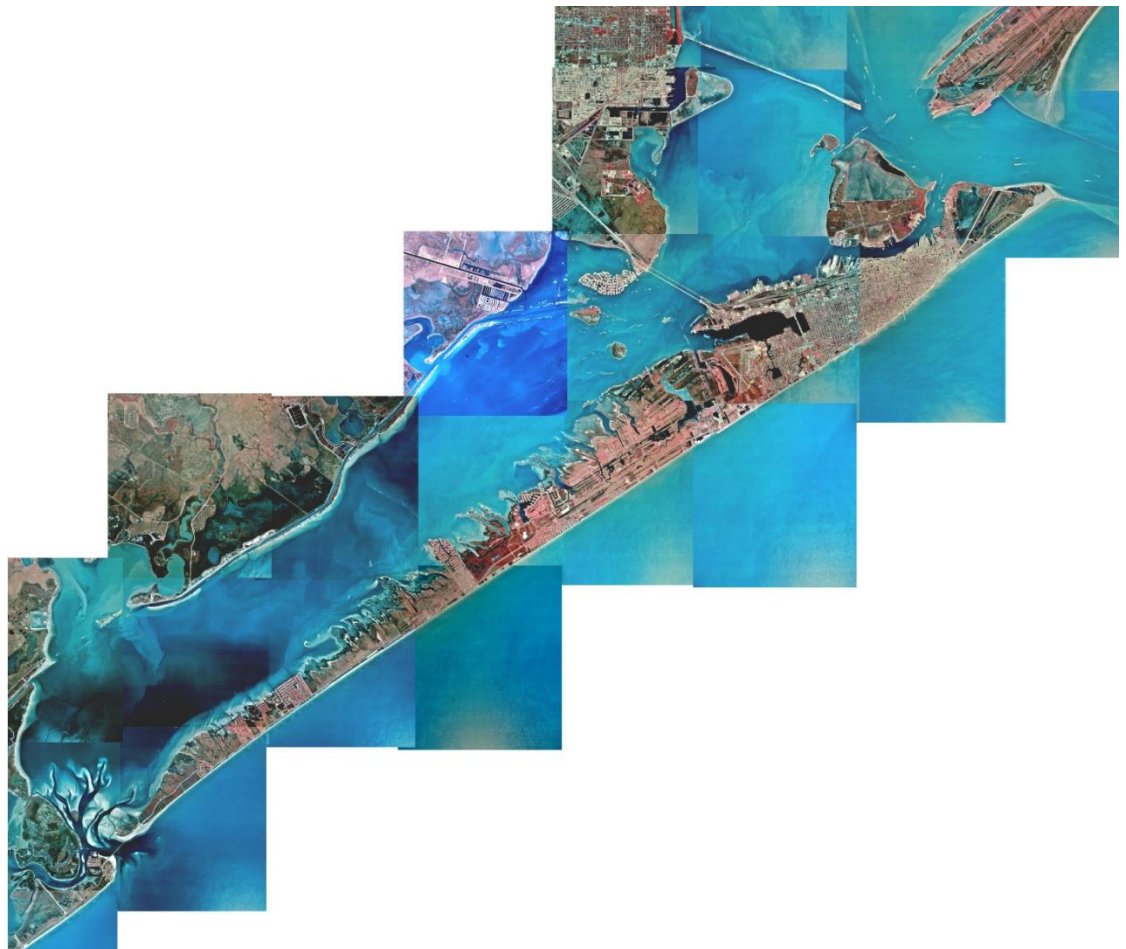


**US Army Corps
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Engineer Research and
Development Center

Galveston Island, Texas, Sand Management Strategies

Ashley E. Frey, Andrew Morang, David B. King

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Final report

Approved for public release; distribution is unlimited.

Abstract:

A study was conducted by the Engineer Research and Development Center and the U.S. Army District, Galveston to support a sand management plan for the Galveston Park Board of Trustees. The long-term management plan encompasses not only Park Board managed areas, but the entire shoreline of Galveston Island. In the first phase of the project, a sediment budget was redeveloped and GenCade, a numerical model, was calibrated for Galveston Island. After discussing potential solutions and actions with the Galveston Park Board, engineering analyses and numerical modeling were conducted to quantify the performance of each selected alternative. The long-term solution is a wide beach along Galveston Island which is filled through backpassing plants on both ends of the island. This solution will require a large volume of sand for the initial construction, so sand management solutions were identified and offshore sand sources were researched. Shorter-term and smaller scale beach nourishment activities were also provided as options within the strategy.

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Preface

This report describes engineering studies that were conducted by the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC/CHL), Vicksburg, MS, for the U.S. Army Engineer District, Galveston (SWG), and the Galveston Park Board of Trustees. This study develops a sand management plan to address coastal erosion problems along Galveston Island from the Galveston entrance channel to San Luis Pass.

This report was prepared by Ashley E. Frey and Andrew Morang of the Coastal Engineering Branch (CEB), Navigation Division (HN) and David B. King of the Coastal Processes Branch (CPB), Flood & Storm Protection Division (HF), ERDC/CHL with support from Robert C. Thomas and Kimberly E. Townsend of SWG. During the study and publication of this report Ms. Tanya Beck and Dr. Jackie Pettway were chiefs of the CEB and HN, respectively, and Mr. Mark Gravens and Dr. Ty Wamsley were chiefs of the CPB and HF, respectively. Dr. Kevin Barry and Mr. Jose Sanchez were the Deputy Director and Director of CHL.

COL Jeffrey R. Eckstein was ERDC Commander. Dr. Jeffery P. Holland was ERDC Director.

Unit Conversion Factors

In this document, most units are reported as United States customary units, in keeping with common usage. Some of the analyses were performed in metric units, but the results are reported in U.S. standard units.

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
square feet	0.09290304	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
yards	0.9144	meters

1 Introduction

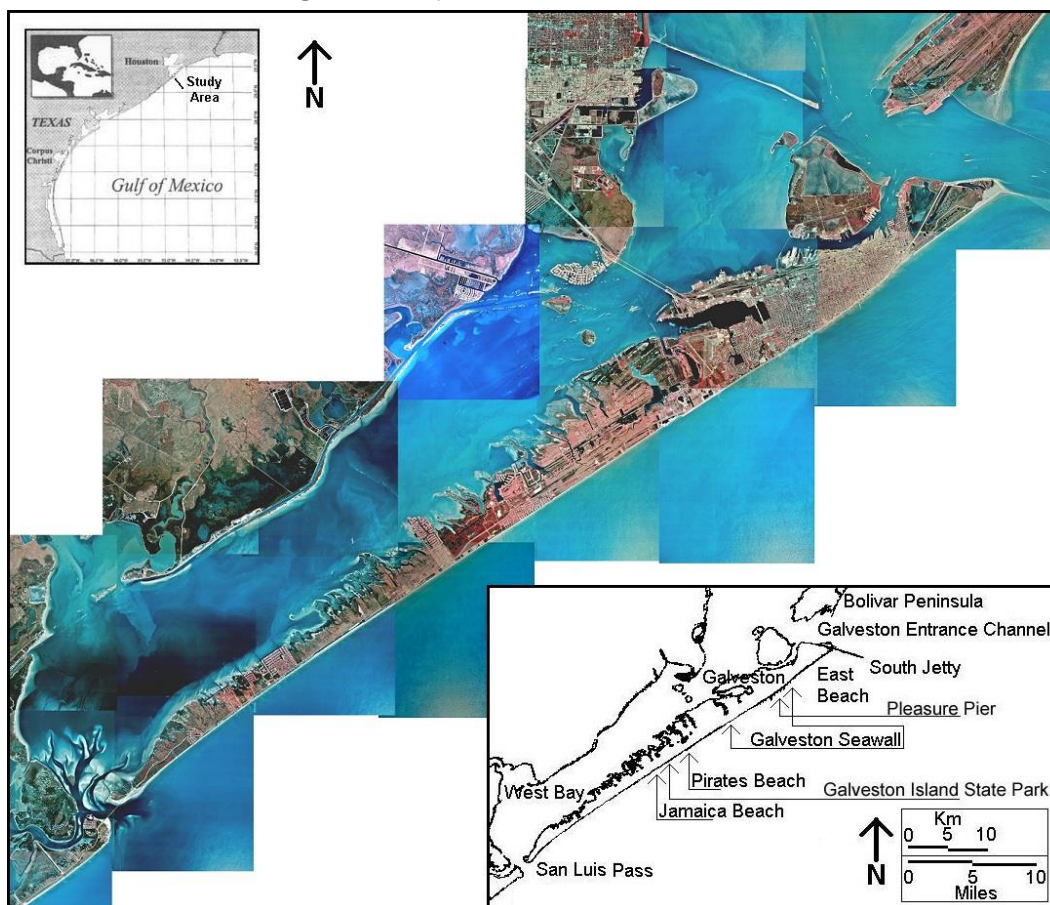
The Galveston Park Board of Trustees (GPB) enlisted the aid of the U.S. Army Engineer District, Galveston (SWG) and the U.S. Army Engineer Research and Development Center's Coastal and Hydraulics Laboratory (ERDC/CHL) in developing a long-term sand management plan for Galveston Island. This report represents one step in that process. By combining a review of the technical literature with a suite of engineering analyses and numerical modeling, this report presents a broad look at alternatives that are technically realistic and have the potential for long-term sustainability. Economic, environmental, and societal issues will require extensive additional analysis and deliberation prior to refinement, selection, and implementation of a chosen alternative.

1.1 Geographic Setting

Galveston Island is a 29-mile long sandy barrier island along the upper Texas coast (Figure 1), located about 45 miles south-southeast of Houston and about 70 miles west-southwest of the Texas border with Louisiana. The island varies from about 0.6 to 3 miles in width and is oriented with the long axis running from east-northeast to west-southwest at an angle of approximately 235°.

To the southeast, the island faces the Gulf of Mexico. The island is separated from the Bolivar Peninsula to the northeast by the Galveston Entrance channel, which is the main channel into Galveston Bay. This jettied, deep-draft channel, which provides access to the ports of Galveston and Houston, is one of the busiest shipping entrances in the United States. The U.S. Army Corps of Engineers, SWG, maintains the jetties and navigation channels. To the northwest, the island is separated from the mainland by an arm of Galveston Bay known as West Bay. To the southwest, Galveston Island is separated from the adjacent coastline (Follets Island and the mainland) by San Luis Pass, a modest-sized (Jarrett 1978) downdrift-offset, natural (undredged and unjettied) inlet. While the pass is a fairly typical non-migratory Texas inlet (Price 1951), the shoals and inlet margins are dynamic.

Figure 1. Study area, Galveston Island Texas.



The entire island, other than the town of Jamaica Beach is incorporated within the city of Galveston (population, about 49,000). The eastern third of the island, which contains the residential and commercial heart of the city, is protected by a seawall and raised land elevation which was initiated following the devastation caused by the Galveston Hurricane of 1900. The western portion of the island has limited development of single family beach homes, subdivisions, and condominiums, interspersed with undeveloped areas.

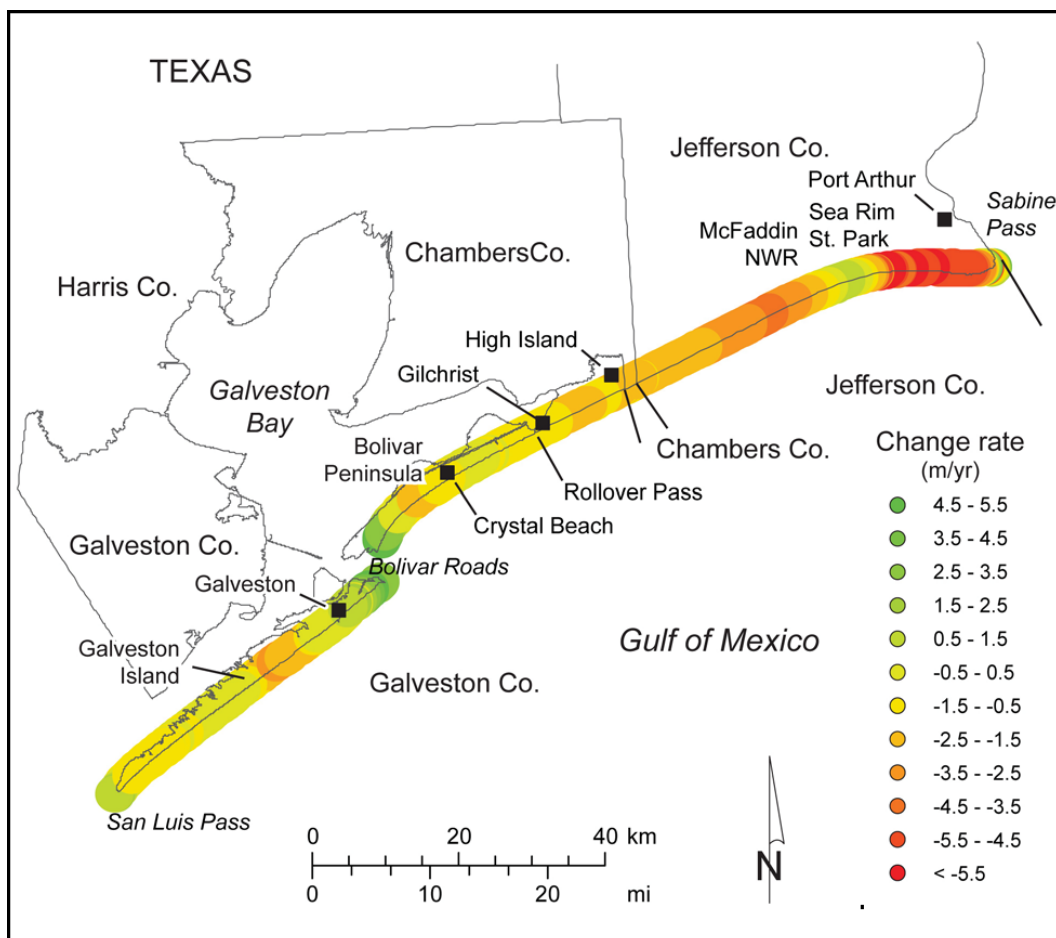
1.2 Sediment transport in the study area

Along most of the northern and central Texas coastline, the direction of the net longshore sediment transport is to the southwest (Hall, 1975; Mason, 1981; USACE, 1983). However, there is a reversal in the net direction (a divergent nodal zone) along the western portion of the Galveston seawall, and east of this region the direction of net sediment transport is toward the Galveston Entrance Channel to the northeast (King, 2007; Morang, 2006). To the west of this zone, the net sediment

transport direction is southwestward towards the portion of the island lacking a seawall and, eventually, towards San Luis Pass. The primary reason for this reversal is due to changes in wave refraction over the complex offshore bathymetry.

It is important to note that on any given day, the transport direction can be in either direction along any section of the coastline, depending upon wave conditions at the time. The net direction is the predominant direction of transport averaged over intervals of a year or longer. The location of the reversal should be thought of as a zone, not a point, because there are year-to-year, as well as seasonal variations in the wave field as it approaches the island. It is also important to note that throughout most of the study area, daily variations in the wave conditions make the potential gross transport an order of magnitude greater than the net transport (King 2007). Most of West Galveston Island is experiencing long-term erosion as seen in Figure 2; however, both tips of the island are accreting.

Figure 2. Net long-term shoreline change rate on the Upper Texas coast calculated through 2007; from Paine (2011).



Another hallmark of the region is the lack of rivers that deliver sand to the coast. East Galveston Bay was formed at a lower sea level stand as the Trinity River valley. Today, most sandy material carried by the Trinity River is deposited in Lake Livingston (Phillips and Musselman 2003). Sediment from the lower Trinity River is derived from scour and bank erosion and is largely stored in the delta in Trinity Bay (Phillips et al. 2004). Sand that is currently on the beaches within the study area is either reworked from relic deposits or remains with the shoreline as it retreated landward at the end of the last ice age (see King (2007) for further discussion). Thus, the coastal zone of Galveston Island and nearby barrier islands is sand-limited, consisting of a sand veneer perched on a mud substrate, with minimal new supply entering the system. Mud outcrops can be occasionally seen on Bolivar Peninsula, and even (rarely) on Galveston Island. The sand in this system is very fine, with typical median grain sizes in the range of 0.15 mm (2.75 phi).

1.3 Report Organization

This report is organized into ten chapters. Chapter 1 discusses the geographic setting of the study area. Chapter 2 is a summary of the sand management alternatives that are supported by the engineering analyses. Chapter 3 describes the sediment budget, while Chapter 4 provides background on the numerical modeling with GenCade. Chapter 5 lists sand management options near East Beach, and Chapter 6 discusses the sand management options near San Luis Pass. Chapter 7 describes the large-scale beach fill and covers the reach alternatives. Chapter 8 discusses the GenCade alternatives. Conclusions are summarized in Chapter 9.

2 Sand Management Alternatives

2.1 Objectives of this sand management study

Beach restoration alternatives for Galveston Island will require substantial quantities of sand, both for initial fill and for periodic renourishment. Renourishment will be required on a continuing basis because, once placed on the beach, portions of the fill will be carried along the shore by wave-generated longshore currents away from the placement sites. The main focus of this study has been to use engineering approaches to better understand the details of the physical processes at work on the Galveston beaches to be able to quantify the sediment needs for various alternatives. This has been done through updating an existing sediment budget along Galveston Island and developing the GenCade numerical model for the island.

Based on discussions with the GPB, Galveston Island was divided into six reaches (Figure 3 and

Table 1) as follows:

- Reach 1: ~14th Street to 61st Street. This reach covers the eastern portion of the Galveston seawall that contains the groin field. Several small beach fills have been placed in this location in the past two decades. Net sediment transport along this reach is to the east (toward East Beach). Along the seawall, a nodal zone exists where net longshore sediment transport diverges, some moving east and some moving west. The divergence zone cannot be precisely defined and moves within Reaches 1 and 2.
- Reach 2: 61st Street to 103rd Street. This reach covers the western portion of the Galveston seawall. Currently there is no exposed beach along most of this reach.
- Reach 3: 103rd Street to State Park. This reach extends from the western end of the seawall to the Galveston Island State Park. The region is experiencing erosion, and net sediment transport is to the west.
- Reach 4: State Park to Pointe San Luis. This reach is further west along west Galveston Island. As with Reach 3, this reach is experiencing long-term erosion and net transport is to the west.
- Reach 5: Pointe San Luis to San Luis Pass. This reach covers the western tip of the island and experiences strong episodes of erosion and accretion related to the inlet dynamics of San Luis Pass. Net transport is westward into the pass.
- Reach 6: South Jetty to ~14th Street. This reach covers the eastern tip of the island, including East Beach. This region has experienced long-term accretion.

Figure 3. Study area, Galveston Island, Texas. Red boxes are sediment budget cells used in the study (not labeled to reduce clutter).



Table 1. Location of reaches along Galveston Island.

	Park Board Reach	Location	Sediment Budget Cell	Latitude	Longitude	Distance (ft)
1	East End	14 th Street	E end 1_6	29.2965°	-94.7795°	18,400
	West End	61 st Street		29.2664°	-94.8262°	
2	East End	61 st Street		29.2664°	-94.8262°	16,200
	West End	103 rd Street	W end 1_6	29.2419°	-94.8686°	
3	East End	103 rd Street	E end 1_7	29.2419°	-94.8686°	38,600
	West End	State Park	W end 1_7	29.183°	-94.9695°	
4	East End	State Park	E end 1_8	29.183°	-94.9695°	52,900
	West End	Pt. San Luis	W end 1_9	29.0948°	-95.1015°	
5	East End	Pt. San Luis	E end 1_10	29.0948°	-95.1015°	6,300
	West End	San Luis Pass	W end 1_10	29.083°	-95.1159°	
6	East End	South Jetty	E end 1_5	29.3316°	-94.7253°	21,700
	West End	14th Street	W end 1_5	29.2965°	-94.7795°	

Although some of the alternatives described in this plan will be specific to a reach, it is assumed that in many cases, alternatives will involve a combination of reaches. Additionally, the sand management plan must be adaptive; for example, if erosion rates change in the future, there must be options to adjust the beach fill volumes and renourishment intervals.

2.2 Sand Management and Placement Alternatives

2.2.1 Overview

Table 2 lists alternatives from most to least comprehensive. These will be reviewed in the following sections.

Table 2. Overview of alternatives.

Plan	Coverage (reaches)	New Material (offshore or other sources)	Management and recycling of existing sand sources and dredge material	Performance monitoring	Notes
1. Comprehensive beach fill	1 - 5	√	√	√	Beach revitalization plan
2. Limited area beach fill	1, 2, 3(?)	√	√	√	Most critical areas only
3. Systematic recycle	1, 2		√	√	Reuse existing sediment in system without external new sediment
4. Present action plan	1, 2		√		Reacts to storms or emergencies
5. No action					Baseline

2.2.2 Plan 1. Reach 1 through 5 Comprehensive Alternative

Plan 1 is the comprehensive beach fill along the entire Galveston Island over Reaches 1-5, with systematic (semi-continuous) maintenance (renourishment) and beach monitoring. This includes improved management of existing sand accumulations at East Beach, Big Reef, and San Luis Pass, and recycling of dredge material.

This will be the most expensive alternative, and may foster significant development along the central and west Galveston Island. This project would be expected to have a backpassing plants at East Beach and possibly at San Luis Pass, with sediment pipelines to redistribute sand onto the beaches. From a regional sediment management perspective, Galveston Island as a whole is a logical, relatively isolated unit, and would gain advantages from management of the entire island's beach as a unit.

It is worth noting that a 25-mile long project on Galveston Island would be the longest beach fill project ever constructed in the United States. For comparison, the initial placement of the Miami Beach Restoration Project between 1976 and 1981 nourished 10 miles of beach at a cost of \$64 million dollars (Frohling 1986; Dean and Dalrymple 2004). The Sea Bright to Manasquan Inlet, NJ Beach Erosion Project (currently the largest) nourished 21 miles of beaches and was constructed between 1994 and 2001 at a cost of \$195 million dollars (USACE webpage).

2.2.3 Plan 2. Beach fill in limited areas

Plan 2 is similar to the comprehensive Plan 1 except that a beach fill will only be placed in the most vulnerable areas along the island. Reach priority is related to the historical rates of erosion and accretion, amount of infrastructure, and the likelihood that beach fills will be appropriate in the future. Reach 1 is considered to be the most likely candidate for a fill, while Reaches 5 and 6 are currently accreting and are not expected to require any fill unless conditions change.

2.2.3.1 Reach 1 Alternative

Placing a beach along the eastern end of the seawall is expected to be at least a component of any final design plan. Not only is it the GPB's highest priority, but it is assumed that it will have the highest visitor use and the lowest construction and maintenance costs. The material placed on Reach 1 needs to be the highest quality beach sand. It must be compatible with the sand presently on the beach, particularly the grain size and color.

2.2.3.2 Reach 1 & 2 Alternative

This alternative is described in detail in Chapter 7. It involves placing a beach fill in front of both Reaches 1 and 2. While muds, clays, and silts should not be placed along Reach 2, slightly finer material that is not suitable in Reach 1 could be placed here. Sand placed in Reach 2 needs to be tapered into the beach beyond the end of the seawall to mitigate the end effects caused by the present right-angle structure.

2.2.3.3 Reach 1 through 3 Alternative

A fill covering the entire seawall as well as the unarmored beach in Reach 3 will mitigate the erosion now present at the end of the seawall. Pre- and post-construction monitoring is required to monitor fill stability. A

disadvantage of this alternative is that backpassing distances from East Beach are large (approx. 10 miles).

2.2.3.4 Reach 1, 2 and 4 Alternative

A beach fill development that includes all of the seawall plus the far west end of the island will likely be easier and less expensive to construct and maintain than the Reach 1 through 3 alternative discussed above.

2.2.3.5 Reach 5 and Reach 6 Alternative

These reaches already have wide beaches and therefore only need volume for dune construction. They are currently accretive, and it is not expected that they will experience significant long-term erosion in the future.

2.2.4 Plan 3. Recycle existing sediment only without new material

This plan involves recycling and managing the sediment that currently accumulates at East Beach/Big Reef and at San Luis Pass. It also involves recycling dredge material for beach use but does not include using new material from offshore sources for beach placement. The GenCade modeling (Chapter 8) demonstrated that this alternative will result in shoreline advance, but the time scale is over decades. For a beach revitalization plan, it will be more effective to add new fill (Plans 1 and 2) and recycle existing material for maintenance.

2.2.5 Plan 4. Continue existing management

This plan continues the present practice of reacting to storms and emergency conditions on an as-needed basis. This normally consists of truck hauling sand from East Beach to the beaches along the base of the seawall. This process is inefficient and disruptive, does not effectively use sand already in the system, and has not stabilized the beaches along much of Galveston Island. In addition, material dredged from the Federal navigation project is not beneficially used on beaches. This is not recommended as a strategy for Galveston Island.

2.2.6 Plan 5. No action plan.

This is used as a baseline for the GenCade modeling (Chapter 8). It is not recommended as a strategy for Galveston Island.

2.2.7 Fundamental Constraints

Two important constraints need to be appreciated in considering any major beach fill project on Galveston Island. The first is that sediment supplies are limited compared with other large constructed beaches around the country. The beach sand now on Galveston Island needs to be acknowledged as a precious commodity, and creative ways must be considered in its optimal use and conservation.

The second is that there is a divergent nodal zone along the western portion of the Galveston Seawall (in Reach 2). In Reach 1, the net direction of transport is to the east while in Reaches 3 and 4, it is to the west. This has several subtle impacts. For example, if a beach fill is selected that covers the entire seawall and a backpassing plant is only built at the east end, then a portion of that fill will be transported off the west end of the seawall without the possibility of it being recycled.

2.3 Sand Source and Delivery System Alternatives

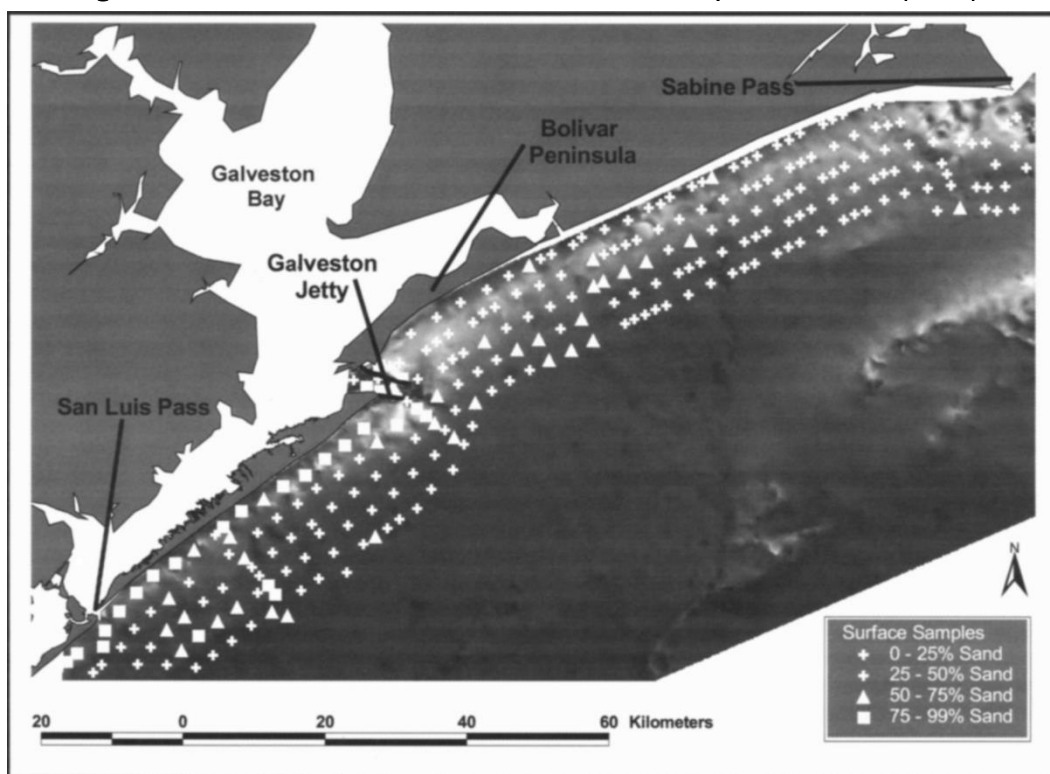
An integral part of developing alternatives for where the sediment is to be placed is determining where the source material is to be obtained along with the available options for transport. The most expensive component of most beach fill projects is the cost of the sediment, and there is a near linear relationship between the sediment's cost and the distance it must be transported. Thus the closest source or sources of available, beach-quality sediment are almost always the first to be utilized.

2.3.1 Offshore Dredging

Offshore deposits are the most common source of sediment for large beach renourishment projects in the United States. However, offshore sediments along the Texas coastline are largely mud-dominated and unsuitable for recreational beaches. Researchers (e.g., White et al. 1985; Siringan and Anderson 1994; Anderson and Wellner 2002; Finkl et al. 2004; Williams et al. 2012) who have investigated offshore sediments near Galveston Island have generally identified only limited pockets of sand. Most of the usable material has been located too close to shore (within the active surf zone) to be usable. However, potential offshore areas remain that require further study (Finkl et al. 2004). TxSed maintains an active database of offshore sand resources which can be accessed at:

<<http://gisweb.glo.texas.gov/txsed/index.html?config=config-Corp.xml>>.
Figure 4 shows surface sample sediment sizes near Galveston Island.

Figure 4. Percent surface sand in offshore sediment samples. From Finkl (2004).



Ample sediment supplies do exist further offshore. Morton and Gibeaut (1995) estimate that Heald Bank, which is approximately 35 miles offshore contains roughly 585 million cubic meters of sediment. They estimate that Sabine Bank, which is twice as far away, holds approximately 1.2 billion cubic meters of beach quality sand. However, Texas projects to date have not utilized these sources because of transportation costs.

The lack of nearby sources of beach-quality sediments imposes limitations on the design of economically viable alternatives. For most of the large-scale alternatives considered in this study, it is likely that some amount of material will be required from Heald Bank or some other offshore source over the project lifetime.

2.3.2 Channel Dredging

Dredging of the Galveston Entrance Channel is discussed separately from offshore dredging, as it is performed on a regular basis by the USACE to maintain the navigation channel. Sediment is currently deposited offshore

near the tip of the South Jetty. It will be a good regional sediment management strategy to use that material. However, quantities available will be dictated by channel navigation requirements, not by the amounts necessary for initial construction or maintenance of the beach fills. Also, some percentage of the dredged material (the fines) will not be suitable for beach placement (see Chapter 3).

The analysis of dredging records indicates that on average, 1,098,000 yd³ of beach quality sediment is dredged from the Galveston Entrance channel, anchorage area, and inner and outer bar channels every year (Appendix A, Tables A1, A2, and A4). However, if the South Jetty were sand tightened, some of this material would accumulate on East Beach and be available for backpassing.

2.3.3 Truckhaul Backpassing

Most previous beach fills along the eastern portion of the seawall involved truck hauls of sediment from East Beach (see Appendix B). This is proven technology and costs per yard of placed material are generally understood. However, limitations of truck capacity, highway noise and congestion, etc. make this methodology practical only for small fills.

There are a number of ways to better manage the sand on East Beach for truckhaul backpassing. These options, which include reducing the transmission through the South Jetty and reducing Aeolian transport, are presented in more detail in Chapter 5.

2.3.4 Pipeline Backpassing

A pipeline backpassing system is discussed in Chapter 5. It is assumed that this will be a key component of any alternative. If a fill is only placed in front of the seawall, then only a backpassing system on the east end of the island will be constructed. However, if the fill covers the entire island, then backpassing plants at both ends are envisioned. When compared with an alternative truck haul system, the substantially higher initial costs in infrastructure are expected to be outweighed by lower operating costs and higher transport capacity. However, a detailed cost analysis will be required. On East Beach, it is expected that the backpassing system will be developed in concert with a sand tightening of the South Jetty.

Moving forward with pipeline backpassing will require additional design, permitting, and economic and environmental analyses. The first step is to gain the support of the residents of Galveston. If the city accepts the plan, it will be easier to obtain permits and receiving funding. If pipeline backpassing is chosen for Galveston, one option is for the operation to only run at night such that tourists and residents will be minimally bothered by noise or pumping. Additionally, video cameras should be mounted near the discharge locations. These cameras should have a live feed available online so residents and others can see the work in progress. Phones should be set up along the seawall and west end, so that concerned residents or tourists may inform of a possible issue with the operation. Finally, it is recommended that signs be placed along the seawall and west end to inform residents, children, and tourists about the process and operations of backpassing as a part of basic policy management.

2.3.5 Alternative Sources

Following the 1900 Galveston Hurricane, the first segment of the Galveston Seawall was constructed, and the elevation of the town was raised using sediments dredged from West Bay. However, these sediments were generally muds and are not considered usable as beach-quality sediment. The authors have not located any reports that indicate an availability of beach-quality sediments in either local interior water bodies such as West Bay or in local upland locations. Other potential sources include:

- The fillet at the north side of the north jetty (requiring barge transport)
- Portions of Big Reef, especially the underwater accumulation that slopes down into the Federal channel
- The sand accumulation north of the south jetty.

For future investigation, the practicality of using recycled glass as a potential sediment source could be investigated. See Finkl and Kerwin (1997), Edge et al. (2002), and Makowski et al. (2011, 2013) for its experimental use in limited trials.

2.3.6 Combination of Sources

Regardless of the alternative chosen, the final solution is likely to be a creative mix of most or all of these alternatives.

2.4 Estimated Sediment Volumes for Different Combinations of Reaches

Values in this section should be considered order of magnitude estimates, which are subject to substantial modification and refinement based upon additional studies. They are presented with the intent that they represent a starting point in the discussion leading to the development of a preferred alternative. Additionally, these volumes represent a wide beach along Galveston Island. Because of the difficulty in locating enough sand to construct a single wide beach along the entire island at one time, smaller beach nourishment options and other more short-term alternatives are also presented.

The discussion below is divided into three parts: volumes of sediment needed for an initial fill, volumes moved by longshore transport which need to be backpassed, and volumes which can be considered as lost to the system and will need to be replaced over the lifetime of the project.

2.4.1 Initial Fill Volumes

Calculated initial fill volumes are given in Table 3. This includes a 200-ft berm/beach along the seawall, and a dune with beach/berm along the remainder of the island. The derivation of these amounts is presented in Chapter 7.

Table 3. Initial fill volumes by reach (200-ft beach at seawall, 300-ft remainder).

Scenario	Length of Reach (ft)	Initial Fill Volume (yds ³)	Initial Fill Volume with Advanced Nourishment (yds ³)
Reach 1	18,400	560,000	840,000
Reach 2	16,200	2,131,600	3,197,000
Reach 3	30,000	2,518,800	3,778,200
Reach 4	51,700	4,407,900	6,611,850
Reach 5	12,300	471,800	707,700
Total:		10,000,000	15,000,000

The most convenient locations to obtain initial fill material are from the two ends of the island. A crude estimate of all the beach-quality sediment available from the east end of the island (the sandy portions of Big Reef and of East Beach east of Boddeker Road) is 3,000,000-6,000,000 yd³. It should be mentioned that much of this volume is along East Beach, so it is unlikely this total volume could be mined due to recreation and environmental restrictions. If only the areas that meet present-day requirements to mine are included, the volume available drops to about 1,802,200 yd³. Based upon field work of Israel et al. (1987), Wallace et al. (2010) estimate that the San Luis Pass flood shoal contains an approximate volume of 11,800,000 yd³ of beach quality sand. However, it is expected that if permits are issued that allow any of the flood shoal to be mined, this sediment will need to be shared with Brazoria County and some amount will be reserved as ecological habitat. Thus a reasonable guess is that a maximum of 4,000,000 yd³ would be available for beach fills on Galveston Island. Thus, these sources, at most, could be expected to generally provide the initial fill volumes for of about half that needed for the entire island. Presumably, the rest of the material would need to be obtained from Heald Bank, unless closer sources are located.

It is also important to note that backpassing plants at each end of the island would only need to backpass on the order of 250,000 yd³ per year after the initial fills are placed. It is unlikely that these plants would be used as the sole transport mechanisms for the initial fill, as it would take multiple years to transport the needed initial fill volumes. Instead, much of the initial fill will likely be placed by dredges.

2.4.2 Backpassing Volume Rates

The backpassing volume rates are derived from the sediment budget. Because only the two ends of the island are accreting, the amount of material that needs to be backpassed yearly is the amount that is transported into the two end reaches. The sediment budget shows that approximately 41,000 yd³/yr of sediment moves from Reach 1 to Reach 6. Additionally, up to 356,000 yd³/yr moves into the Reach 6 cell from offshore. The sediment budget calculations also show that about 251,700 yd³/yr moves from Reach 5 to Reach 6. However, all but 11,600 yd³/yr moves into San Luis Pass or is bypassed to the west side of the pass. The GenCade alternatives (Chapter 8) include a variety of backpassing rates and discharge locations along the reaches.

2.4.3 Sediment Losses and Gains over the Project Lifetime

While much of the sediment that is in motion in the surf zone stays in the surf zone, the system is not entirely closed. There are ways that sediment can leak out of (and into) the system. Other processes, such as sea level rise, can be treated as a sediment loss. As some of these processes are non-linear, it is easiest to treat them all on a project lifetime basis. These processes must be specifically accounted if the beaches are to maintain a long-term stability.

2.4.3.1 Storm Losses

Hurricanes and other storms are thought to generally alter the beach profile by flattening it. That is, they erode sand from the upper part of the beach (the part that is normally dry; the dune, the berm and the foreshore slope) and deposit it within the surf zone. However, some beach sediment is carried inland by storm overwash, and there is mounting evidence that large storms also carry sand offshore, seaward of the surf zone, where it is lost to the beach system. It should be noted that this type of transport is fundamentally different from the day-to-day longshore transport within the surf zone. While longshore transport can erode a beach, the sediment is not lost from the nearshore. With the type of system being proposed for Galveston Island, the sand that is moved by longshore transport can be captured at a downstream location and backpassed to where it is needed. However, offshore, storm-deposited sediments will be mixed with the prevailing mud substrate and become unrecoverable. Thus, they represent a permanent loss to the system.

Numerous authors have made reference to this type of sediment behavior along the Texas coast during storm events. The 1915 Hurricane was the first major hurricane to hit Galveston following the construction of the seawall. Qualitative reports indicate that after the storm, the beach never recovered its pre-storm width (USACE 1981, p. 13). Hayes (1967) reports on offshore sand lenses following Hurricanes Carla (1961, Port O'Connor) and Cindy (1963, High Island). Morton et al. (1994) discusses beach recovery in the years following Hurricane Alicia (1983, San Luis Pass). Gibeaut et al. (2002) discusses episodic beach erosion caused by Tropical Storms Josephine (1996, Galveston County) and Francis (1998, Galveston County). Several authors discuss long-term beach impacts following Hurricane Ike (2008, Galveston Entrance Channel), including Watson

(2009), Dellapenna and Johnson (2010), Goff et al. (2010), Hawkes and Horton (2012), and HDR (2014).

From a geologic perspective, Wallace et al. (2010) used sediment cores collected at depths of 4 to 8 meters (13 to 26 ft) off Galveston Island to calculate that over the last 2660 years, beach sediment has been transported seaward of the surf zone from the whole island length at an average rate of 150,000 yd³/yr. He also concluded that washover rates have been minimal on Galveston Island.

This topic will require further study. However, this mechanism does represent a permanent sediment loss to the system that will need to be accounted for if long-term beach stability is to be achieved. In this report, the Wallace et al. (2010) average storm loss rate will be used. As the island is approximately 150,000 ft long, the loss rate conveniently works out to a cubic yard of sand per foot of beach per year. The lifetime amounts needed are shown in Table 4 for each of the reaches. These values are primarily intended for planning purposes. While the erosive events are episodic, appropriate renourishment, which introduces new sand to the system, should be planned on a regular basis.

Table 4. Storm and Sea Level Rise project lifetime sediment losses (yd³).

Scenario	Storm	Sea Level Rise		
		Minimum	Medium	Maximum
Reach 1	920,000	4,770,400	6,433,200	11,721,500
Reach 2	810,000	4,200,000	5,664,000	10,320,000
Reach 3	1,500,000	7,777,800	10,488,900	19,111,100
Reach 4	2,585,000	13,403,700	18,075,900	32,934,800
Reach 5	615,000	3,188,900	4,300,400	7,835,600
Reach 6	1,085,000	5,625,900	7,587,000	13,823,700
Total	7,515,000	38,966,700	52,549,400	95,746,700

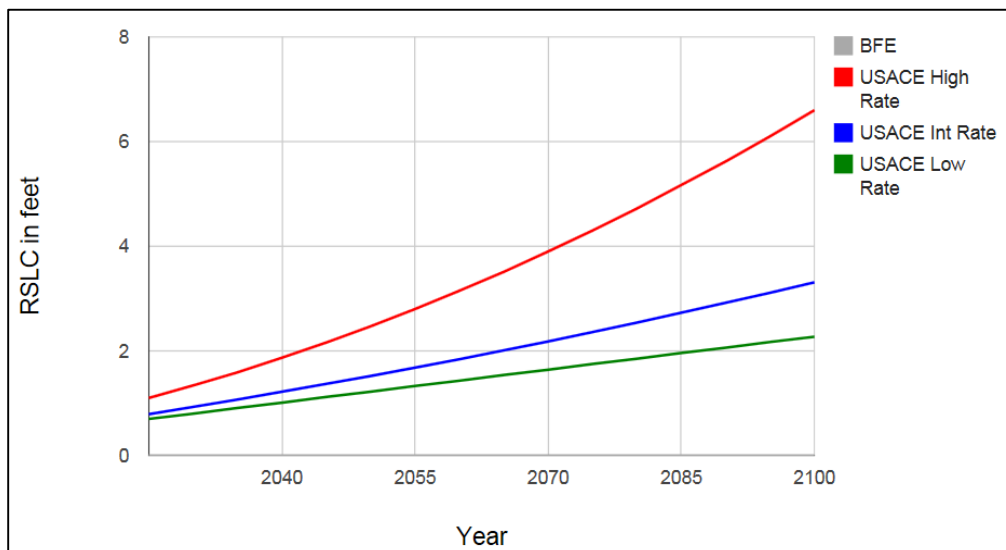
2.4.3.2 Sea Level Rise

It is USACE policy that all coastal projects consider ramifications of sea level rise and have issued specific guidance for doing so.

Figure 5, the predicted low, medium, and high curves for sea level rise at Galveston over the expected project lifetime (2025-2075), was obtained using the sea level rise calculator available at the website:

<<http://www.corpsclimate.us/ccaceslcurves.cfm>>. This calculator incorporates the Corps of Engineers guidance found in USACE (2011) as updated by USACE (2014a).

Figure 5. Relative Low, Medium, and High Sea Level Curves (RSLC) based upon USACE Guidance for the Galveston TX, Pier 21 NOAA Tide Gauge: 8771450.



The procedure used in this report is to add sufficient sediment to raise the entire beach profile (from the dune crest to the depth of closure; ~ 4000 ft in the cross-shore direction, as shown in Figure 37) by the same amount as sea level rises. The project lifetime amounts needed are shown in Table 4. The high curve should be used for planning purposes, but the amount of new material introduced into the system should be based upon the sea level rise curve as it actually happens. Renourishment should occur at regularly scheduled intervals.

2.4.3.3 Sediment Incompatibility

Additional issues must be addressed if the grain size distribution of the fill material does not closely match the native sediment at the site. This is not likely to be an issue if material is taken off the beach and backpassed along the island to where it is needed. However, sediments dredged from the channel or offshore may contain more fines (silts and clays) than the native beach sediment. In this case, allowances must be made for a certain percentage of the fill material being winnowed by wave action from the beach face. This analysis must wait until the source of the fill is finalized. For further discussion, see National Research Council (1995), Gravens (2008), and Dean (2002).

2.4.3.4 Longshore Transport Sediment Gains

The only outside source of sediment which is made available by longshore transport is the amount transported from the Bolivar Peninsula through the North Jetty into the Galveston Entrance Channel, which is estimated as 110,000 yd³/yr from Figure 10. This material could be used on Galveston beaches whenever channel maintenance dredging occurs.

2.4.3.5 Onshore Transport Sediment Gains

Figure 10 indicates that there is a substantial onshore transport of sediment at East Beach (355,700 yd³/yr). This sediment may be derived from the offshore dredge disposal site (Morang 2006) or from the collapse of the ebb delta following jetty construction (Morton 1977; Siringan and Anderson 1993). Regardless of the source, the material will accumulate on East Beach, particularly if the South Jetty is sand tightened. Rather than allowing that to occur, it is preferable to include this material with the amount that is to be backpassed. GenCade modeling indicates that most of the material arrives on the beach near the South Jetty at the eastern tip of East Beach. While the source may be poorly understood, this is a significant addition of new sediment to the system, and if its arrival continues throughout the project lifetime, would amount to a total addition of 17,785,000 yds³.

2.5 Short-term alternatives

The sand placement alternatives presented in Section 2.4 assume unlimited funding and sand. Both of these factors will constrain the type of beach that can be built along Galveston Island. Therefore, this study includes a number of smaller-scale alternatives that can be implemented in the short-term.

At present, beach placement generally only occurs after a major event like Hurricane Ike, when sufficient funds are available to correct hot spots or build small beach fills. Beaches are relatively narrow, and they are not nourished at any set interval. While this process can be continued into the future, it is not a sand management strategy. Additionally, the present actions do little to recycle the existing sand on the island. Sand is a precious commodity in Galveston. There is a limited volume of beach-ready sand, and once it moves into the Galveston Entrance Channel or into San Luis Pass or further down the coast, that sand is lost unless it is

replaced through beneficial use dredging, mining, or backpassing. Since the coast is one of the main reasons tourists visit the area, there should be a better policy in place than emergency and spot placements.

In the short-term, Reach 1 is the highest priority. It is the “Face of Galveston,” and one of the main attractions for tourists. If funding and sediment supply are limited, the beach along Reach 1 should be nourished prior to nourishing any of the other beaches. Even small beach fills of 100,000 yd³ renourished every 5 years could help keep the beach from retreating to the seawall. This option will not widen the beach to a desired 200 ft width, but, at the minimum, will provide future generations with a beach similar to the present conditions.

Additionally, if there is not enough funding or sand for a large-scale beach nourishment project immediately, another option would be to place about 250,000 yd³ of sand along the beach and then renourish the same volume every 5 to 10 years. While more material would be lost over time than an initial large-scale placement, a specified renourishment interval would protect the existing beach and provide a slightly wider beach for tourists.

2.6 Other possible alternatives

In addition to the large-scale beach fill, backpassing, and low-level, short-term alternatives, a few other alternatives were considered during this study. One of these alternatives looks at the big picture and may be more ambitious than the Galveston Park Board is prepared to take on, while others are alternatives geared to research.

The Houston area has been growing constantly. In 2012, the greater Houston area became the fifth largest metropolitan area with 6.22 million people (Pulsinelli 2012). It is expected that under a moderate growth scenario, the Houston metropolitan area will grow to 10.274 million by 2050 (Greater Houston Partnership Research Department 2014). The population could reach 14.41 million by 2050 under a fast growth scenario (GHPRD 2014).

If the population in and around Houston doubles over the next 50 years, then the number of tourists who visit Galveston and the population of Galveston will substantially increase. At present, most of the hotels are located along the seawall east of 61st St. If tourism doubles or triples, more hotels will need to be built further to the west along the seawall or even

along the west end. Additionally, as the population of Galveston Island increases, high-rise condominiums could be built to meet the increased demand for real estate and property. If the population increases significantly, the west end of Galveston Island could look more like present day Galveston Island behind the seawall. One idea to protect the entire island is to extend the seawall. It would be costly, require many permits, and take years, but it is an option when considering the long-term, multi-century strategy of population growth in the face of rising sea level. It would drastically change the shoreline of the island and require periodic nourishment in front of the seawall. This proposal is currently being considered in the Coastal Texas Protection and Restoration Reconnaissance Study (in progress, late-2014).

Another option along the west end of Galveston Island is nearshore berm placement. During Fiscal Year 2015, the SWG plans to place material dredged from the entrance channel in the nearshore along the west end of the seawall. As of late-2014, plans are still in progress. Nearshore placement is a way to use wave action to move sand onshore without placing it directly (mechanically) on the beaches. The berm at Ft. Myers, Florida, was constructed with dredged material from Matanzas Pass. The dredged material contained greater than 10 percent fines, which Florida law does not allow for subaerial placement (Beck et al. 2012). Therefore, not only could a nearshore berm be placed in shallow water along the west end, a demonstration could be conducted to determine how finer material would react. Both short- and long-term monitoring of the placement would be necessary. The Coastal and Hydraulics Laboratory has experts in this area and is conducting research sponsored by the Coastal Inlets Research Program (CIRP).

This study does not include engineering calculations or analyses for a nearshore berm placement; if a decision is made to move forward with a nearshore berm, significant engineering analyses and design would need to be conducted prior to construction.

2.7 Additional Considerations

2.7.1 Need for Phased Development of the Selected Alternative

Regardless of the alternative chosen, this will be large project with many unique features. No amount of predictive modeling can provide all the answers. It will be important to implement an adaptive management

strategy and to seek appropriately flexible design strategies. A short section of the beach fill should be constructed first, and then it should be monitored to make sure it is responding as expected. If it is, construction may continue along the rest of the reaches. If the beach is not responding as expected through studies and modeling, the design should be modified before continuing to other reaches. If backpassing is chosen in addition to initial large-scale beach fills, the rate of backpassing should start low to ensure the system is functioning properly and the plant does not have an adverse effect near the jetty. Once it is confirmed that the system is working, the rate of backpassing may be increased.

2.7.2 Additional Studies

This report should be considered as a preliminary examination of the project. More detailed investigations will be required to guide and refine the selection of a final alternative. Several places in the report specifically mention the need to perform additional studies. The application of an advanced economic model such as Beach-FX will provide a detailed analysis of projected costs and benefits of different alternatives. Benefits can include not only enhanced tourism from beach construction but also such items as storm damage reduction benefits. Other types of analyses will include the detailed design of the components of the bypassing system and beach fill.

2.7.3 Data Collection Needs for Monitoring

A well-developed monitoring program will be a key component of this project and a requirement for an adaptive management strategy. Certain types of data should be collected for the life of the project and continuously analyzed to stay on top of trends and issues as they arise. For certain data sets, such as beach surveys, the collection process should start well before construction begins. Following construction, beach survey data should be collected once a month for the first three months. Then they should continue every 6 months and after severe storm events. Georeferenced vertical aerial photography should be taken every three months. The profiles and aerial photography will be used to analyze shoreline change and movement of the sand. If the shoreline responds as expected, the next phase of implementation of a wide beach along Galveston Island may proceed.

2.7.4 Funding

Any option which develops a wider beach along part or all of Galveston Island will be expensive. A number of funding streams can be tapped to help cost-share. First the Galveston Park Board receives funding for beach nourishment. One dollar for each vehicle that enters any of the beach parks goes to beach nourishment funding. About \$200,000 is collected annually. Additionally, 0.5667 cents out of the state hotel occupancy tax and umbrella and chair concessions at the parks goes toward nourishing the beaches. The tax provides about \$600,000 annually, and the account has not been tapped in about 3 years. This means the Galveston Park Board has close to \$2,000,000 available for beach nourishment. As of late-2014, the Galveston Industrial Development Corporation (IDC) has a fund balance of \$3,000,000 for beach nourishment. Any future beach nourishment projects should involve cooperation with the IDC.

For projects that involve the beneficial use of dredge material from the Galveston Entrance Channel, the Galveston Park Board should work with the USACE SWG and serve as a non-federal sponsor so that the material can be placed on the beaches of Reach 2. Other non-federal sponsors could include the Texas General Land Office (GLO) and the IDC.

The GLO also provides funding through the Coastal Erosion Planning and Response Act (CEPRA) Program. The main purpose of CEPRA is to implement coastal erosion response projects and studies to reduce the effects of erosion and better understand the coastal processes. Typical projects considered for funding include beach nourishment, dune restoration, demonstration projects, and shoreline stabilization. Any of the options discussed so far fall under the typical projects. A nearshore berm placement or placement of finer material on the beach might be reasonable projects to request funding. Applications for the last CEPRA funding cycle were due July 1, 2013, for FY2014-2015. Based on those dates, the next applications will probably be due in the summer of 2015 for FY2016-2017.

Another possible source of funding is through FEMA. However, emergency FEMA funds are normally only available when a beach has eroded to a point where emergency work is needed or facilities have been damaged during a storm event. Even if one of these requirements is met, the applicant must also provide design studies, plans, and documents for the original nourishment and any renourishments, details and

documentation for the maintenance plan, and pre- and post-storm profiles. Based on these requirements, FEMA funding would be only available for the Galveston beaches after the beach is nourished and a storm event causes significant damage afterwards.

In summary, funding for the beach fill may be available from Park Board revenues, the Galveston IDC, the GLO CEPRA program, and the Park Board can partner with the SWG to beneficially use dredge material. In addition, under some circumstances, FEMA funds may be available after major storms.

2.7.5 Additional Considerations

Several additional considerations deserve mention. It is fundamentally important to have community involvement and support. This should be started as early as practical and citizens should have the feeling that their concerns are being addressed.

Environmental concerns will be a major factor. Environmental leaders should be looked on as partners who can help promote eco-tourism. Opportunities for habitat mitigation, restoration, and enhancement should be sought out.

Other, more engineering-type activities should be included in any final plan. For example, the 100+ year old Galveston Seawall should be analyzed in light of the expected rise in sea level.

2.7.6 Basic Beach Management Policy

In order to protect a new, wider beach and dune system, it is necessary to implement an improved beach management and maintenance policy. The Galveston sand management plan should be seen as an island revitalization strategy rather than simply beach renourishment. By widening the beaches, Galveston could become be a prime vacation destination for many Texans.

First, with an improved beach and the potential for more tourists due to population growth, there are many improvements that can be made to the Galveston beaches. The Galveston Pleasure Pier reopened a few years ago with new dining, shops, and rides, and is now a main attraction for visitors. An improved and expanded boardwalk is one idea to cater to

larger crowds of tourists. Another important part of revitalizing the beach is adding signs and learning activities. Many beach communities have signs that explain the processes along the beach, the need for beach nourishment, and the nourishment policies in place. Sand backpassing is still a relatively rare activity, so including public information about it would be very beneficial for visitors. With signs and learning activities, schools could bring students to the beach for educational field trips. If the children find the trips enjoyable, they will tell their parents, and their families will come for their own visits. If the number of visitors increases dramatically, more bathroom and outdoor shower facilities should be constructed to improve the quality of the beach visit.

In order to accommodate additional tourists, a number of management and maintenance policies should be in place. First, the Galveston Park Board and the City of Galveston must continue to maintain the beaches and dunes. If a dune is damaged due to human alterations or storms, there must be a system in place to restore the dune. At present, the Galveston Park Board's beach maintenance policy includes seaweed maintenance and trash removal from their parks and at the Seawall Urban Park (10th St. to 103rd St). Seaweed is moved away from the shoreline to provide beach access for tourists, but it is not removed from the beaches. However, if the seaweed becomes fly infested, it could pose a health hazard and should be removed. If all of the beaches along Galveston Island are nourished and widened, they should all be maintained by the Galveston Park Board or another group. In addition, sand from the beaches typically deposits along Seawall Boulevard or in parking lots across the street. The Galveston Park Board and the City of Galveston collect the sand and deposit it back on the beaches. This maintenance activity should continue in the future either by removing debris and placing the material back on the beaches or storing it for future use.

When the dunes are constructed, beach grass should be planted and sand fences should be erected to minimize erosion or possibly encourage growth. Dune walkovers should be constructed and located at every parking lot or access point along the west end and at every major street intersection along the seawall. These dune walkovers should be angled to reduce waves and surge from storms. It is very important that visitors understand that they may not walk across the dunes. Therefore, signs stating not to walk on dunes and the reason why should be placed at strategic locations along the dune system.

While the Galveston Park Board and the City of Galveston will probably be responsible for maintaining all of the beaches along Galveston Island, one activity that would encourage the involvement of residents is an annual beach cleaning and grass planting. This event should occur prior to the busy summer season. Participants would need an instructional session to ensure they understand proper techniques, but it would be a great activity to bring the City together and allow residents to take pride in their beaches.

Finally, an increase in the number of visitors to the Galveston beaches could cause parking problems. At present, visitors park along the seawall, at one of the parks, or on the beach. In the future, additional or larger parking lots should be added so that visitors do not park on side or residential streets. The Galveston Park Board should limit the number of vehicles, enforce speed limits, and specify locations on the beaches that allow driving.

2.7.7 Additional Information

Members of the Galveston Park Board may find this list of references helpful in thinking about this project and making informed decisions.

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3 Galveston Island Sediment Budget

3.1 Background

Morang (2006) calculated a sediment budget for the north Texas shore between Sabine Pass and San Luis Pass as part of the Sabine Pass to Galveston Bay, Texas - Shoreline Erosion Feasibility Study. Using additional and more recent data, the budget has been revised for Galveston Island. The mechanics of the budget process will not be described herein and can be reviewed in the earlier report. The present study includes 11 budget cells, extending from just north of the north jetty to San Luis Pass. This new budget represents average pre-Hurricane Ike conditions covering the mid-1980s to mid-2000s. Hurricane Ike was such a powerful and destructive event, its sediment effects are still being evaluated, and post-Ike beach fills (when data was available) have not been included in the placement averages.

The budget in the entrance channels was based on two sources of dredging data:

- Mid-1980s to approx. 2010: internal District dredging database supplied by SWG
- 2010-2013: spreadsheet based on District RMS data (Tricia Campbell, Operations Manager, SWG, personal communication, February 21, 2014).

Table A1 in Appendix A lists dredging volumes used in this analysis. The values used in the 2006 analysis are included for comparison. Units in the table are yd³ per dredging contract or event.

Table B1 in Appendix B lists Gulf side beach fills or sand placements. These data were originally supplied by Shiner Moseley and Associates and updated by Coastal Strategies Group, LLC, in 2014. As stated above, post-Hurricane Ike beach fills have not been included in the placement averages. West Bay dredging was tabulated by Atkins Global (2012), but these events did not affect the ocean side beaches.

Beach volume changes were based on shoreline change statistics and cross-shore beach profiles. Texas Bureau of Economic Geology supplies shoreline shapefiles via their web page (<http://www.beg.utexas.edu/coastal/>),

accessed 10 Oct. 2014). The Texas shoreline change project has been ongoing since the late 1990s and is the definitive source of shoreline change statistics for the Texas coast. The statistics used in this study cover historical change through 2007, and in many areas include over 100 years of data (Paine, Mathew, and Caudle 2011; 2012; Figure 6). Short-term post-2010 shoreline change rates were not used because of the extreme influence of Hurricane Ike (Paine, Caudle, and Andrews 2013).

Figure 6. Example of shoreline change transects from Texas BEG and 2002 cross-shore beach profiles.



Texas A&M University conducted cross-shore beach surveys during August and September of 2002 under contract to SWG. Profiles were spaced at ½-mile intervals (approx. 1000 yd) and were oriented

perpendicular to the local shoreline (Figure 6). They extended from the dune or a prominent man-made feature (e.g., seawall or building) to approximately the 10 m water depth. These profiles were also used in the 2006 study. Some 2006-2007 profiles were available for some areas, but their origins were different, and significant time would have been required to adjust the two dates to make them directly comparable.

Computing volume change required a series of steps:

1. Import the 2002 profiles into the Beach Morphology and Analysis Package (BMAP) software (Sommerfeld et al. 1994).
2. Using the BEG values from each 50-m transect, compute a simple arithmetic mean for the shoreline change for each budget cell along the coast.
3. Obtain an average profile based on all cross-shore profiles within each cell
4. With the translation tool in BMAP, translate the average profile the appropriate distance seaward (shoreline advance) or landward (retreat).
5. Using the area under the curve (computed by BMAP), multiply by the length of the cell to obtain a total sediment volume in yd³. For this study, we used a depth of 10 ft as the active zone (the black box in Figure 7).

The SWG collected sediment samples in select locations in its dredged channels and in the disposal areas. These were tabulated and plotted in ESRI™ ArcMap® Geographic Information System (GIS) software for the 2006 study, providing a convenient way to visualize the sediments in different portions of the channels (Figure 8, Figure 9). Based on the samples located landward of the tip of the south jetty, an average sand content of 86 percent has been used in the budget computations.

Figure 7. Example of procedure used to compute area under curve for two profiles using BMAP software. These are average profiles for a specific cell, and one profile has been translated an amount equal to the average shoreline change (either retreat or advance) for that cell. Volume under each curve is supplied in units of yd³/ft.

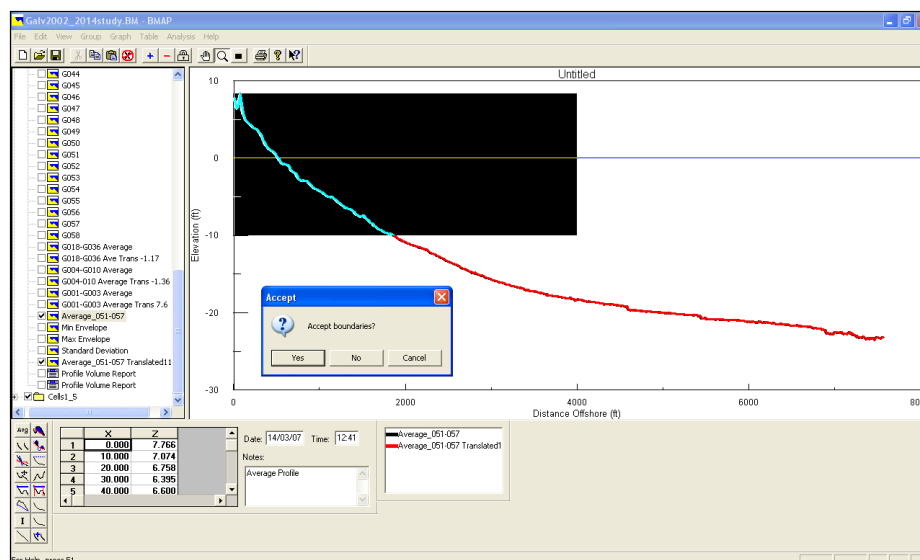


Figure 8. Gravel, sand, silt, and clay distributions of sediment samples from Galveston inner bar and anchorage areas. Numbers represent sand percentage. Background photograph, May 22, 2012.

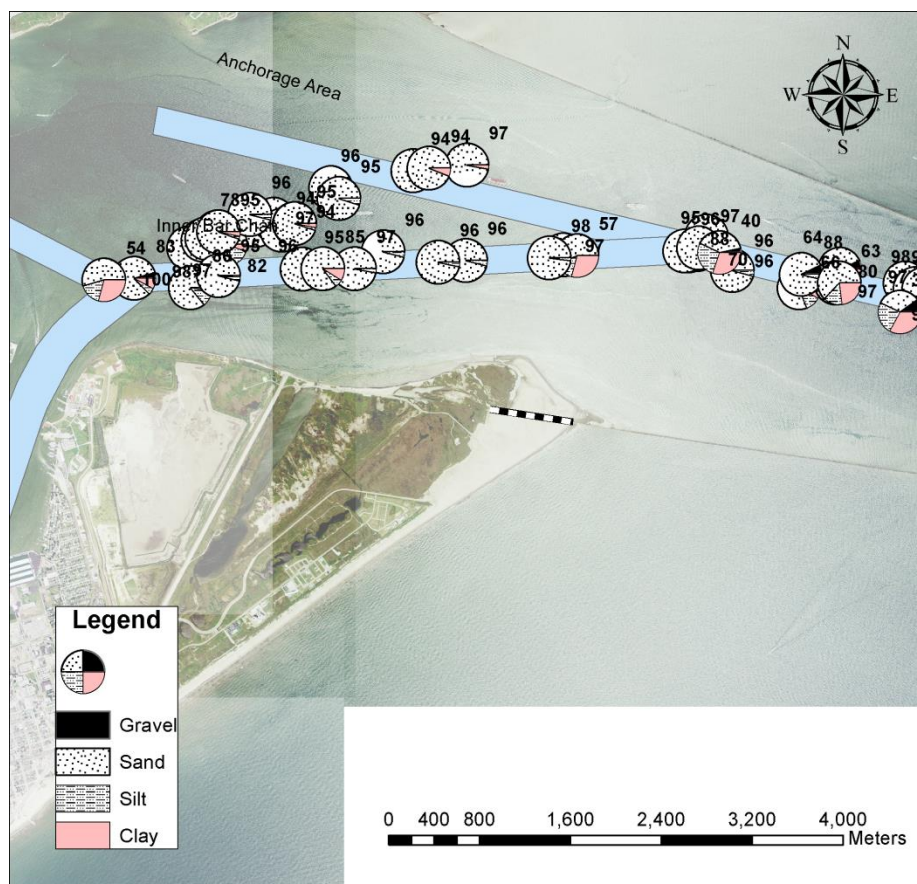
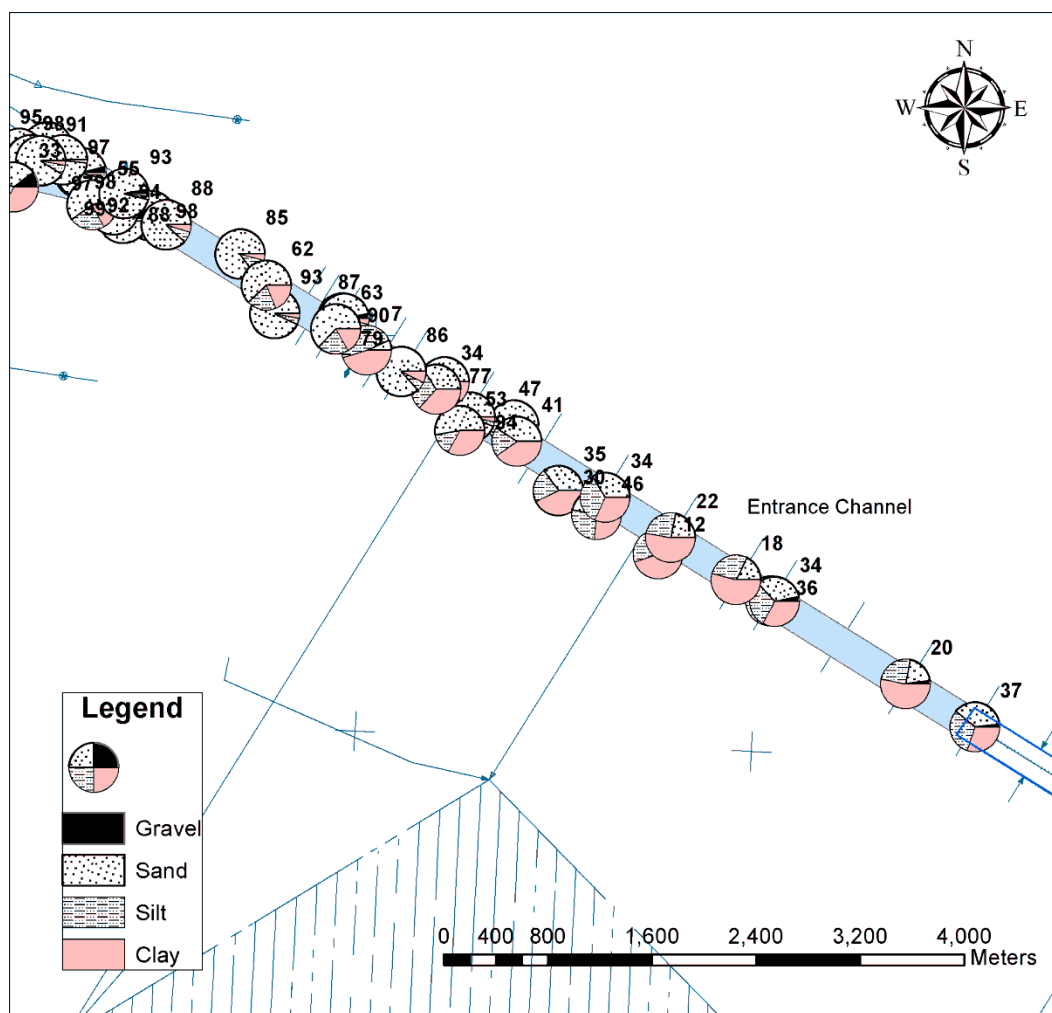


Figure 9. Gravel, sand, silt, and clay distribution for samples along the entrance channel. Numbers represent sand percentage.



3.2 Results

Table C1 in Appendix C summarizes the fluxes, placements, and volume changes in each cell. The second column lists the parameters used in the budget (such as ΔV). These are the same parameters used in the SBAS software. The third column contains the expected values (multi-year average) used for this budget (in yd^3/yr). Note that some parameters do not apply for some cells, and the values in column 3 are blank.

Error estimates are difficult to predict. Estimates of error, or \pm values, had to be computed for each parameter. In Table C1, column 4 contains the minimum (-) values, and column 5 contains the maximum (+) values.

- Beach volume (ΔV) was the term with greatest variability over time. Beach retreat was computed from the BEG shoreline change statistics. But during a mild winter, a beach may experience

negligible retreat, while during a harsh winter, retreat may be much greater than the multi-year average. For this study, the minimum value of ΔV was assumed to be 50 percent of the average, while maximum was two times or 200 percent.

- Placement (P). The P term was reliable for most sites along Galveston Island because truck loads are tabulated. But some nourishments may not have been recorded or were performed unofficially. The maximum P value is assumed to be 25 percent greater or $1.25P$.
- Dredge volume (R) for the navigation channels was based on spreadsheets from SWG. The operations manager is confident that the volumes reported for each contract are accurate representations of the volume actually removed from the channel, and that shoaling during the production did not significantly change the reported volumes. Therefore, \pm values are the same as the reported volume.

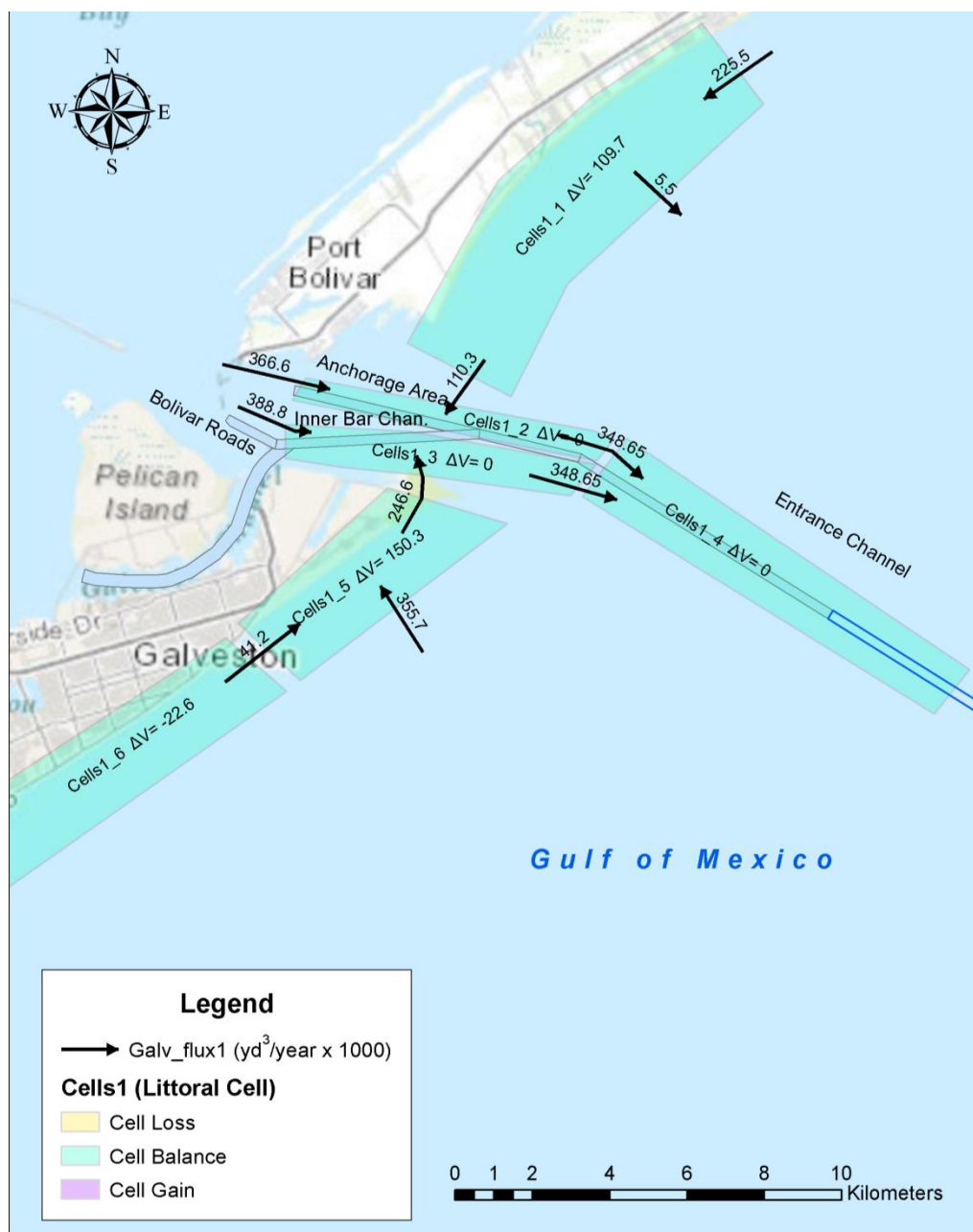
3.2.1 Cell 1_1: Galveston North Fillet

Cell 1_1 is north of the Galveston north jetty. This cell, the ones in the channel, and Cell 1_5 (East Beach) are interconnected with a complex pattern of sediment exchange (Figure 10).

The zone north of the north jetty has accumulated a significant quantity of sand since the jetties were built in the 1880s. Even since the 1970s, the beach has advanced, indicating that sand input exceeds sand losses through the porous jetty. Whether sand passes south through the north jetty is not immediately obvious based on the beach morphology. Just north of the jetty is a marshy, open water area rather than a traditional fillet built up against the structure. A comparison of 1952 and 2002 photographs shows that the open water area has remained (Figure 11). Two reasons may account for the marshy zone:

1. Wave energy in this area is low because of the shadow effect of the jetty. Therefore, littoral currents lose most of their load a few kilometers north of the jetty.
2. Sand moves through the porous jetty at a rate sufficient to prevent the accumulation of a fillet directly against the structure.

Figure 10. Sediment budget cells in the Galveston Entrance area. Units are in $\text{yd}^3/\text{yr} \times 1000$. ΔV represents volume change in each cell (beach accretion or erosion).



An opening was cut in the north jetty in 1964 to allow the passage of small boats. Cross-shore profiles from the 1960s and 1970s show that the seafloor became deeper in a semi-circle around the cut over the following years, indicating sand loss into the channel (Robert C. Thomas, SWG, personal communication, March 10, 2014). Whether sand passes through the jetty away from the cut is less clear. Radioactive tracer studies in the 1960s showed that following release of material at 3- and 6-ft water depth north of the jetty, tracer was detected south of the structure. The authors concluded that some material may pass through the porous structure, but

the patterns indicated that most of the material passed through the small boat opening (Ingram, Cummins, and Simmons 1965).

Figure 11. Bolivar Peninsula, May 22, 2012. Despite growth of the beach updrift of the jetty, there is still a marshy, open water area immediately north of the structure. The boat cut is at the right side of the jetty (photograph from the Texas Natural Resources Information System).



Based on translating the 2002 profiles by 1.12 m/year end-point rate, $\Delta V = 109,700 \text{ yd}^3/\text{yr}$.

Assumption 1. Sand movement through the jetty into the Galveston anchorage area equals about 110,000 yd^3/yr . This is based on the total volume dredged from the anchorage area (Cell 1_2) multiplied by the

average sand percentage of sediment samples from the inner and outer bar channels (86 percent).

Assumption 2. Sand loss offshore is minor, about 5,500 yd³/yr. This term is necessary to balance the cell considering fillet growth, loss through the jetty, and littoral transport.

3.2.2 Cell 1_4: Galveston Entrance Channel

This cell covers the portion of the channel from Sta 31+000 seaward past the ends of the jetties. Average 1979-2013 maintenance dredging was 697,000 yd³/yr.

Assumption: The majority of the material that fills the dredged channel comes from Galveston Bay and the inner bar channels. Some material may come from the ebb shoal during storms. Tests of radioactive tracers in the 1960s showed that material released near the outer end of the north jetty moved quickly around the north jerry and thence into the navigation channel (Ingram, Cummins and Simmons 1965). Surveys using sidescan sonar might be able to resolve bedform patterns to test whether the ebb shoal contributes material to the channel.

3.2.3 Cell 1_2: Anchorage Area

The anchorage area is north of the inner and outer bar channel. Dredging from 1978 to 1997 averaged 128,000 yd³/yr.

Assumption 1: Half of the material that moves out to Cell 1_4 (Entrance Channel) passes through this cell. The volume out is 349,000 yd³/yr.

Assumption 2: Littoral input from Cell 1_1 (north of the north jetty) is 110,000 yd³/yr. Based on over 60 samples (Figure 8), the average sand percentage of bottom samples equals 86 percent. It is possible that these samples, taken during dredging operations, are biased towards coarser grain sizes. One reason is that the cutter head, as it moves across the bottom, stirs up the fines, which dissipate. Also, the overflow from the hopper carries away many fines. However, without some other geotechnical data, such as a sampling grid consisting of bottom grabs and box cores, we used the percentages as stated in the 1950s to 1990s USACE dredge reports. For Cell 1_2, the only likely source of sand is littoral material passing through the north jetty. There is no likely sand source in

Galveston Bay. Although some sand is carried down the Trinity River, it is deposited in Livingston Lake, and the delta in upper Trinity Bay is too far from the Galveston entrance to serve as a source (Phillips and Musselman 2003).

Assumption 3. To balance the cell, the remaining material that fills the anchorage area consists of silt and mud from Galveston Bay (approx. 367,000 yd³/yr).

3.2.4 Cell 1_3: Inner and Outer Bar Channel

This channel follows the south jetty and provides access to Galveston Harbor and the Houston ship channel. 1980-1999 dredging averaged 273,000 yd³/yr.

Assumption 1: This cell is the source of half of the material that moves out to Cell 1_4 (Entrance Channel), 249,000 yd³/yr.

Assumption 2: Littoral input is around 247,000 yd³/yr. Based on over 60 samples, the material removed from the channels averages 86 percent sand (see discussion in Cell 1_2 paragraphs). The 21 west-most samples had even higher sand content, almost 93 percent (Figure 8). The unusually high sand content is unexpected, considering that most of Galveston Bay is a muddy environment. The only likely source of this sand is littoral material passing through the south jetty via Big Reef and wind-blown sand from East Beach.

Assumption 3. To balance the cell, the remaining material that enters (and passes through) the inner and outer bar channels consists of silt and mud from Galveston Bay (approx. 389,000 yd³/yr).

3.2.5 Cell 1_5: East Beach (Park Board Reach 6)

East Beach, located south of the south jetty, has grown steadily in the 120 years since the jetty was built. Unlike the fillet to the north, here sand has accumulated directly against the jetty. The jetty is porous, as shown by the steady growth of Big Reef, a sand body that projects northward into the navigation channel (Figure 11). The reef is occasionally mined for sand for beach nourishment (Appendix B).

Based on translating 2002 profiles by +11.25 ft/year, with an active depth of -10 ft, $\Delta V = +150,000 \text{ yd}^3/\text{yr}$.

Assumption 1. Sand movement through the jetty into the inner and outer bar channel (with temporary storage in Big Reef) area equals $247,000 \text{ yd}^3/\text{yr}$. This value is based on dredging of the bar channels multiplied by the average sand percentage of sediment samples (86 percent).

Assumption 2. Onshore sand movement equals $356,000 \text{ yd}^3/\text{yr}$. This is the only way to balance the cell considering fillet growth, loss through the jetty, and minor littoral input from the south.

Determining exactly how much material moves onshore near East Beach needs to be evaluated in greater detail. Seismic studies conducted by Texas A&M University detected sandy facies offshore south of the jetty, making an offshore sand source feasible (Timothy Dellapenna, Assistant Professor, Department of Oceanography, Texas A&M University, personal communication, Nov. 12, 2003). Dellapenna and Johnson (2012; their Figures 15 and 16) show sand and coarse sand facies off East Beach based on side-scan sonar surveys and vibracores.

The 1960s movable bed model studies also demonstrated bed movement onshore. With wave direction of S 29° E and S 37° E, bed movement was divided, some material moving north of the south jetty but most onto East Beach. With wave direction of S 37° E and S 66° E, bed movement was exclusively onto East Beach (Plates 59-62 in Simmons and Boland (1969)). Based on 1960s model studies (specific reference not cited), USACE (1993) also concluded that some of the material deposited in the offshore disposal area could feed Big Reef. However as a contrary hypothesis, Hall (1975) wrote that the net sediment transport in the lower shoreface was towards the southwest and parallel to Galveston Island. Principal sediment transport agents were near-bottom currents generated by tides, which were superimposed on a semi-permanent current flowing toward the southwest. He concluded, "Sandy material placed in the dredged material disposal area has little chance to ever return to the channel and will probably enter the longshore transport system and nourish beaches farther down the Texas coast." (Hall 1975; p. vi). Hall based his conclusions on theoretical considerations of bed shear calculated from

monthly vertical current profiles. It is unclear if he considered large-scale morphological factors such as the growth of East Beach over time.

3.2.6 Cell 1_6: Galveston Seawall (Park Board Reaches 1 and 2)

The Galveston Seawall protects the Gulf shore of Galveston Island for a total distance of 17,200 yd (9.76 mi). The east portion of the wall is now inland because of the growth of East Beach, leaving the western 12,000 yd with direct Gulf exposure. The City of Galveston has historically been concerned about retaining a beach at the foot of the wall to provide recreation and protect the structure. As a result, a series of groins were built in the mid-20th century to trap or retain sand, and the City and private interests have placed sand on the beach at various times. Based on 1985 to 2008 records, average annual placement is approximately 60,000 yd³ (excluding the 2009 post-Ike fill).

Assumption 1. Because of the rigid seawall, the shore is essentially fixed, although the beach at the base of the wall has retreated over the years. Average shoreline change has been -0.72 ft/year, resulting in $\Delta V = -22,600 \text{ yd}^3/\text{yr}$ (Figure 12).

Assumption 2. This cell is a divergence zone. At the west end of the seawall, there is clear morphological evidence that net drift is to the west because the shore has cut back (Figure 13). Therefore, drift is to the west out of the west end of the cell. This budget study assigned 50 percent of the littoral transport at each end, or 41,000 yd³/yr to the east and the same amount to the west.

3.2.7 Cell 1_7 (Park Board Reach 3 and East Part of 4)

From Cell 1_7 and continuing west, net littoral is to the west according to King's (2007) wave modeling studies. This agrees with most of the published literature for this part of Texas coast. The beach in Cell 1_7 has retreated 3.39 ft/year, resulting in $\Delta V = -110,000 \text{ yd}^3/\text{yr}$.

Assumption 1. Beach placement is approximately 15,000 yd³/yr. Beach nourishments have been reported at Sunny Beach, Sands of Kahala, Spanish Grant, and Bermuda Beach, but records are incomplete.

Assumption 2. All the material removed from the beach moves west, with $Q_{LST2} \approx 166,000 \text{ yd}^3/\text{yr}$.

Figure 12. Sediment budget for central Galveston Island. Units are in $\text{yd}^3/\text{yr} \times 1000$. P represents annual sand placement at beach communities.



Figure 13. Eroded beach just beyond the west end of the Galveston seawall (February 19, 2003). This is the border between Cells 1_6 and 1_7. Sand has been placed on the beach to protect the dune in front of the hotel.



3.2.8 Cell 1_8 (Park Board Reach 4)

Cell 1_8 is a semi-stable section of Galveston Island, with ΔV of -19,900 yd³/yr (Figure 14).

Assumption 1. Minor placements at Sea Isle equal 5,000 yd³/yr.

Assumption 2. Littoral material entering the east side of the cell continues on out the west side, with $Q_{LST} \approx 191,000$ yd³/yr.

3.2.9 Cell 1_9: West Beach (Park Board Reach 5)

Cell 1_9 includes an eroding section of Galveston Island, with average retreat of 2.74 ft/year. This results in ΔV of -43,400 yd³/yr.

Assumption. With the addition of approximately 17,000 yd³/yr of beach material to the incoming littoral drift, littoral transport out the west side of the cell increases to 251,000 yd³/yr.

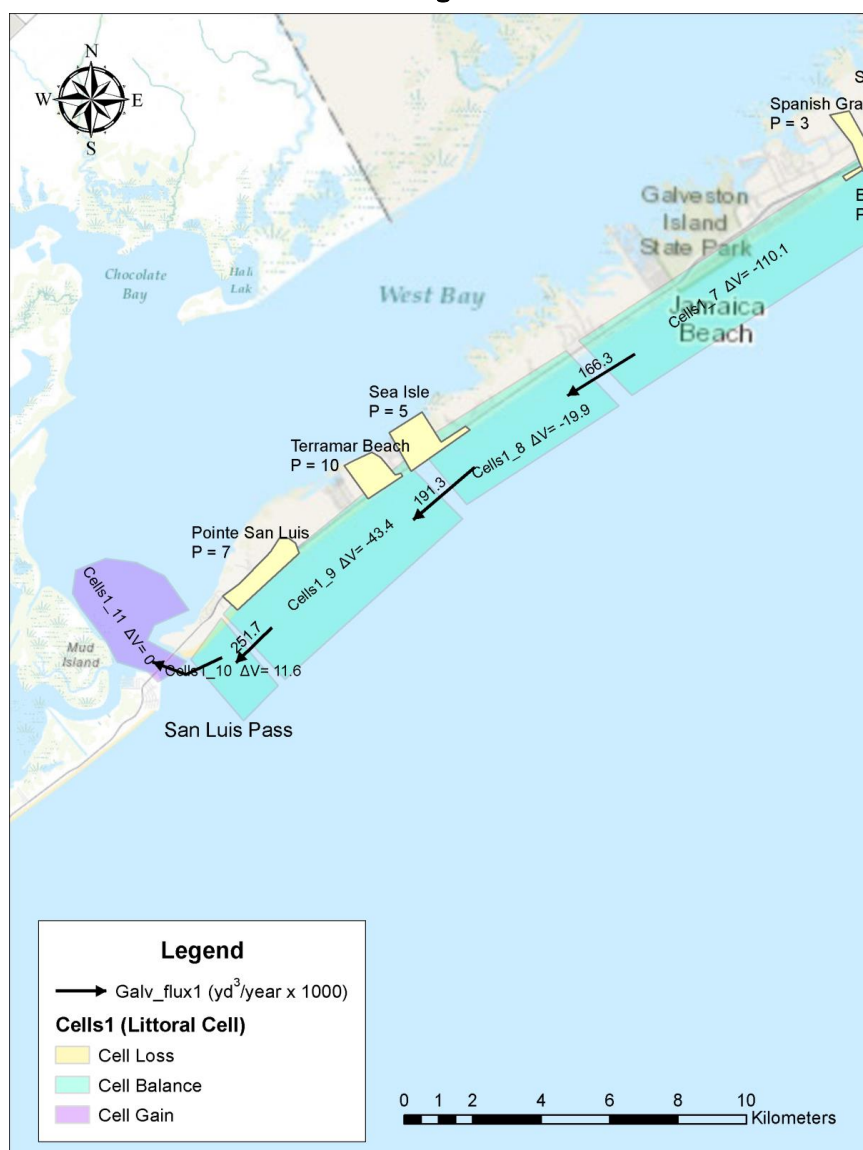
3.2.10 Cell 1_10: San Luis Pass East (Park Board Reach 5)

This cell includes the dynamic section of shore on the east side of the mouth of San Luis Pass. The pass has been in approximately this location since before 1853 (Mason 1981). Because the pass is unstructured, the marginal flood and ebb channels have migrated back and forth over time.

The shoreline east of the mouth has advanced 3.68 ft/year in the last 25 years, resulting in $\Delta V = 11,600 \text{ yd}^3/\text{yr}$.

Assumption. All remaining littoral material not accounted for in beach growth enters San Luis Pass (Figure 14). Therefore, $Q_{\text{sink}3} = 240,000 \text{ yd}^3/\text{yr}$. It is possible that some material bypasses the mouth, but the west side of the pass does not have an obvious attachment bar, as is common at inlets with ebb shoals that bypass littoral material.

Figure 14. Sediment budget along southwest end of Galveston Island. Units are $\text{yd}^3/\text{yr} \times 1000$. Annual volumetric change in the San Luis Pass flood shoal is unknown.



3.2.11 Cell 1_11: San Luis Flood Shoal

Most researchers believe San Luis Pass is a major sediment sink. Water depths range from -22 ft at the Gulf end of the Pass to only zero or -1 ft at the distal portions of the flood shoal (Atkins Global 2002). The ebb shoal may contain 4 million yd³ of sand, but growth or loss rates are unavailable (James Gibeaut, Bureau of Economic Geology, University of Texas, personal communication, Nov. 12, 2003). Bathymetry coverage is insufficient to determine the quantities of sand involved. Some material may enter from the west side of the pass, but we have insufficient data to compute volume.

Assumption 1. The flood shoal is a sink for all littoral material entering the pass. Sediment input is at least 240,000 yd³/yr. The numbers cannot be refined until complete bathymetry surveys are available to document growth of the shoal.

Assumption 2. Some sediment may be moving from the flood shoal to the deeper portions of West Galveston Bay West Basin, but quantities were not reported by Atkins Global (2012). This flux will be treated as zero.

Mason (1981) discusses the inlet's history and stability and suggests that it is a significant sediment sink, as well as a potential sand source for beach renourishment.

4 GenCade Calibration and Alternatives

GenCade (Frey et al. 2012; Frey et al. 2014) was applied to Galveston Island to model shoreline change and longshore transport and to evaluate structural and engineering alternatives. This chapter describes the process used to set up and calibrate the model.

4.1 GenCade Background

GenCade is a one-line shoreline change, sand transport, and inlet sand-sharing numerical model (Frey et al. 2012) based on the synthesis of Cascade (Larson et al. 2003), a design-scale, planning-level model, and GENESIS (Hanson and Kraus 1989), a project-scale, engineering design-level numerical model. GenCade calculates shoreline change in response to coastal structures and engineering activities such as groins, jetties, inlet dredging, seawalls, breakwaters, beach fills, and bypassing. The model was developed by updating the existing GENESIS code and incorporating the capabilities of Cascade. Development of GenCade began in 2009, and the first official release occurred in 2012. The newest version of the model (GenCade_v1r6.exe) was used for this study.

As a one-line model, GenCade is constrained by a number of standard assumptions consistent with the type of model. These assumptions are as follows and are described in more detail in Frey et al. (2012; 2014):

- The beach profile shape remains constant
- The shoreline and seaward depth limits of the profile are constant
- Sand is transported alongshore by the action of breaking waves and longshore currents
- The detailed structure of the nearshore circulation is ignored
- There is a long-term trend in shoreline evolution.

Some of the assumptions stated above have been stretched due to the processes on and around Galveston Island and the proximity to the Galveston Entrance Channel. Additionally, wind-blown transport and the possible movement of sand from the Ocean Dredged Material Disposal Site (ODMDS) to Galveston Island are not well known and should be researched. Wind driven surf-zone currents are also not included in the model. For these reasons, it is important to consider the GenCade model results qualitatively and note that many of the alternatives modeled will

greatly affect the coastal processes so additional studies and analyses should be conducted before moving forward with any alternative.

4.2 Numerical modeling overview and approach

Two separate GenCade grids were developed for Galveston Island. The first grid model extends from the jetty at the Galveston Entrance Channel to the end of the seawall. The second GenCade grid model covers the extent from the end of the seawall to just north of San Luis Pass. Two separate grids were developed since it is difficult to resolve the significant erosion directly downdrift of the end of the seawall. Because there is little sand in front of the seawall south of 61st Street, the end of the seawall effectively blocks most sand from moving north to south or south to north. Since very little sand moves from the seawall portion of Galveston to the west end, it was reasonable to develop two separate grids.

The United States Customary System was applied in both models. The horizontal coordinate system is State Plane, Texas South Central (FIPS 4204). The horizontal datum is NAD83 and the vertical datum is NAVD88.

The GenCade grid alignment is such that the water is to the left when facing in a positive direction along the grid. The seawall grid is oriented at a 237° angle from north while the west end grid is at an angle of 236°. The grid angle should match the angle of the shoreline as closely as possible which is why the angles of the two grids are slightly different. When standing along the grid and facing the water, transport is negative to the left and positive to the right. Waves were imported in meteorological convention, but GenCade converted them to shore normal.

The GenCade model termed the “Seawall grid” extends from the south jetty at the Galveston Entrance Channel to the very end of the seawall (Figure 15). The grid consists of 685 cells ranging from 50 to 200 ft. The smallest cells are along the seawall near the groin field. The length of the grid is approximately 10.4 mi.

The west end grid extends from the end of the Galveston seawall to just north of San Luis Pass (Figure 16). There are a total of 470 cells along the west end grid. Constant cell spacing of 200 ft was used. The grid is approximately 17.8 mi long.

4.3 Data inputs used in both grids

4.3.1 Initial shoreline position

The 1995 shoreline position from the Bureau of Economic Geology (BEG 2014) was used as the initial shoreline position for calibration. The shoreline was smoothed to remove any extreme undulations in shoreline position. In order to use the smoothed shoreline for both the seawall grid and the west end grid, the shoreline was split into two segments at the end of the seawall. Although more recent shoreline positions were available from BEG, these possible calibration periods would have included Hurricane Ike. Because Hurricane Ike made such a large impact on Galveston Island, it would not be reasonable to include it in the calibration process. Chapter 3 describes in more detail why Hurricane Ike should not be included in modeling and analyses.

4.3.2 Regional contour

The regional contour was developed from the existing shorelines provided by BEG. The 1995, 2000, 2001, 2002, 2010, 2011, and 2012 shorelines were analyzed. Previous shorelines were also analyzed, but some of the shoreline trends seen over the last 20 years did not occur further in the past, most likely due to the shoreline continuing to respond to the extended seawall constructed in the early 1960s. The seven shorelines were smoothed to eliminate extreme fluctuations in the shoreline position and later were averaged to develop the regional contour.

4.3.3 Waves

Hindcast waves from WIS (Wave Information Study) were used to drive the models. A single wave station was used as input for each grid model. Station 73070 was used to drive the seawall grid model. The wave gauge was positioned at cell number 655 and the water depth was 32.8 ft. For the west end grid, the WIS Station 73067 was used which had a water depth of 42.65 ft and was positioned at cell 276. A sensitivity analysis was conducted with many other wave stations. The hindcast waves in the Gulf of Mexico were recently updated to include 1980 to 2012. These waves were analyzed to determine which years were the most representative of typical conditions. It was determined that 1985, 1986, 1992, 1995, and 2012 were the years which experienced calculated net transport rates nearest to the average net transport from 1980 to 2012. The waves from these five years were used as the wave input for GenCade. The hindcast

waves from 1995 to 2000 were also tested as the wave input for the model, and the results were very similar to those with the representative waves.

4.4 Seawall grid domain

In addition to the information provided above, there are also some inputs and parameters unique to the seawall grid domain.

4.4.1 Beach fills

From 1995 to 2000, only one beach fill was constructed along the length of the seawall grid. In 1995, a 710,000 yd³ fill was placed along 19,000 ft of the seawall. In GenCade, beach fills are represented by average added berm width, date, and location. The 710,000 yd³ beach fill is equivalent to an added berm width of 40.54 ft based on estimated berm height and depth of closure values.

A second beach fill was constructed in 1999. Although the volume is recorded as 9,613 yd³, the approximate length and location are unknown. Since the beach fill was relatively small and the location was not known, it was not included within the model.

4.4.2 Groins

Each of the groins along the seawall was added to the model. An aerial photograph was used to map the locations of each groin. A seaward depth of 6 ft was specified for all of the groins. Initially a permeability of 0.3 was chosen for all of the groins; however, the permeability of each groin was adjusted between 0 and 0.99 during the calibration process.

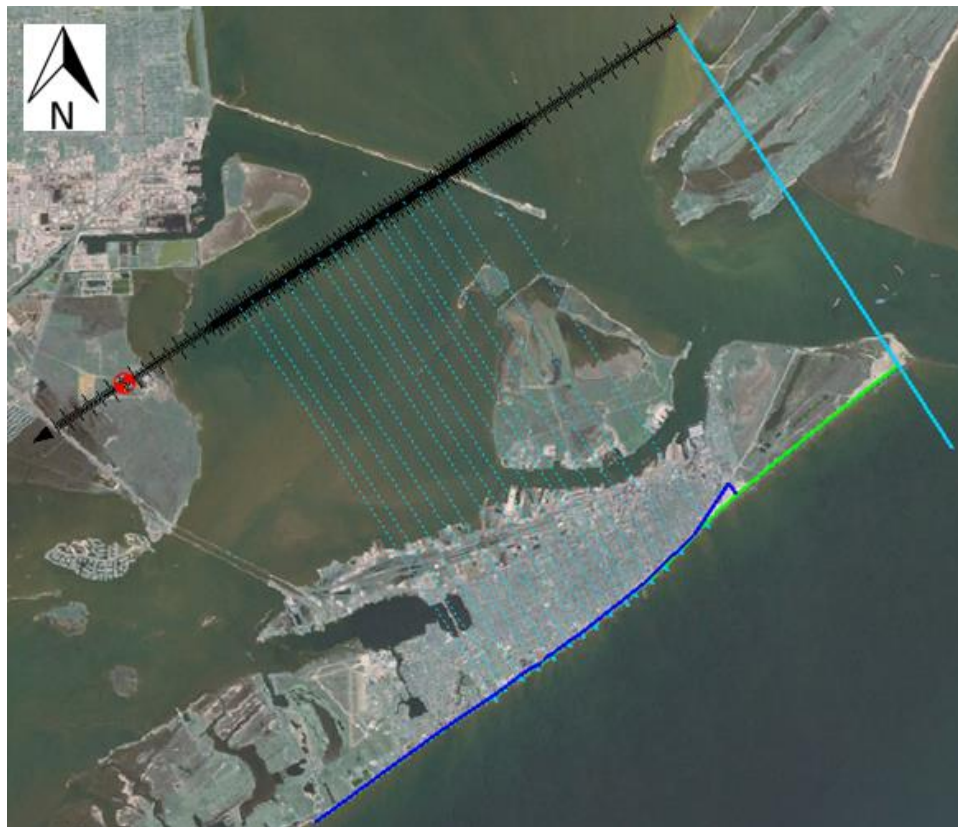
4.4.3 Seawall

The seawall was included in the model by drawing a line on top of an aerial photograph. This seawall line was then converted to an arc before being added to the model. Some manual adjustments to the seawall were made during the conversion from the conceptual model (real-world coordinates) to the GenCade model (grid cells), due to the cell spacing in the vicinity of the seawall.

4.4.4 Lateral Boundary Conditions

A gated boundary condition was specified at the left boundary of the seawall grid. First, a groin was created at the boundary. A groin was specified, because the Galveston Entrance Channel was not included in the model, so there was no inlet adjacent to the jetty. Also, only a groin can be used to specify a gated lateral boundary condition. However, shoreline change and longshore transport are calculated in the same manner at jetties and groins. The other piece of information necessary to specify a gated lateral boundary condition is the length of the groin from the shoreline to the seaward tip. In this case, this length was 7451 ft. A pinned boundary condition was chosen for the right lateral boundary condition.

Figure 15. GenCade setup for seawall grid.



4.5 West end grid

4.5.1 Beach fills

Two beach fill projects were conducted between 1995 and 2000. Both were small and occurred in 1999. The first fill was constructed in front of the Pirates' Beach West subdivisions. The fill consisted of 19,500 yd³ and

extended 7,785 ft along the shore. This is equivalent to an added berm width of 3 ft for GenCade. The second beach fill was located at Beach Pocket Park Number 2. The volume of this beach fill was only 1,200 yd³ and 485 ft long (added berm width of 2.35 ft in GenCade).

4.5.2 Lateral Boundary Conditions

Moving boundary conditions were specified at both of the grid boundaries. The left end of the grid corresponded with the end of the seawall. Initially, a gated boundary condition with a groin was used, but a simple moving boundary condition produced more reasonable results. The shoreline change specified for the moving boundary condition was -18 ft over the entire simulation. The shoreline at the right boundary has changed significantly due to the complex processes at San Luis Pass. From 1995 to 2000, the shoreline accreted 780 ft which was the input for shoreline change for the moving boundary condition.

Figure 16. GenCade setup for west end grid.



4.6 Calibration summary

In addition to the setups described previously, GenCade also requires a number of parameters in order to run the model. The same parameters

were used for both the seawall grid and the west end grid. The models were run for five years from January 1, 1995, to December 31, 1999, with a time step of 0.1 hr. Based on the beach profiles used for the sediment budget, a berm height of 4 ft and depth of closure of 20 ft were specified. The berm height is the elevation for the typical berm while the depth of closure is the depth of the seaward limit of sediment transport for the time period modeled. A median grain size of 0.17 mm was based on previous literature and sediment samples.

GenCade was calibrated with the measured shoreline change and transport rates. The calibration process requires iterating the calibration parameters to match the measured shoreline change and the magnitude and direction of sediment transport. The calibration parameters which produced the best match to the measured shoreline change and transport rates are shown in Table 5. In addition, a wave angle of offset of 8 degrees was specified in order to match the direction of transport east of the seawall. Without this offset, the model calculates net transport to the west all along Galveston Island. K1 and K2 are the sand transport calibration coefficients which were selected from a previous GENESIS study of Galveston Island (King 2007).

Table 5. GenCade parameters for calibration.

Parameter	Value
Start Date	1/1/1995
End Date	12/31/1999
Time Step	0.1 hr
Recording Time Step	168 hr
Effective Grain Size, mm	0.17
Average Berm Height, ft	4
Average Depth of Closure, ft	20
K1	0.4
K2	0.2
Angle Offset	8°

Figure 17 compares the measured and calculated shoreline change rates per year along all of Galveston Island. Initially, GenCade did not predict accretion adjacent to the south jetty of the Galveston Entrance Channel. In order to balance the cell in the sediment budget, a term of 355,700 yd³ per year of sediment was added to the cell from offshore. It is assumed that volume comes from the ODMDS. Although the source of the sediment is

unknown, material must come from a source other than longshore transport in order to advance the shoreline at the observed rates. In order to calibrate the model, a volume of 355,700 yd³/yr was added to the cells adjacent to the jetty. Although this volume allows the calculated results to nearly match the observed shoreline change, it is difficult to predict if or how much sand may move onshore in the future. For that reason, a number of rates of onshore sand movement are modeled in the alternatives section. The modeled shoreline change in the groin field matches fairly well with the observed rates. Along the west end of the seawall, a few feet of erosion is observed. However, the model predicts little to no change in shoreline position. The reason is most likely because the model requires the beach profile shape to be constant along the grid x-axis. The model does not know that the western end of the seawall lacks sand in the offshore profile which makes it difficult to build a beach onshore. Along the west end, GenCade predicts erosion for the first 10 miles as expected. The model calculates substantial accretion near the boundary but does not predict as much accretion further from the boundary as observed.

Figure 17. Measured and calculated shoreline change for 1995 to 2000.

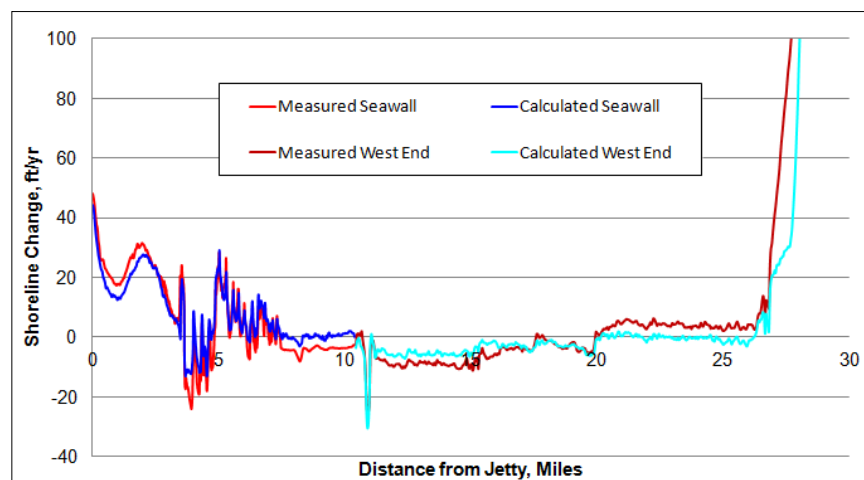


Figure 18 shows the net annual mean transport along Galveston Island. As expected from the sediment budget, the transport direction is to the northeast along East Beach and the first section of the seawall. A divergent nodal point occurs along the seawall, and then transport starts to move to the southwest. Transport along the west end is consistently to the southwest. The transport rate to the west increases at the very far end of the west end and then promptly switches back to the east. San Luis Pass is not included in the model, so transport, sources, and sinks associated with

the inlet do not exist in the model. In order for the calculated shoreline to move nearly 800 ft at the boundary in the 5 year period, the model must transport the sand from off the edge of the grid.

Figure 18. Net annual mean transport from 1995 to 2000.

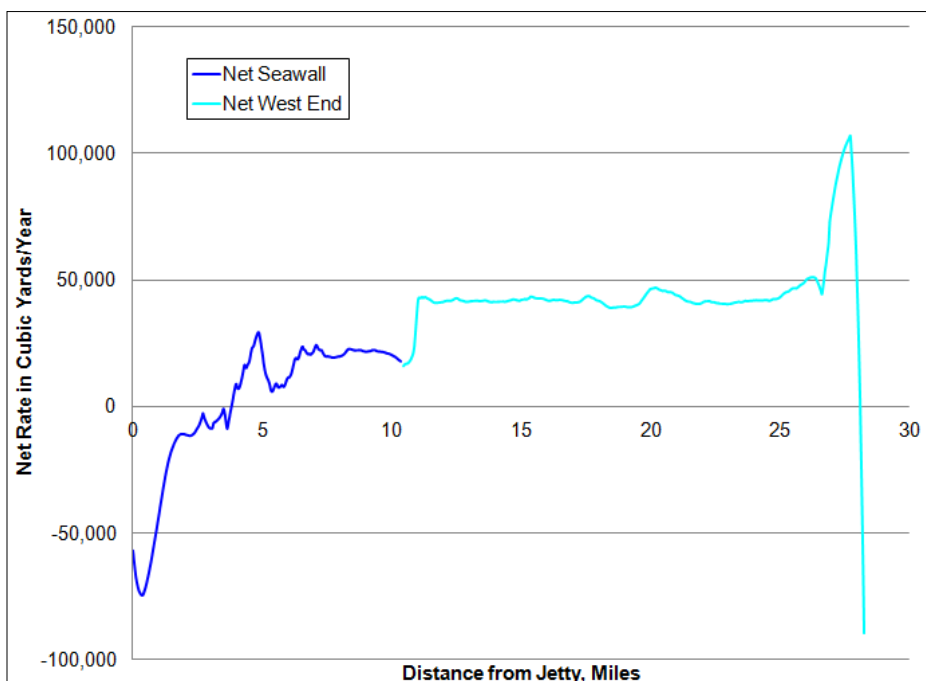


Table 6 describes the calibration statistics. The Root-Mean-Squared (RMS) Error and the Brier Skill Score provide goodness-of-fit statistics and scores for the GenCade results. The RMS Error is the difference between the measured and modeled shoreline change. The Brier Skill Score reflects the level of agreement between the measured and calculated values; a score of 1 means the measured and calculated values are in perfect agreement while a value greater than 0.8 is excellent and a value less than 0.3 is poor (USACE 2014b).

Table 6. Statistics for GenCade calibration.

Cell	Average Shoreline Change, ft/year		RMS Error, ft/year	Brier Skill Score
	Measured	Modeled		
Jetty to first groin	18.2	15.1	3.8	0.96
Groin field	1.6	5.5	5.0	0.82
Seawall west of groin field	-3.4	0.5	4.0	0.87
West end (to 13 Mile Rd)	-8.1	-5.2	3.6	0.84
13 Mile Rd. to Jamaica Beach	-3.3	-2.9	1.3	0.87
Jamaica Beach	-0.7	-1.5	1.1	-0.27
Jamaica Beach to Indian Beach	-3.3	-3.4	0.9	0.94
Indian Beach to Sea Isle	4.1	0.5	3.8	0.22
Sea Isle area	3.6	-0.4	4.1	-0.23
West end 1	5.7	1.2	4.7	0.54
West end 2	91.3	50.0	45.5	0.79

5 East Beach Sand Management Options

5.1 Significance of Big Reef and East Beach

Along the northeast end of Galveston Island, net transport is to the northeast, as verified by the Gulfward advance of the shoreline since the 1850s. East Beach grew from a detached separate island in 1838 to a recurved spit in 1850 (Morton 1974). The south jetty, constructed in the 1880s, trapped sand and formed a fillet. This broad, almost flat, fine-grained beach now serves as a recreational resource for Galveston.

Although millions of yd³ of sand accumulated in East Beach, the jetty was permeable, allowing some sand to pass through into Galveston entrance channel. The sand accumulated north of the jetty, forming a sand body that is now known as Big Reef (Figure 8). It was first evident as early as 1919 as a body of sand extending out into the channel (USACE 1993). Over time, the reef has expanded and contracted in response to storms and hurricanes, but surveys during the 20th century show that it continues to rebuild after storm events.

The significance of Big Reef is that it demonstrates that sand is being recycled through the system. The 1993 Section 22 report (USACE 1993), the previous sediment budget study (Morang 2007), and the current study conclude that sand moves onshore south of the south jetty. Much of this material passes through the jetty and into the channel, but some accumulates on the beach, where Aeolian processes can move it northward to Big Reef and further into the channel. As Big Reef grows northward, it impinges on the Federal navigation channel and has to be dredged (USACE 1993). The dredge material is subsequently placed in the USACE disposal area south of the end of the south jetty. Waves move the material onshore, and the cycle begins again. The continuous shoaling is a challenge in maintaining the navigation channel, and the recycling of material adds to overall costs. This chapter presents some alternatives to improve regional sediment management:

1. The reef or East Beach could be mined as a source of beach-quality sand.
2. Sand could be intercepted before it reaches the present dry beach.

3. The volume of sand reaching Big Reef could be reduced via sand-tightening, potentially reducing channel infilling and eventually reducing maintenance costs.
4. Aeolian transport could be reduced.

The City of Galveston Park Board of Trustees has two permitted sand removal areas on the reef. One is at the west end near the culverts to East Lagoon. The other is on the unvegetated sand flats at the east side of the reef, an area known as R.A. Apffel Park (Ray Newby, Texas General Land Office, personal communication, August 11, 2006). Much of the rest of Big Reef is now partially vegetated and is a nature preserve. Therefore, a large proportion of Big Reef may not be available as a sand source. However, in the listing of sand sources in Chapter 2, both permitted sand removal areas and restricted areas are included in the calculations since environmental requirements might change in the future.

Previous mining at Big Reef is documented in Appendix B. Starting in February 2003, the Board of Trustees used a jet pump and conventional dredge to remove 119,000 yd³ of sand from the submerged west portion of the reef. The reef had grown to the extent that it blocked the culverts to East Lagoon, and the project had the dual purposes of restoring circulation and mining sand. The material was placed in a temporary dredged material placement area (DMPA) near the west end of the jetty. In mid-April, trucks moved 82,500 yd³ to the west end of the Galveston seawall and built a 2400 ft-long beach about 50 yd wide. The remaining 35,000 yd³ was fine-grain and possibly unsuitable for beach use. Regardless of its quality, it was reclaimed by the elevated seas from Hurricane Claudette, which made landfall near Port O'Conner on July 15, 2003. The storm surge level was 2.30 m MLLW at Pleasure Pier at 0554 CDT, July 15, 2003. An aerial photograph taken on July 27 shows a fan of sand pushed over the south jetty and extending out into the entrance channel (Figure 19). This example supports the hypothesis that significant sand from the open coast makes its way into the Houston-Galveston Ship Channel (Morang 2007).

In early 1995, the City of Galveston nourished the 3.7-mi-long beach at the groin field area with 710,000 yd³ of sand from an offshore source. In January 1998, 1999, and 2000, the city added material amounting to about 70,000 yd³ per year to supplement the initial project (Ravens and Sitanggang 2002). East Beach was scraped to provide the required sand.

The Board of Trustees has continued to remove sand from East Beach/Apffel Park using trucks and place it on an as-needed basis in front of hotels to enhance tourist appeal. The quantities have not been carefully tabulated, but are in the range of 10,000s of yd³ per year rather than 100,000s. Trucks removed 25,000 yd³ of sand between May and June 2006 and carried it to Jamaica Beach at the west end of the island.

Sand mining is not possible all year. The sand flats near the south jetty are piping plover habitat but are not a nesting area. In addition, sea turtles are beginning to nest on East Beach, which may stop mining operations from mid-March to the end of September.

Figure 19. July 27, 2003 photograph of Galveston south jetty taken after Hurricane Claudette. A fan of sand extends into the entrance channel to the right. View looking approximate northeast with the ship channel on the right and East Beach on the left (courtesy of Texas BEG).



5.2 Option 1: East Beach sand sources

Three areas on Big Reef and a triangular zone next to the jetty on East Beach may be suitable for beach-quality sand. These are shown Figure 20 with their approximate surface areas. The areas were traced from June 2006 aerial photographs provided by the Texas Bureau of Land Management. The volumes in Table 7 assume removing a uniform layer across each area. The 1-yd and 2-yd layers could probably be processed with backhoes and trucks, while the 5.5-yd layer might require dredging equipment. Clearly, the areas and thicknesses would be adjusted based on engineering, environmental, and economic criteria or available equipment (for example, a buffer zone must be left near the jetty and around the nesting habitat on the exposed reef), but the analysis shows that up to 2,000,000 yd³ could be mined if a 5.5-yd-thick layer were taken out while still leaving the vegetated portion of Big Reef intact.

Table 7. Potential Big Reef mining volumes.

Polygon	Area (m ²)	Vol. 1.1 yd layer (yd ³)	Vol. 2.2 yd layer (yd ³)	Vol. 5.5 yd layer (yd ³)
Big Reef Area1	195,000	255,100	510,100	1,275,300
Big Reef Area2	19,660	25,800	51,400	128,600
East Beach Area1	60,900	79,700	159,300	398,300
Total	275,560	360,600	720,800	1,802,200

Studies have already been conducted to evaluate the feasibility of mining these areas. For example, PBS&J (2007) determined that there were only three anomalies in a rectangle region north of the south jetty (larger than Areas 1 and 2 of this study). They interpreted them to be modern boat wrecks. In the 1993 Section 22 report, USACE 1993 calculated that 2.4 million yd³ was available from the submerged portions of Big Reef if dredged to -20 ft, while preserving the above-water habitat areas. Several mechanical systems could be used, including jet pumps, a simple fixed bypassing system, and a shore-based dragscraper system.

Potentially, even more of East Beach could be mined, such as the unvegetated area south of the jetty. But, the beach is a popular recreation area and some sections may be unavailable as a sand source.

Another potential source of sediment is the underwater portion of Big Reef that extends north into the channel. It consists of a high proportion of sand, similar to the samples from the navigation channel (Figure 8). A dredging plan can be designed once contemporary bathymetry data is available.

Figure 20. Potential sand-mining areas on Big Reef and East Beach. Units are in hectares (= 10,000 m²). The area labeled “Unavailable” is used for recreation but could possibly be scraped occasionally.



5.3 Option 2: Deposition basin off East Beach

The sediment budget concludes that net northeastward-directed transport along East Beach is about 41,000 yd³/yr, while onshore transport is about 360,000 yd³/yr. Therefore, one option to consider is trapping some of the material that moves onshore before it reaches the surf zone and the beach. This could be accomplished by dredging a temporary deposition basin offshore of East Beach parallel to the shoreline.

Dredging a deposition basin would have two benefits. First, it would yield beach-quality sand. Second, any material that the basin traps will not move onto East Beach and, thereafter, onto Big Reef or into the navigation channel (in turn, helping reduce dredging requirements).

Any number of configurations of basins can be designed. One example is for a rectangle 3,000 yd long by 150 yd wide. If located in water about 5 yd deep, the basin would be about 1000 yd offshore (Figure 21). This water depth is suitable for several reasons. First, it is approximately the limit of the active zone (closure depth) here, and therefore would primarily trap incoming material rather than absorb sand from the beach. Second, barges and equipment can work in this depth. Final choice of a basin will be dictated by operational factors, equipment available, and bottom sediments. If the basin were excavated to a depth of 1 yd, it would yield about 450,000 yd³ of sand; 2 yd would supply 900,000 yd³ from initial construction.

The sediment budget calculated that onshore sediment movement along East Beach is about 360,000 yd³/yr. If we assume that this supply is evenly distributed along East Beach, then the 3,000 yd-long basin might trap about half of the landward-moving sediment, or about 180,000 yd³/yr. If we assume about 50 percent efficiency, the basin will trap about 90,000 yd³/yr. The actual rate of infilling would have to be monitored with bathymetry surveys, but a reasonable estimate is that the basin might have to be re-dredged about every five years.

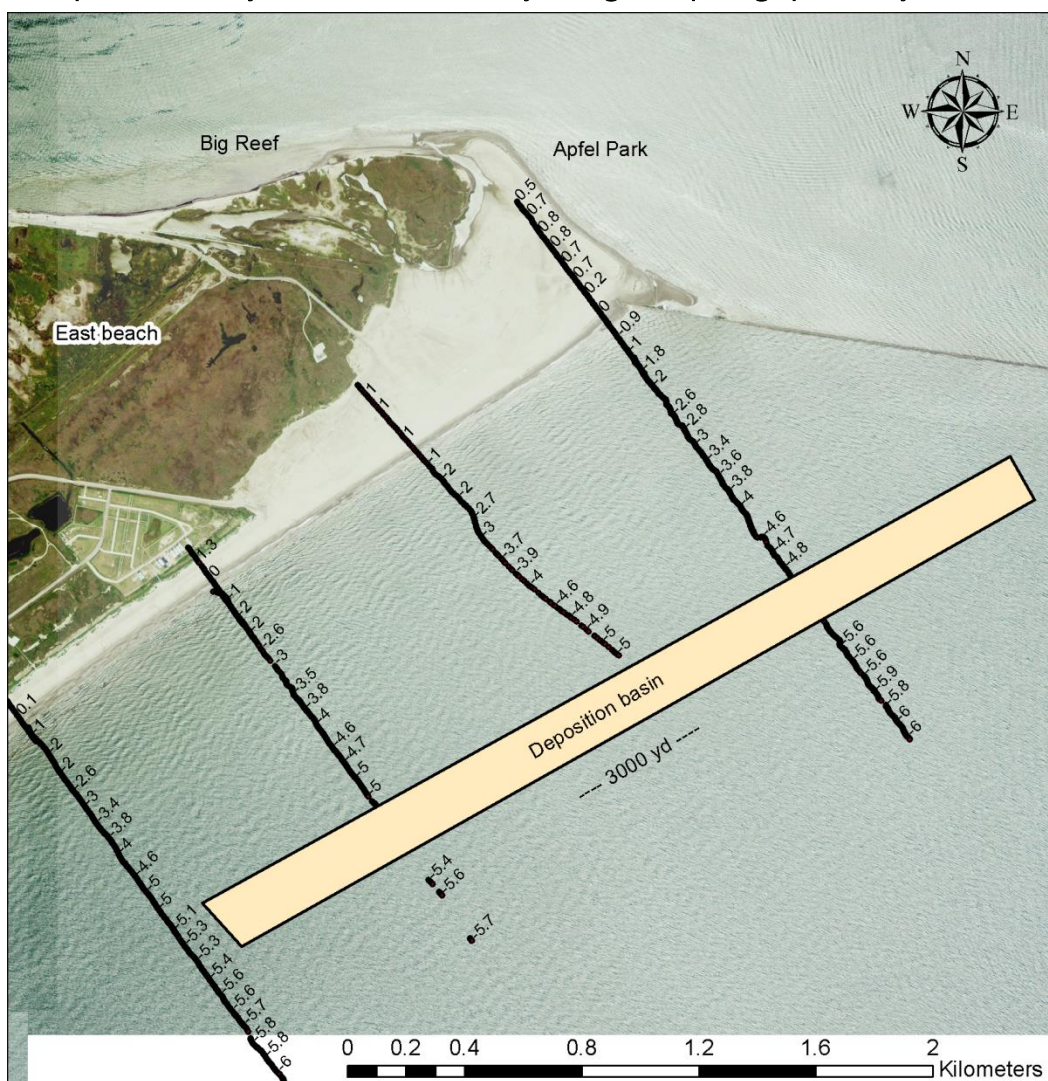
Table 8 lists options for different lengths of basins (all assume 150 yd wide). The volumes in the last column will vary depending on the efficiency of the basin as a trap. Environmental and permit factors will have to be investigated, and an offshore geotechnical survey will be needed to determine if the material removed during initial construction is suitable for beach placement.

Table 8. Sediment basin parallel to East Beach.

East Beach coverage (percent)	Length (yd)	1 yd depth initial volume (yd ³)	2 yd depth initial volume (yd ³)	Annual vol. trapped at 50% efficiency (yd ³)
50	3000	450,000	900,000	90,000
75	4500	675,000	1,350,000	135,000
100	6000	900,000	1,800,000	180,000

Note: Initial dredged volume based on basin 150 yd wide

Figure 21. Proposed deposition basin off East Beach. Dimensions and locations of basin could change depending on sediment needs. Profile elevations in m, NAVD 1988. 2002 profiles courtesy of Texas A&M University. Background photograph 22 May 2012.



5.4 Option 3: Reduce transmission through south jetty

Over the past century, the south jetty trapped the sand that now constitutes East Beach. Despite this trapping, significant amounts of sand enter the Galveston channel, either by Aeolian movement or by transmission through the jetty. Therefore, one option to obtain beach-quality sediment and reduce channel shoaling would be to prevent or reduce transmission through the jetty. The resulting sand fillet could then be mined as needed. This is similar in concept to Option 2, except that it adds sand tightening of the structure to further increase the rate of sand accumulation off East Beach.

Morphological evidence indicates that the south jetty continues to be porous. Figure 22 is a close-up of the shoal that extends north of the south jetty (east of the main body of Big Reef). The arrows point to areas where the jetty is particularly porous and from where channels have cut across the shoal. Channel 1 (closest to the beach) appears to have enough flow to maintain an open mouth. At arrows 2 and 4, scour holes appear to have formed north of the jetty. The most likely explanation is that wave setup and the flood tide pushes water through the jetty. The post-hurricane Claudette photograph (Figure 19) demonstrates that the water also carries a significant amount of sand over and through the jetty into the Galveston channel, at least under storm conditions.

The porosity of the jetties has long been recognized, and SWG has made efforts to reduce void space. Sargent and Bottin (1989) reported that in 1935-1936, an asphaltic cap was placed on two sections of the south jetty from sta 196+55 to sta 230+59 and at a section near the outer end. "Prior to the cap, a seal course of asphaltic concrete was placed in the void spaces." These sections of the jetty are now under the sand on East Beach, and there is no documentation on whether the sealing was effective in reducing transmission. The last pre-Ike rehabilitation work was in 1962-1966, when the outer 70 m of each jetty was rebuilt as a head section and a portion of the north jetty was rehabilitated. "In many cases core stone was exposed, or cover layer stone was not tightly interlocked. Due to these conditions and use of large core stone during original construction, the jetties were considered too pervious (*sic*) to wave, tide, and sediment motions." (Sargent and Bottin 1989). Background information on sealing and tightening can be found in Simpson et al. (1990), and an evaluation of sand tightening at Port Everglades, FL, is in Rosati and Denes (1990).

Figure 22. Areas of the south jetty with enough permeability for significant water flow. Aerial photograph March 2006. Water depths along survey profile in m, NAVD 1988.

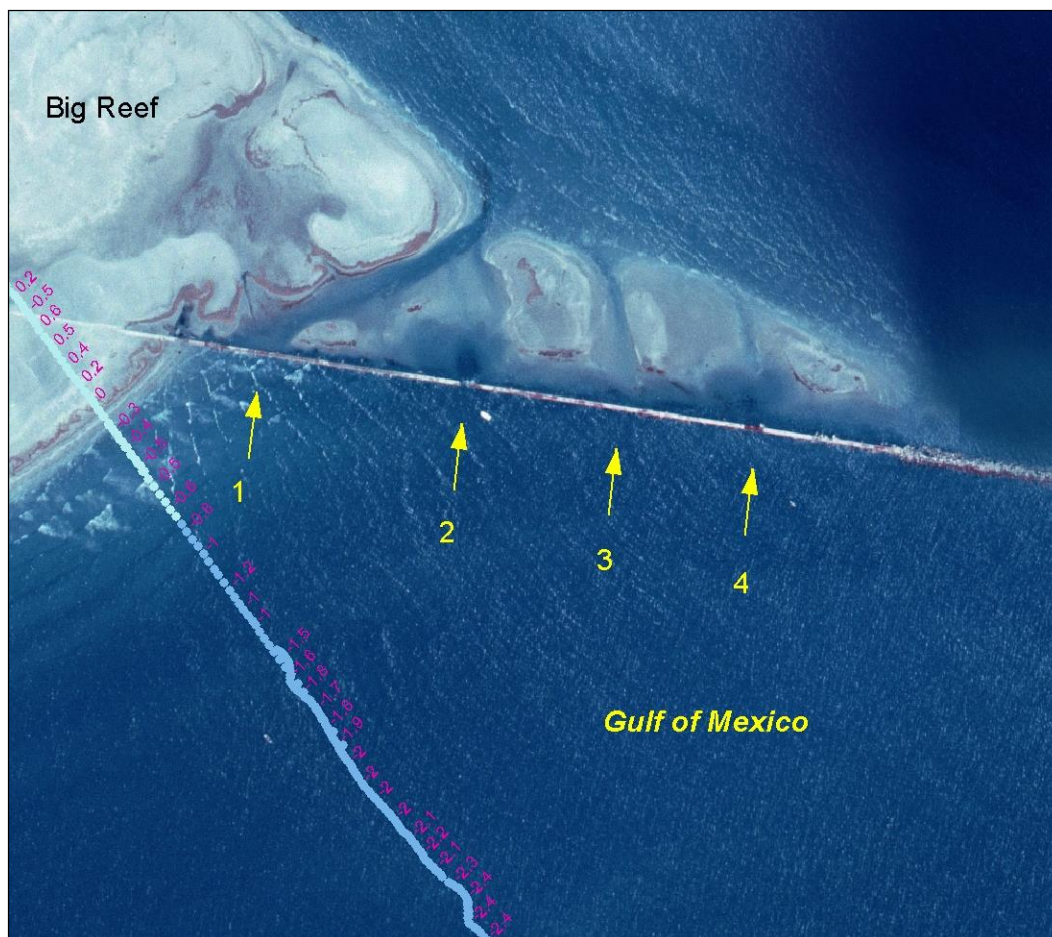
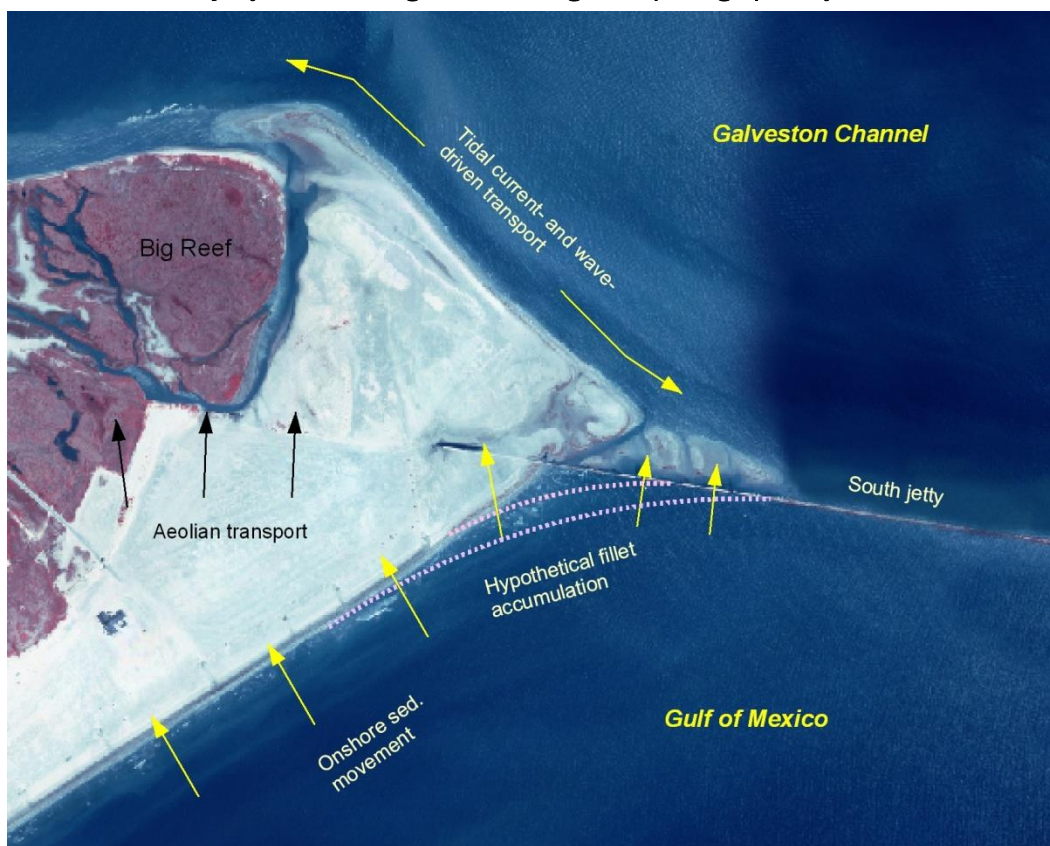


Figure 23 shows hypothetical sediment pathways through and over the south jetty. Some of the movement is probably from Aeolian transport (to be discussed below), but much of the wave and current transport probably occurs through a 500-yd section of the jetty that extends out from the current shoreline. Sealing this portion of the jetty would be difficult but might be possible using grout or by placing a cap over the structure. Another option might be to place a temporary, sand-filled geofabric groin parallel to the jetty. This geofabric groin's effectiveness could be monitored and it could be removed if ineffective.

Some of the material that moves shoreward to East Beach probably accumulates on the beach, while the rest moves via littoral currents eastward toward the jetty. A reasonable assumption is that 50 percent moves in the littoral system. Therefore, potentially, 180,000 yd³/yr might accumulate in a fillet (Figure 23). The dashed lines in the figure are hypothetical only because accumulation would vary depending on

removal. The fillet would need to be mined regularly because otherwise the sand fillet would soon reach the end of the sand-tightened portion of the structure. Thereafter, currents would move sand through the more porous jetty further seaward, negating the benefits of the sand-tightening project.

Figure 23. Hypothetical sediment pathways over and through south jetty. Arrows are symbolic and length does not represent magnitude or rate. Dotted lines show hypothetical fillet growth if the jetty were sand-tightened. Background photograph May 2006.



Big Reef contains about 9 million yd^3 of sand, according to calculations made at Texas A&M University (Timothy M. Dellapenna, Assistant Professor, Dept. of Marine Sciences, Texas A&M University at Galveston, personal communication, August 9, 2006). The feature began to develop at least before 1919, based on historical shoreline maps (USACE 1993). Nine million divided by 100 years results in a volume of about 90,000 yd^3/yr , about one half the 180,000 yd^3/yr hypothesized to move through the jetty. Considering losses into the navigation channel and occasional dredging, the growth rate of Big Reef was likely greater than 90,000 yd^3/yr .

5.5 Option 4: Reduce Aeolian sand transport

5.5.1 Background

Aeolian transport is a major factor along much of the south Texas coast. Persistent southeast winds along North Padre and Mustang Islands are a key agent in moving sand across the barrier islands. Unimpeded by vegetation, significant volumes of sand are transported toward Laguna Madre and Corpus Christi Bay and contribute to shoreline advance on the west sides of the islands (Morton and Paine 1984). At Mansfield Pass, wind-blown sediment may be responsible for about 25 percent of the channel shoaling (Nicholas C. Kraus, Engineer Research and Development Center, Vicksburg, MS, personal communication, August 17, 2006).

Anecdotal information indicates that Aeolian processes move significant sand on Galveston Island. Giardino et al. (2000) reported that when San Luis Beach, in front of the San Luis Hotel, was nourished in 1985, wind transported a significant volume over the seawall. "On numerous visits to the site, the investigators observed sand blowing from the beach and over the top of the Seawall. So much sand was deposited on the road, which occupies the top of the Seawall, that patches of sand up to 10 m² and 10 cm thick were measured on one occasion. In addition, the merchants complained regularly that the doorways of their businesses were blocked by "sand dunes." On East Beach, the Galveston Park Board sometimes has difficulty maintaining roads to the recreational facilities because of the constant blowing sand (Ray Newby, Texas General Land Office, personal communication, August 11, 2006). Along the Seawall, work crews from both the Park Board and the City collect sand that has blown onto the road and relocate it to the beach (Mario Rabago, Deputy Director, Galveston Park Board of Trustees, personal communication, October 14, 2014). Enough sand sometimes accumulated to impact drainage. USACE (1993) considered wind-blown transport to be one of factors contributing to the growth of Big Reef.

5.5.2 Aeolian transport at East Beach – Big Reef

The wind-blown sand transport from East Beach to Big Reef can be calculated using the procedure in Chapter III-4 of the *Coastal Engineering Manual* (Hsu and Weggel 2002). Based on this procedure, annual northward transport is between 10,000 and 20,000 m³ (13,000 and 26,000 yd³) (Figure 24 and Table 9).

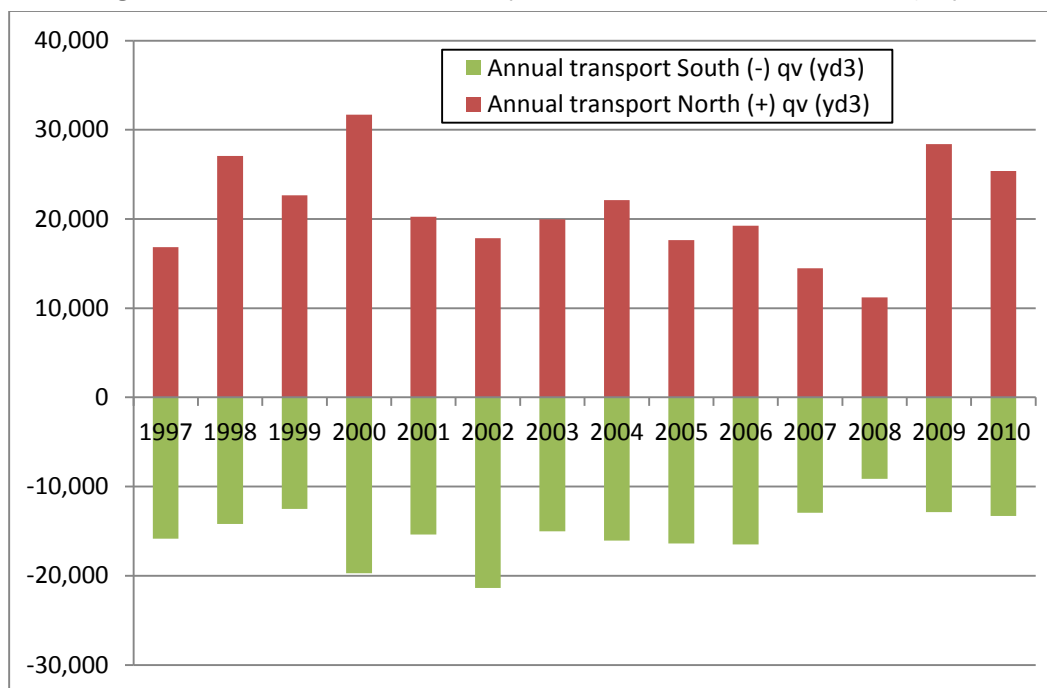
Figure 24. Annual Aeolian transport (yd³) across East Beach at the south jetty.

Table 9. Aeolian transport East Beach and Big Reef, Galveston.

Year	Annual transport North (+) q _v (m ³)	Annual transport South (-) q _v (m ³)	Annual transport North (+) q _v (yd ³)	Annual transport South (-) q _v (yd ³)
1997	12,871	-12104	16,840	-15,830
1998	20,703	-10840	27,080	-14,180
1999	17,308	-9559	22,640	-12,500
2000	24,243	-15086	31,710	-19,730
2001	15,484	-11755	20,250	-15,380
2002	13,633	-16322	17,830	-21,350
2003	15,278	-11485	19,980	-15,020
2004	16,903	-12265	22,110	-16,040
2005	13,473	-12506	17,620	-16,360
2006	14,702	-12589	19,230	-16,470
2007	11,068	-9901	14,480	-12,950
2008	8,565	-6986	11,200	-9,140
2009	21,699	-9825	28,380	-12,850
2010	19,403	-10159	25,380	-13,290
Sum:	225,334	-161,383	294,730	-211,090

The computation procedure is lengthy and is described in Appendix D. Wind measurements were based on the NOAA instrument at Pleasure Pier (Sta. 8771510) for the period 1997 to 2010. NOAA discontinued wind measurements there in 2011, so to extend the analysis for later years, data from another site would be needed. The next most appropriate station would be Galveston Bay Entrance North Jetty (Sta. 8771341). Rainfall and pan evaporation data were from the Beaumont Research Center, the closest site to Galveston with evaporation measurements. Spot comparison with Galveston rainfall shows that the rain climate at Beaumont is similar. Beaumont data was used exclusively rather than mixing Beaumont evaporation with Galveston rainfall because there are differences in local cloud cover, wind, and rainfall.

The results are realistic on a month-to-month basis. During the fall, winter, and spring, the strongest winds usually occur when a cold front crosses the coast. During the pre-frontal period, winds blow from the southeast, moving sand over East Beach and north to Big Reef. As the front passes, the winds switch abruptly to the north, often accompanied by rain. The rain typically only lasts for a day or two, but strong winds persist for days, slowly turning from north to northeast and finally to the east. As a result of these frontal passages, during many years, the greatest Aeolian transport to the south was during October, and December, and January (Figure 25, Figure 26; figures are in their original metric units). The fronts diminish in strength by March or April because the Gulf of Mexico's water has cooled and there is less energy transfer between the atmosphere and the surface waters. By late spring, persistent southerly winds transport sand north onto Big Reef, and summer transport is predominantly to the north (Figure 27).

These calculations lead to several conclusions. First, the approximate balance between northward and southward transport is surprising. This suggests that the growth of Big Reef over time has been largely due to water-borne sand carried through the jetty, with wind-blown as a lesser contributing factor. Certainly, some of the wind-blown sand that moves south will fall into the Gulf, where currents will move it northeast and through the jetty. But, this gain may be balanced by the loss of northerly-blown sand, which falls into the Galveston channel and is carried away by tidal currents.

In light of the anecdotal evidence that blowing sand can be a major factor on Galveston Island, the magnitude of Aeolian transport is less than expected. There are no obvious factors to change the magnitude of the analyses. The computation provides an hourly transport in units of $\text{m}^3/\text{m-hr}$. This value is multiplied by 720 m, the length of the south jetty that crosses open sand (Figure 28). Much more open (non-vegetated) beach exists southwest of the jetty, so it might be valid to use a larger multiplier, possibly 1000 m. Also, the sand diameter used in this analysis was 0.116 mm. This was based on an average of six samples collected at beach profiles. The sand on the open beach may be finer, which would result in greater transport. Nevertheless, increasing the length multiplier and decreasing grain size might double the transport, but not cause a magnitude change. In the NOAA data, some days had missing wind data, but these were not common enough to make a major change in volumes.

Annual Aeolian transport northward ($\approx 21,000 \text{ yd}^3$) is approximately half the annual littoral drift value of $41,000 \text{ yd}^3/\text{yr}$ computed in the sediment budget, but much less than the predicted onshore transport of $360,000 \text{ yd}^3/\text{yr}$. With Big Reef containing around 9 million yd^3 of sand, it would have taken almost 400 years to develop if supplied only by wind-blown sand. Therefore, water-borne supply must have been the prime source of sand for the growth of Big Reef.

Figure 25. 2000 Aeolian sand transport across 720-m south jetty crossing bare beach (m^3/month ; northerly transport is positive +; note: metric units as per original calculation units)

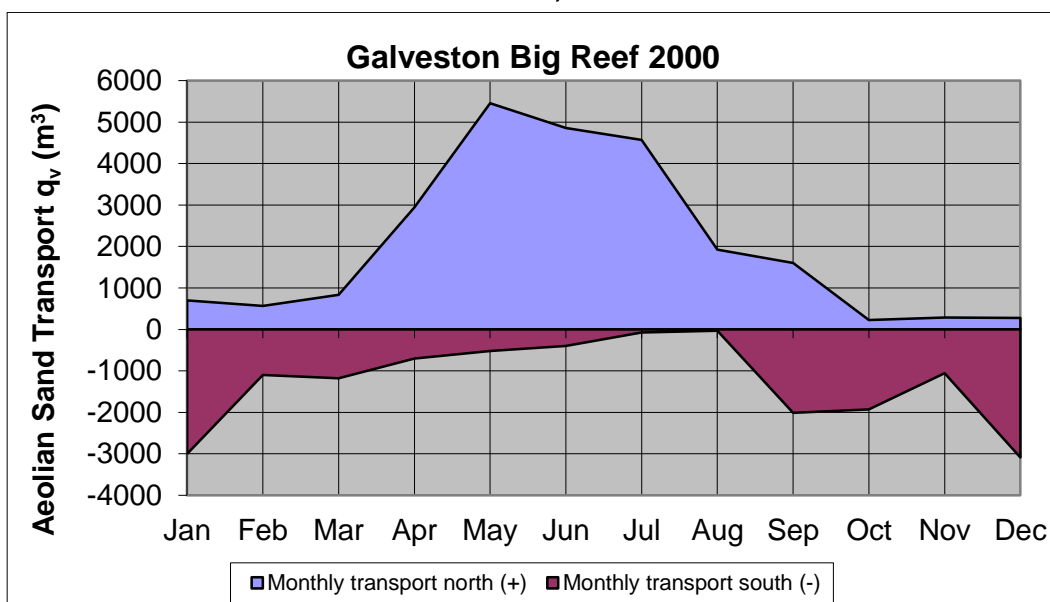


Figure 26. 2010 Aeolian sand transport showing the characteristic summer-winter pattern (m^3/month ; northerly transport is positive +).

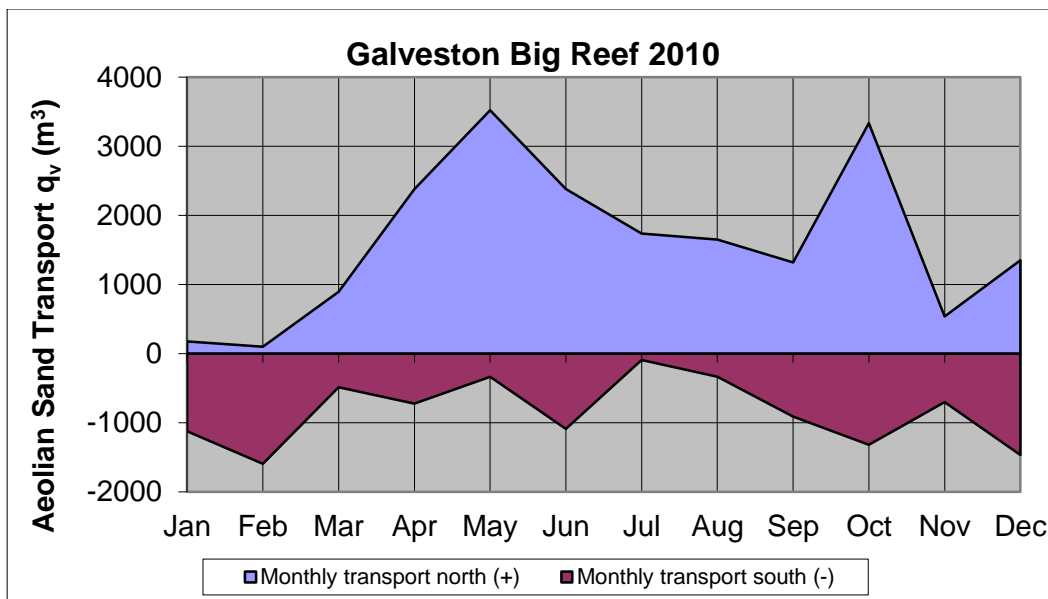


Figure 27. During summer months, the dominant sand transport is to the north (positive values). June 2000 is shown as an example.

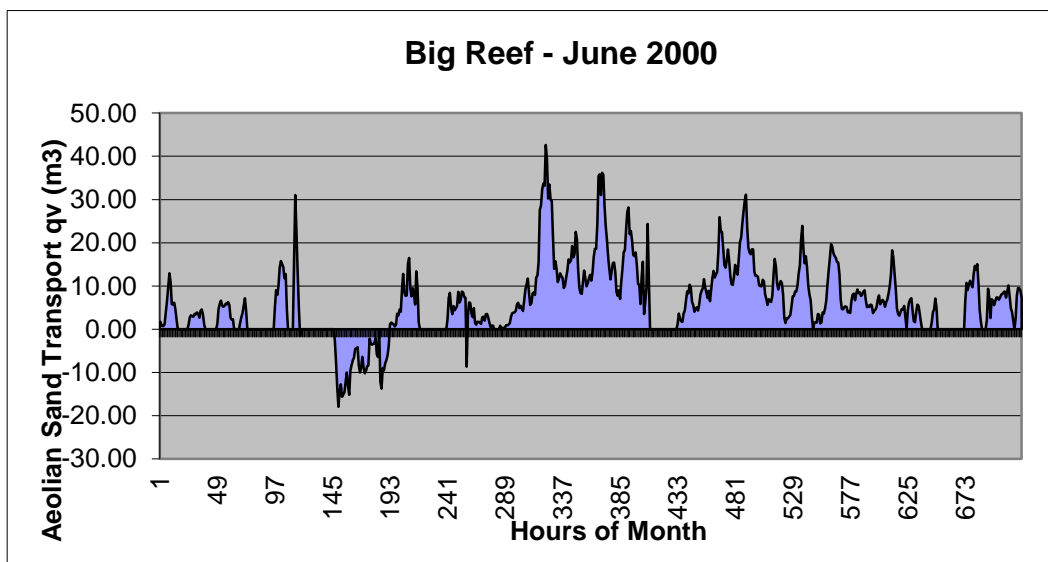


Figure 28. Jetty segment used for computation of Aeolian sand transport. Background photograph May 22, 2012.



5.5.3 Alternatives

Aeolian transport can be reduced by three practices:

1. Moisture
2. Install mechanical sand traps such as sand fences to build dunes
3. Vegetation (both on dunes and flats)

The first option is commonly used in the mining industry to control dust and sand. It would probably be impractical to set up watering systems on East Beach, although seawater is readily available. The San Jacinto Placement Area west of East Lagoon was formerly marshy, but now is used by the USACE to dispose of sand from the USACE and Coast Guard docks

and other areas. In the 2012 aerial photographs, at least 80 percent of the area within the levees was unvegetated. The vegetation grows naturally, but for weeks or months, fine sand and silt is mobile. A watering system could probably reduce wind transport until the vegetation becomes established.

A second option would be to encourage dune construction by installing sand fencing. Once new dunes formed, they would have to be vegetated to reduce their mobility. It is difficult to find quantitative data on dune growth. Woodhouse (1978) described 20 years of dune experimentation in coastal areas from the mouth of the Columbia River in Oregon through southern California and the Gulf of Mexico to Cape Cod, Massachusetts, and Brampton et al. (2000) describe techniques used in Scotland. Hsu and Weggel (2002; Table III-4-13) reproduced some measured dune growth rates from experiments conducted in the 1960s by the Coastal Engineering Research Center (original citation not listed, but possibly Woodhouse (1978)). For tests at Padre Island, Texas, the annual rate of sand volume accumulation was in the range of 3.0 to 3.7 yd³/ft (Table 10). These results can be extrapolated to East Beach by drawing hypothetical sand fences across the open areas of East beach and multiplying the length of the fencing by the growth rate. Padre Island is a windier location than Galveston, so it is appropriate to use the lower volume (3.0 yd³/ft/year). The results are surprising; just placing fences on the bare areas shown in Figure 29, a length of 13,000 ft, might annually trap 39,000 yd³ of sand.

Table 10. Measured dune growth rates at Padre Island, TX.

Type	Wood fencing (3 fences, 3 lifts)	Wood fencing (4 fences, 3 lifts)	Sea oats
Average rate (m ³ /m-year)	8.7	7.61	9.2
Average rate (yd ³ /ft-year)	3.5	3.04	3.67
Source: Excerpt from <i>Coastal Engineering Manual</i> Table III-4-13 (Hsu and Weggel 2002).			
Original measurements: 1960s experiments conducted by Coastal Engineering Research Center (citation unavailable)			

A third option to reduce wind-blown sand would be to plant the bare portions of East Beach and improve the vegetation over the areas that now have grass and other plants. It is unclear how the 1960s experiments were

conducted, but if sea oats were planted in rows on East Beach similar to the sand fencing, then the trapping rate for 13,000 ft of oats might be about 47,000 yd³ in a year.

The San Jacinto placement area is also bare after dredge material has been impounded and the material has dewatering. The bare zones grow vegetation quickly (Tricia Campbell, Operations Manager, SWG, personal communication, 8 May 2014), but temporary fencing or seeding might be worthwhile to reduce wind-blown transport.

In summary, a program for installing sand fencing and planting extra vegetation on East Beach might trap 39,000 - 47,000+ yd³/yr. This alternative is a relatively low cost way to trap sand in a sand management program. In addition, fencing could also be placed in the San Jacinto placement area if needed.

Figure 29. Purple lines are hypothetical sand fences drawn over bare areas for calculating potential dune formation. Length of sand fences approx. 6,700 m (22,000 ft). Background photograph May 22, 2012.



5.6 Option 5: Sand backpass system

Sand backpassing is the process of mechanically moving sand away from an inlet or harbor mouth back some distance to the updrift beaches. In the case of Galveston entrance, backpassing would entail mechanically moving sand from East Beach to the west to the beaches in front of the seawall (Figure 30). As demonstrated in the sediment budget, much of the sand accumulating at East Beach has an offshore source. Therefore, a pumping plant would not only be backpassing sand but would also be adding new material not previously in the littoral zone. The purpose of a backpassing system would be to:

1. Intercept sand before it accumulates on East Beach and/or passes through the south jetty.
2. Move sand west along the Galveston seawall without the use of trucks.

The concept of a mechanical backpassing system is simple:

1. A fixed or semi-movable pumping/dredging plant is located in the region where significant sand accumulates. The material is entrained into a pipeline.
2. A pipeline runs along the beach to a discharge location where the sand is needed.
3. Booster pumps are located along the pipeline as needed, depending on the distance of transport.
4. Discharge is made on the beach in one or several locations.

Most research on artificial sand movement at inlets has been on bypass systems (Clausner 1999; Boswood and Murray, 2001; Per Bruun 2005), but the concepts are applicable to backpassing. Backpassing has been performed at Miami Beach and St. Augustine Inlet, FL, Cape May, North Wildwood, and Avalon, NJ, Ocean Beach (San Francisco), CA, and Corpus Christi Beach, TX. BMT (2010) examined the feasibility of backpassing at the Tweed River entrance, Australia.

Another study will be needed to design the specifics of a backpassing system. The Galveston Park Board, in conjunction with the SWG and state agencies, would have to decide what volume of sand to backpass annually and the total distance. The system could target 50,000, 100,000 or more yd³ per year. Then the mechanics of pipe diameter and pump capacity would be engineered. The intake plant could be a fixed unit (as at South Lake Worth Inlet, FL) or a jetpump mounted on a tracked crane, as at

Indian River Inlet, DE (Figure 31). Bypassing plants can be a viable option instead of periodic dredging (Melton and Clausner 2004). One intriguing option for the intake is to use a remote-controlled jetpump such as the Punaise (Williams and Visser, 1997). As another option, a small dedicated dredge could be purchased, similar to units used at Rudee Inlet, VA, or Mexico Beach, FL. These are operated by municipal employees year-round.

Figure 30. Proposed backpassing system with multiple outlets along west portion of seawall.

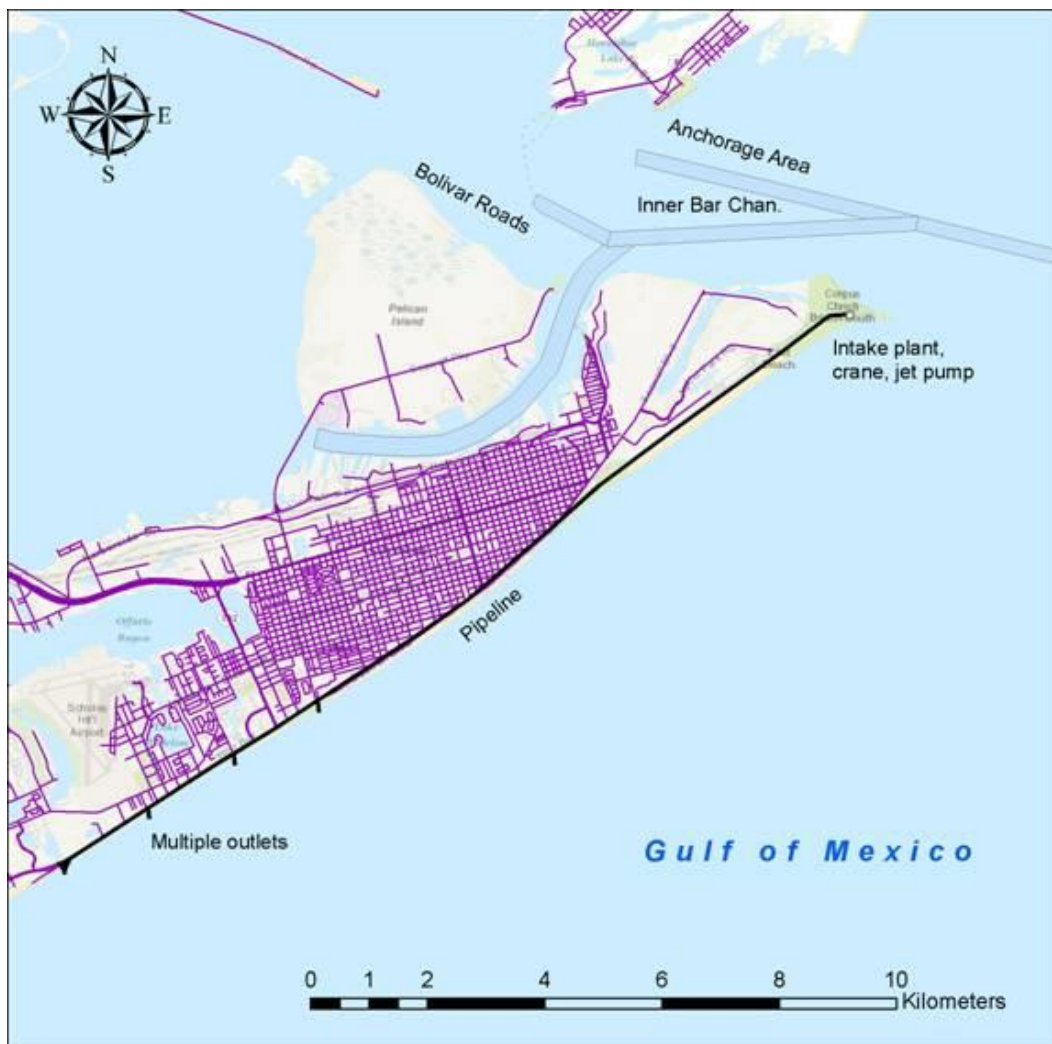


Figure 31. Mobile backpassing system used at Indian River Inlet, DE (photograph from from USACE Philadelphia District. Here, the pipe crosses the inlet via the highway bridge.



Galveston would be an excellent location for a backpass system because the pipeline does not need to cross a waterway. The pipe could be located at the base of the seawall and buried under a dune for aesthetic considerations. The location would allow for relatively easy construction and maintenance with truck-operated equipment from Seawall Boulevard above. Another design consideration is the ability to rotate the pipe to prevent the bottom from wearing out due to sand friction. Several outlets could be installed in the pipeline to allow nourishing different parts of the beach on a scheduled basis or as needed if hot spots develop. The outlets need to be located along the west half of the seawall to minimize sand returning towards East Beach. If booster pumps are needed, they could be disguised in buildings made to be aesthetically pleasing. Electric booster pumps have a low noise output compared to diesel. Table 11 lists advantages and disadvantages of various options for a backpassing system.

Table 11. Sand backpassing system, Galveston, Texas.

Feature	Advantages	Disadvantages
Intake at East Beach	Max. sediment input, far from most tourist activity, limited visual impact.	Possible objection from fishermen and beach drivers.
Crane-based intake	Flexible, can be moved when pit forms. Familiar equipment; can be operated by municipal employees.	Maintenance (corrosion issues), staff needed, must be moved before storms.
Fixed intake on jetty	Reinforced for storm protection	Initial construction costs. May not be optimum location if fillet changes. Must be removed if backpassing is discontinued.
Jet pump or Punaise intake	Submerged, minimal visual impact	Must be manually relocated when/if needed. Electric power supply needed. Initial purchase cost.
Pipeline crossing East Beach		Need crossovers for beach traffic. Possible visual objections unless buried.
Pipeline along Seawall Blvd.	Simple construction and access for maintenance. Ability to rotate pipe.	Visual objections.
Pipeline along base of seawall	Largely out of sight, can be buried with sand dune	Possible damage in exceptional storms. Maintenance more difficult.
Multiple outlets	Can adjust nourishment as needed along beach	
Booster pumps (if needed)		Noise, visual issues, diesel fumes, maintenance costs

6 San Luis Pass Sand Management Options

Much of west Galveston Island is experiencing erosion, but the western tip of the island, near San Luis Pass, is experiencing accretion. Net longshore transport is to the southwest along this section of coast, so sediment placed on west Galveston Island beaches will eventually end up in the unstructured San Luis Pass if not interrupted. This section addresses the location for a sediment trap and the rate of sediment delivery.

San Luis Pass is located at the southwest end of Galveston Island. Figure 1 shows the location of the natural pass that opens into West Bay. There is a small crescent shaped ebb shoal, with several channels. The pass is dominated by an extensive flood shoal complex in West Bay (Figure 14). The inlet has been in its present position since at least 1852 and has no jetty structures for navigation purposes. The channel(s) have changed orientation and position over time at this mixed energy inlet (a mix of both wave-dominated and tide-dominated conditions throughout the year). From 1930 to 1961, a single channel migrated to the south. After 1973, the channel migrated northward until 1990, and since 1990, multiple channels have been present in the central location of the pass (Gibeaut et al. 2003).

In the larger regional sediment management picture, the flood shoal at San Luis Pass is a large sink supplied by sand from the open coast. This material is essentially lost from the littoral system due to concerns about dredging in this sensitive environment; however, in recent years the GLO has begun investigating the feasibility of using sediments from San Luis Pass. Morang (2006) and Coast & Harbor Engineering (2007), using different methods, concluded that the San Luis Pass flood delta is accreting at a rate of $\sim 100,000 \text{ yd}^3/\text{yr}$. Coastal & Harbor Engineering (2007) concluded that the grain material is close to 100 percent sand. Because no sand enters West Bay from rivers, the growth of the flood shoal must be fed by sand entering from the Gulf of Mexico via tidal currents (Atkins Global 2012).

6.1 Install groin to reduce west-moving littoral transport

Because net littoral sand movement at the west end of Galveston Island is to the southwest, one option for obtaining beach-quality sand would be to install a groin perpendicular to the shore to trap the littoral material and regularly mine the resulting fillet. A groin placed near San Luis Pass could

potentially block a significant portion of the net transport (Q_{LST}) of 250,000 yd³/yr (see Cells1_10 in Figure 14). Again, two assumptions need to be made:

1. If we assume that the bulk of the transport occurs in less than 2 m (6 ft) water depth, a groin would need to be about 500 ft long on this flat sloping shoreface.
2. A reasonable estimate of the efficiency of the groin is that 50 percent of the littoral material might be trapped, or about 130,000 yd³/yr.

Trapping some of the sediment that normally would move toward the pass would potentially reduce accumulation on the ebb shoal, in the natural channel, and on the flood shoal. This groin may be permeable to allow some passage of sediment so the impact on the pass shoreline and ebb and flood shoals would be controlled. The exact location and porosity of this jetty would need further design work, but a tentative location would be near the boundary of Cells1_10 and Cells1_9.

As the new fillet filled, it would need to be dredged on a regular cycle. The sand could be carried east by barge to use as beach fill. The fillet could also be excavated by backhoe and the sand carried by truck

6.2 Install fixed or mobile backpassing plant

Similar to the concept of the backpassing plant proposed for East Beach, two options could be used at a fillet created by a groin. First, a fixed backpassing pump system could be installed on the groin. Second, a semi-mobile crane-based pump could be deployed on the fillet beach, similar to the unit used at Indian River Inlet, DE.

Depending on the distance to the east that the sand is to be pumped, booster pumps will need to be considered in the engineering design. For example, the distance from the proposed groin location to Jamaica Beach is 9.7 miles, much further than sand is usually pumped in beach nourishment projects. This option may not be feasible because of construction and pumping costs.

6.3 Dredge an offshore deposition basin

Similar to the offshore deposition proposed for the East Beach area, a basin could be dredged near the west end of the island. The sand from the

initial construction could be used as beach fill in other locations, and the periodic re-dredging would provide a regular source of additional sand. The exact size and location of a basin would need to be based on numerical modeling. A basin could be combined with a shore-perpendicular groin (section 6.1 above) to provide extra trapping capacity.

7 Proposed Large-scale Beach along Seawall

This section describes one possible design for a grand wide beach along the entire seawall. One of the goals of the Galveston Park Board is to construct an attractive beach to serve multiple purposes:

- Enhance recreation opportunities;
- Protect the base of the seawall and provide storm damage reduction;
- Protect the west end of the seawall and mitigate the erosion of the present beach.
- Reduce the need for irregular and disruptive emergency beach fills using trucks.

This proposed beach includes the Board's Reaches 1, 2, and part of 3. An important feature is it continues west beyond the end of the present seawall, thereby eliminating the erosion hot spot at the right angle bend. The proposed beach then continues smoothly towards San Luis Pass.

7.1 General information

Beach fill design is usually based on a planned (or desired) template and advance fill. The *planned template* includes features such as dunes, beach height (above a water level datum) and dry beach width. *Advance fill* is the amount of extra fill that is installed such as beach erosion will only remove this additional material until the next planned renourishment. The amount of advance fill must be determined with numerical models, wave data, and budget considerations. For example, if the renourishment cycle is 5 years, and the beach is expected to retreat X ft/year, then the advance fill must be adequate to build the beach out an additional $5X$ ft beyond the planned template. *Coastal Engineering Manual*, Chapter VI-4, provides details on of beach fill design (Gravens et al. 2008).

Sand for initial construction could come from a combination of:

- Offshore sand sources;

- Maintenance dredging of the Galveston navigation channels;
- The offshore (northern) portion of Big Reef;
- Possibly the USACE offshore disposal area.

Establishing design parameters for a borrow area include numerous factors that must be considered:

- Type of site (*i.e.*, offshore, navigation channel dredging)
- Distance from project
- Accessibility
- Morphology and stratigraphy
- Sediment composition: grain size, material, sorting, percent fines
- Costs of mobilization/demobilization, extraction, transport, placement
- Borrow sand consistency and volume
- Environmental factors:
 - impact on habitat
 - threatened and endangered species
 - water quality
 - turbidity/suspended sediments
 - archeological sites

Hydrodynamic design parameters include:

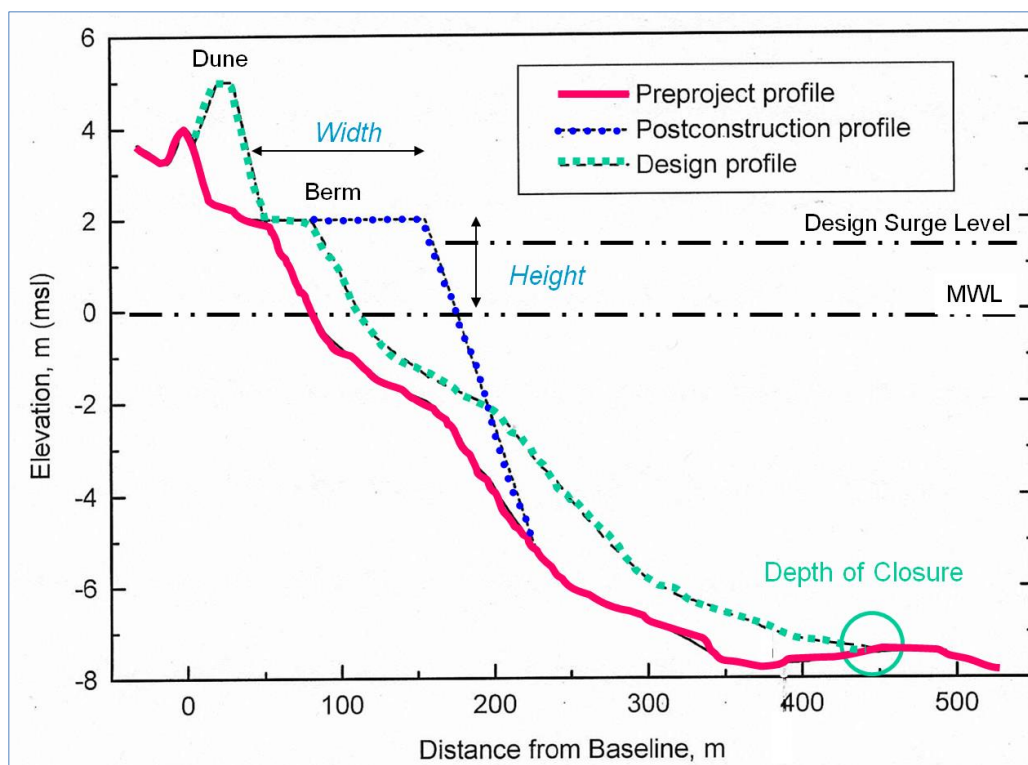
- Wave climate

- Tide (non-storm) water level range
- Storm surges
- Tropical and extra-tropical storms (intensity, duration, frequency, seasonal and annual trends)
- Currents, winds, drainage
- Design level of protection (*i.e.*, 100-year storm)

Public education is critical before a beach construction project. First, the public must understand that there will be equipment on the beach along with noise, fumes, and restricted access. Second, the beach will adjust and become narrower after construction. During placement, sand is usually pumped onto the upper shoreface, forming a wide beach (blue post-construction line in Figure 32). Bulldozers move the sand and build the dunes and other features specified in the plan. Over time, the sand is distributed by wave action across the shoreface, and the upper beach becomes narrower (green line). The public must be informed that the sand has not been “lost” but rather has been redistributed to conform to the natural shoreface profile in this region. The sand on the profile will protect the new subaerial beach.

Another factor to consider is construction schedule. On one hand, mobilization and demobilization costs are expensive. Additionally, if the project is divided into short sections, the short beaches are subject to end losses. Each successive stage expends considerable effort and cost replacing sand lost during the previous winter. End losses (or beach half-life) can be calculated by a procedure in the *Coastal Engineering Manual* Part V-4 (Gravens et al. 2008). However, this large-scale beach fill would extend almost 20 miles. In this case, the advantages of a slow, incremental approach would outweigh the cheaper cost of constructing the project at one time. Constructing the beach fill incrementally and modifying the design, if necessary, would result in a better beach fill. Finally, the large-scale beach fill would likely take over a year to build due to the amount of sand and environmental windows, which could require construction interruptions.

Figure 32. Example of post-construction template versus intended design profile.



7.2 Proposed beach

The proposed all-island beach includes the following characteristics:

- Length: 24.3 mi. This would extend from approximately 11th or 12th Streets to near San Luis Pass (Figure 33 and Figure 34). Because it will extend along the entire island, and specifically beyond the west end of the seawall, the intent is to eliminate the end effects that plague the present beach west of 103rd Street.
- Depth of closure: 20 ft. The active depth is not well determined for Galveston. King (2007) used 6.0 m (19.7 ft) for his GENESIS modeling. Brown and Kraus (1994) used 15 ft, while Howard (1999) used 4 m (13.1 ft). Wallace et al. (2010), looking at a geological perspective, concluded that 8 m (26 ft) was more suitable to include the total region over which active sand movement occurred. The most suitable way to determine the depth in a study area is to compare repetitive cross shore profiles collected at the same zero origin (Morang and Birkemeier 2005), but such a time-sequence of profiles are not available along Galveston Island. For this study, the depth of 20 ft was used to match the previous GENESIS numerical modeling and GenCade modeling presented here.

- Berm elevation is 4.0 ft NAVD88 based on the 2002 profiles (Table 12).

Table 12. Berm elevation

Sed. Budget Cell	2002 Profile	Berm elev. (ft. NAVD88)
1_5 (East Beach)	52, 55, 56, 57	4
1_6 (Seawall)		none
1_7	35	2
1_8		none
1_9	04, 05	4
1_10 (San Luis Pass)	02, 03	4

- Width (as requested by Park Board, but can be adjusted depending on sediment availability, features desired, and budget):
 - Option 1: Dune: 100 ft and berm/beach: 200 ft with berm at approx. 4 ft NAVD88 elevation.
 - Option 2: Same as above for the non-seawall portions of the island; no dune along the seawall and berm/beach: 200 ft wide.

Figure 35 shows the shape of the template for Option 1 (note vertical exaggeration). At the seawall (upper panel) the dune crest is 40 ft at an elevation of 14 ft, approximately level with the top of the seawall. The front of the dune has a slope of 1:3, dropping down 10 ft to a 50-ft berm at 4 ft elevation. Then the beach foreshore slopes down to the water at an angle of 1.5° . The total beach width is 270 ft.

Option 2 is simpler along the seawall, and consists of a flat berm 50 ft wide. Then the beach foreshore slopes down to the water at an angle of only 1.5° .

The template at the western beaches is essentially the same as Option 1 except that the dune needs a rear slope. At the same 1:3 slope, this adds 30 ft to the template, for a total beach width of 300 ft (lower panel).

The volume of sand needed to build the template was computed at each cross-shore profile by superimposing the template and moving the existing profile seaward an appropriate amount to match the toe of the template at the 270 or 300 ft distance (Figure 36 and Figure 37). Sand volumes were

computed using BMAP software (Sommerfeld et al. 1994) in the synthetic profiles, beach fill module.

In Reaches 3, 4, and 5, the design was based on an average profile derived from the cross-shore profiles within the reach. Note that along the seawall, the proposed beach fill begins at the structure. But further west, there is no obvious baseline. The analysis in this section is based on the 2002 Texas A&M profiles, which usually started at the seaward crest of the dune. The volume of sand needed for a proposed beach will vary depending on where the new dune is built, in other words, what zero position is selected. Sand needed for each reach (without overfill – see Tables E1 and E2):

- Reach 1 (seawall east)
 - Option 1: 1,942,000 yd³
 - Option 2: 560,000 yd³
- Reach 2 (seawall west)
 - Option 1: 3,654,000 yd³
 - Option 2: 2,132,000 yd³
- Reach 3: 2,519,000 yd³
- Reach 4: 4,408,000 yd³
- Reach 5: 472,000 yd³

Figure 38 shows the fill in the western-most part of Galveston Island, Reach 5. Here, only a dune would be needed because significant sand already exists on the shoreface.

As described above, the amount of overfill will have to be determined based on the intended interval to renourish. If including a 50 percent overfill, the total volume for Option 1 is 19,500,000 yd³, while Option 2 is 15,000,000 yd³. This overfill is an estimate only. Unlike typical open coast beaches, the seawall has modified the nearshore environment, and the

beach retreat rates from BEG may not reflect the retreat that would occur at a true sandy shore.

A post-construction monitoring program will be necessary to monitor fill stability, measure retreat, and check for hot spots (if any develop). Another factor to consider is that unusually severe tropical storms could cause major erosion. A contingency nourishment plan would need to be in place to repair the beach rapidly.

Figure 33. Proposed comprehensive beach fill from East beach to San Luis Pass.



Figure 34. East end of fill begins at approx. 11th Street, to taper into East Beach.

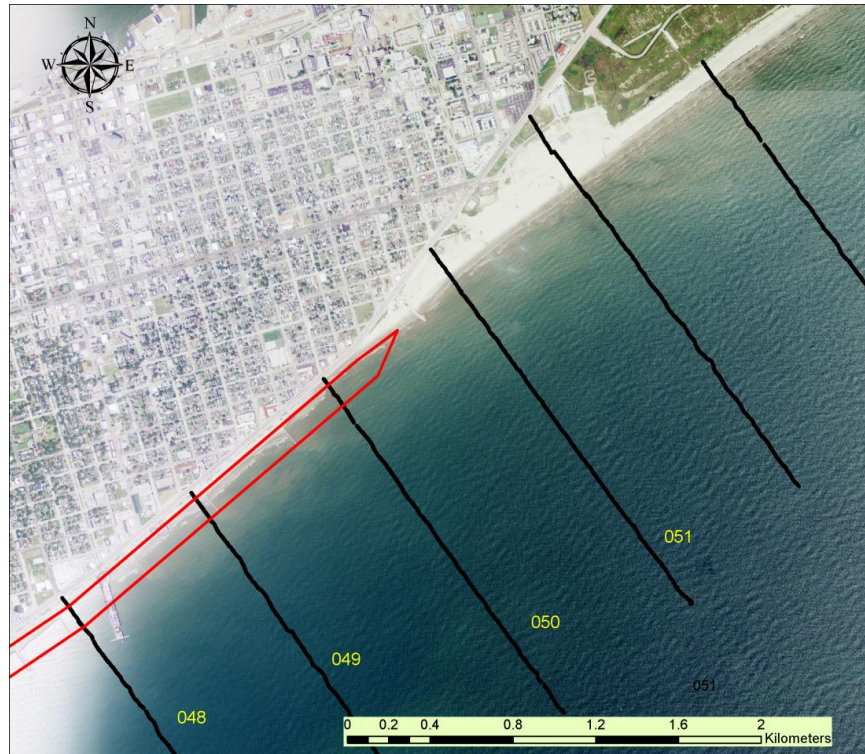


Figure 35. Template at Seawall for Option 1 (upper panel) and along western beaches (lower panel).

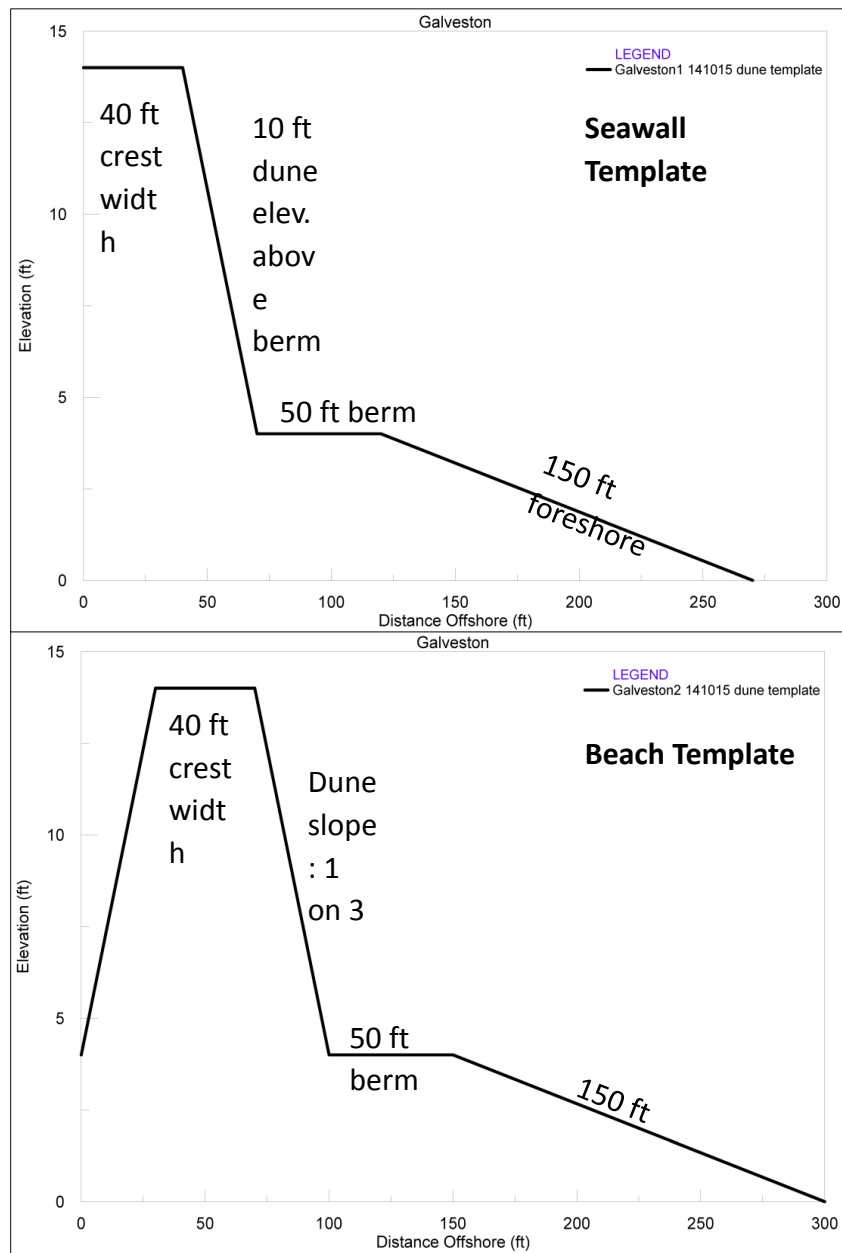


Figure 36. Proposed Option 1 template along seawall at Profile 050. Red shows above-water fill extending to approximately the elevation of the present seawall. Blue shows the translated underwater seabed. Active depth = -20 ft. NAVD88.

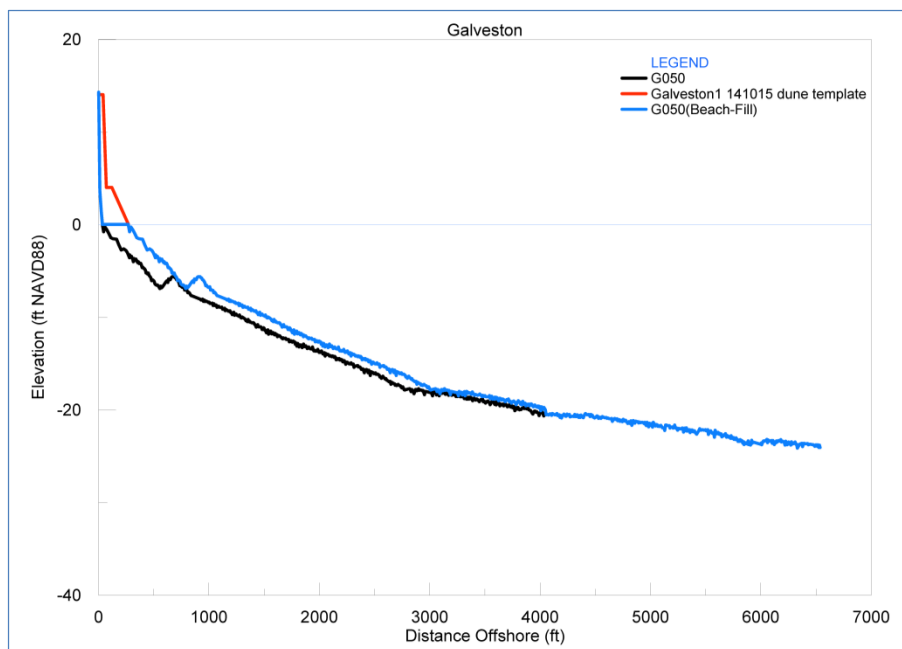


Figure 37. Proposed template along beach west of the west end of the present seawall, based on Profile G036 (full profile not shown).

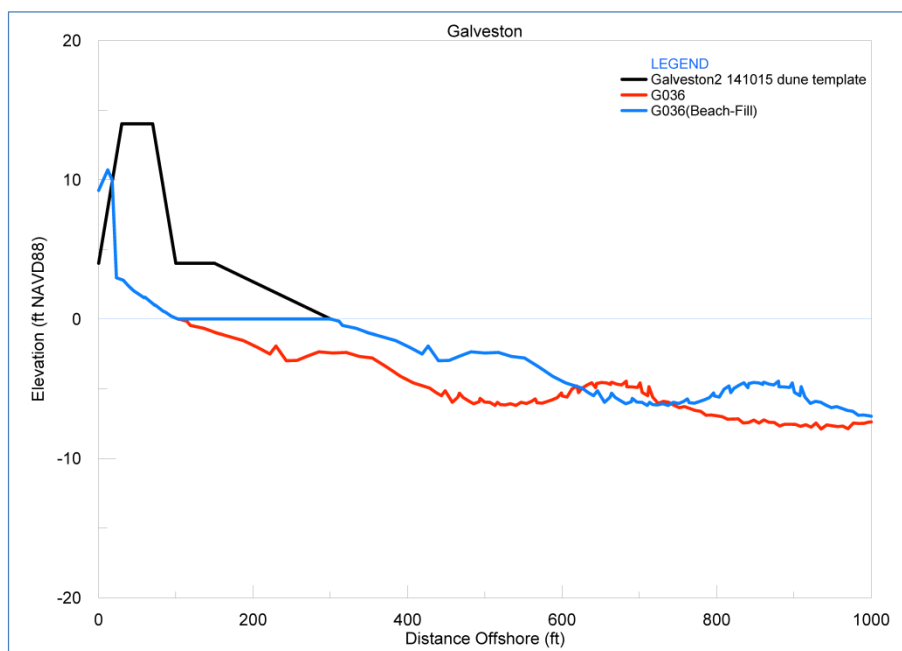
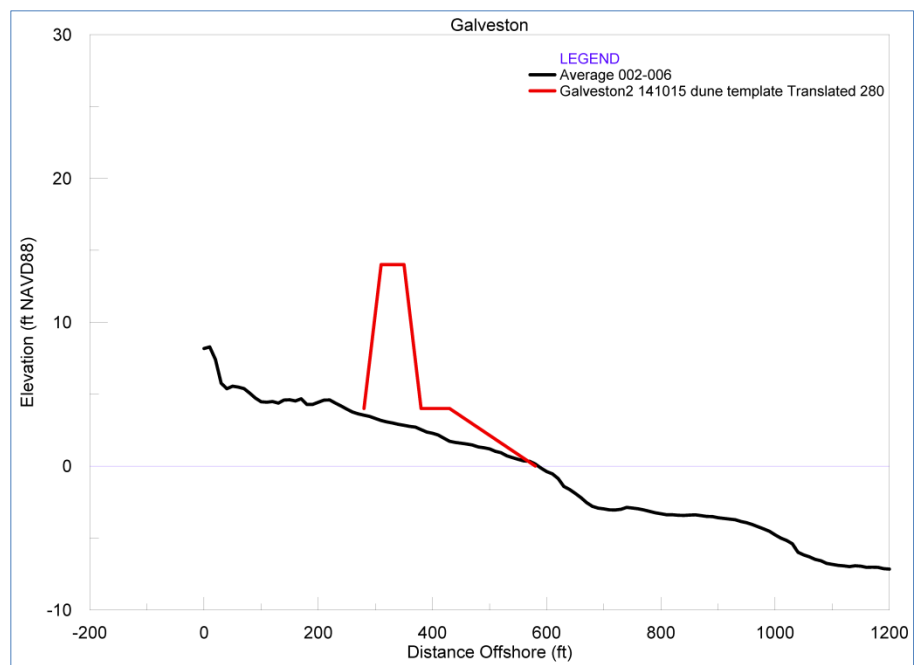


Figure 38. Example of dune constructed in Reach 5. No offshore fill would be needed.



8 GenCade Alternatives

A variety of alternatives were conducted with GenCade (Table 13). In addition to “No Action” cases, structural alternatives, beach fills, and backpassing were modeled. One of the beach fill options was a placement of 250K cu yd every other year. Based on Table 13, this option was modeled with different source terms, with groin modifications, and with the placement along Reach 1 only and along Reaches 1 and 2.

Table 13. List of Alternatives.

	Source Term = 0K cu yd/yr	Source Term = 180K cu yd/yr	Source Term = 356K cu yd/yr	Reach 1	Reach 1 and Reach 2	Galveston Park Board properties (along Reach 3)	Reach 3 (First 1.5 miles)	Reach 3	Reach 3 and Reach 4	Groin Modifications	Large-Scale Beach Fill
No Action	X	X	X								
Structural Alternatives											
Groin Modifications		X									
Sand Tighten Jetty		X	X								
Beach Fills - Seawall Grid											
125k cu yd/yr		X		X							
100K cu yd/5 yr		X		X							
250K cu yd/2 yr	X	X	X	X	X					X	
500K cu yd/2 yr		X		X	X						
1M cu yd/2 yr		X		X	X					X	
500K cu yd/5 yr		X		X	X						
1M cu yd/5 yr		X			X						
2M cu yd/5 yr		X		X	X						
Large-scale beach fill				X	X						
Backpassing - Seawall Grid											
100K cu yd/yr		X	X	X	X						X
250K cu yd/yr		X	X	X	X						
356K cu yd/yr		X	X	X	X						

Beach Fills - West End												
5K cu yd/yr						X						
5K cu yd/2 yr						X						
5K cu yd/5 yr						X						
5K cu yd/10 yr						X						
10K cu yd/2 yr						X						
10K cu yd/5 yr						X						
20K cu yd/yr						X						
20K cu yd/2 yr						X						
20K cu yd/5 yr						X						
20K cu yd/10 yr						X						
50K cu yd/yr							X	X				
50K cu yd/2 yr							X	X				
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250K cu yd/2 yr									X			
250K cu yd/5 yr									X			
250K cu yd/10 yr									X			
1M cu yd/2 yr									X			
1M cu yd/5 yr									X			
1M cu yd/10 yr									X			
Large-scale beach fill												
Backpassing - West End												
50K cu yd/yr							X	X				X
150K cu yd/yr									X			X
200K cu yd/yr							X	X				X
300K cu yd/yr									X			X

First, a “No Action” case was run for the 50 year time period to determine what would happen to the Galveston shoreline if no additional beach fills were added. In the GenCade calibration, a source term of 355,700 yd³/yr was added to the shoreline near the jetty to account for the increase in sand northeast of the 10th St. groin. Since it is unknown whether or not this rate of sand moving onshore will remain the same or decrease, rates of 0, 180, and 356K yd³/yr were simulated to illustrate how much the rate of sand coming onshore affects the shoreline of Galveston Island.

Figure 39 and Figure 40 compare the shoreline change along the seawall after 10 and 50 years, respectively, with different source terms. After 10 years, when a source term of 356K yd³/yr is added, the shoreline advances up to 225 ft in some areas northeast of the first groin. When no source term is added, the shoreline is predicted to retreat up 90 ft. After 50 years, different source terms greatly affect the final shoreline. When 356K yd³/yr is added, the shoreline advances nearly 1,000 ft, but no addition of sand results in up to 300 ft of retreat. After 50 years, the difference in shoreline reaches about 3.5 mi from the jetty, near the location of the first groin. It is important to keep in mind that the rate of sand moving onshore will greatly impacts the shoreline up to the first groin. The amount of sand available in this region of Galveston Island (previously identified as Reach 6) will dictate which of the backpassing options are available. Unless otherwise specified, all figures showing shoreline change along the seawall grid was modeled with 180K yd³ of material moving onshore near the jetty. Since it is not well known how much material, if any, will continue moving back onshore in the future, it is recommended that a sand study take place before proceeding with any alternatives listed in this chapter. Along the seawall, total shoreline change is less than 50 ft in 50 years; however, the seawall restricts the shoreline from eroding much further.

Figure 39. Total shoreline change along seawall after 10 years.

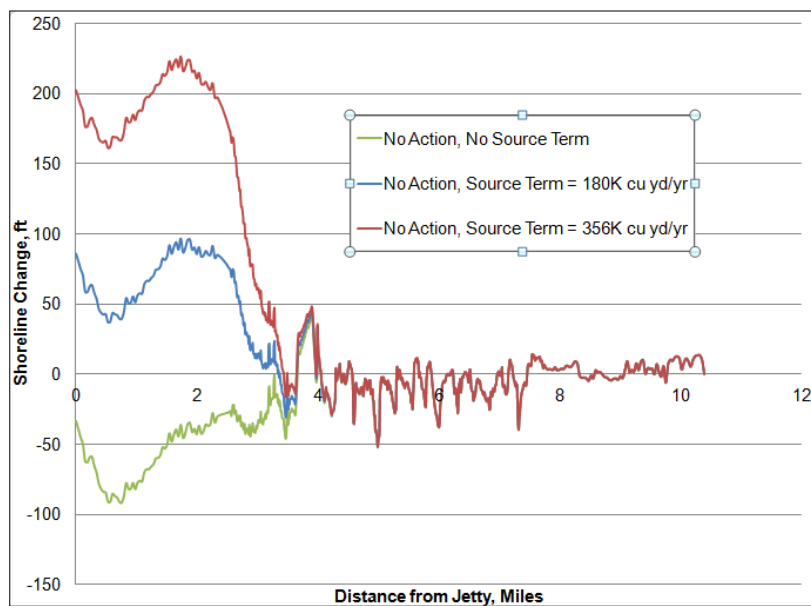
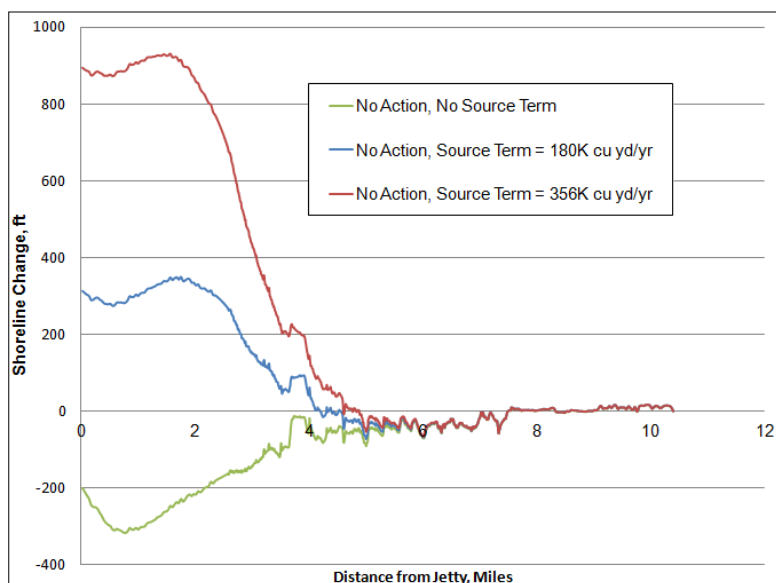


Figure 40. Total shoreline change along seawall after 50 years.



The west end grid was also run for 10 and 50 years to determine the effects on the shoreline if no additional sand is placed. Similar shoreline trends to the calibration take place. For example, just downdrift of the west end of the seawall, the shore continues to erode. After 10 years, the maximum erosion is about just over 50 ft while after 50 years, the erosion increases to over 200 ft. This is to be expected based on historical shorelines in the area. Additionally, the shore accretes near San Luis Pass. Figure 41 only extends to 10 mi west of the seawall in order to focus on the erosion near the west end. After 50 years, accretion near San Luis Pass reaches nearly 1,000 ft. In Figure 42, it looks like there is a slight dip in total shoreline change around 17 mi. The dip is due to the shape of the regional contour which is based on the shapes of the historical shorelines. When viewing the shorelines through the SMS, the decrease in accretion at that location is not as noticeable.

Figure 41. Total shoreline change along the west end after 10 years.

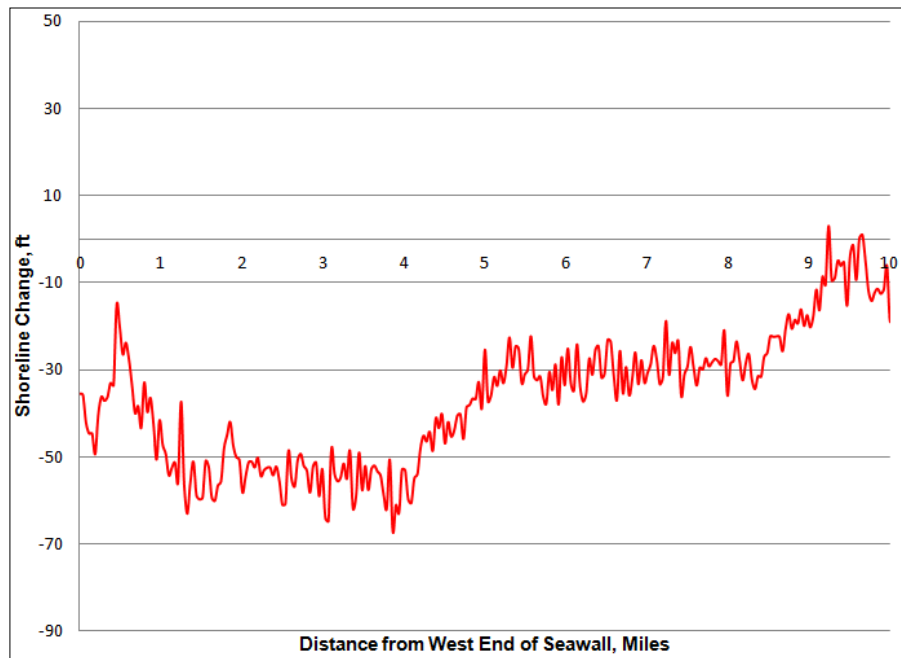
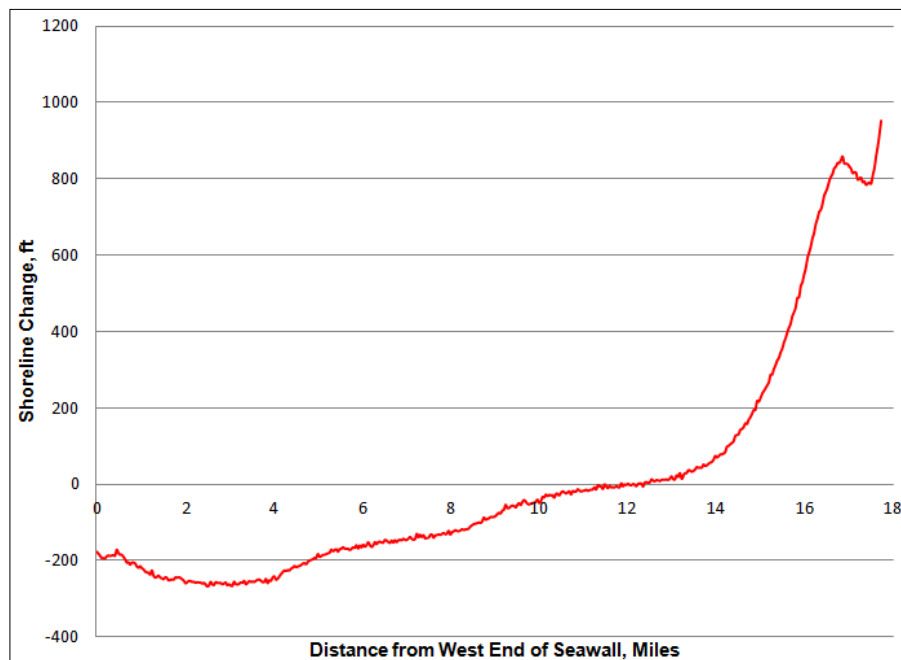


Figure 42. Total shoreline change along the west end after 50 years.



This chapter will describe several different types of alternatives. First, structural alternatives in front of the seawall will be presented. Even if structural alternatives will not be pursued, it is important to consider all possible alternatives at the beginning. Then different beach fill options in front of the seawall will be presented. The simplest beach fill alternative will consist of a minor fill every five years. This alternative would be

representative of conditions when limited funding is available and beach fill were only placed periodically. Then different beach fill volumes with different intervals will be shown. Sand in these scenarios would likely be brought in by trucks. Alternatives will consist of Reach 1 only and Reach 1 and Reach 2 beach fills. Finally, a large-scale beach fill with periodic renourishment will be described. In addition, several rates of backpassing from near the jetty to in front of the seawall will be presented. The lower priority area is the west end of Galveston Island. Beach fills of various volumes and nourishment intervals were modeled as well as alternatives where sand is backpassed from near San Luis Pass to Reaches 3 and 4. It should be noted here, that all alternatives conducted on the west end should be considered in conjunction with alternatives in front of the seawall. However, it may occur that the Galveston Park Board of Trustees decides to nourish the west end of the seawall prior to nourishing Reach 2.

8.1 Structural alternatives in front of seawall

Numerical modeling with GenCade was conducted to determine if modifying the groins in front of the seawall would affect shoreline change. In the first alternatives, all of the groins along the seawall were lengthened by 500 ft. Then the groins were shortened by 250 ft. There was also interest in the effects of the 10th Street groin, so the model was run with the groin removed while all of the other groins were left untouched. All of the groins were removed in the final structural alternative.

The first alternatives compared the lengthened groins and shortened groins to the no action case. Figure 43 shows the shoreline change for each alternative after 10 years from two to eight miles west of the jetty. The shoreline change is the total over the 10 year period, so 100 ft of shoreline change in the figure is equivalent to 10 ft/yr. All of the figures shown in this chapter show total shoreline change, so that the reader can easily see how the alternatives affect the position of the shoreline in the short-term (10 years) and the long-term (50 years). Less than two miles and more than eight miles were not shown in Figure 43 because the alternatives produced nearly identical results in those areas. As expected, when the groins are lengthened, they capture more sand adjacent to each groin. Also, when the groins are shortened, they have little effect on the shoreline.

The biggest impact of the modified groins can be seen close to the 10th Street groin (about 3.5 mi west of the South jetty). Northeast of the 10th St.

groin, the lengthened groin alternative resulted in shoreline advance of about 40 ft while the shortened groin alternative produces a shoreline loss of about 40 ft.

Figure 44 shows shoreline change for the no action case, lengthened groins by 500 ft, and shortened groins by 250 ft after 50 years. The shoreline when the groins are shortened is not very different from the no action results. When the groins are lengthened by 500 ft, the shoreline between each of the groins recedes around 50 ft compared to the no action case.

It was also necessary to determine the impact of the 10th St. groin. Figure 45 shows shoreline change after 50 years for the no action case, the no groins case, and the removal of the 10th St. groin case. The 10th St. groin is located at 3.5 miles west of the jetty. When the 10th St. groin is removed, the shoreline advances slightly more than the no action alternative. About 1.5 miles west of the groin, removing only the single groin no longer has an impact on shoreline change. When all of the groins are removed, the shoreline does not erode as much as the no action case, although the shoreline still erodes from the initial position. Figure 46 compares the no action case to the no groins case near the 10th St. groin. The initial shoreline is red while the calculated 50 year shoreline is in green. The left image is the no action case while the right image shows the shoreline with the groins removed. It should be noted that both images show the location of the groin to better compare the accretion in the area. While it is difficult to see, the calculated shoreline advances more when the groins are removed.

Although the structural alternatives result in slightly different calculated shorelines than the no action alternative, none of the structural alternatives alone resulted in shoreline advance along the seawall. For that reason and the difficulty in designing effective structures, it is not recommended to modify the structures as a part of the sand management strategy. Some of the structural alternatives were modeled in conjunction with beach fills, and those alternatives are presented later in this chapter.

Figure 43. Total shoreline change with and without groin modifications after 10 years.

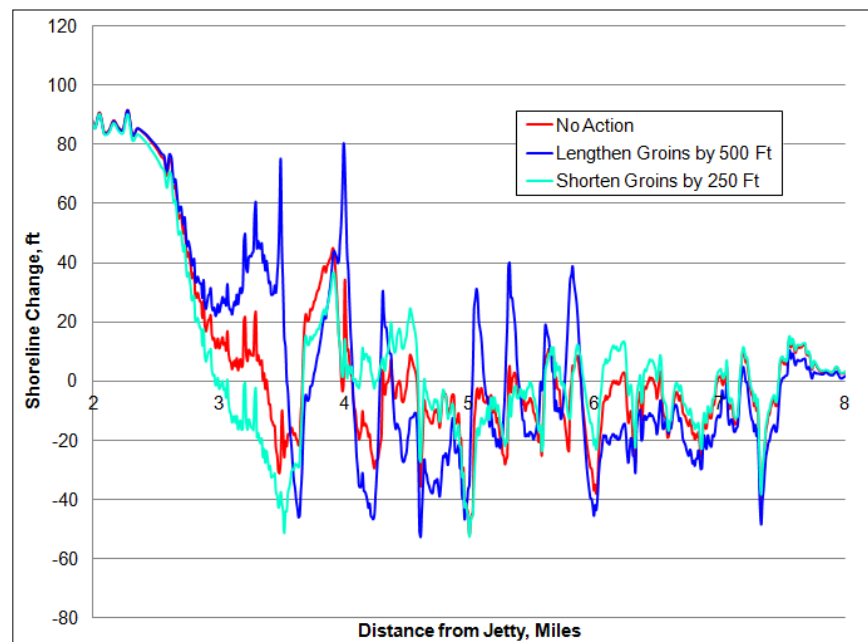


Figure 44. Total shoreline change with and without groin modifications after 50 years.

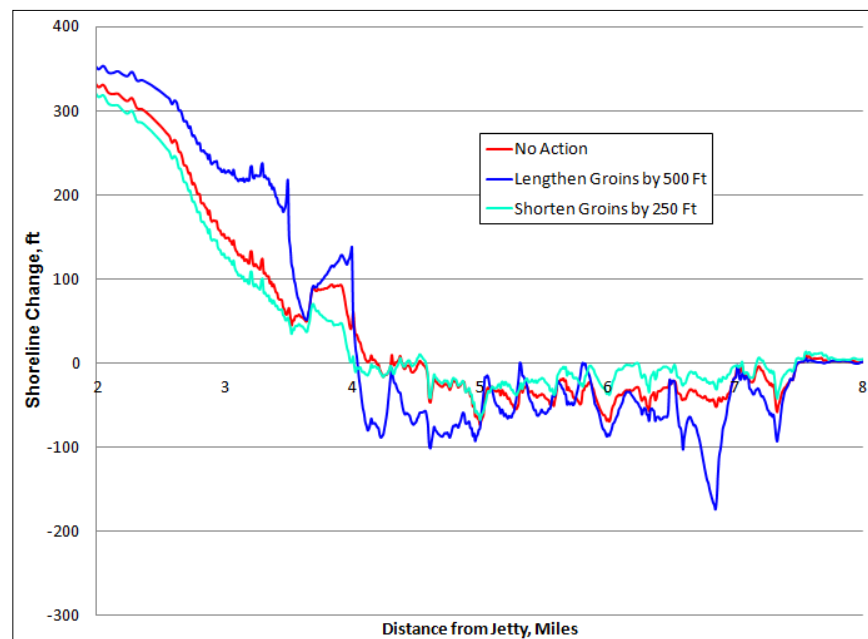


Figure 45. Total shoreline change with and without groin after 50 years.

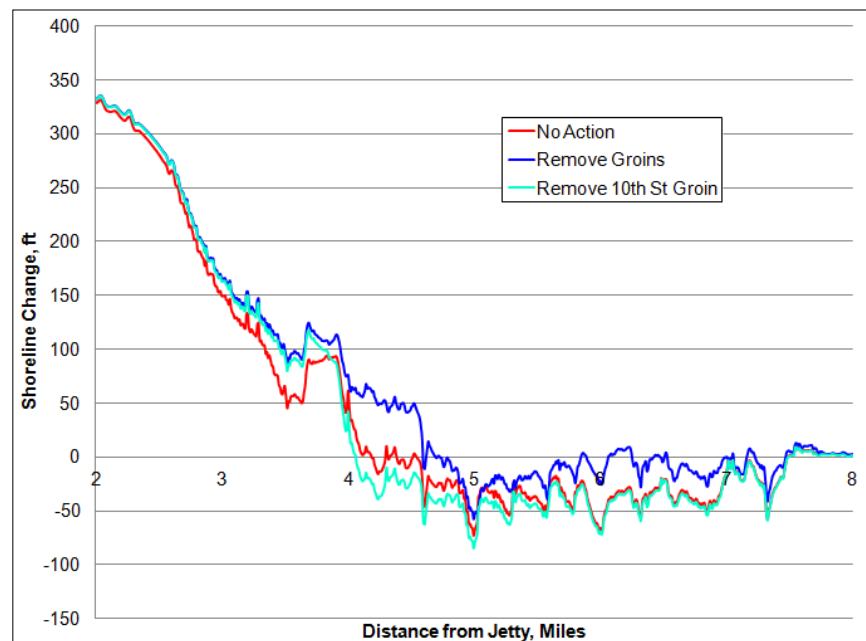


Figure 46. SMS image of the shoreline after 50 years (green) compared to initial (red) with the 10th St. groin (left) and without (right).

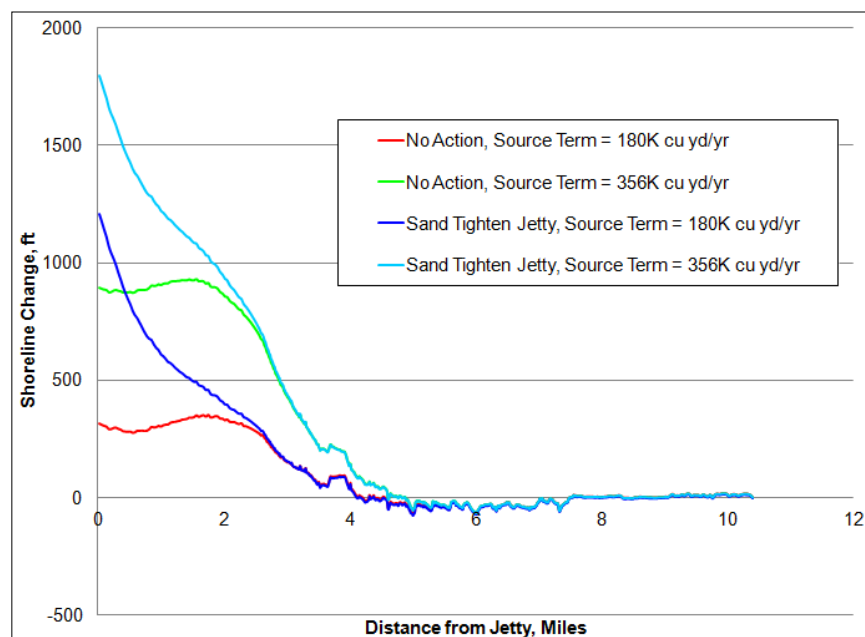


8.2 Sand tightening the Galveston Entrance Channel jetty

Another alternative discussed in preliminary scoping was sand tightening of the Galveston Entrance Channel jetty. In the no action alternative, the jetty permeability was 0.1. When the jetty is sand tightened, the permeability becomes zero, so that no sand moves through the jetty. In Figure 47, the shoreline change after 50 years for the no action case was

compared to the sand tightening cases. The model was run with a source term of 180,000 yd³/yr and 356,000 yd³/yr. When the source term is 180,000 yd³/yr, sand tightening results in shoreline advance of about 900 ft compared to about 300 ft with no action. With a source term of 356,000 yd³/yr, the shoreline change near the jetty increases from 1200 ft to 1800 ft. The impacts of sand tightening only extend about 2.6 miles from the jetty. Although sand tightening the jetty results in further sand advance near the jetty compared to the no action case, it is not recommended that this alternative be considered alone. Sand tightening could result in more sand adjacent to the jetty, so it should be considered in combination with sand backpassing.

Figure 47. Comparison of total shoreline change for no action and sand tightening with 180K yd³/yr and 356K yd³/yr source terms after 50 years.



8.3 Beach fill alternatives along the seawall

Many beach fill alternatives were modeled with GenCade. The alternatives are classified by levels where Level 1 is considered very minor and probably most similar to the type of beach nourishment presently taking place in Galveston presently while Level 4 is the most significant. Level 4 represents an initial wide beach along Reaches 1 and 2 with periodic renourishment. The alternatives in this section start with Level 1 and end with Level 4.

8.3.1 Level 1 – Small beach fill in Reach 1

The beach fill alternative representing Level 1 is the smallest of the beach fills presented. It is meant to represent the type of beach nourishment that presently takes place along the seawall: small, infrequent nourishments. At this time, a beach fill in front of the seawall is considered to be purely cosmetic and for recreation instead of a necessity to protect the shoreline since a shoreline protection structure is already in place. The Level 1 beach fill consists of an initial beach fill of 100,000 yd³ and an additional 100,000 yd³ placed every 5 years. The beach fill is placed along Reach 1 only. The sand for this beach fill is likely to be brought by trucks from near the jetty. The purpose of this beach fill is to show whether or not a small beach fill in front of the seawall will widen the beach compared to a no action condition. This alternative is the least expensive, so if funding is a concern, it is probably the most likely alternative.

Figure 48 and Figure 49 compare the 100,000 yd³ beach fill renourished every 5 years to the no action scenario. After 10 years, two 100,000 yd³ beach fills have been placed on Reach 1; however, there is little advance from the no action case. In most locations along Reach 1, the advance from the no action case is less than 10 ft. Even though a minor beach fill is placed, there are some locations along Reach 1 that experience erosion from the initial shoreline. After 50 years, a total of 1 million yd³ will be placed along Reach 1. In all locations along Reach 1, the Level 1 beach fill advances at least 50 ft from the no action case. After 50 years, the Level 1 beach fill advances from the initial shoreline about 25 ft, but the future beach is not expected to look significantly wider than the present day beach. The no action case has eroded to near the seawall, so although the Level 1 case does not widen the beach from the initial condition, it does protect the seawall.

Figure 48. Total shoreline change after 10 years for the no action case and a 100,000 yd³ beach fill renourished every 5 years.

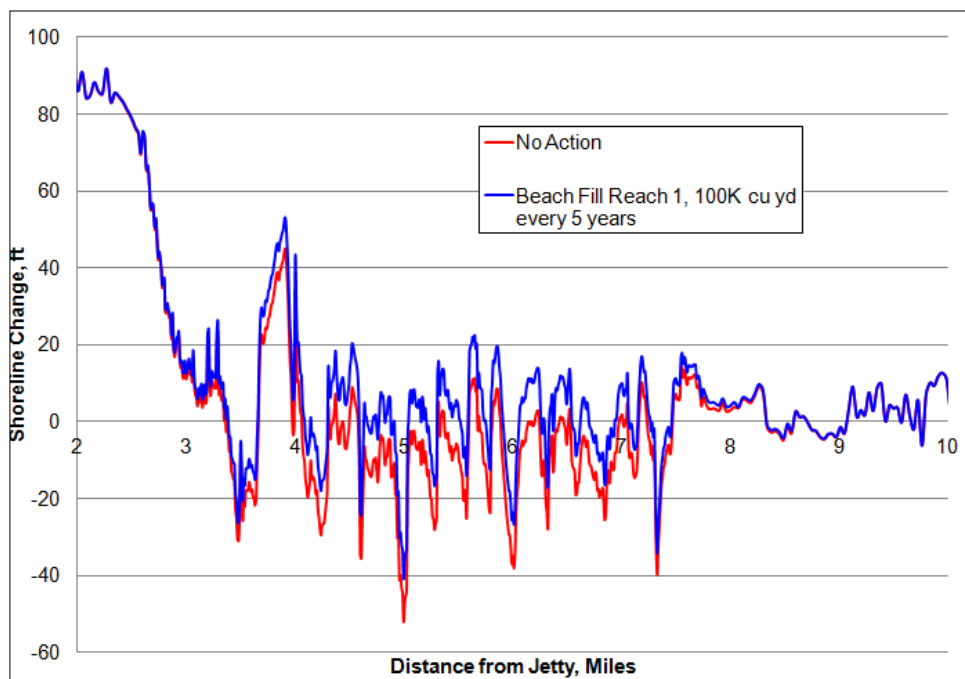
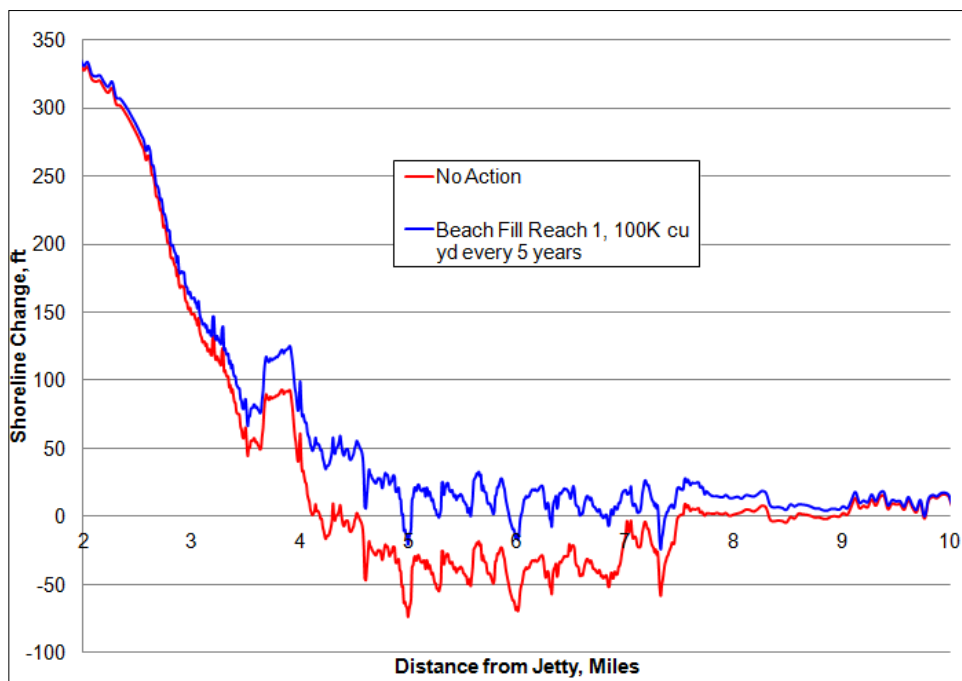


Figure 49. Total shoreline change after 50 years for the no action case and a 100,000 yd³ beach fill renourished every 5 years (total added sand = 1 million yd³).



8.3.2 Level 2 – Beach fills on Reach 1

Level 2 beach fills consist of larger scale nourishment projects along Reach 1. Several of these alternatives would provide a wide, recreational beach along Reach 1, but they would require periodic nourishment. The volumes range from about 250,000 yd³ to up to 2 million yd³. None of these beach fills include a larger fill at the beginning; the same volume is placed at the beginning and during renourishment. The reason the initial placement is not larger than the volume of renourishment is because it might be difficult to find enough sand at the beginning to construct a large-scale beach fill. Level 4 alternatives include a large beach fill at the beginning of the simulation with renourishment over the rest of the simulation. It should be noted that some of these alternatives require large volumes of sand every couple of years. There is a lack of available, beach compatible sand near to Reach 1. Some of the sand could be mined from Big Reef and trucked to Reach 1, but it is likely that other options like mining from Heald Bank would be necessary.

The first Level 2 alternative is a 250,000 yd³ beach fill renourished every other year. The total placement after 50 years is 6.25 million yd³. Figure 50 compares the 250,000 yd³ beach fill every other year alternative to the no action case after 10 years with the source term near the jetty varying from 0 to 356,000 yd³/yr. The purpose of showing three different source term rates is to illustrate how much that term affects the shoreline to near the 10th St. groin. While the source term is not nearly as important for the beach fill options as the backpassing options, it is still necessary to better understand where the sand comes from before proceeding to construct large scale beach fills. After 10 years, the 250K yd³ beach fill alternative has added 1.25 million yd³ of sand to Reach 1, and the beach has advanced about 50 ft. With no source of material near the jetty, GenCade predicts erosion of almost 100 ft about 0.75 mi from the jetty. When 356,000 yd³/yr is added to the shore near the jetty, the shoreline advances more than 200 ft in some areas. After 50 years, the shoreline in Reach 1 advances more than 200 ft (Figure 51). As the sand disperses, the seawall west of 61st St. begins to receive some material. The sand on the eastern section of the seawall moves to the east, so it makes sense that the shoreline advances from the no action case up to 2 miles east of the 10th St. groin. It should also be noted that the source term rate has a significant impact on the shoreline. With a 356,000 yd³/yr source, the shoreline advances more than 900 ft while removing the source term results in

erosion of almost 300 ft. The effects of the source term can be seen nearly 2 miles west of the 10th St. groin.

Figure 50. Total shoreline change after 10 years for the no action case and a 250K yd³ beach fill renourished every other year.

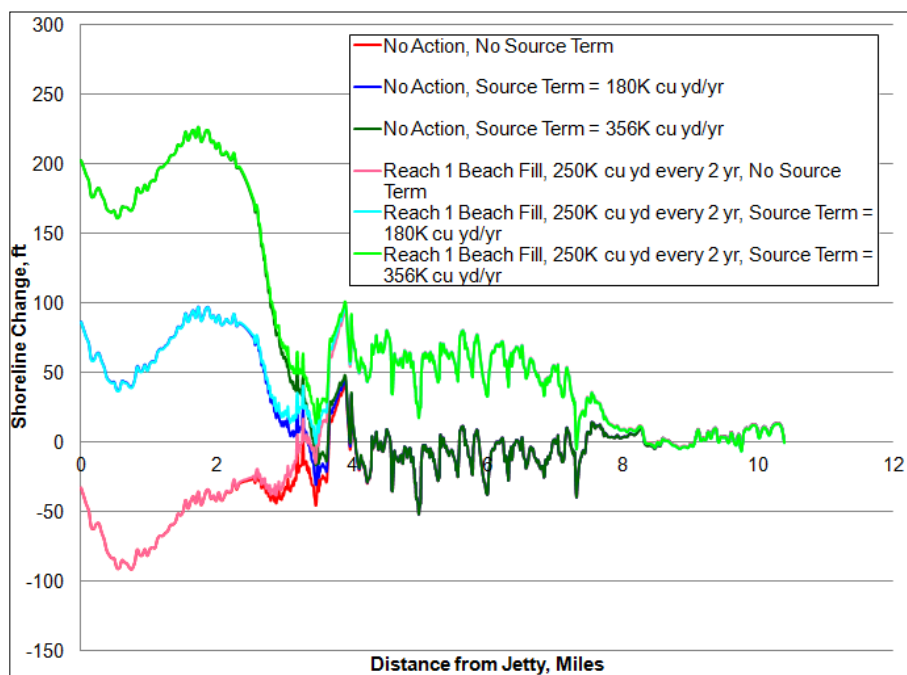
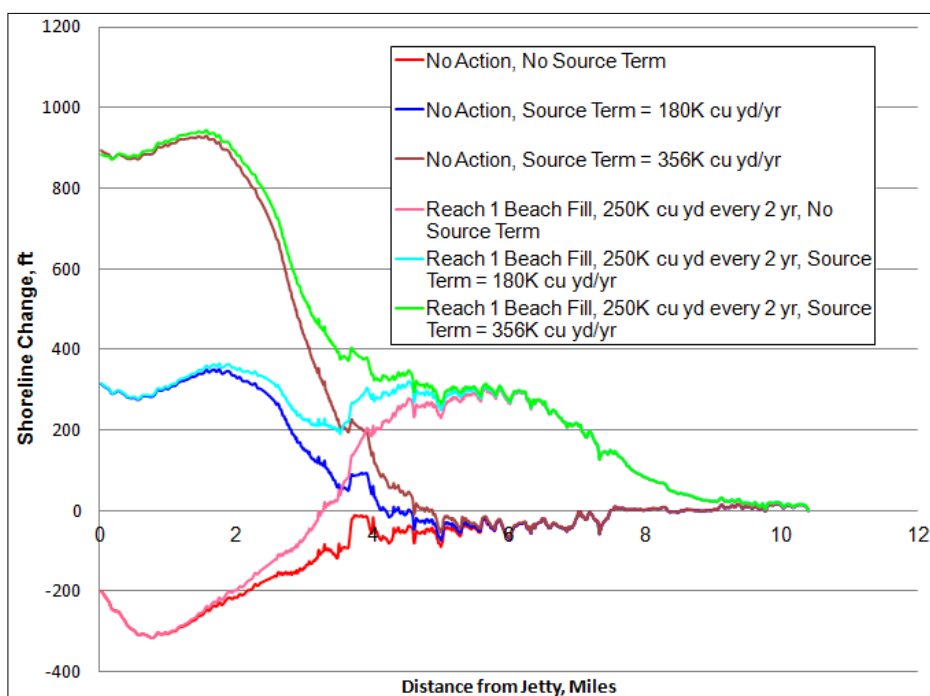
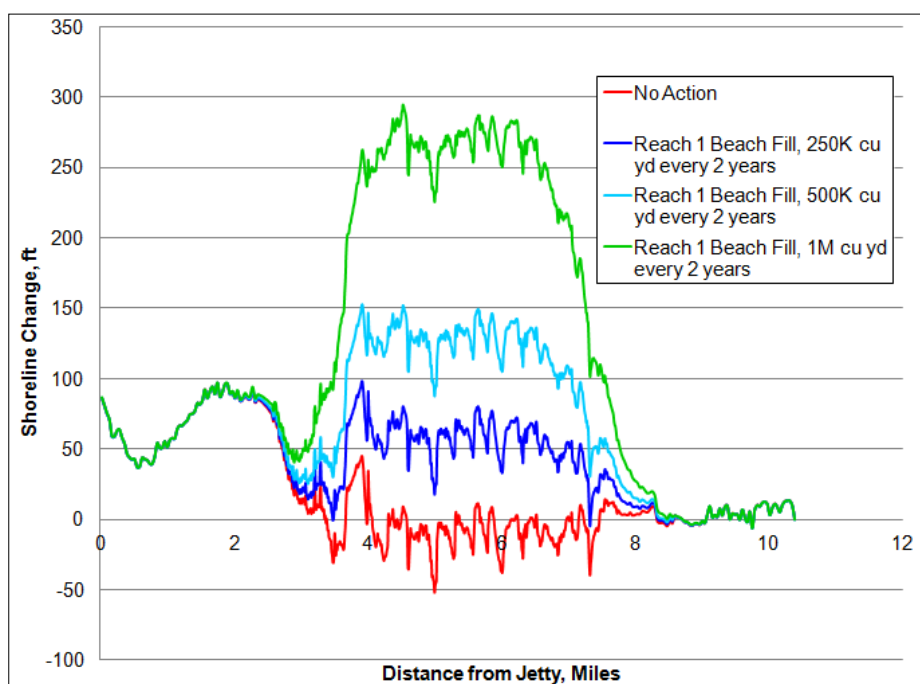


Figure 51. Total shoreline change after 50 years for the no action case and a 250K yd³ beach fill renourished every other year.



Larger beach fills of 500,000 and 1 million yd^3 every other year were compared with the 250,000 yd^3 placement every other year case. The total placement along Reach 1 after 50 years is 12.5 million and 25 million for the 500,000 and 1 million yd^3 cases, respectively. Figure 52 compares the total shoreline change for all three cases after 10 years. It should be noted that all of the shorelines presented in subsequent figures will include a source term of 180,000 yd^3/yr . Although simulations with source terms of 0 and 356,000 yd^3/yr were modeled, it becomes repetitive to show source terms of 0, 180,000, and 356,000 yd^3/yr in each figure. A source term of 180,000 yd^3/yr is shown in the figures, because it is the middle term and is probably the most representative of the rate of sand moving onshore since it is unlikely that more than 350,000 yd^3/yr will continue to move onshore for a total of 50 years especially if the ODMDS is the source of sand and that sand is used beneficially instead. After 10 years, the shoreline advances more than 250 ft in Reach 1 for the 1 million yd^3 every 5 years case and about 125 ft for the 500,000 yd^3 every 5 years case.

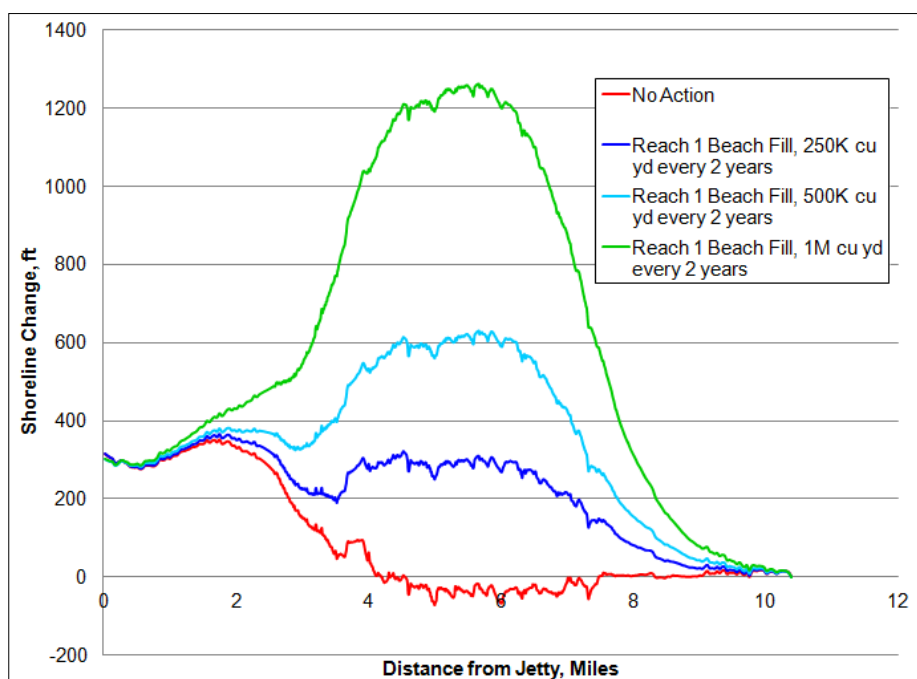
Figure 52. Total shoreline change after 10 years for the no action case and 250,000 yd^3 , 500,000 yd^3 , and 1 million yd^3 beach fills renourished every other year.



After 50 years, almost the entire shoreline from the jetty to the end of the seawall is affected by the beach fills (Figure 53). The 1 million yd^3 every other year alternative advances the shoreline in Reach 1 by 1200 ft. This would provide an extremely wide beach in front of the seawall. However, some tourists might complain that the walking distance from the seawall

to water is too far. It is also not practical to place 1 million yd³ of material along the beach every other year for 50 years since usable sand near Galveston Island is limited. The 500,000 yd³ every other year alternative results in shoreline advance in Reach 1 of 600 ft. The sand from these beach fills also moves east and west from Reach 1. The shoreline from 1.25 mi to 9 mi west of the jetty advances when the beach fills are in place.

Figure 53. Total shoreline change after 50 years for the no action case and 250,000 yd³, 500,000 yd³, and 1 million yd³ beach fills renourished every other year.



Larger beach fills with longer renourishment intervals were also modeled. A 500,000 yd³ beach fill renourished every 5 years is compared with a 2 million yd³ initial beach fill that is renourished with 2 million yd³ every 5 years. After 50 years, the total volume placed for the 500,000 yd³ case is 5 million yd³ while the 2 million yd³ case placed 20 million yd³. Figure 54 compares the two cases with the no action alternative after 10 years. After 10 years, the shoreline in Reach 1 advances about 50 ft when 250,000 yd³ is placed every 5 years. When 2 million yd³ is placed every 5 years, the shoreline advances about 200 ft after 10 years which is about Galveston Park Board's preferred beach width. However, it is important to note that if the periodic placements are discontinued, the shoreline will retreat and the shoreline could look similar to the no action alternative after 50 years. After 50 years of placing 2 million yd³ on the beach every 5 years, the shoreline advances up to 1000 ft (Figure 55). The 500,000 yd³ placement every 5 years results in shoreline advance of 200 ft. Both alternatives will

result in a wider beach along the eastern portion of Galveston Island and the far eastern portion of Reach 2.

Figure 54. Total shoreline change after 10 years for the no action case and 500,000 yd³ and 2 million yd³ cases renourished every 5 years

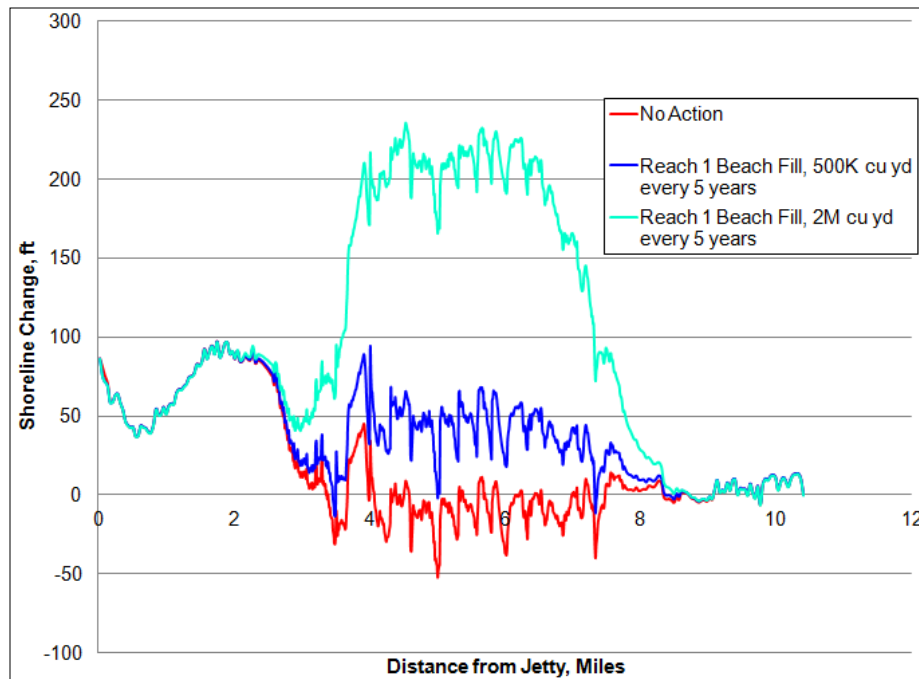
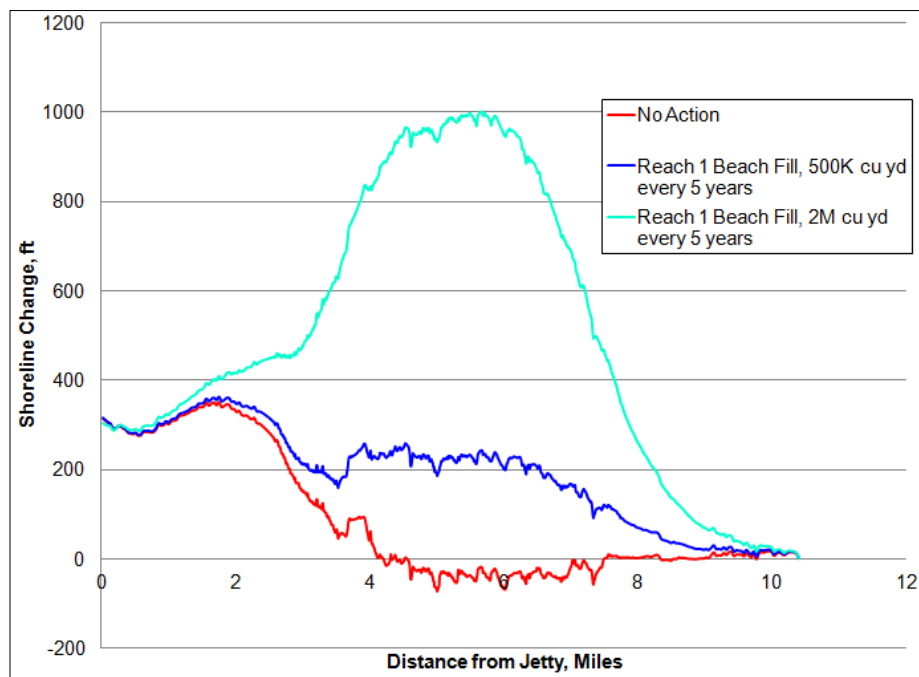


Figure 55. Total shoreline change after 50 years for the no action case and 500,000 yd³ and 2 million yd³ cases renourished every 5 years



Another set of alternatives consists of an initial beach fill of 125,000 yd³ with renourishment of 125,000 yd³ every year. Each beach fill is small, but over 50 years, the total volume placed on the beach reaches 6.25 million yd³. Different placement options over Reach 1 were considered. First, the beach fill was placed with consistent volume over each part of Reach 1. Then, a second option placed sand in different location along the seawall. Every other year the 125,000 yd³ was placed on the northeastern half of Reach 1 while the 125,000 yd³ was placed on the southwestern half of Reach 1 during the other renourishment cycles. Finally, the material was placed in four locations along Reach 1. In year 1 and every four years, material was placed on the furthest northeast quarter of Reach 1. In year 2 and every four years, material was placed on the second quarter. Then material was placed on the third quarter in year 3 and the fourth quarter in year 4. The purpose of these alternatives was to determine if the location along Reach 1 made any difference when the same total volume was added. Figure 56 and Figure 57 show the alternatives after 10 years and 50 years. The alternatives are almost identical. The total shoreline change after 10 years is slightly different when the material is rotated between two placement locations versus four locations, but the results are so similar. Therefore, it does not matter whether the Galveston Park Board wishes to place in specific locations or along all of Reach 1; after 10 years, the results will be similar since sand will move along the shore.

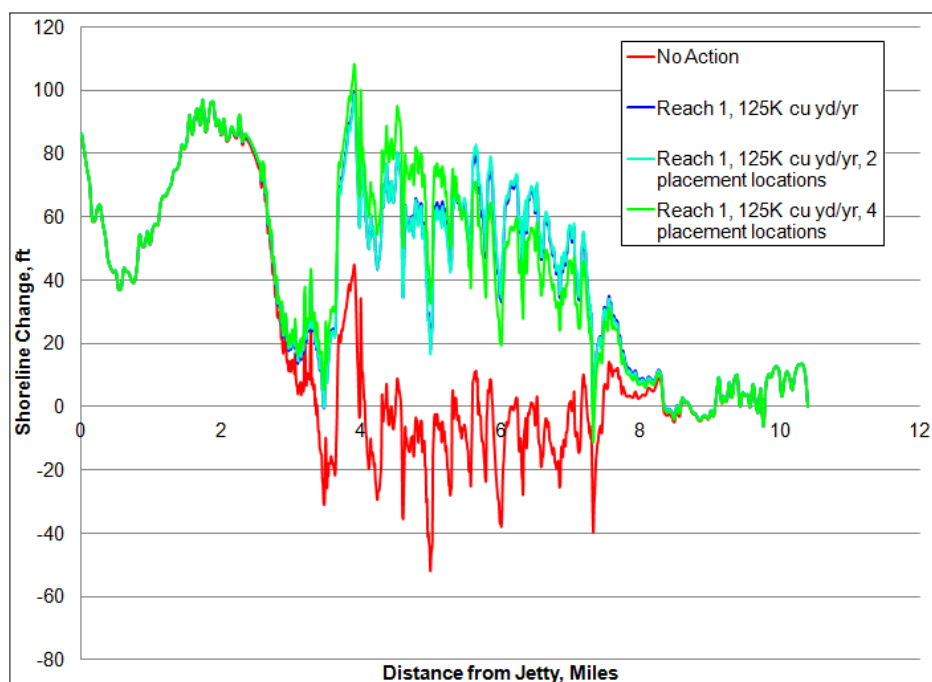
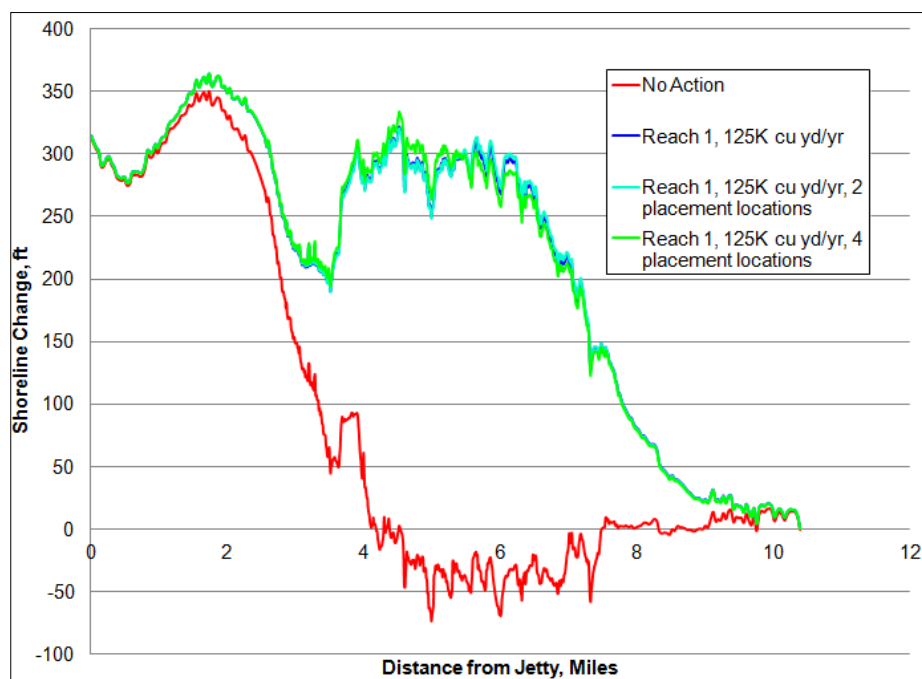
Figure 56. Total shoreline change after 10 years for 125,000 yd³ beach fills.Figure 57. Total shoreline change after 50 years for 125,000 yd³ beach fills.

Figure 58 and Figure 59 compare the no action alternative to the 250,000 yd³ every other beach fill in Reach 1 with modifications to the groins. In the first alternative, the groins are lengthened by 500 ft and they are removed in the second alternative. After 10 years, altering the groins

does not make much difference. While lengthening the groins causes the shoreline to advance closest to the groins and recede between groins, the average shoreline advance is very similar to the alternatives where the groins are not adjusted or removed. After 50 years, changes to the structures are minimal. While the shoreline shape for each case looks slightly different, each case results in shoreline advance around 300 ft. Figure 60 shows shoreline change with and without groins with a 1 million yd³ beach fill renourished every 2 years. Groin modification has an even smaller impact when paired with a larger beach fill. After 50 years with a 250,000 yd³ beach fill placed every other year, it is important to note that the existing groins are nearly buried, so they would have little effect compared to the alternative where the groins are removed. The shoreline will still respond to the lengthened groins. Additionally, a wider beach will encourage more tourists to visit, but the lengthened groins could be dangerous to swimmers. Based on the GenCade simulations, modifying the groins does not increase shoreline advance. If a groin modification is considered an option in the future, additional studies must be conducted prior to construction.

Figure 58. Total shoreline change after 10 years for 250,000 yd³ beach fills renourished every other year with and without modified groins.

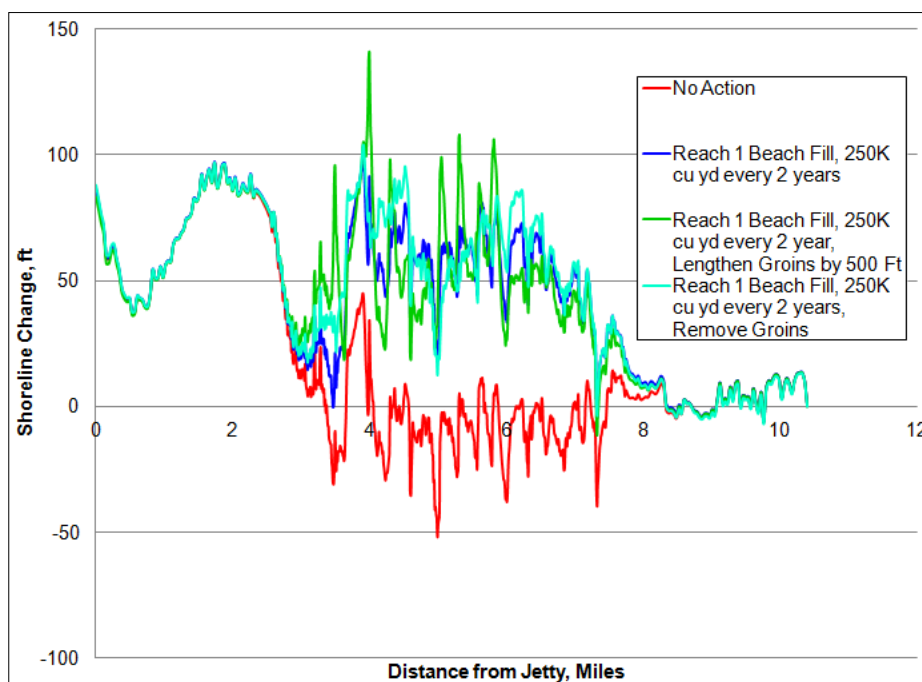


Figure 59. Total shoreline change after 50 years for 250,000 yd³ beach fills renourished every other year with and without modified groins.

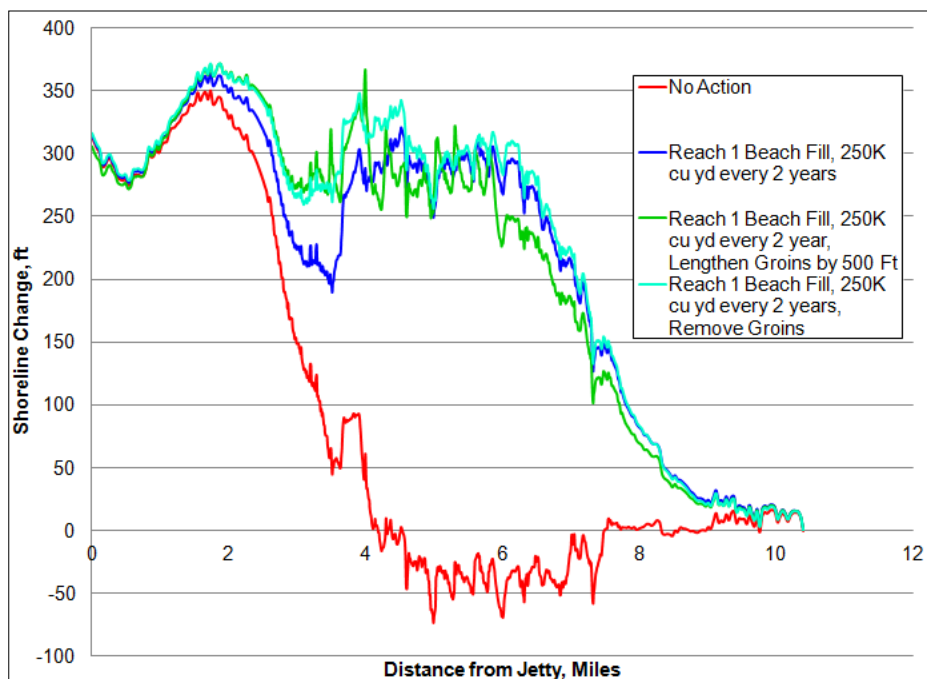
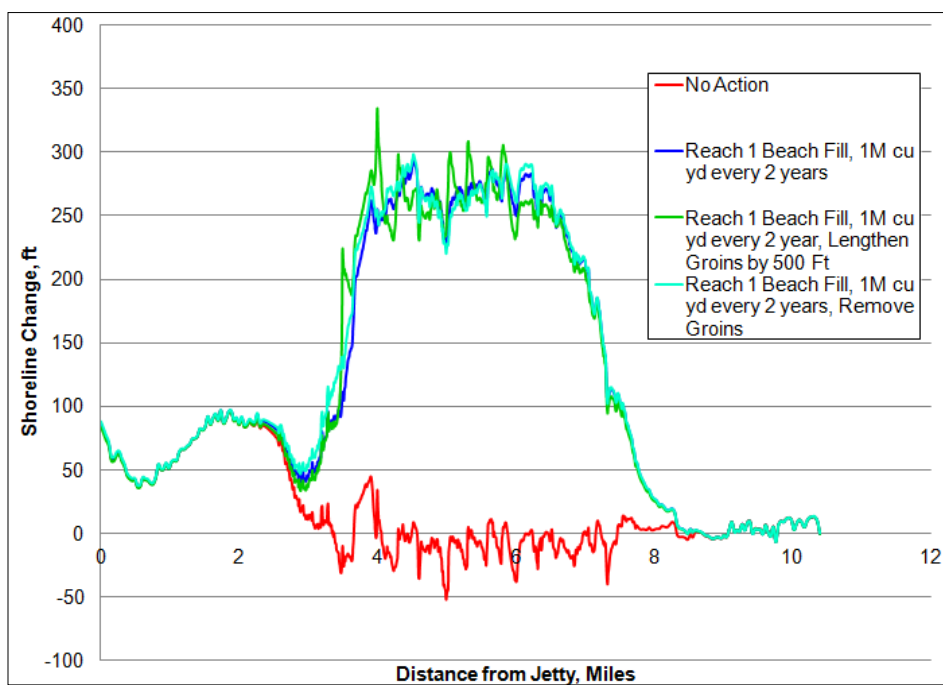


Figure 60. Total shoreline change after 10 years for 1 million yd³ beach fills renourished every other year with and without modified groins.



8.3.3 Level 3 – Beach fills on Reach 1 and Reach 2

Level 3 consists of beach fills being placed on Reaches 1 and 2. In many cases, the same volumes and renourishment intervals used in the alternatives in the previous section are shown here. The reason this is done is so the Galveston Park Board can decide if it is more advantageous to place sand on Reach 1 versus Reaches 1 and 2.

The first set of alternatives compare 250,000, 500,000, and 1 million yd³ initial fills renourished with the same volumes every 2 years. Figure 61 shows total shoreline change for each alternative after 10 years. The shoreline advances about 40 ft when 250,000 is placed every 2 years (1.25 million yd³ total after 10 years), while the 500,000 yd³ alternative advances the beach by 75 ft. The shoreline advances 150 ft after 10 years when 1 million yd³ of material is placed every 2 years. After 50 years, the shoreline advances about 200 ft with placements of 250,000 yd³ every other year and up to 800 ft when 1 million yd³ is placed every other year (Figure 62).

It is important to keep in mind some of the underlying parameters of GenCade. First, GenCade does not know that there is not much sand underwater in front of the seawall. Therefore, it will take less sand to build a beach in the simulations than will actually occur. Also, GenCade requires an input for berm height and depth of closure. These values remain constant across the entire grid x-axis and cannot be adjusted in specific areas. Additionally, GenCade assumes an equilibrium beach profile. Profiles in different areas along the shore indicate different offshore bathymetries out to the depth of closure. In reality, much of the sand placed in front of Reach 2 will move offshore to build the active profile and it will take more sand than expected to build the beach. For those reasons, if a beach is to be built on Reach 2, an incremental approach with monitoring and adaptability is highly recommended.

Figure 61. Total shoreline change after 10 years for 250,000, 500,000, and 1 million yd³ beach fills renourished every other year placed on Reaches 1 and 2.

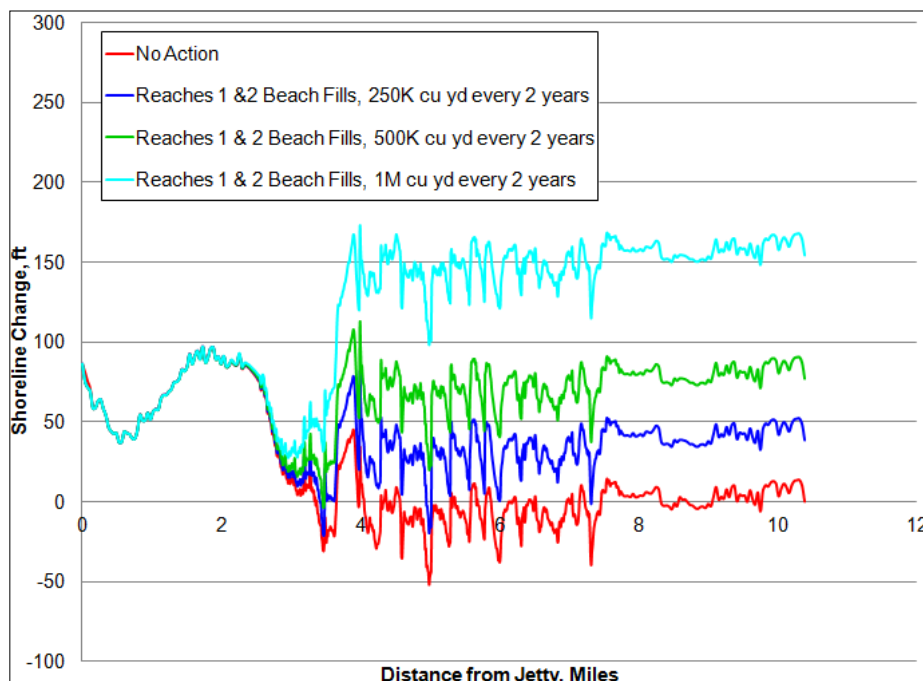


Figure 62. Total shoreline change after 50 years for 250,000, 500,000, and 1 million yd³ beach fills renourished every other year placed on Reaches 1 and 2.

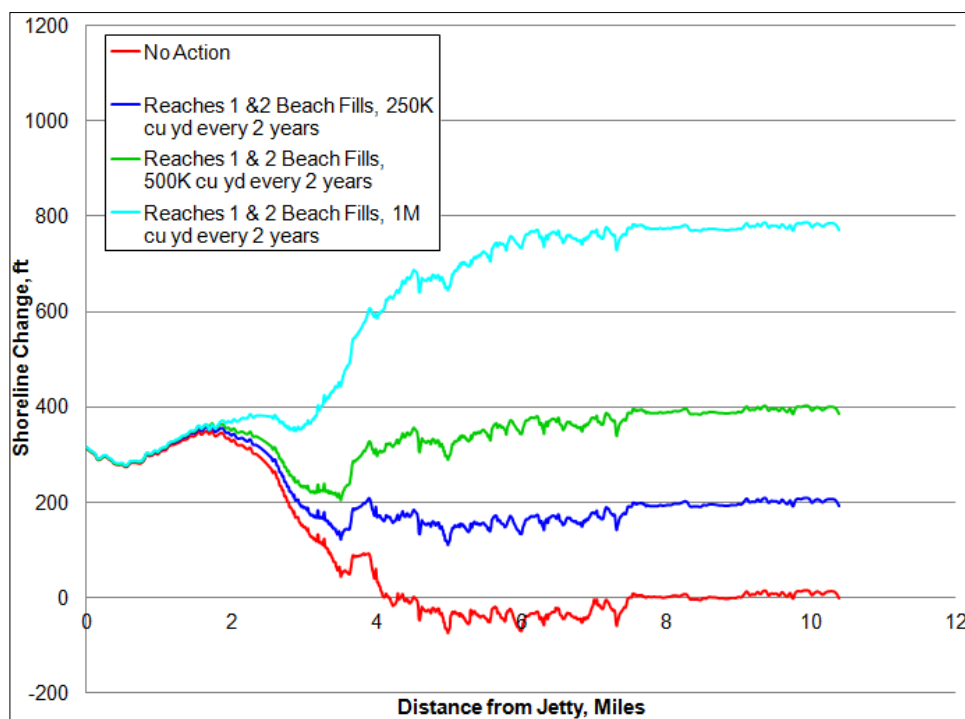


Figure 63 and Figure 64 compare 250,000 yd³ placed every other year on Reach 1 versus Reaches 1 and 2. After 10 years, when the beach fill is only

placed on Reach 1, the shoreline advances about 60 ft in that reach. The beach fill has not dispersed significantly by 10 years, and the shoreline change matches that of the no action case just after 8 miles west of the jetty. The shoreline advances between 30 and 40 ft when the material is placed in Reaches 1 and 2. While the shoreline does not advance as much in Reach 1 as the case with placement only in Reach 1, the advance in Reach 2 is very significant. After 50 years, the Reach 1 placement results in a shoreline advance in that reach of 300 ft. Reach 2, which begins about 7.3 mi west of the jetty, experiences slight shoreline advance from the no action case up to about 9 mi west of the jetty. When the sand is placed on both reaches, the shoreline advances between 150 ft (in Reach 1) and 200 ft (in Reach 2). If sand and money was unlimited and the sand located just offshore of Reach 2 was similar to the profiles of Reach 1, the Galveston Park Board would need to decide whether a 100 ft wider beach on Reach 1 was more beneficial than a slightly less wide beach that extended to the end of the seawall.

Figure 63. Total shoreline change after 10 years for 250,000 yd³ placed every other year on Reaches 1 and 2.

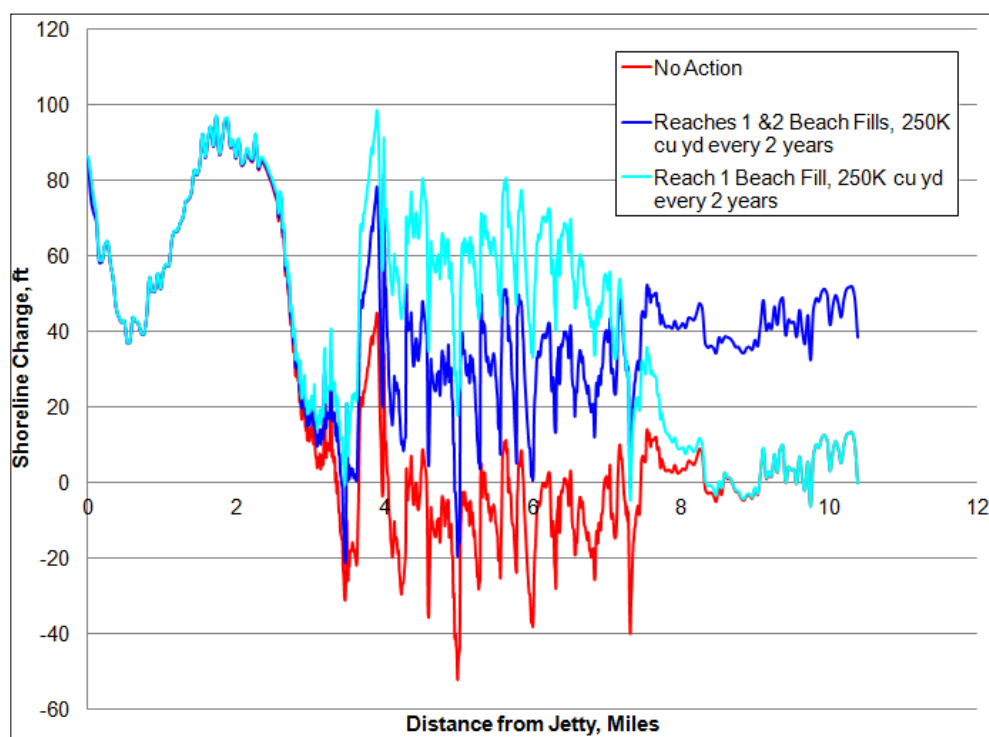
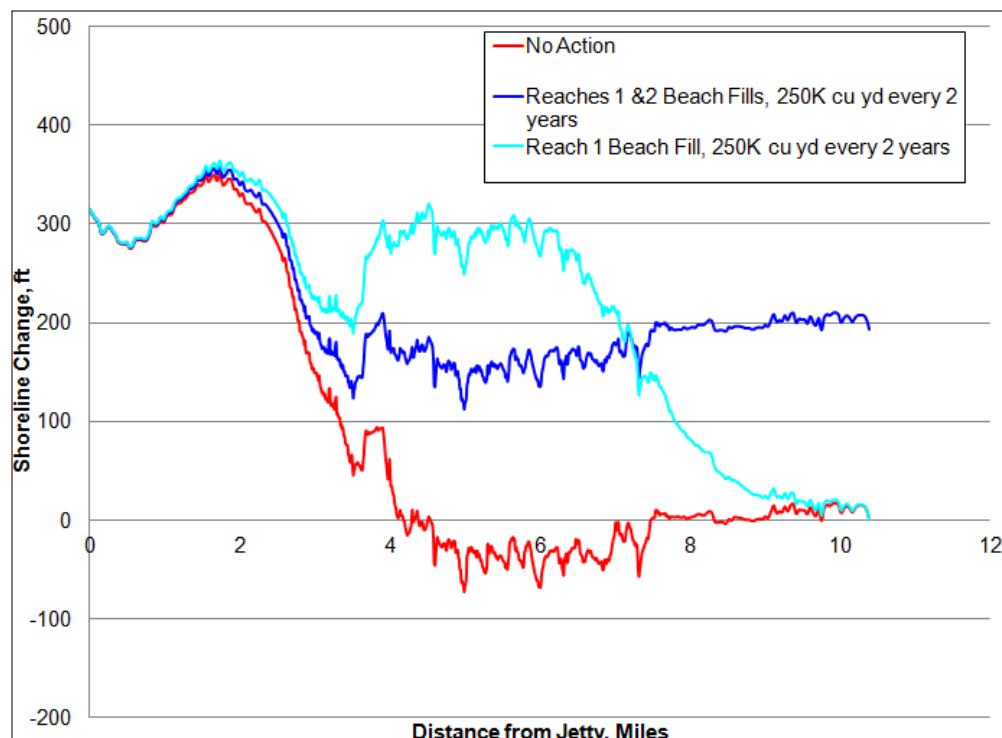


Figure 64. Total shoreline change after 50 years for 250,000 yd³ placed every other year on Reaches 1 and 2.



The next alternatives include placing 500,000, 1 million, and 2 million yd³ on Reaches 1 and 2 every 5 years. Figure 65 compares the total shoreline change after 10 years. After 10 years, when 500,000 yd³ is placed over Reaches 1 and 2 every five years, the beach advances about 40 ft. Increasing the rate of beach fill placement to 1 million every five years results in an advance of 70 ft from the initial shoreline while a 2 million yd³ placement every five years produces a beach 120 ft wider than the initial. Figure 66 compares the results after 50 years. The beaches in Reaches 1 and 2 advance a total of 115 ft, 275 ft, and 600 ft from the initial shoreline for the 500,000, 1 million, and 2 million yd³ placements every five years, respectively. The 2 million yd³ every five year beach fill alternative also results in an advanced shoreline more than 1.5 mi east of the 10th St. groin.

Figure 65. Total shoreline change after 10 years for 500,000, 1 million, and 2 million yd³ placed on Reaches 1 and 2 every 5 years.

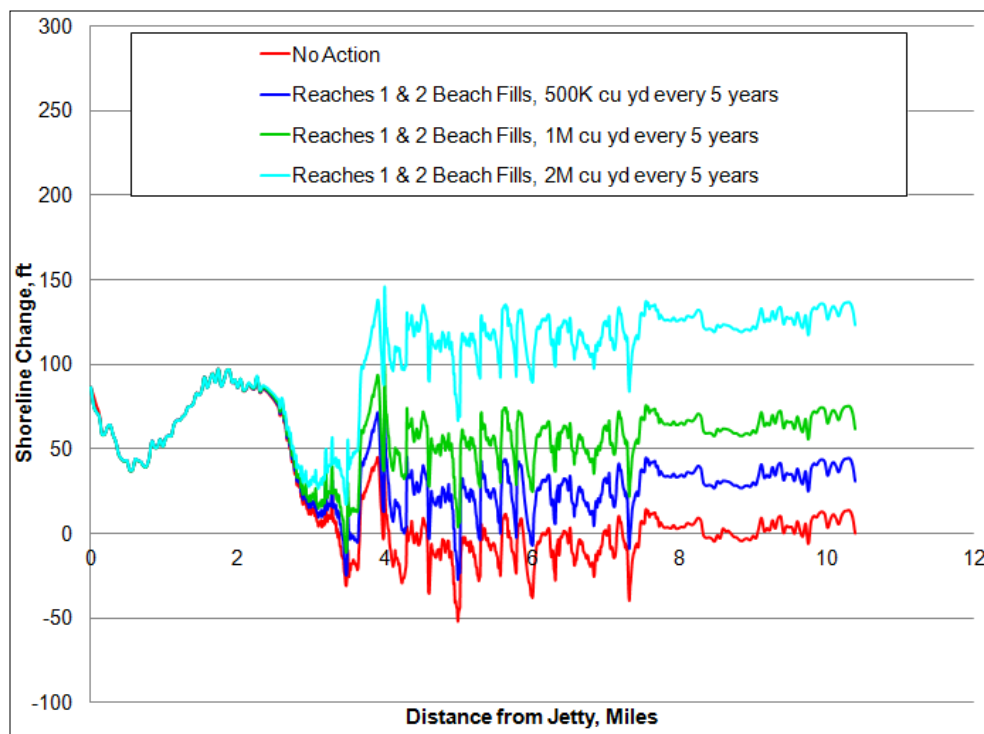
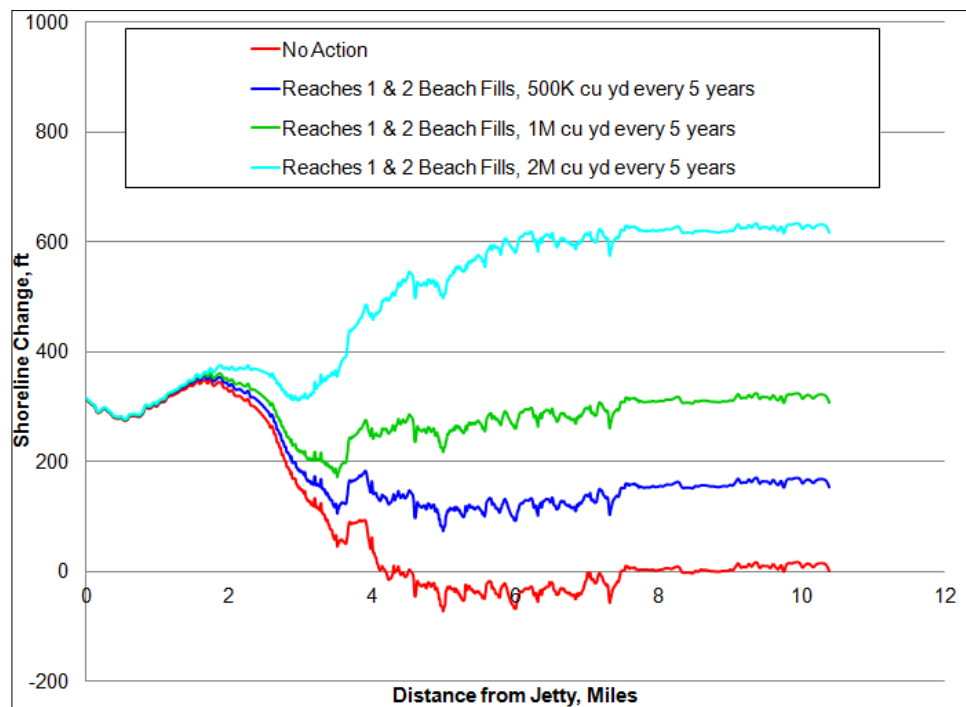


Figure 66. Total shoreline change after 50 years for 500,000, 1million, and 2 million yd³ placed on Reaches 1 and 2 every 5 years.



In addition to comparing beach fill volumes and renourishment intervals, it is also important to determine if the volume distributed on Reaches 1 and 2 makes a difference in the shoreline advance or retreat. In Figure 67 and Figure 68, all of the alternatives include a beach fill of 500,000 yd³ renourished every other year. The amount of sand placed on every linear foot of Reaches 1 and 2 is identical in the first alternative. In the second alternative, two-thirds of the sand is placed on Reach 1 while three-fourths is placed on Reach 1 in the final alternative. The reason these alternatives were simulated is because the Galveston Park Board said that Reach 1 is the highest priority. After 10 years, the shoreline advance for the three alternatives is not too different. The alternative with 375,000 yd³ placed on Reach 1 every other year results in the widest beach in Reach 1 and the narrowest beach in Reach 2. It is easier to see the impact of the different distributions of volume after 50 years. When the fill is distributed evenly across the entire seawall, the shoreline advances 350 ft in Reach 1 and 390 ft in Reach 2. When 367,000 yd³ every other year is placed on Reach 1 and 133,000 yd³ every other year is placed on Reach 2, the beach in Reach 1 increases to 425 ft wide while the beach in Reach 2 is only 300 ft wide. Finally, the alternative with 375,000 yd³ and 125,000 yd³ every other placed in Reaches 1 and 2 results in the shoreline of Reach 1 advancing 485 ft while Reach 2 only advances 225 ft. Over 50 years, the total volume placed on the beaches is 25 million yd³. This is a very large volume, so the beaches will advance significantly regardless of the distribution of placement. The same type of analysis could be conducted with smaller volumes and longer renourishment intervals, and the significance of the distribution should be similar. However, finding enough sand to place on the beaches may be difficult.

Figure 67. Total shoreline change after 10 years for 500,000 yd³ placed every 2 years in different locations.

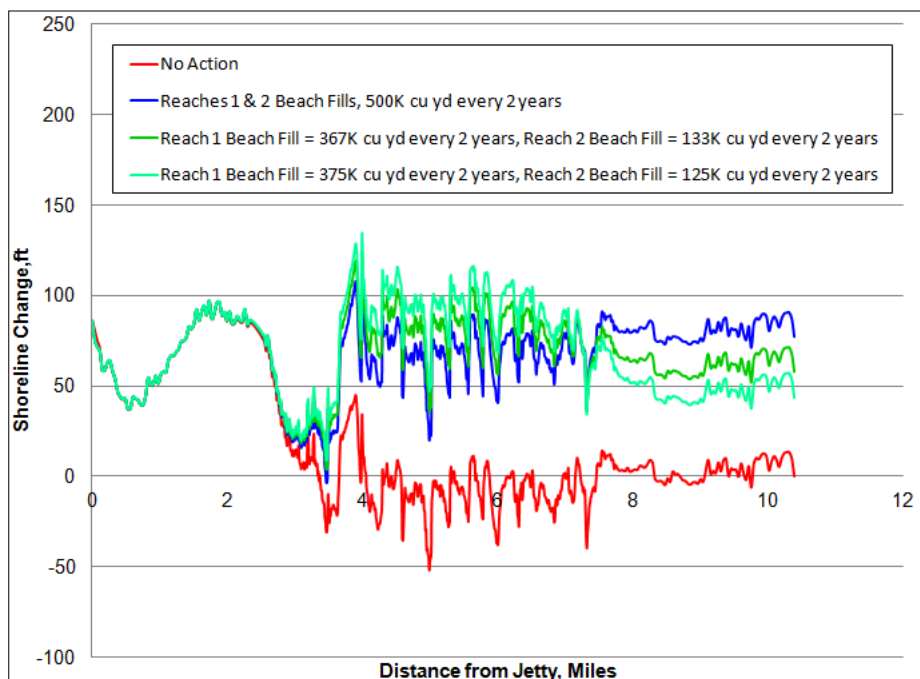
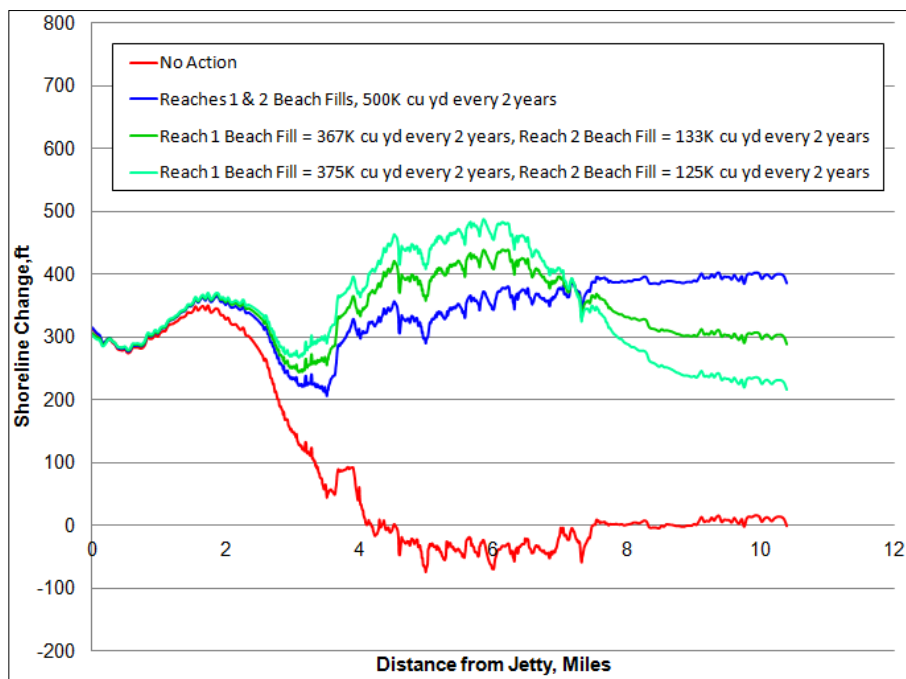


Figure 68. Total shoreline change after 50 years for 500,000 yd³ placed every 2 years in different locations.



8.3.4 Level 4 – Large-scale beach on Reach 1 and Reach 2

The final beach fill alternative for Reaches 1 and 2 is the large-scale beach fill described in Chapter 7. Initially, 1,942,000 yd³ is placed on Reach 1 and 3,654,200 yd³ is placed on Reach 2. Two separate alternatives were modeled in GenCade. Since a large-scale beach fill will be extremely costly, an alternative where material is placed only along Reach 1 is compared to the full beach fill on Reaches 1 and 2. Figure 69 compares these two cases and the no action alternative after 10 years. The beach fill cases are identical along the majority of Reach 1 where the maximum shoreline advance is about 110 ft. The large-scale beach fill advances the shoreline in Reach 2 by 250 ft.

Figure 70 compares the alternatives after 50 years. A percentage of the sand moves northeast towards the jetty, so that the shoreline adjacent to the first groin has advanced more than the no action case. Much of the shoreline advance seen after 10 years has eroded away along Reach 1, but the beach along Reach 2 is still very wide.

Figure 69. Total shoreline change after 10 years for the large-scale beach fills.

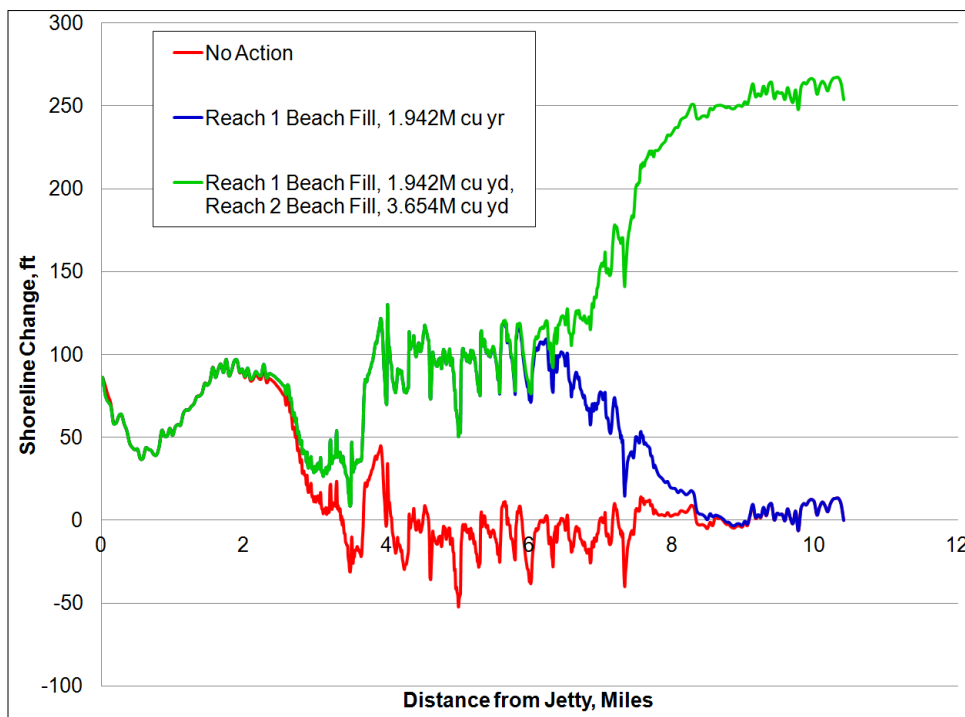
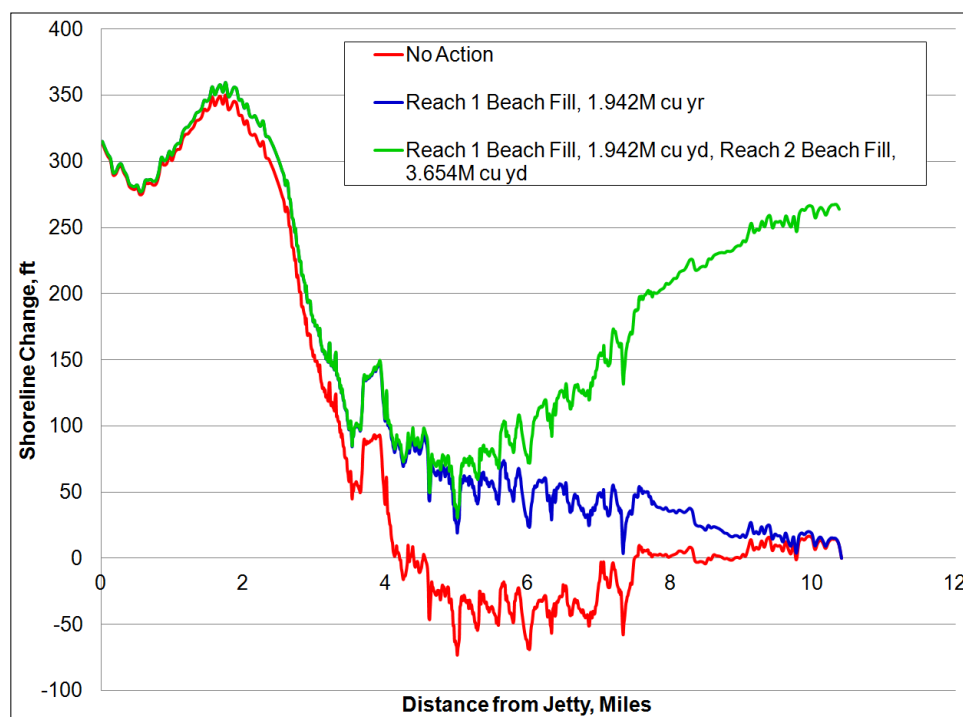


Figure 70. Total shoreline change after 50 years for the large-scale beach fills.

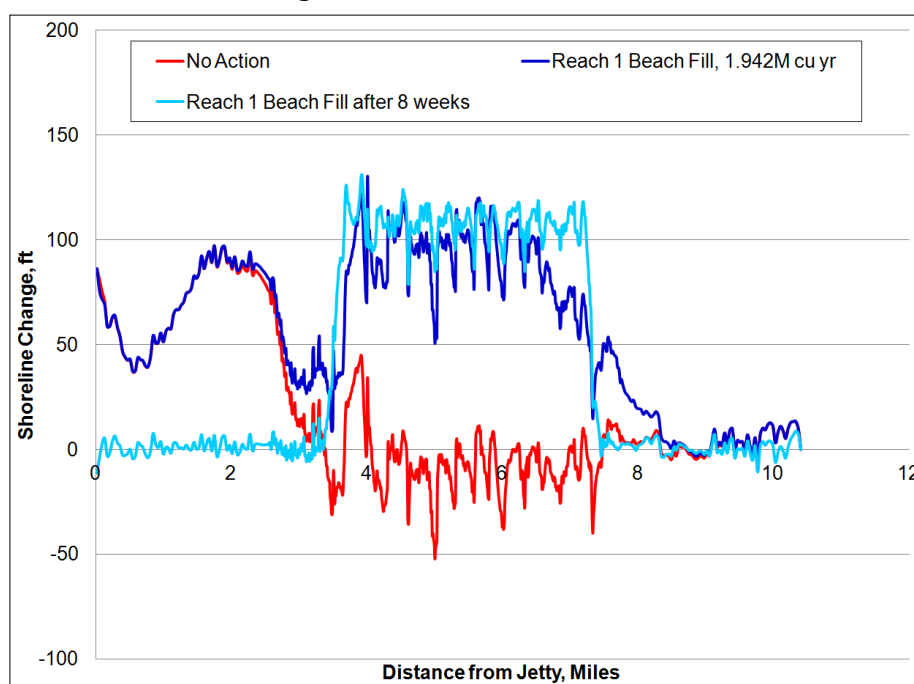


In addition to modeling the alternatives, another analysis determined the amount of material needed along each reach for different nourishment intervals in order to keep the same volume of material on the reaches. Each initial beach fill construction was completed after eight weeks within the simulation. A large-scale beach fill will take much longer than this to complete. When only the beach fill on Reach 1 was constructed, the reach loses a total of 113,000 yd³ after 2 years. Much of that sand is transported into Reach 2. After 5 years, a total of 195,000 yd³ is lost from Reach 1. Finally, after the 50 year simulation, the total loss of sand in Reach 1 is 741,000 yd³. If the beach is renourished every 2 years, an average of 31,000 yd³ would need to be placed each time. With a five year renourishment interval, the beach would need 82,000 yd³ each time. However, most of the losses occur early in the simulation. If 31,000 yd³ was placed on the beach after two years, it would not widen the beach enough to reach the width right after initial construction. Figure 71 compares the shoreline position after 10 years versus the position immediately after the beach fill construction.

In the chapter on the large-scale beach fill, an overfill factor of 50 percent is assumed. If the initial beach fill is increased to 2,913,300 yd³, then the total volume added to Reach 1 after 50 years is 1,874,400 yd³. Therefore, if

the beach is overfilled at the beginning, the beach would only lose about 68,000 yd³ from the original beach fill volume, so the beach would be very similar to the shape of the beach after initial construction when no overfill was added.

Figure 71. Total shoreline change after beach fill construction in Reach 1 and after 10 years.



The same analysis was conducted for the alternative with beach material placed along Reaches 1 and 2. When a beach fill is constructed along both Reaches 1 and 2, the total volume added to the beaches is 5,596,400 yd³. After 2 years, only 13,000 yd³ is lost from Reach 1 and 41,000 yd³ is lost from Reach 2. Reach 1 loses 16,000 yd³ and Reach 2 loses 73,000 yd³ after 5 years while Reach 1 loses 96,000 yd³ and Reach 2 loses 290,000 yd³ after the 50 year simulation. There are two reasons that Reach 1 does not lose much sand compared to Reach 2. First, the beach is wider along Reach 2. This material begins to disperse and starts moving into Reach 1. Second, about 9 million yd³ of sand moves onshore near the jetty. While most of the sand accumulates near the jetty, some of it will come onshore further to the west near Reach 1. Figure 72 shows the comparison of the shape of the beach fill immediately after construction and after 10 years. The biggest change in the shoreline shapes is near the transition of Reaches 1 and 2 where the shoreline at the end of Reach 1 advances and the shoreline at the beginning of Reach 2 retreats. The model does not predict erosion near the west end of the seawall because of a pinned

boundary condition. In reality, a large percentage of this sand will move offshore or towards the west end of Galveston Island.

An alternative with overfill was also modeled. The total volume of sand in this case increases to 8,394,600 yd³. At the end of the 50-year simulation, the volume of sand in each reach is greater than the volume placed in the beach fills without overfill. Since the beach fill is so large, only a small percentage of the sand volume moves off the grid towards the west end. Additionally, typical waves were used to drive the simulations. If Galveston Island is impacted by large and numerous storms within the 50-year period, it is very likely that sand will be transported out of the system. Sea level change is not accounted for in GenCade, so some additional material will be lost.

Figure 72. Total shoreline change after beach fill construction in Reaches 1 and 2 after 10 years.



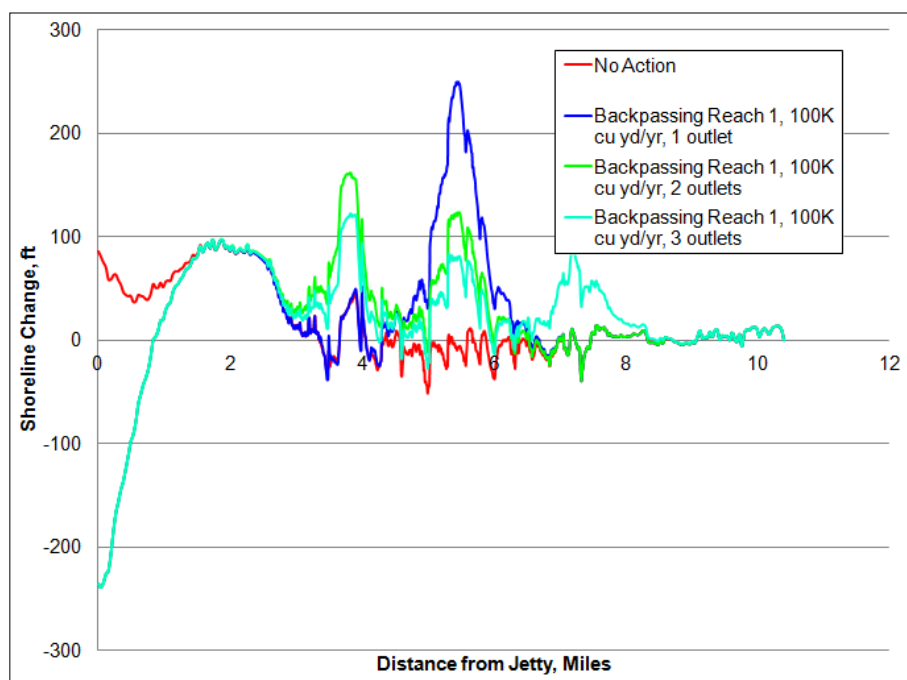
8.4 Backpassing alternatives along seawall

All backpassing alternatives involve removing the backpassed amount from the shoreline near the jetty and placing it on the reach. When a larger rate is backpassed each year than is fed from offshore sources and longshore transport, there will be a loss of sand near the jetty. In some cases, the model predicts significant erosion near the jetty. Since it is unknown how much material comes from offshore sources each year, a

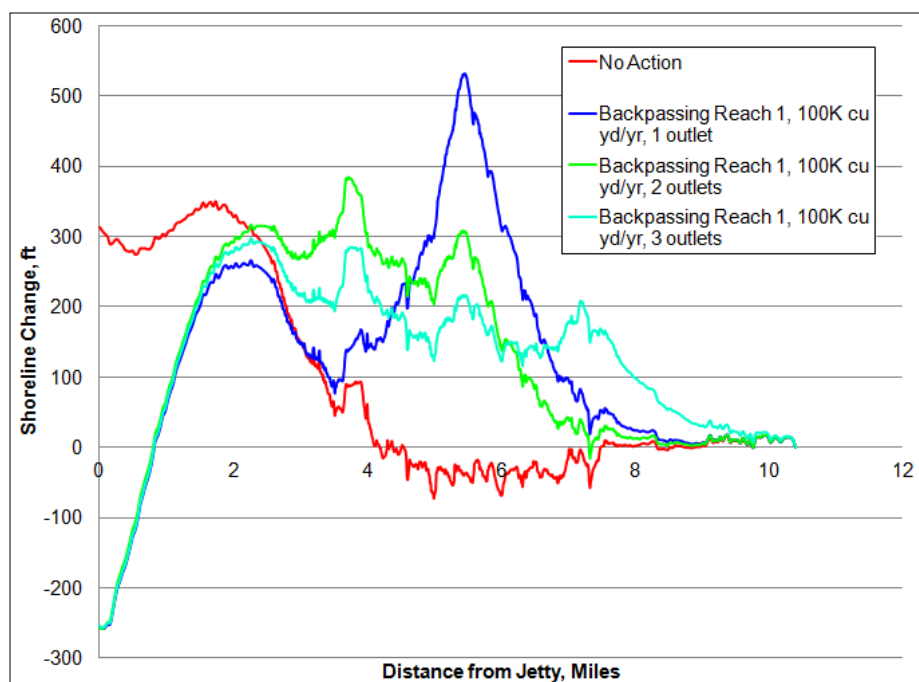
study must be conducted before moving forward with construction on a backpassing plant. Additionally, once operations begin, it is recommended to start with a small yearly volume to ensure the system is working properly and there is sufficient material to backpass.

8.4.1 Level 1 – Backpassing in front of groin field

The first level of backpassing consists of backpassing from the near the jetty to Reach 1. The first alternatives compare a single outlet along the seawall to alternatives with multiple outlets. Most likely the system will be designed with multiple outlets along the beach, but it is important to illustrate how the shoreline will respond to a single outlet versus multiple outlets (where the placement location can be adjusted). In Figure 73, total shoreline change is shown for a no action case as well as 100,000 yd³/yr of backpassing with one, two, and three outlets along Reach 1. If a single outlet is placed at a central location on Reach 1, the maximum shoreline advance is about 250 ft; however, the effect is very localized. About a mile away from the outlet, the shoreline advance is almost identical to the no action alternative. If there are two outlets, the maximum shoreline advance decreases to about 150 ft. There are two locations along the seawall which experience significant shoreline advance, but the shoreline recedes to near no action conditions between the outlets. Finally, with three outlets along the seawall, there are three distinct locations of shoreline advance of just under 100 ft. In between each outlet, the shoreline does not advance as far, but the shoreline does not recede to the no-action conditions. Although only 100,000 yd³/yr is backpassed, about 225 ft of erosion occurs near the jetty. In these cases, a source term of 180,000 yd³/yr is used. If sand moves onshore at a greater rate, the erosion in this area will be less.

Figure 73. Total shoreline change after 10 years for 100,000 yd³ of backpassing.

After 50 years, 5 million yd³ of material has been backpassed from near the jetty. Regardless of the number of outlets, the beach will be much wider than the no action case (Figure 74). If only a single outlet is used, the beach will be more than 500 ft wide at the outlet point but only about 100 ft wide near the 10th St. groin and near 61st St. With two outlets, the maximum shoreline advance is about 350 ft. The shoreline between the outlets advances more than 200 ft while the backpassing has a limited effect more than 7 mi from the jetty. With three outlets, the average shoreline advance along Reach 1 is about 200 ft. This is the only alternative where some of the sand has moved to Reach 2 and created a beach. The maximum erosion near the jetty is similar to the erosion after 10 years, but the impacts of backpassing are felt further from the jetty.

Figure 74. Total shoreline change after 50 years for 100,000 yd³ of backpassing.

The following figures all compare different source terms and bypassing rates with three outlets. In order to have a more uniform beach, there must be more outlets. Figure 75 compares two cases with 100,000 yd³/yr backpassed onto Reach 1 with three outlets after 10 years. One case includes a source term near the jetty of 180,000 yd³/yr while the other has a source term of 356,000 yd³/yr. These figures are included in this report to reiterate how much of an impact the rate of sand moving towards the jetty has on the shoreline east of the 10th St. groins and on the amount of material that can safely be backpassed to Reach 1. The no action case in the figure includes a source term of 180,000 yd³/yr. The effects of the source term are felt up to the 10th St. groin. While both source terms result in erosion near the jetty, the source term of 356,000 yd³/yr advances the shoreline up to 0.5 mi east of the jetty. After 50 years (Figure 76), the source term impacts the shoreline up to 5 mi west of the jetty. If 356,000 yd³/yr is added to the beach, the shoreline advances up to 800 ft in some areas east of the 10th St. groin and the erosion near the jetty is only about 100 ft. The 180,000 yd³/yr source term results in erosion of more than 200 ft near the jetty and up to 100 ft of advance along East Beach.

Figure 75. Total shoreline change after 10 years for 100,000 yd³ of backpassing with different source terms.

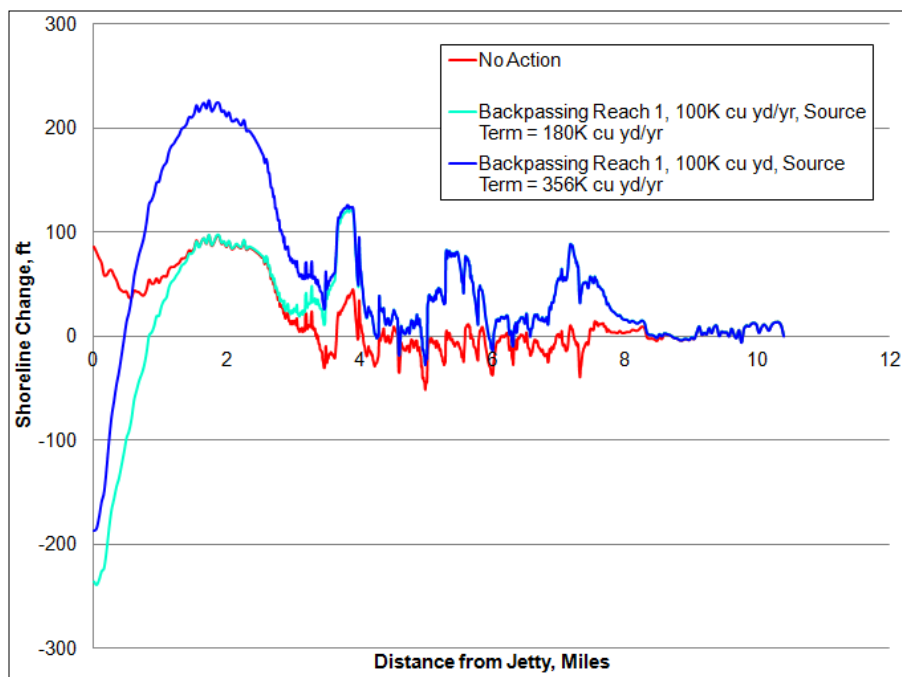


Figure 76. Total shoreline change after 50 years for 100,000 yd³ of backpassing with different source terms.

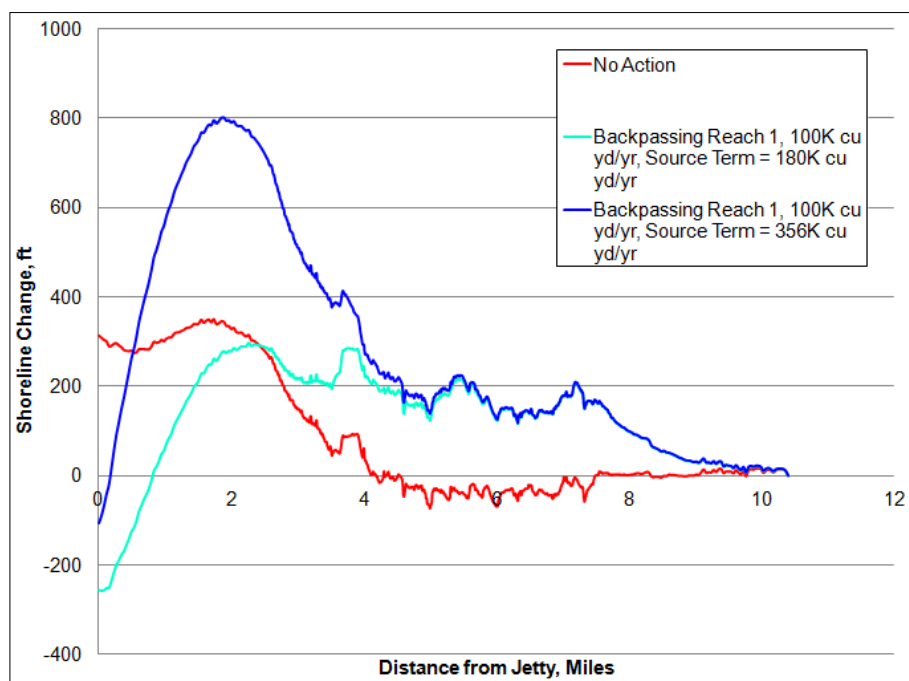
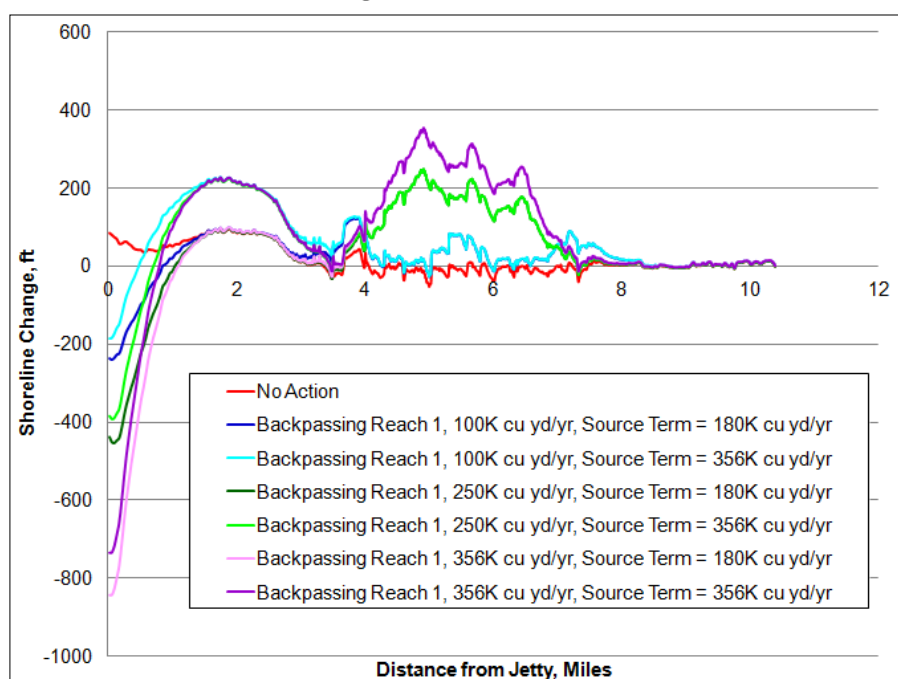


Figure 77 and Figure 78 compare total shoreline change for backpassing rates of 100,000, 250,000, and 356,000 yd³/yr with different source terms for 10 and 50 years. The 356,000 yd³/yr backpassing results in up to

300 ft of advance in Reach 1. However, even when 356,000 yd³/yr of sand comes from offshore, there is almost 800 ft of erosion along the jetty. Presently a fillet has formed near the jetty, and even though the shoreline will recede significantly from the present day shoreline, it will not erode enough to undermine the jetty. The 250,000 yd³/yr backpassing rate advances the beach about 200 ft in Reach 1. The maximum erosion near the jetty for both the 180,000 and 356,000 yd³/yr source term is around 400 ft.

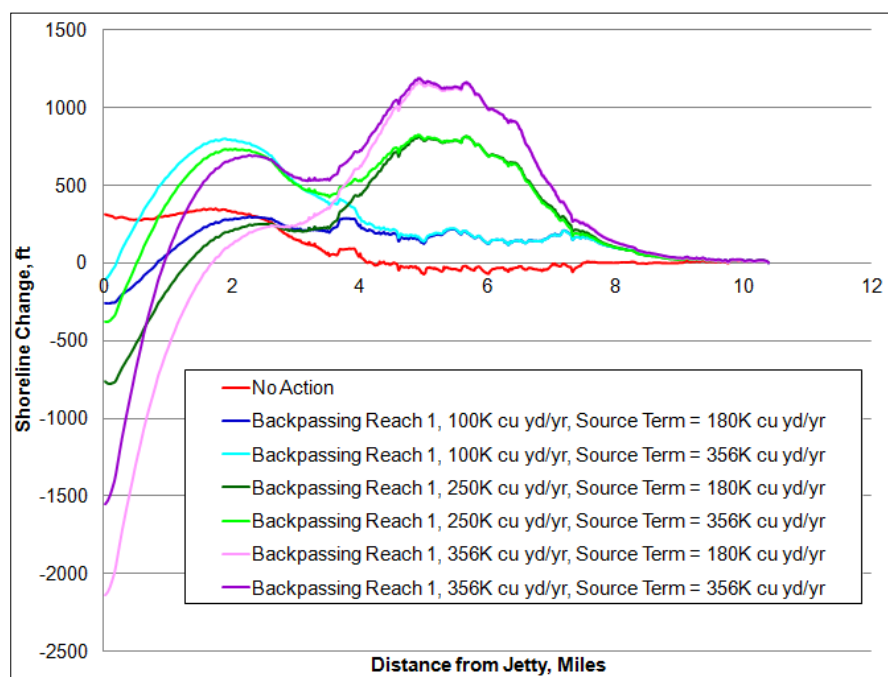
Figure 77. Total shoreline change after 10 years for 100,000, 250,000, and 356,000 yd³ of backpassing with different source terms.



After 50 years (Figure 78), the beach on Reach 1 is larger than 10 years, but the erosion near the jetty and East Beach has increased. When 356,000 yd³/yr is backpassed onto Reach 1, the maximum shoreline advance from the initial shoreline is about 1200 ft. This option provides a very wide beach all along Reach 1 and into part of Reach 2. Unfortunately, over 2000 ft of erosion occurs near the jetty when 180,000 yd³/yr comes from offshore. This is unsustainable and will undermine the jetty. Some of the material is depositing a couple of miles from the jetty and has yet to be transported by longshore drift to the jetty. For that reason, other parts of the East Beach experience advance. The 250,000 yd³/yr backpassing option results in a 750 ft wide beach while the 100,000 yd³/yr backpassing option provides a 200 ft wide beach. The Galveston Park Board only prefers a 200 ft wide beach, so the 250,000 and 356,000 yd³/yr

backpassing options are probably not necessary. However, the best option would be to fill the beach first and then begin backpassing since it will take a long period of time to build the beach to the required width with only backpassing.

Figure 78. Total shoreline change after 50 years for 100,000, 250,000, and 356,000 yd³ of backpassing with different source terms.



A final option is to construct the large-scale initial beach fill of 1,942,200 yd³ with backpassing. The 100,000 yd³/yr backpassing rate was combined with the large-scale beach fill to show the impact the initial beach fill has on the width of the beach. Figure 79 compares the 100,000 yd³/yr of backpassing with three outlets with and without the beach fill after 10 years. Figure 80 compares the two alternatives after 50 years. After 10 years, the average beach width along Reach 1 increases from 40 ft to 130 ft. The average beach width increases from 180 ft to 260 ft after 50 years when a large-scale beach fill was placed initially.

Figure 79. Total shoreline change after 10 years for 100,000 yd³ of backpassing with and without an initial beach fill.

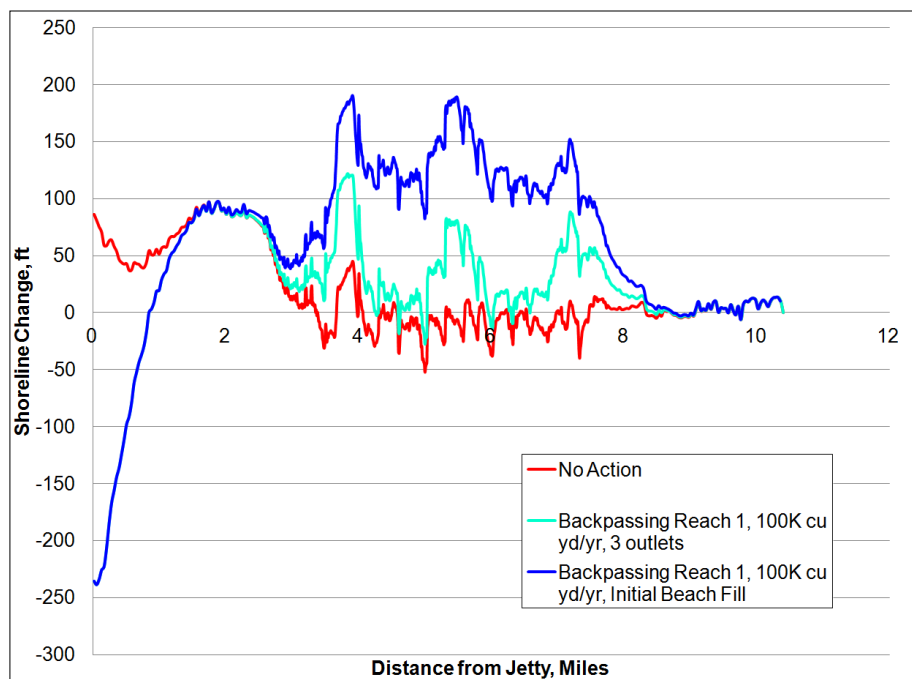
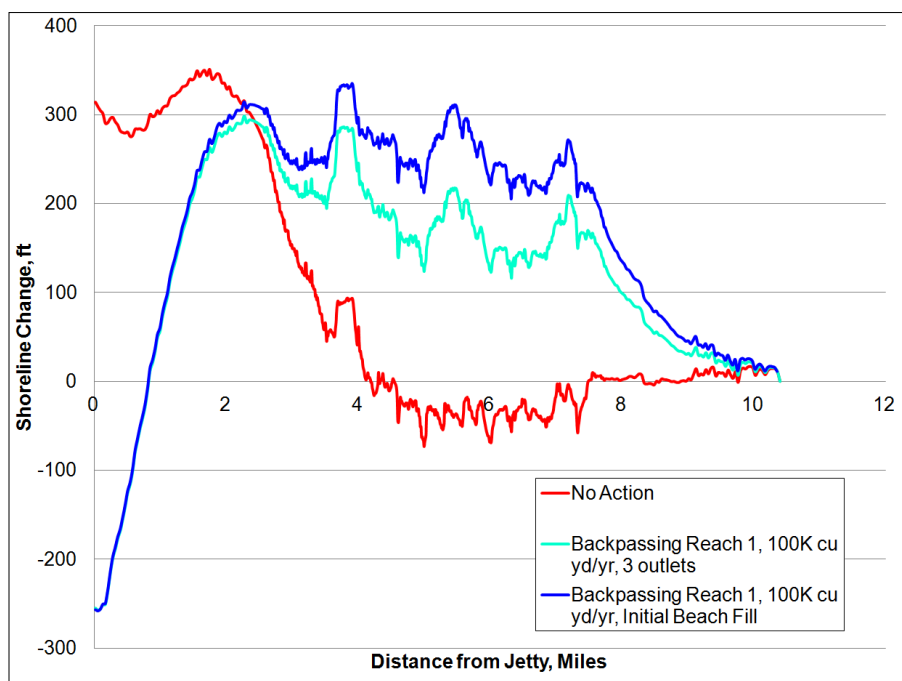


Figure 80. Total shoreline change after 50 years for 100,000 yd³ of backpassing with and without an initial beach fill.

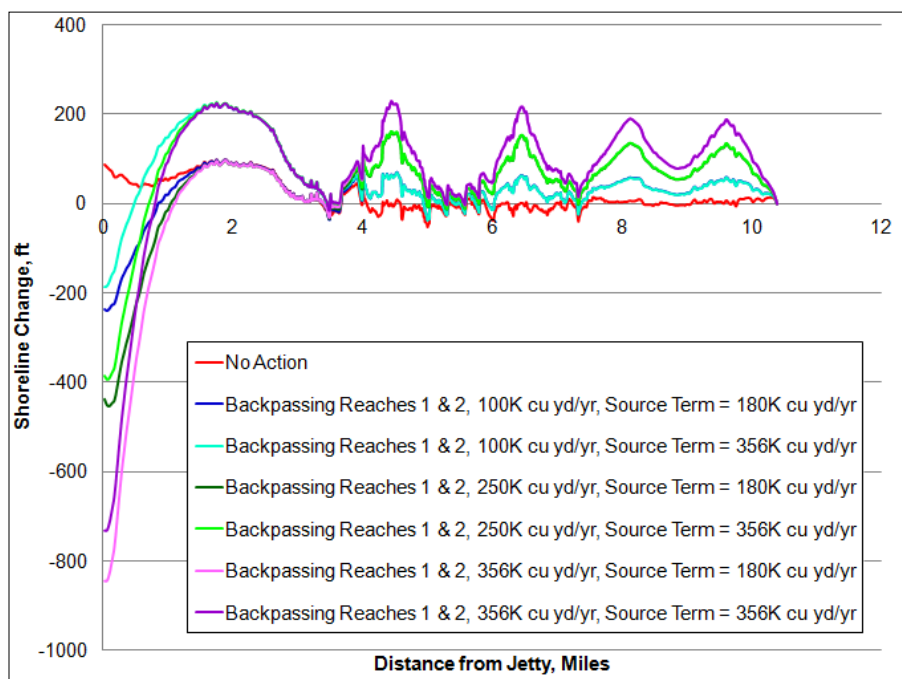


8.4.2 Level 2 – Backpassing in front of seawall

Level 2 consists of various rates of material being backpassed on Reaches 1 and 2. In all of the alternatives, there are two outlets on Reach 1 and two outlets along Reach 2. If it is determined that backpassing is the suitable option, the locations of the outlets can be adjusted.

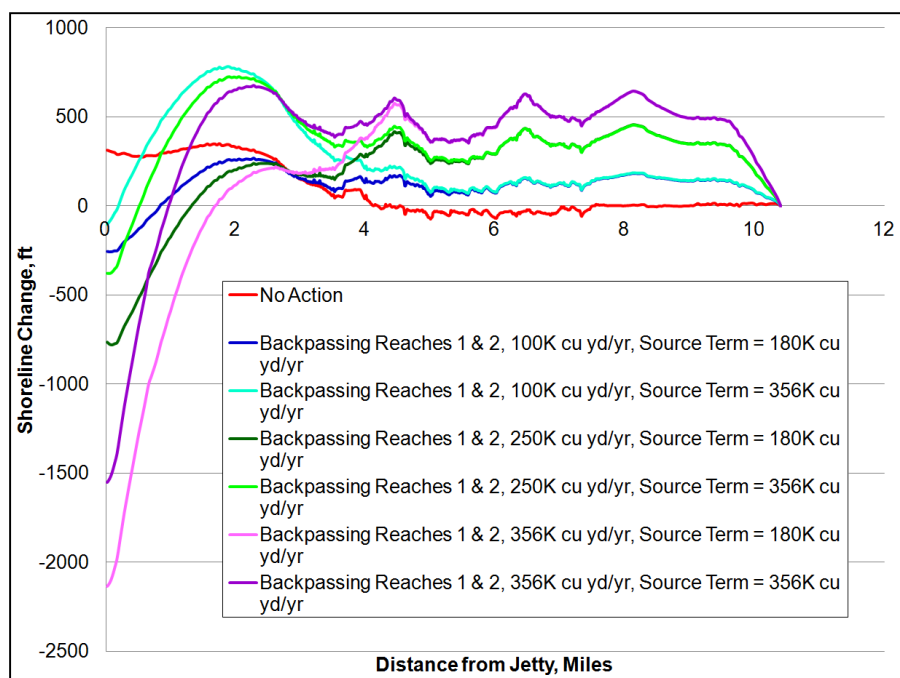
Figure 81 shows backpassing at rates of 100,000, 250,000, and 356,000 yd³/yr onto Reaches 1 and 2 from near the jetty after 10 years. Source terms of 180,000 and 356,000 yd³/yr are compared. The backpassing rate of 356,000 yd³/yr provides a maximum advance of 200 ft along the reaches. At 100,000 yd³/yr backpassing rate, the beach is only about 50 ft wide. With larger volumes of sand being backpassed at each outlet, the more likely it is that the beach width will not be uniform. When 356,000 yd³/yr is backpassed, the beach between two outlets only advances about 50 ft in some areas. It is recommended to adjust the location of the outlet along the beach to make the beach shape more uniform. Similar to the previous alternatives, it is important to keep in mind how much backpassing affects the shoreline near the jetty. When 180,000 yd³/yr moves onshore and 356,000 yd³/yr is backpassed, the shore retreats more than 800 ft near the jetty and retreat occurs compared to the initial shoreline for the first mile.

Figure 81. Total shoreline change after 10 years for 100,000, 250,000K, and 356,000 yd³ of backpassing on Reaches 1 and 2 with different source terms.



The total shoreline change after 50 years for the same scenarios is shown in Figure 82. After 50 years of backpassing 356,000 yd³/yr, the shoreline advances between 400 and 600 ft. The sand has dispersed more than after 10 years, so the shoreline between the outlets experience similar rates of advance. With 250,000 yd³/yr of backpassing, the shoreline is now about 350 ft wider than the initial shoreline while the 100,000 yd³/yr backpassing rate results in about 125 ft of advance. However, like the other alternatives, the material must come from near the jetty, which results in extreme erosion. When only 180,000 yd³/yr comes onshore and 356,000 yd³/yr is backpassed to Reaches 1 and 2, the shoreline erodes more than 2000 ft. Erosion occurs up to 1.6 miles away from the jetty. Although the 100,000 yd³/yr backpassing rate does not provide a 200 ft wide beach, it is the most reasonable options since it has the least impact along the jetty. If a beach fill is placed before backpassing begins, a lower backpassing rate will be necessary to maintain the beach. Again, before any construction is started, comprehensive studies and engineering design must be conducted.

Figure 82. Total shoreline change after 50 years for 100,000, 250,000, and 356,000 yd³ of backpassing on Reaches 1 and 2 with different source terms.



In order to illustrate how constructing an initial large-scale beach fill helps the backpassing process, the large-scale initial beach fill was added to the 100,000 yd³/yr backpassing alternative. The results after 10 and 50 years are shown in Figure 83 and Figure 84. After 10 years, the alternative with

the initial beach fill and backpassing produces a 140 ft wide beach along Reach 1 and a 280 ft wide beach along Reach 2. Without the initial beach fill, the beaches along Reaches 1 and 2 are only 25 ft and 50 ft wide, respectively. After 50 years, the average width of the beach along Reach 1 increases from 120 ft without the beach fill to 240 ft with the beach fill. Along Reach 2, constructing an initial beach fill increases the maximum beach width from 180 ft to 400 ft.

Figure 83. Total shoreline change after 10 years for 100,000 yd³ of backpassing along Reaches 1 and 2 with and without an initial beach fill.

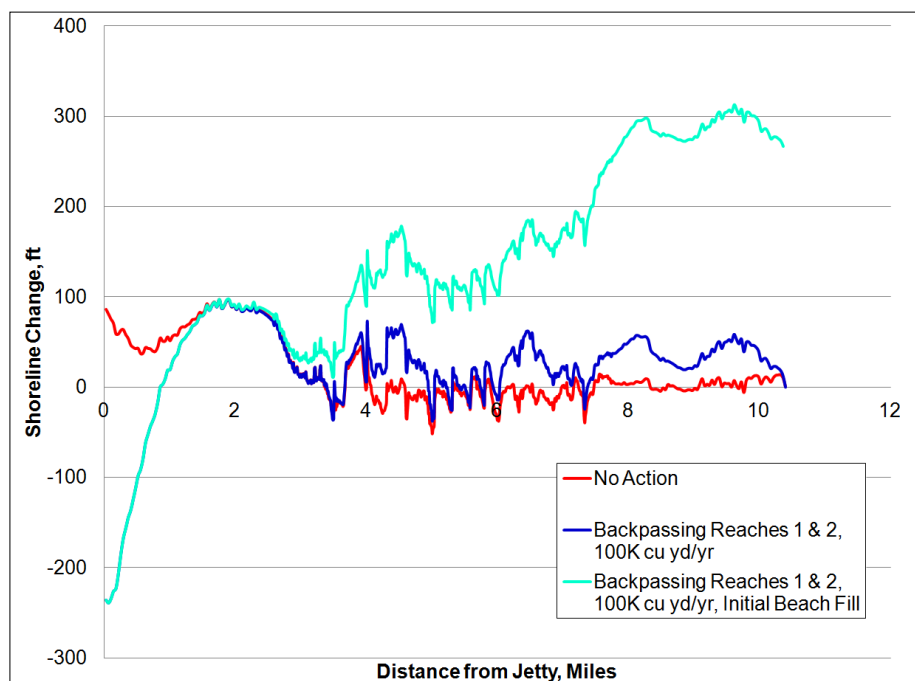
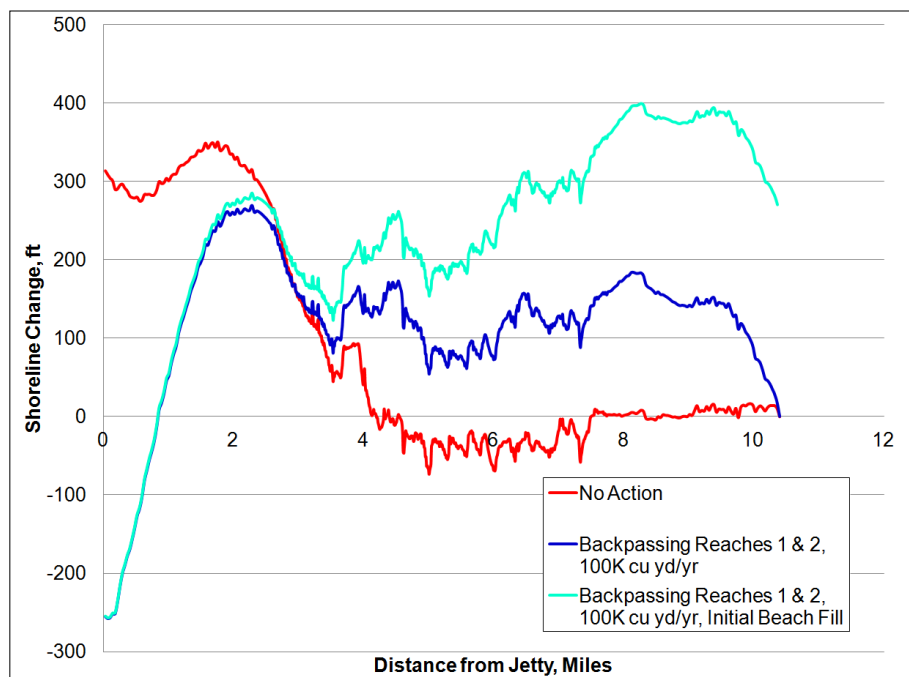


Figure 84. Total shoreline change after 50 years for 100,000 yd³ of backpassing along Reaches 1 and 2 with and without an initial beach fill.



8.5 Beach fills along west end

The GenCade alternatives focus on several levels of beach fills along Reaches 3 and 4. Level 1 consists of small beach fills along Galveston Park Board property (Dellanera RV Park and Pocket Parks 1, 2, and 3). Level 2 is represented by a beach fill along the first 1.5 mi to the west of the west end of the seawall. This short fill attempts to counter the end effects of the seawall. A beach fill covering all of Reach 3 refers to Level 3, while Level 4 is a beach fill in front of Reaches 3 and 4. Because Reach 5 is accreting, no beach fill was placed there.

8.5.1 Level 1 – Small beach fills along Galveston Park Board property

The first alternatives involved adding beach fills at Dellanera RV Park, Pocket Park 1, Pocket Park 2, and Pocket Park 3. The rationale for this level of nourishment is the present restriction on placing material on private property. Therefore, these may be the only locations where nourishment can be placed within the foreseeable future.

In Figure 85 and Figure 86, 5,000 yd³ of material is placed on each of the four Galveston Park Board properties. The renourishment interval ranges from 1 to 10 years. Small beach fills were modeled, because Reach 3 is a

lower priority area. If most of the funding is used in Reach 1, it is not likely that there will be money to fund a large beach fill. Also, each property only extends a short distance alongshore, so a large beach fill would be impractical. After 10 years, these small beach fill have little effect on the parks and Reach 3. While they do provide additional sand compared to the no action case, the shoreline is still receding more than 50 ft. However, this rate of retreat is based on historical shorelines, so it is possible the high rate of erosion may decrease or stabilize in the future especially with beach nourishment placed along the seawall.

After 50 years, the erosion along Reach 3 is even more noticeable. The no action case results in more than 250 ft of erosion. Although the shoreline advances about 30 ft from the no action case, the shoreline still erodes about 220 ft when 5,000 is placed at each location each year. This is a total of 1 million yd³ over 50 years. After 50 years, the sand disperses from each location, so that the entire shoreline receives some benefit. Unfortunately, this beach fill option will not provide reasonable protection along Reach 3.

Figure 85. Total shoreline change after 10 years for 5,000 yd³ beach fills on Galveston Park Board property.

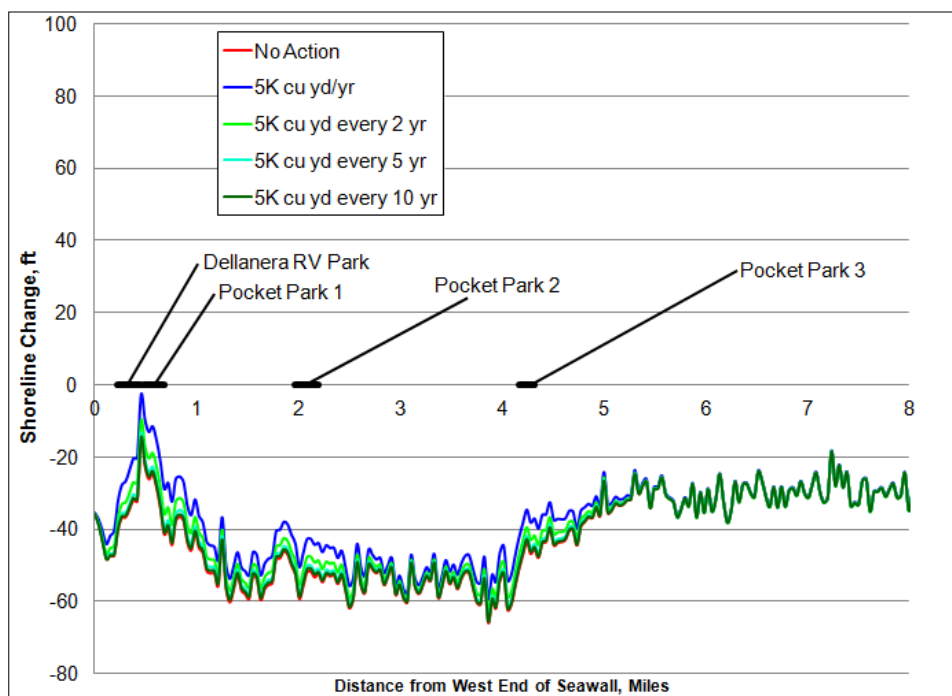
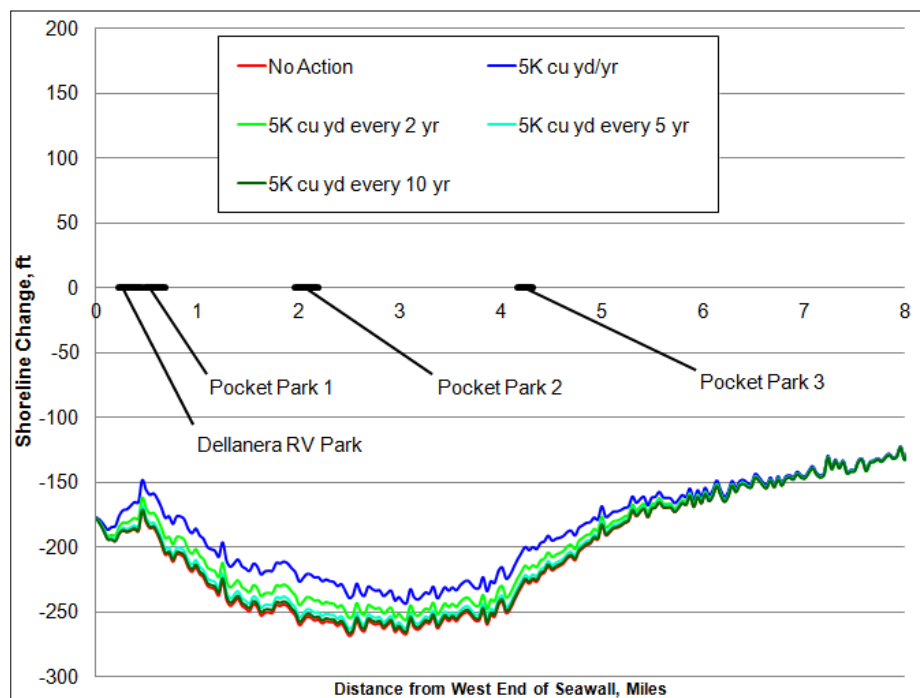


Figure 86. Total shoreline change after 50 years for 5,000 yd³ beach fills on Galveston Park Board property.



Another option is to add 20,000 of sand to each Galveston Park Board property with renourishment cycles every year, 2 years, 5 years, and 10 years. Figure 87 shows each 20,000 yd³ interval option after 10 years. When 20,000 yd³ is placed on each property each year, the shoreline advances near Dellanera RV Park and Pocket Park 1. Erosion occurs at all other locations. When the renourishment interval is longer, the entire shoreline along Reach 3 experiences erosion.

The total shoreline change for each 20,000 yd³ option after 50 years is shown in Figure 88. Even when 20,000 yd³ is placed on each property every year, the shoreline along the reach recedes about 125 ft on average. However, this option reduces erosion compared to the no action case by 100 ft. If the fills are renourished only every five years, erosion is reduced by about 20 ft compared to the erosion in the no action case. It is also important to keep in mind that although 125 ft sounds like severe retreat, it occurs over 50 years. The rate of erosion would be 2.5 ft/yr which much less than historical rates (Figure 2).

Figure 89 and Figure 90 compare 5,000, 10,000, and 20,000 yd³ placed on each property every two years after 10 and 50 years. While each of these beach fills and renourishments might advance the shoreline from the

no action case, they do little to advance the calculated shoreline from the initial shoreline. Figure 91 and Figure 92 compare the 5,000, 10,000, and 20,000 yd³ placements on each property every 5 years after 10 and 50 years. These less frequent nourishments have even less of an impact on the shoreline compared to the no action case.

While these alternatives could be beneficial in the short-term for each property, they will not provide a long-term benefit along Reach 3. Therefore, they should not be considered part of a long-term strategy to build a beach along all of Galveston Island, but could be considered a short-term option if a fill is needed in an emergency condition.

Figure 87. Total shoreline change after 10 years for 20,000 yd³ beach fills on Galveston Park Board property.

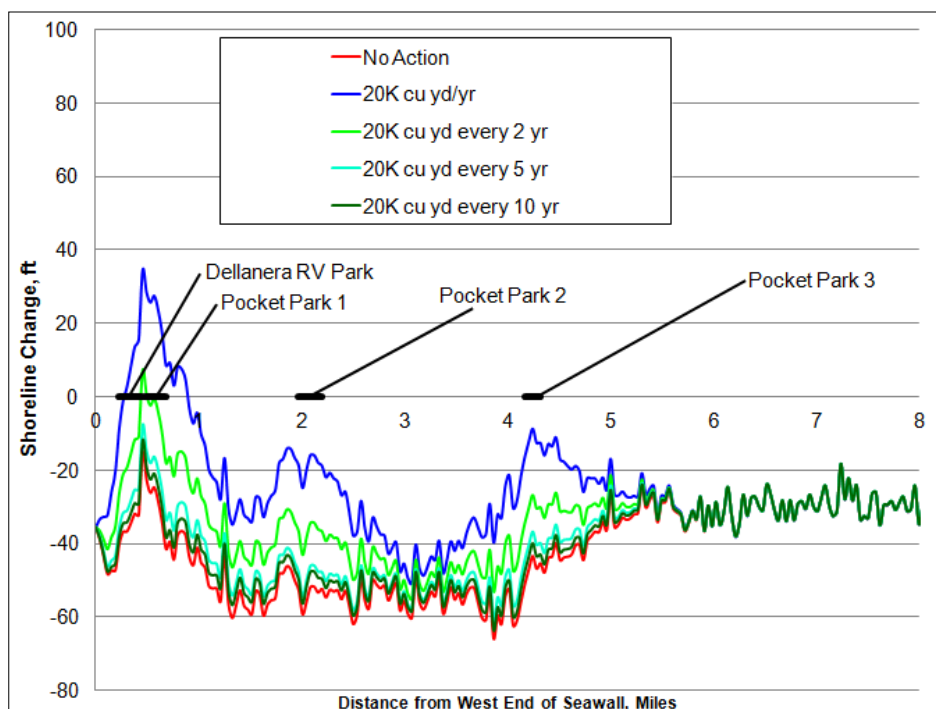


Figure 88. Total shoreline change after 50 years for 20,000 yd³ beach fills on Galveston Park Board property.

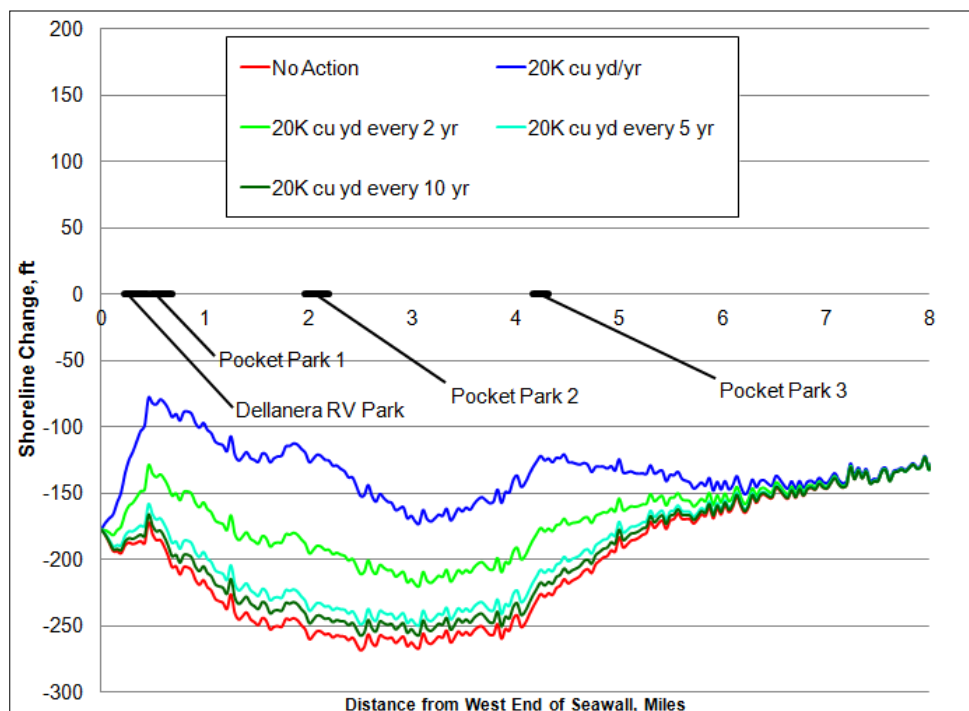


Figure 89. Total shoreline change after 10 years for 5,000, 10,000, and 20,000 yd³ beach fills nourished every 2 years on Galveston Park Board property.

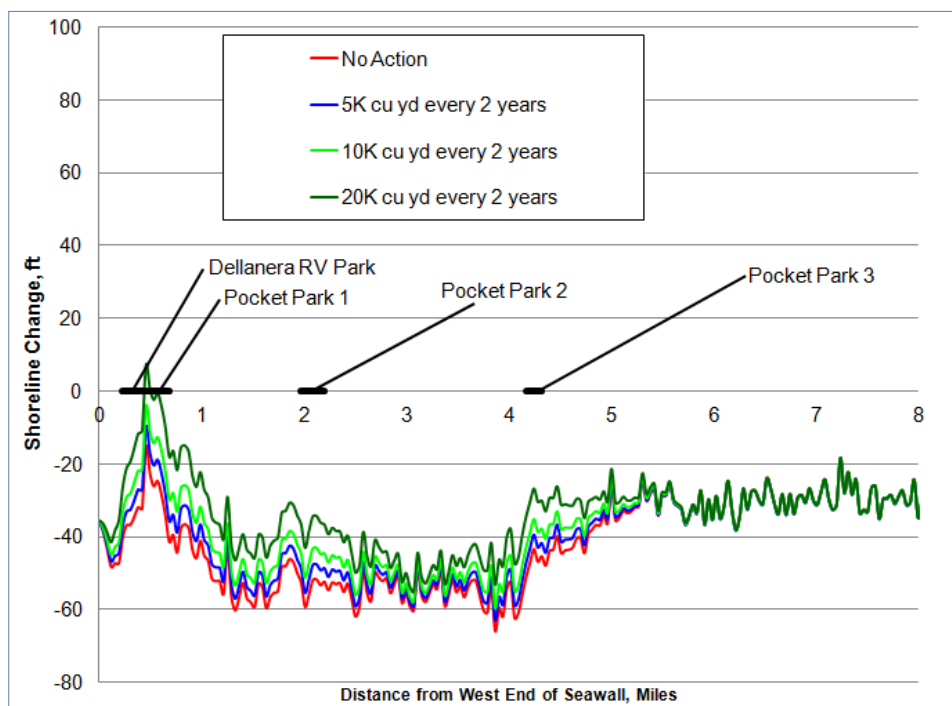


Figure 90. Total shoreline change after 50 years for 5,000, 10,000, and 20,000 yd³ beach fills nourished every 2 years on Galveston Park Board property.

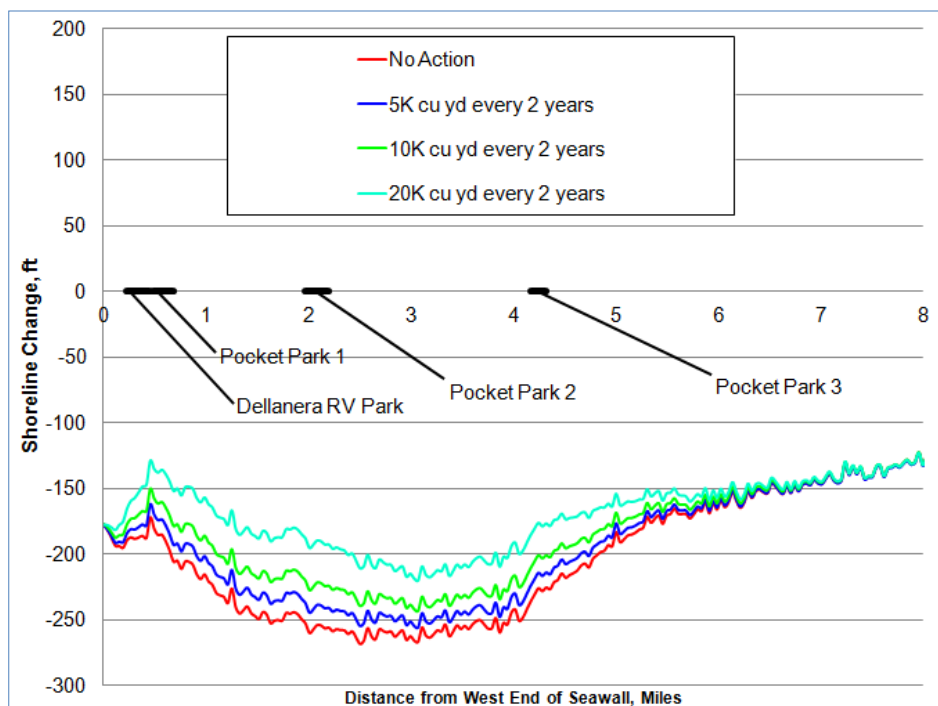


Figure 91. Total shoreline change after 10 years for 5,000, 10,000, and 20,000 yd³ beach fills nourished every 5 years on Galveston Park Board property.

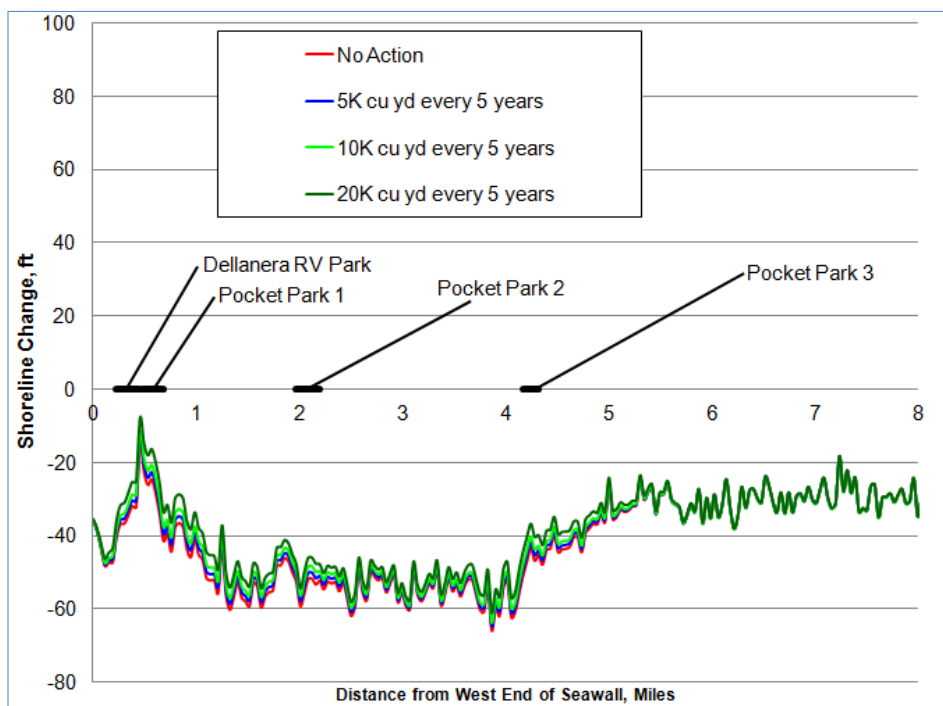
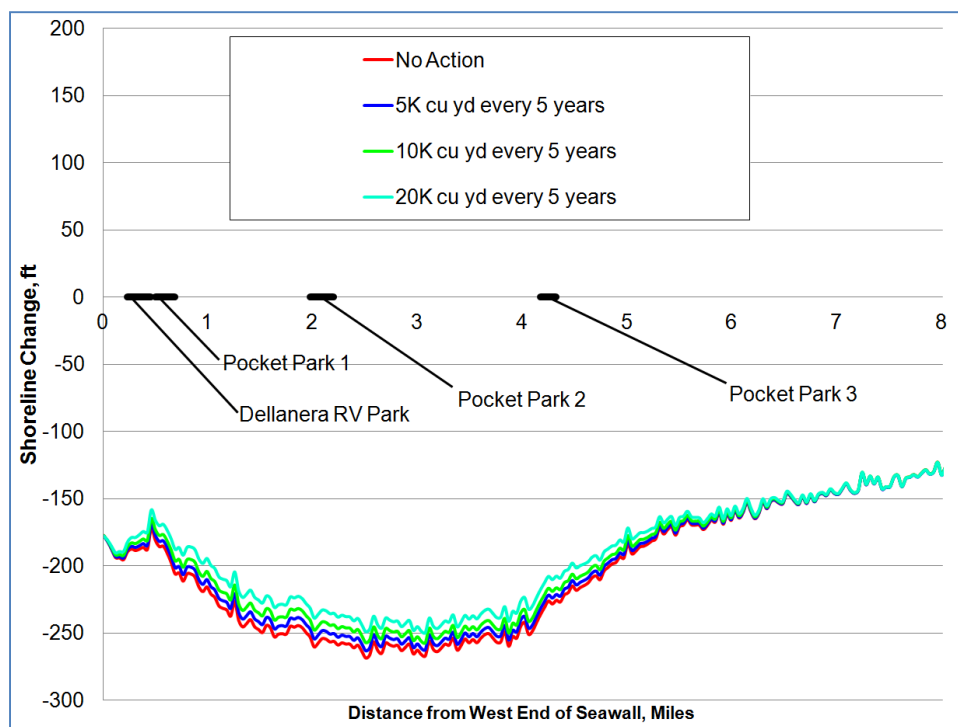


Figure 92. Total shoreline change after 50 years for 5,000, 10,000, and 20,000 yd³ beach fills nourished every 5 years on Galveston Park Board property.



8.5.2 Level 2 – Beach fill along first 1.5 mi of west end

Level 2 consists of a beach fill along the first 1.5 miles of the west end. The purpose of this fill is to help counter the end effects of the seawall. Beach fills of 50,000 and 100,000 yd³ were modeled with renourishment intervals of 1, 2, 5 and 10 years. Similar to the Level 1 beach fills, the initial fill volume is the same as the renourishment volume.

The first two figures, Figure 93 and Figure 94, compare 50,000 yd³ beach fills with renourishment cycles of 1, 2, 5, and 10 years after 10 and 50 years. After 10 years, the shoreline advances up to 40 ft near the seawall, but still recedes about 30 ft at 1.5 mi to the west. The 50,000 yd³ beach fill renourished every year matches the no action case at 2.5 mi west of the seawall, so the beach fill has no effect beyond that point. When 50,000 yd³ is only placed on the beach every 10 years, the effects are very minor. After 10 years, the shoreline recedes at least 55 ft and only provides about 5 additional ft of shoreline at the most compared to the no action case. After 50 years, the shoreline advances about 160 ft near the shoreline but recedes about 100 ft at 1.5 mi west of the seawall when the fill is renourished each year. If the 50,000 yd³ beach fill has a 10 year renourishment cycle, the shoreline erodes 150 ft near the seawall and up to

240 ft at 1.5 mi west. While the model shows a wide beach for the first half mile, nourishment is required every year and the cumulative nourishment in this case is 2.5 million yd³, which is a large volume of sand for a short distance along the beach.

Figure 93. Total shoreline change after 10 years with 50,000 yd³ beach fills nourished every 1, 2, 5, and 10 years along the first 1.5 mi of Reach 3.

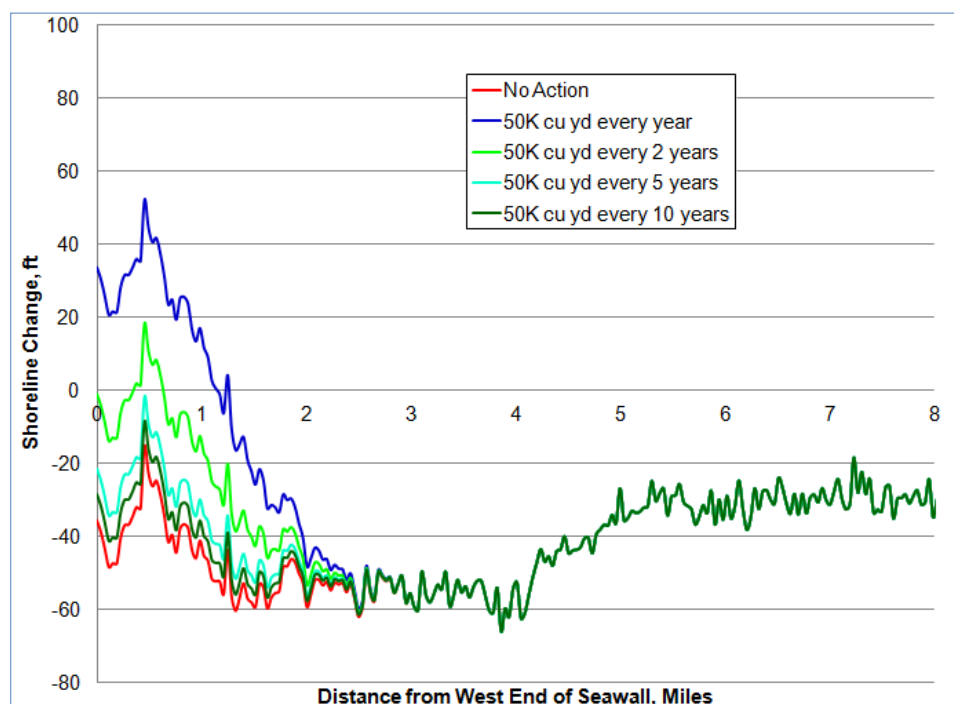
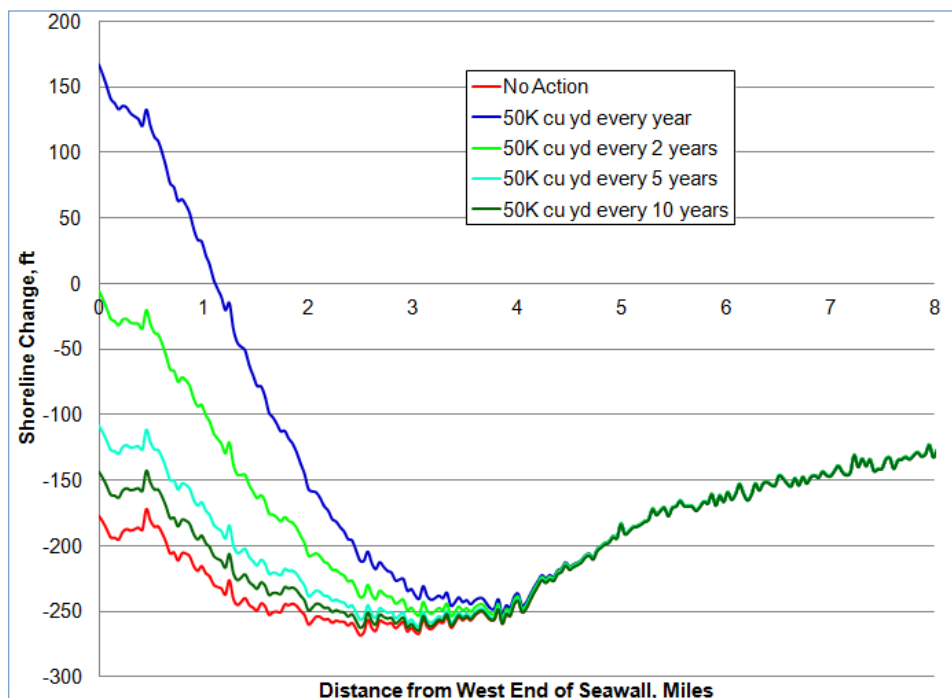
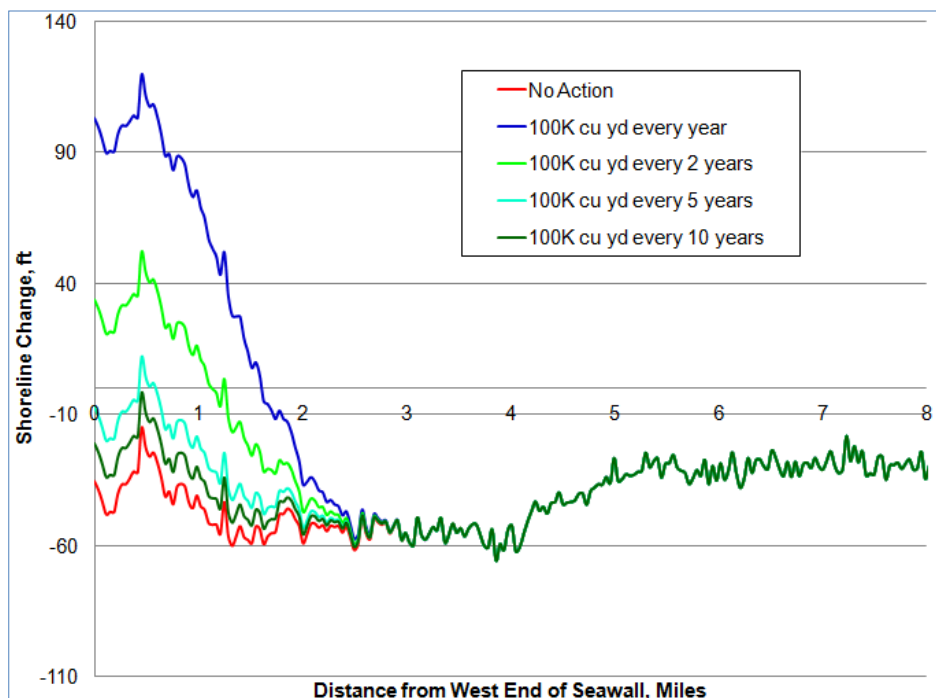


Figure 94. Total shoreline change after 50 years with 50,000 yd³ beach fills nourished every 1, 2, 5, and 10 years along the first 1.5 mi of Reach 3.



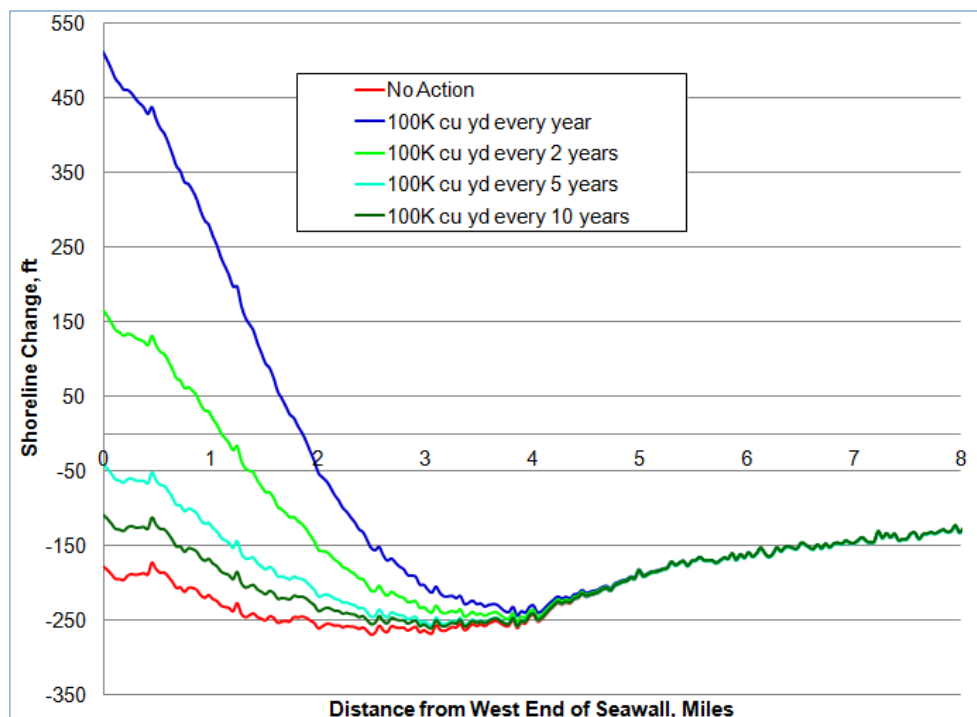
The same renourishment cycles and location were used, but the next alternatives looked at initial and renourishment volumes of 100,000 yd³ (Figure 95 and Figure 96). After 10 years, the 100,000 yd³ fill placed every year option results in shoreline advance of 120 ft total. However, the shoreline at 1.5 mi from the seawall is almost identical to the initial shoreline and it matches the no action case at 2.5 mi west. When 100,000 yd³ is placed every other year, the beach advances almost 50 ft near the seawall but erodes compared to the initial shoreline at 1.1 mi to the west. If 100,000 yd³ is placed every 5 or 10 years, the shoreline erodes compared to the initial along all of Reach 3.

Figure 95. Total shoreline change after 10 years with 100,000 yd³ beach fills nourished every 1, 2, 5, and 10 years along the first 1.5 mi of Reach 3.



The total shoreline change after 50 years for different renourishment cycles of 100,000 yd³ is shown in Figure 96. When 100,000 yd³ is renourished every 5 or 10 years, the entire beach recedes from initial, although the 5-year renourishment cycle provides an additional 120 ft of shoreline near the seawall compared to the no action alternative. The model predicts that 100,000 yd³ of material placed every other year will advance the beach 150 ft near the seawall. The model also predicts a 500 ft wide beach near the seawall with 100K yd³ renourished every year. However, one problem is that two separate grid were used for the calibration and alternatives. The model does not realize that there is seawall adjacent to the grid boundary since a moving boundary condition was used to represent the seawall and the shoreline change at the boundary. It does not make sense that the shoreline could advance beyond the seaward location of the seawall. It should be noted that placing 100,000 yd³/yr along the 1.5 mi closest to the seawall will result in a wide beach adjacent to the seawall, but it is highly unlikely that a beach as wide as predicted in the model could occur.

Figure 96. Total shoreline change after 50 years with 100,000 yd³ beach fills nourished every 1, 2, 5, and 10 years along the first 1.5 mi of Reach 3.



8.5.3 Level 3 – Beach fill along Reach 3

Level 3 refers to a beach fill and renourishment along all of Reach 3. The first alternatives are 50,000 yd³ beach fills renourished over 1, 2, 5, and 10 years. Figure 97 and Figure 98 compare the 50,000 yd³ beach fills with the no action scenario after 10 and 50 years. After 10 years, regardless of the renourishment cycle, the shoreline along Reach 3 erodes from the initial. Renourishing every year results in a total of 500,000 yd³ placed on the beach, but the shoreline still erodes about 50 ft from the initial. However, adding the beach fills results in an advance of 25 ft compared to the no action alternative. After 50 years, the erosion along Reach 3 will be about 250 ft with action. The shoreline erosion when 50,000 yd³/yr of material is placed is between 100 and 170 ft. Although small beach fills along Reach 3 do not advance the shoreline from the initial, they do help decrease the erosion. It is possible that beach fills can be constructed on Reach 3, but they will not protect the shoreline for a long period of time nor are they part of the strategy to develop a 200 ft wide beach all along Galveston Island.

Figure 97. Total shoreline change after 10 years with 50,000 yd³ beach fills nourished every 1, 2, 5, and 10 years along Reach 3.

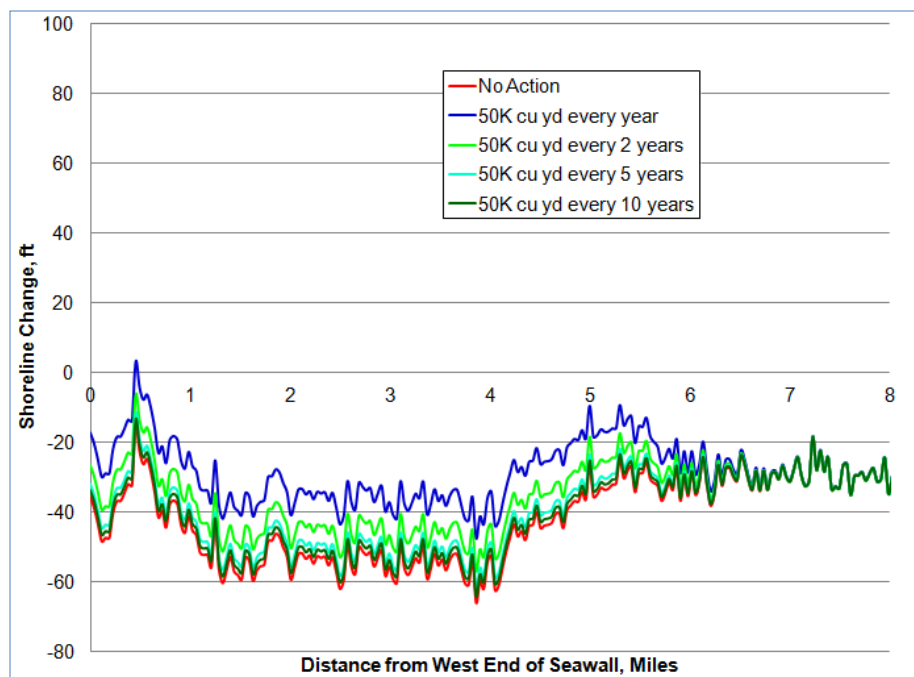
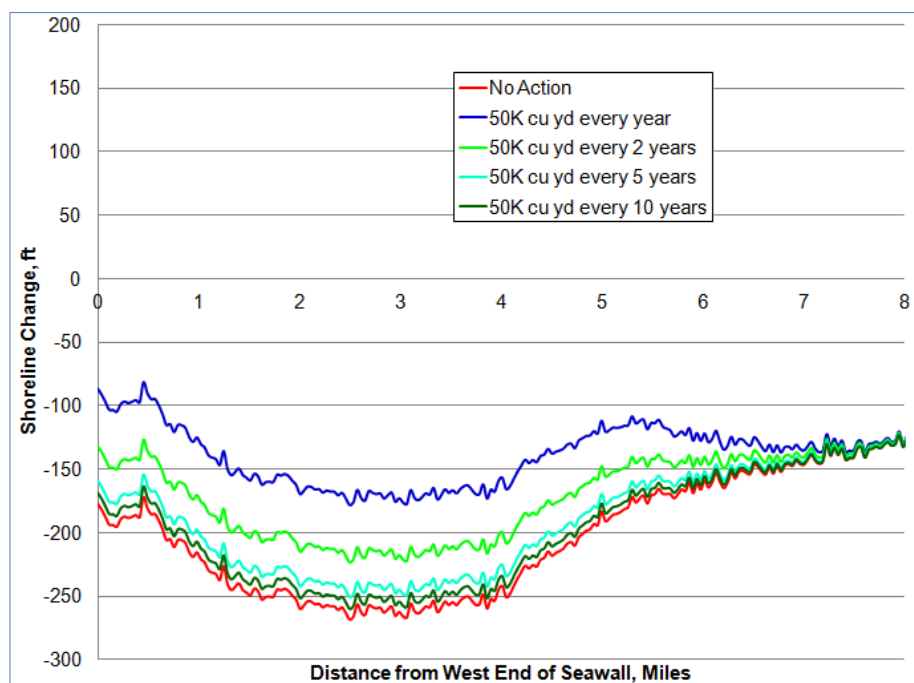


Figure 98. Total shoreline change after 50 years with 50,000 yd³ beach fills nourished every 1, 2, 5, and 10 years along Reach 3.



Similar alternatives along Reach 3 with 100,000 yd³ beach fills were modeled. Figure 99 and Figure 100 compare 100,000 yd³ initial beach fills with 1, 2, 5, and 10 year renourishment intervals and the no action

scenario after 10 and 50 years. After 10 years of placing 100,000 yd³ of sand on the beach every year, the shoreline only erodes about 10 ft. This is about 40 ft less retreat compared to the no action case. It is important to note that 100,000 yd³/yr is 1 million yd³ in 10 years. This is larger than the nourishments in front of the seawall over the last 20 years. If it takes 1 million yd³ to keep the shoreline almost stable, it is possible that improving other locations along the island would be more beneficial. Renourishing every 5 or 10 years has little impact on the shoreline. After 50 years, renourishing every year results in shoreline erosion of about 50 ft, or 1 ft/yr. This is much less than the historical retreat rate in the area. Renourishing the beach fill every other year for a total of 2.5 million yd³ results in erosion of 150 ft. Although extreme erosion occurs in both of these cases, it is still much less than the 250 ft eroded without action.

Figure 99. Total shoreline change after 10 years with 100,000 yd³ beach fills nourished every 1, 2, 5, and 10 years along Reach 3.

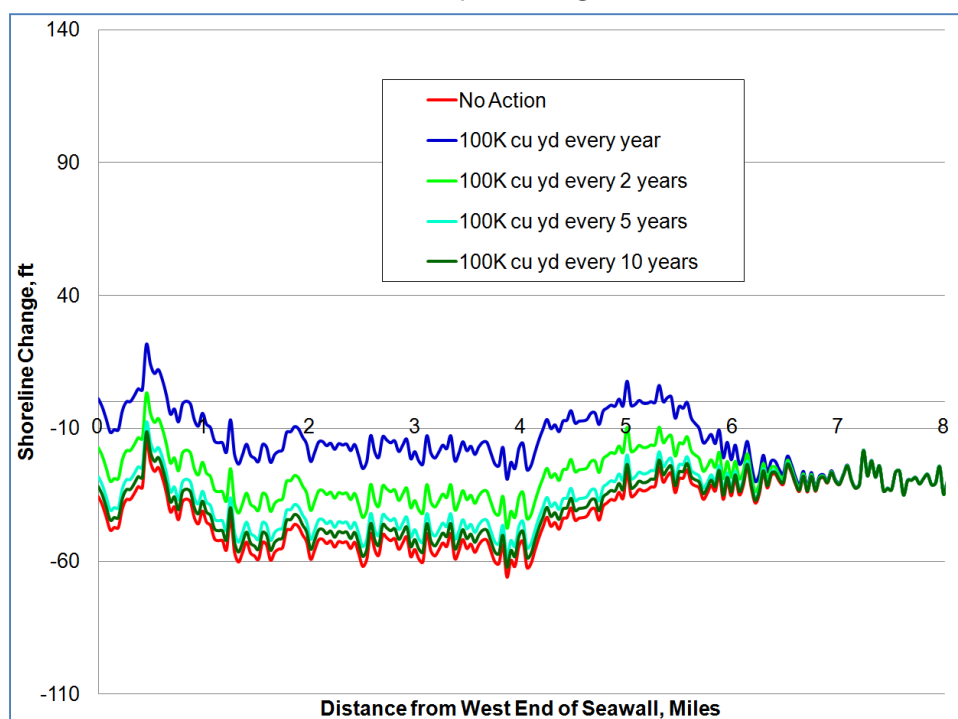


Figure 100. Total shoreline change after 50 years with 100,000 yd³ beach fills nourished every 1, 2, 5, and 10 years along Reach 3.

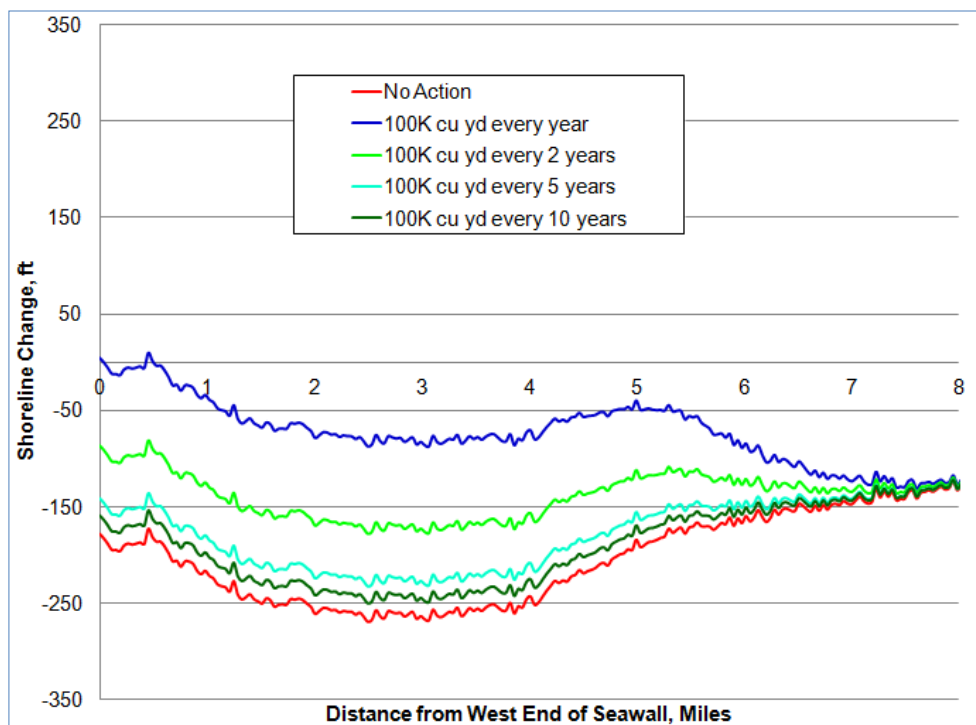


Figure 101 and Figure 102 compare 50,000 and 100,000 yd³ placements renourished every two years over the 1.5 mi closest to the west end of the seawall and over Reach 3 for 10 and 50 years. In Figure 101, the beach placement along the first 1.5 mi have no effect after about 2.5 mi. While the beach fills along Reach 3 do not advance the shoreline compared to the no action case as much as the 1.5 mi long beach fills, they do provide a little additional protection along the remainder of Reach 3. In Figure 102, the 1.5 mi long fills result in advance near the seawall but erode much more than the Reach 3 fills. Beyond 4 mi west of the seawall, the 1.5 mi long beach fills are identical to the calculated shoreline for the no action case. Figure 103 and Figure 104 show similar results when the 50,000 and 100,000 yd³ fills are nourished every 5 years across the first 1.5 mi of the west end and across Reach 3. It is important to show the scenarios together, so that one can see how the location and distance of the beach fill impact the shoreline response along the entire reach.

Figure 101. Comparison of total shoreline change with different beach fill volumes along the 1.5 mi west of the seawall and along Reach 3 after 10 years.

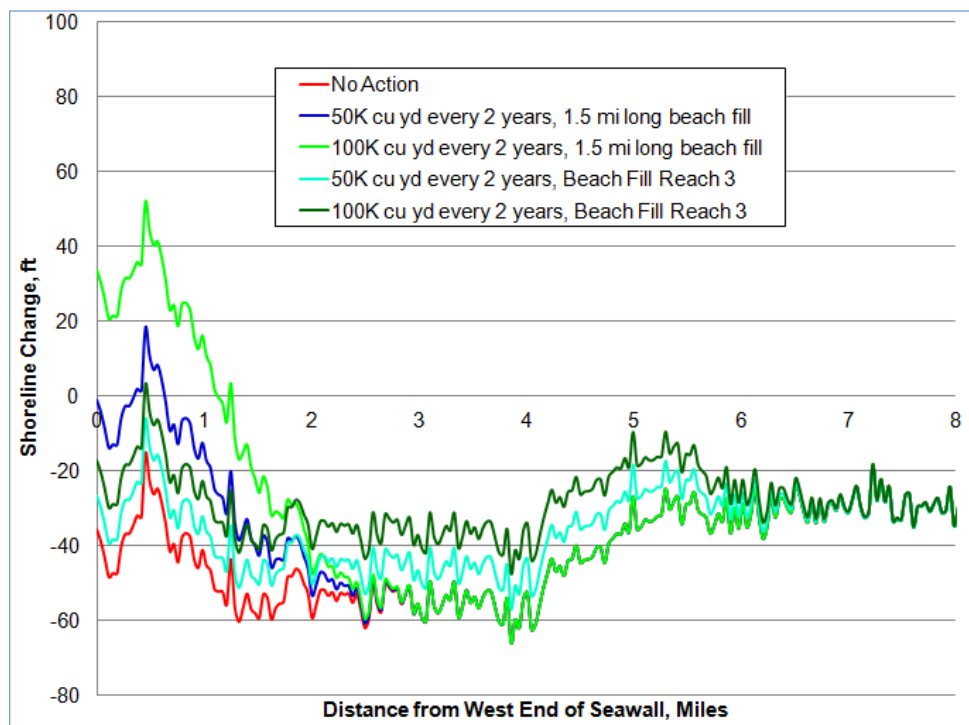


Figure 102. Comparison of total shoreline change with different beach fill volumes along the 1.5 mi west of the seawall and along Reach 3 after 50 years.

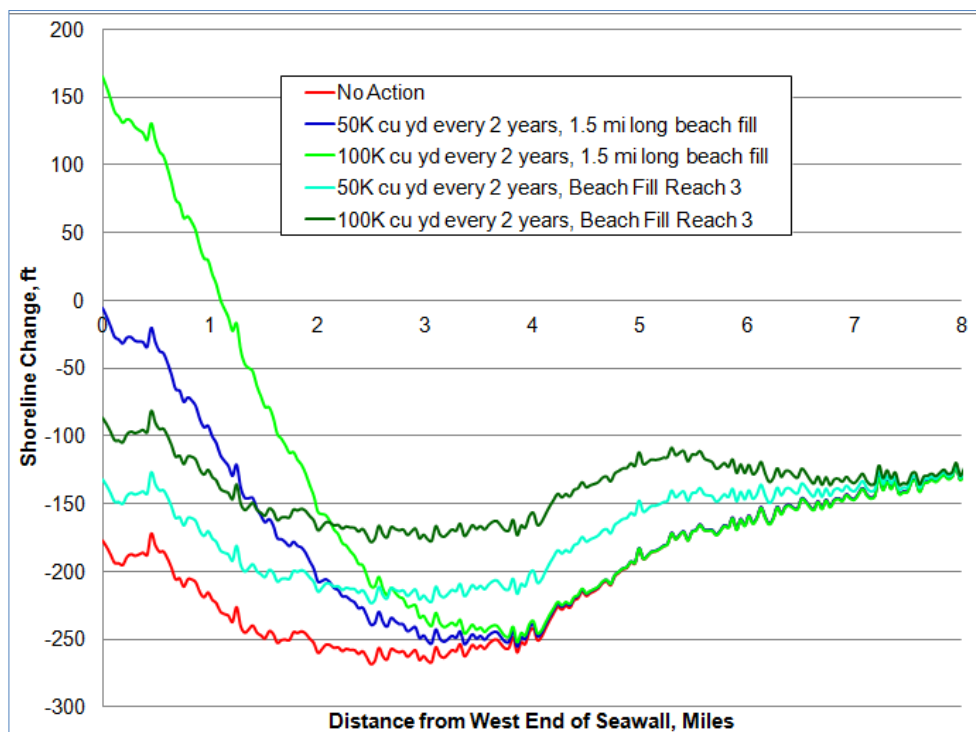


Figure 103. Comparison of total shoreline change with different beach fill volumes renourished every 5 years along the 1.5 mi west of the seawall and along Reach 3 after 10 years.

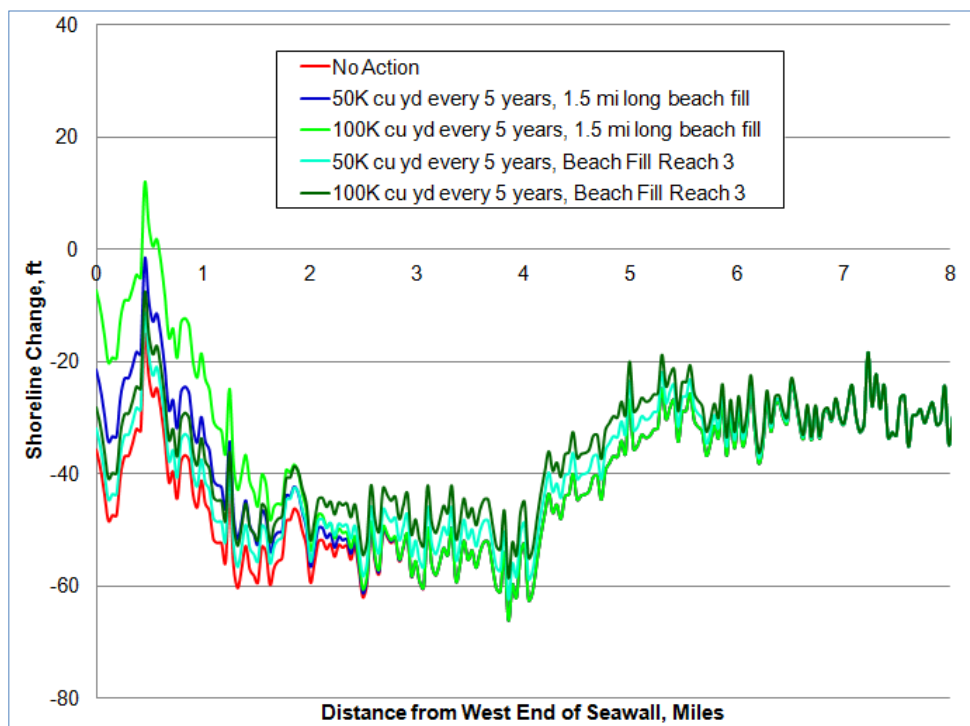
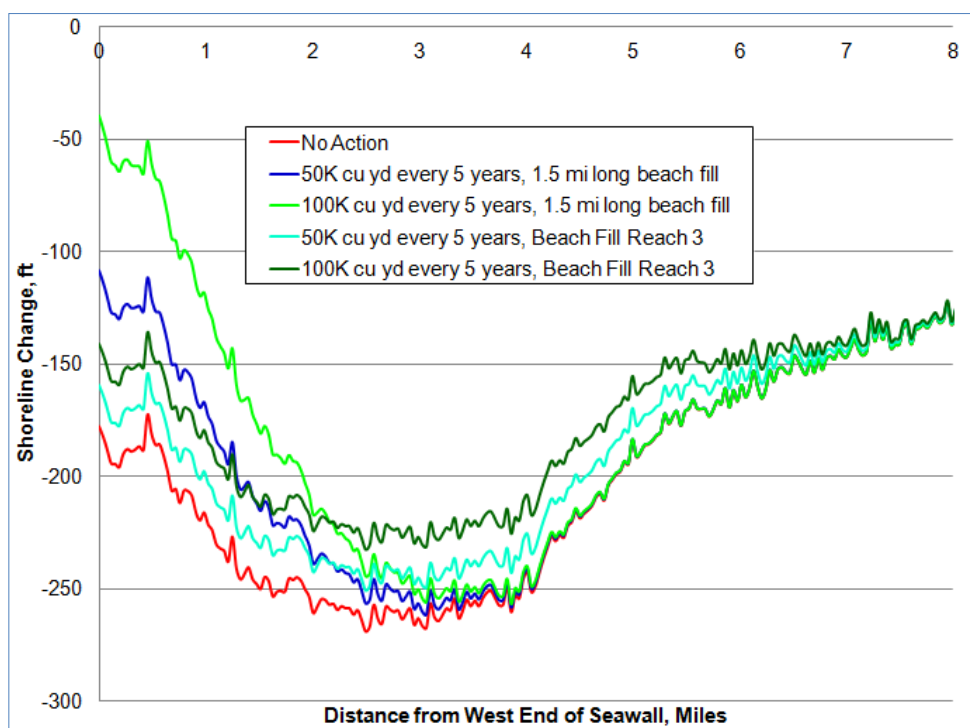


Figure 104. Comparison of total shoreline change with different beach fill volumes renourished every 5 years along the 1.5 mi west of the seawall and along Reach 3 after 50 years.



8.5.4 Level 4 – Beach fill along Reaches 3 and 4

The Level 4 beach fill expands across Reaches 3 and 4. The alternatives consist of 250K and 1M yd³ beach fills renourished over 2, 5, and 10 years. The total shoreline change after 10 years is shown in Figure 105. Placing 1M yd³ of sand across Reaches 3 and 4 every other year for 10 years is the only alternative which results in advance from the initial shoreline. The other alternatives advance the shoreline from the no action case between 5 and 25 ft. The 1M yd³ beach fill renourished every 5 years averages little shoreline change from the initial, but the shoreline erodes closer to the seawall and accretes more than 10 mi from the seawall. The same pattern can be seen after 50 years (Figure 106). The 1M yd³/yr beach fill results in a more than 200 ft wide beach beyond 5 mi west of the seawall. Every other alternative results in erosion less than 7 mi from the seawall. The 250K yd³ beach fill that is renourished every 10 years only results in 10 ft more beach than the no action case. Placing 1.25M over 50 years to see only 10 ft more beach than without action is not a worth the time and money.

Figure 105. Total shoreline change with 250K and 1M yd³ beach fills with different renourishment cycles after 10 years.

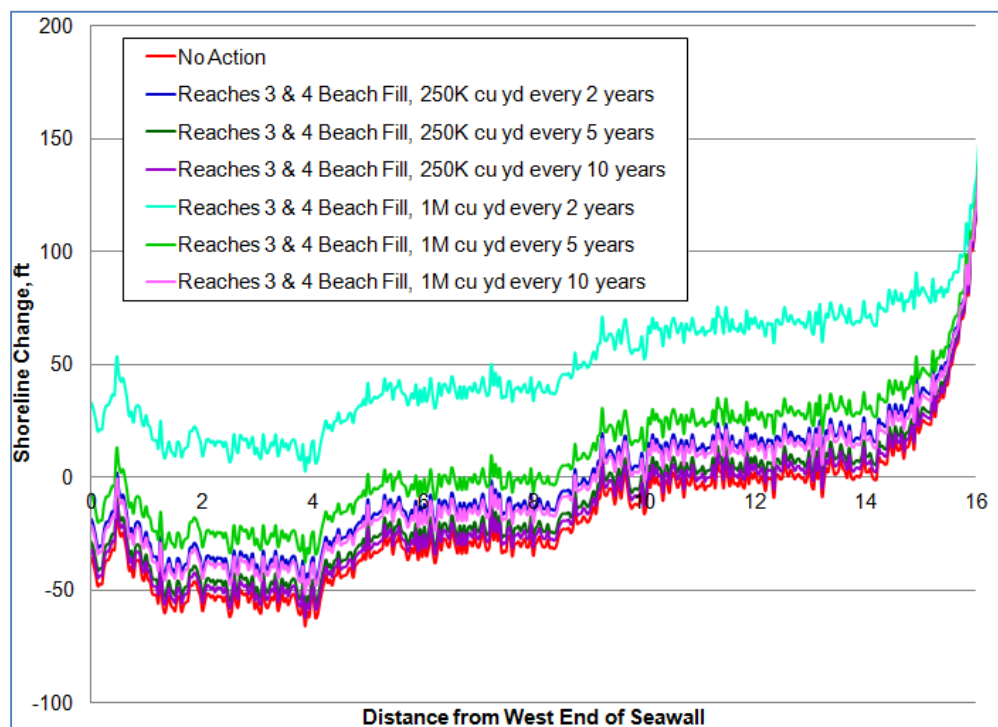
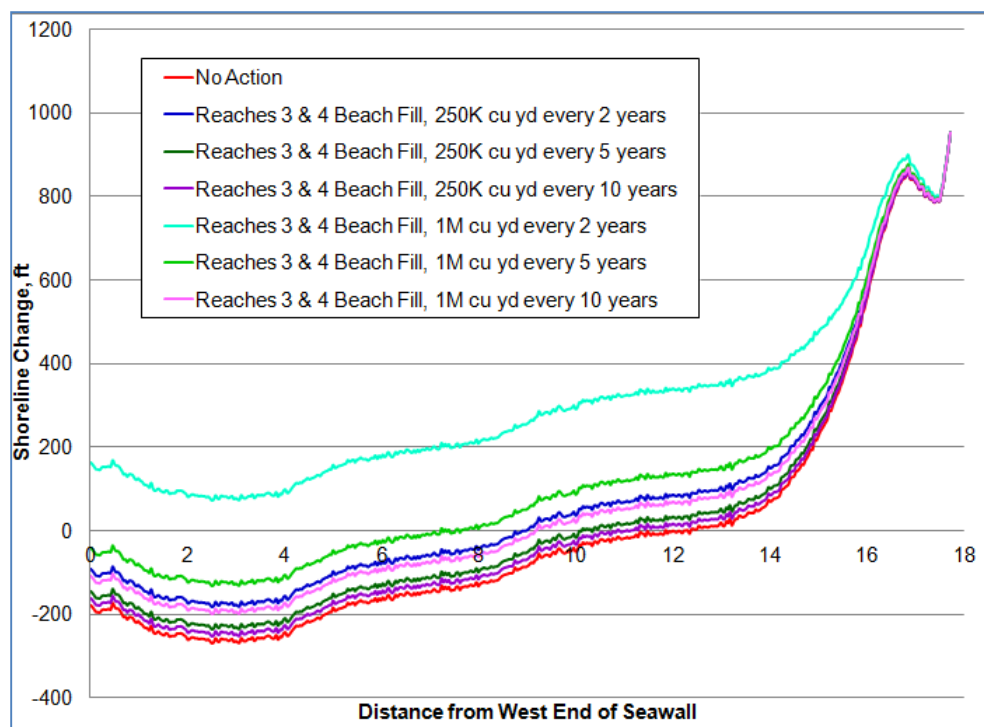


Figure 106. Total shoreline change with 250,000 and 1 million yd^3 beach fills with different renourishment cycles after 50 years.



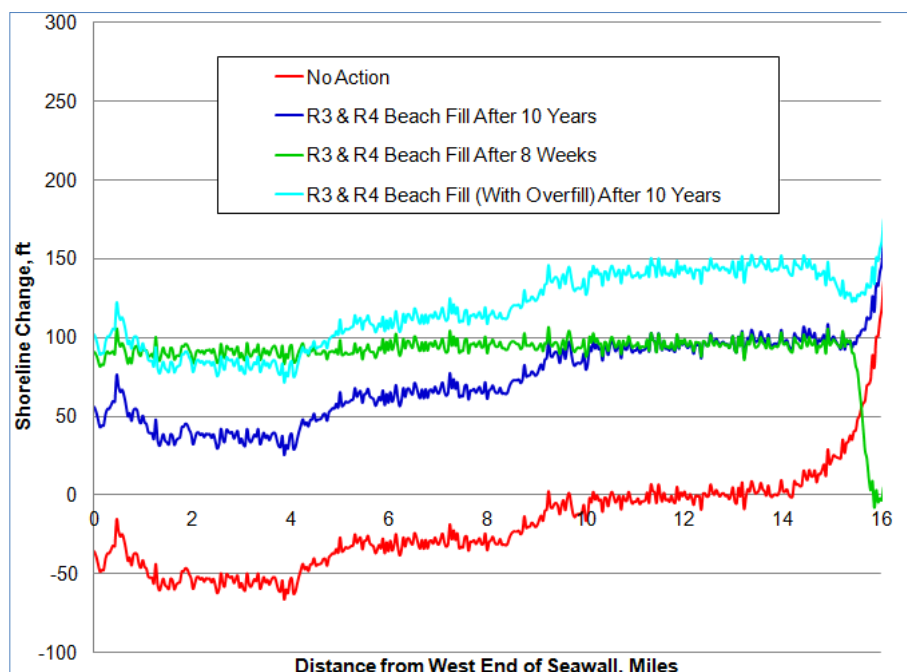
8.5.5 Level 5 – Large-scale beach fill along Reaches 3 and 4

The final alternative consists of a large-scale beach fill along Reaches 3 and 4. If a large-scale beach fill occurs on Reaches 3 and 4, Reaches 1 and 2 would have already been nourished with a large-scale beach fill or a combination of a large-scale beach fill with backpassing. Therefore, this option would be the most expensive and require the greatest volume of sand.

The beach fill is based on the volume calculated in the large-scale beach fill chapter (Chapter 7). Reach 3 requires an initial beach fill of 2,518,800 yd^3 and Reach 4 consists of an initial beach fill of 4,407,900 yd^3 . Each beach fill requires an advanced nourishment on the order of 50 percent. Figure 107 compares the total shoreline change for the no action alternative to the large-scale beach fill with and without overfill after 10 years. The light green represents the position of the shoreline after 8 weeks, which is when the beach fill construction is complete within the simulation. In order to keep the shoreline position similar to the position immediately after the large-scale beach fill, it is necessary to place about 275,000 yd^3 every 2 years or 735,000 yd^3 every 5 years. The majority of that material needs to be placed along Reach 3 because Figure 107 shows that there is very

little change in the shoreline position in Reach 4 from 8 weeks to 10 years. The total sand needed to advance the beaches of Reaches 3 and 4 between 100 and 150 ft from the initial shoreline is 13,526,700 yd³ if renourishing every 2 years or 13,541,700 yd³ if renourishing every 5 years. The main reason this volume is much less than the 1 million yd³/yr is due to the large initial beach nourishment. The large beach fill protects the shoreline for a longer period of time and will not require as large renourishments as when a smaller volume is used for the initial construction and for each subsequent nourishment.

Figure 107. Total shoreline change with a large-scale beach fill along Reaches 3 and 4 after 10 years.



8.6 Backpassing along west end

Three levels of backpassing were considered along the west end of Galveston Island. Each backpassing scenario consists of a backpassing plant near San Luis Pass and outlets along Reaches 3 and 4.

8.6.1 Level 1 – Backpassing

Level 1 backpassing involves either 50,000 or 200,000 yd³/yr from San Luis Pass to a single outlet along the first 1.5 mi of the west end. Specifically, the outlet is located 0.75 mi from the west end of the seawall. Figure 108 and Figure 109 compare the total shoreline change for backpassing of 50,000 yd³/yr and 200,000 yd³/yr after 10 and 50 years.

In addition, the initial large-scale beach fill of 2,518,800 yd³ along R3 was added to the backpassing alternatives for comparison purposes. After 10 years, the influx of sand is confined to the first 2 miles west of the seawall. With a backpassing rate of 50,000 yd³/yr, the maximum shoreline advance is about 50 ft at the outlet. This increases to about 150 ft when the large-scale beach fill is constructed at the beginning of the simulation. The large-scale beach fill on top of the backpassing advances the shoreline about 50 ft from the initial shoreline along Reach 3. The 200,000 yd³/yr backpassing rate results in more than 300 ft of advance at the outlet without the beach fill and more than 400 ft with the beach fill. After about 2 miles, the sand placed on the beach through backpassing has little effect on the shape of the shoreline. After 50 years, the impact of the sand from backpassing extends to about 4 miles west of the seawall. If only backpassing 50,000 yd³/yr and constructing the initial fill, the majority of the shoreline retreats after 50 years. When 200,000 yd³/yr is backpassed and the initial fill is constructed, shoreline advance only occurs up to about 2.3 mi west of the seawall. It is also important to note that when 200,000 yd³/yr is backpassed from near San Luis Pass, this equates to 10 million yd³ over a 50 year period. The shoreline near San Luis Pass no longer advances as expected and actually recedes in some locations. It will be necessary to conduct additional studies and complete detailed engineering design before developing a backpassing plant. GenCade assumes that the shoreline trends that occur in the past will occur in the future. However, it is possible that the shoreline along near San Luis Pass might not accrete at the present rate. If this does not occur, backpassing any amount of sand could erode the shoreline. Therefore, adaptive management is a key component of this plan.

Figure 108. Total shoreline change with backpassing along the first 1.5 mi of Reach 3 after 10 years.

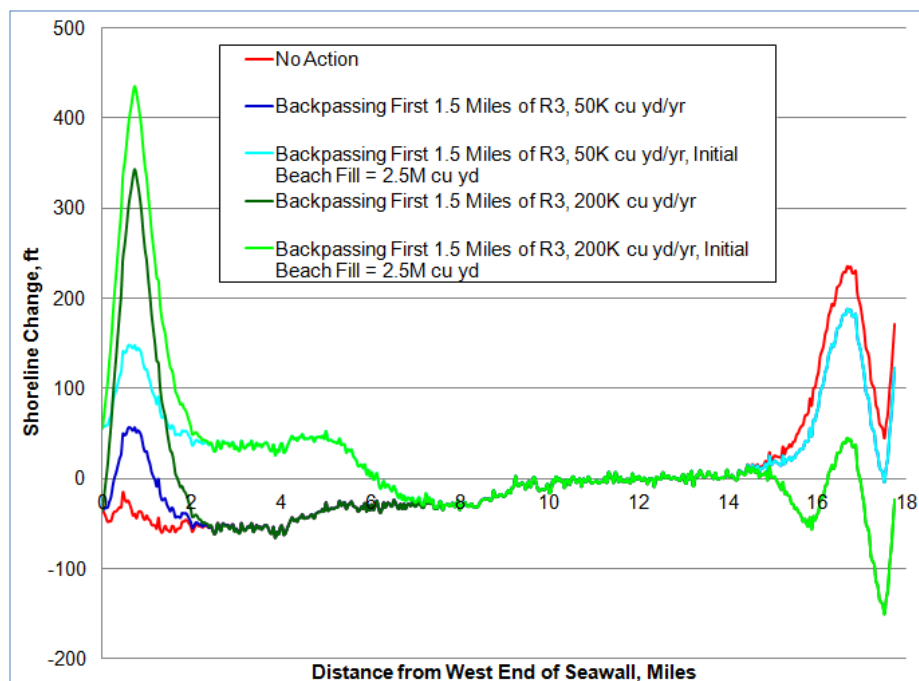
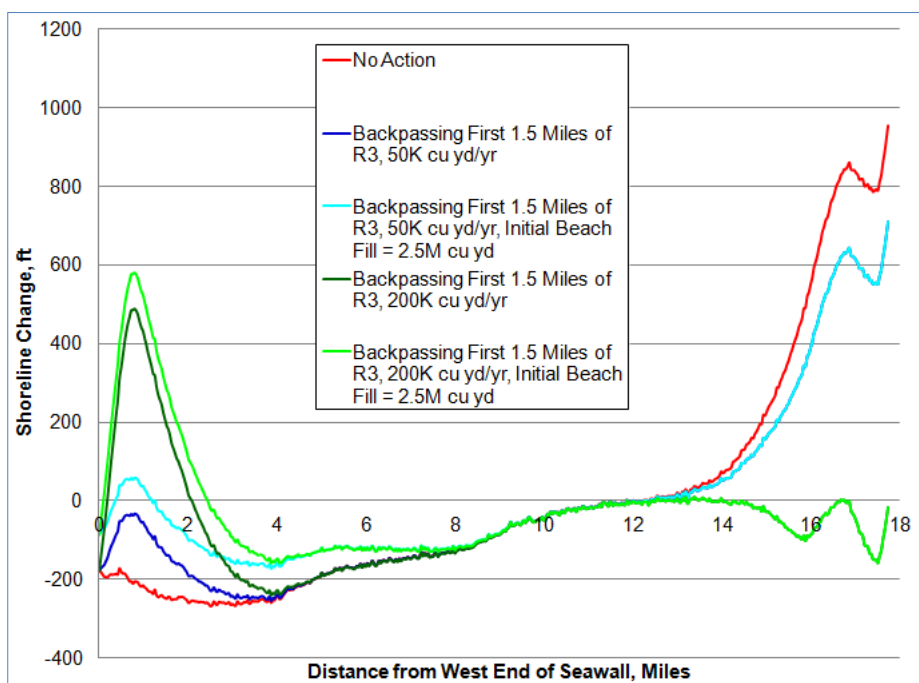


Figure 109. Total shoreline change with backpassing along the first 1.5 mi of Reach 3 after 50 years.



8.6.2 Level 2 – Backpassing along Reach 3

The second level requires backpassing 50,000 or 200,000 yd³/yr of sand from San Luis Pass to four outlets along Reach 3. Figure 110 and Figure 111 show total shoreline change for backpassing with and without a large-scale initial beach fill along Reach 3 for 10 and 50 years. When only 50,000 yd³/yr is backpassed, the beach fill has a much greater impact on shoreline position. The shoreline accretes by about 50 ft with the beach fill but erodes about 30 ft without it. The four outlets are extremely noticeable when 200,000 yd³/yr is backpassed. The sand from each outlet has not reached the sand from the other outlets, so the shoreline position is not very uniform. The average shoreline position advance is 40 ft without the beach fill and 120 ft with the beach fill. After 50 years with 50,000 yd³/yr of backpassing, both the alternatives with and without the beach fill have retreated beyond the initial shoreline. But 250,000 yd³/yr backpassing with the beach fill results in a shoreline advance of 250 ft along Reach 3. With the 250,000 yd³/yr backpassing but without the beach fill, the shoreline advances about 190 ft. In all cases, the shoreline position matches the no action case at about 7.5 mi west of the seawall. Figure 112 and Figure 113 compare the 50,000 cu yr/yr of backpassing case along the first 1.5 mi of Reach 3 to the Reach 3 alternatives for 10 and 50 years.

Figure 110. Total shoreline change with backpassing along Reach 3 after 10 years.

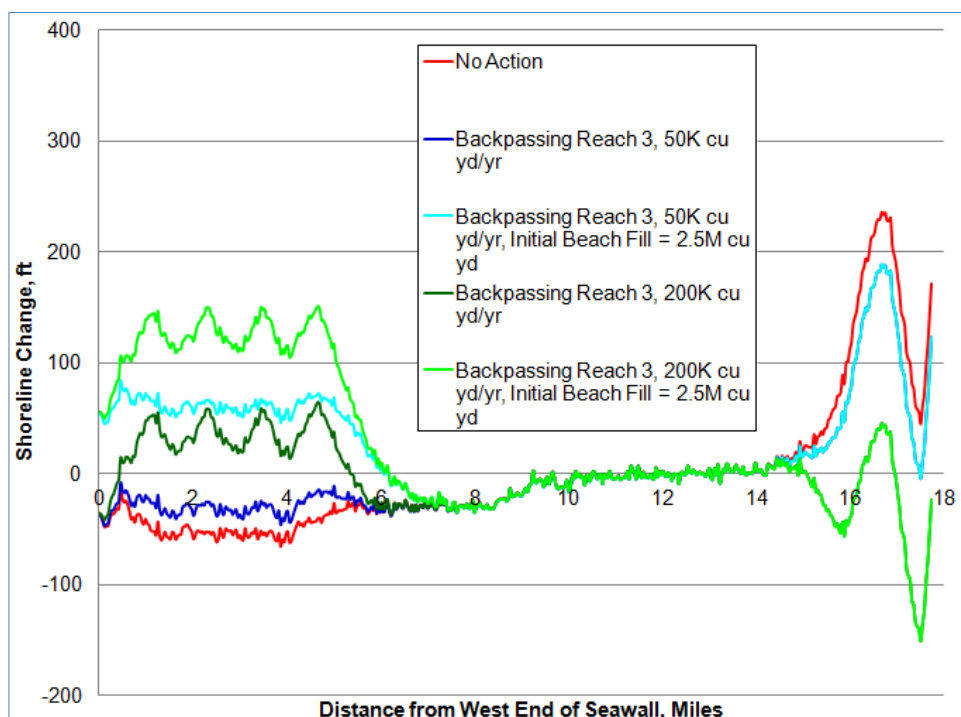


Figure 111. Total shoreline change with backpassing along Reach 3 after 50 years.

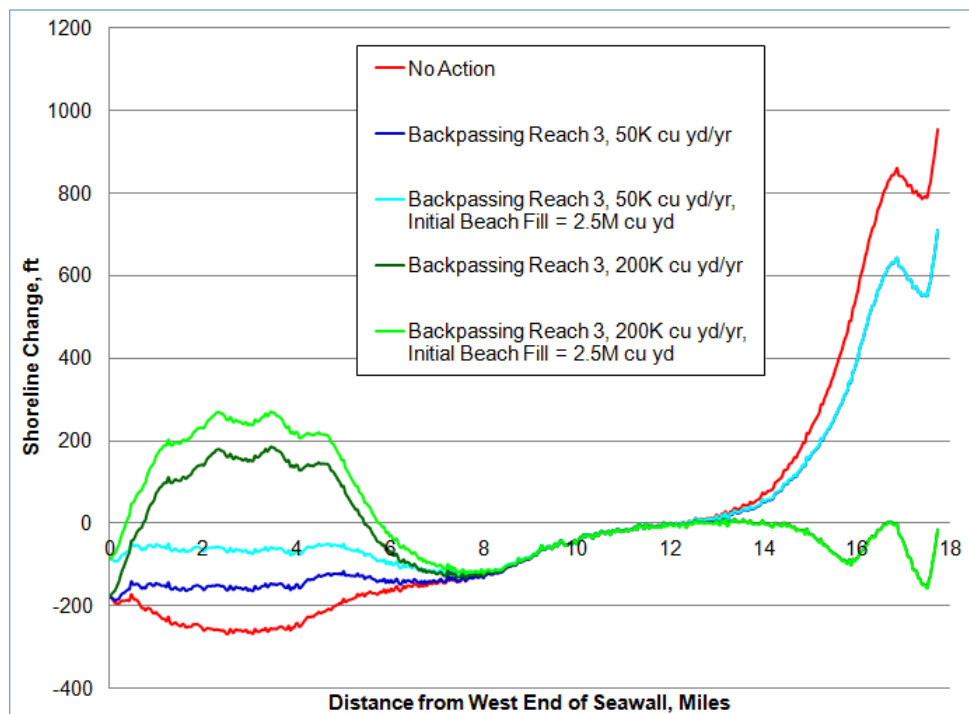


Figure 112. Total shoreline change with 50,000 yd³/yr of backpassing along the first 1.5 mi of Reach 3 and along all of Reach 3 after 10 years.

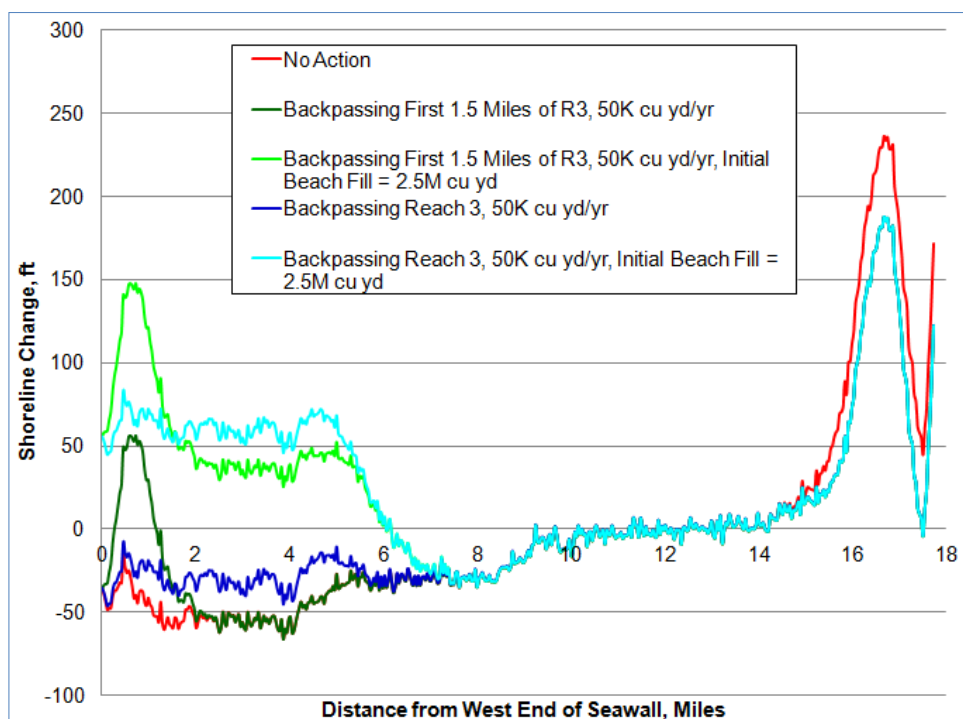
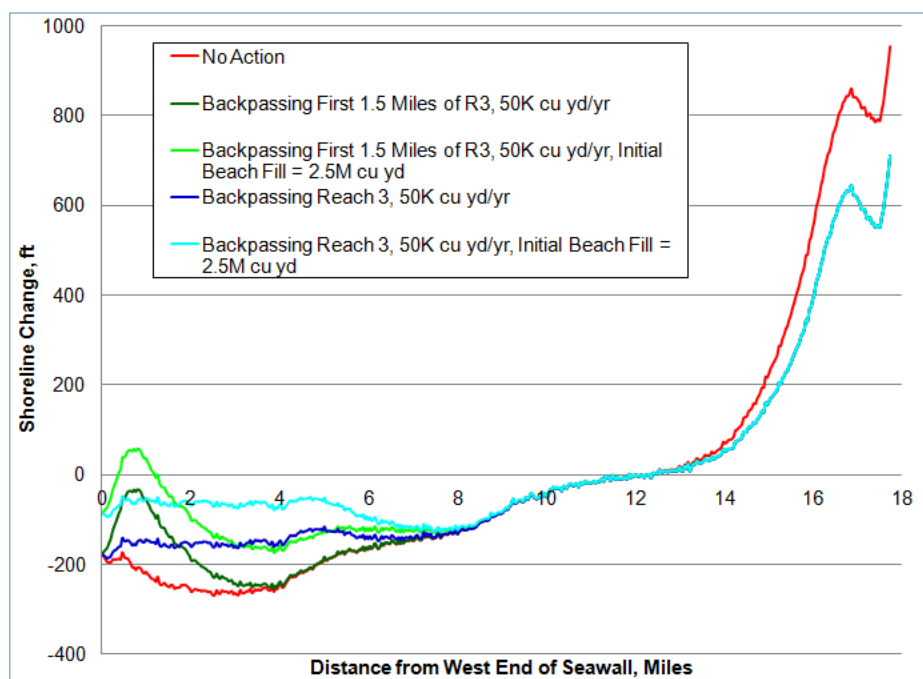


Figure 113. Total shoreline change with 50,000 yd³/yr of backpassing along the first 1.5 mi of Reach 3 and along all of Reach 3 after 50 years.



8.6.3 Level 3 – Backpassing along Reaches 3 and 4

The final level of backpassing, along the west end involves backpassing 150,000 yd³/yr and 300,000 yd³/yr to Reaches 3 and 4. In Figure 114, backpassing 150,000 yd³/yr and 300,000 yd³/yr are compared to the same backpassing scenarios with the large-scale initial beach fill along Reaches 3 and 4 after 10 years. In all cases, the shoreline advances near the outlets. However, about halfway between each outlet, the shoreline recedes to the no action case when 150,000 yd³/yr of backpassing occurs without an initial beach fill. The same type of trend occurs with backpassing of 300K yd³/yr. The shoreline advances about 100 ft near the outlets but recedes to the no action alternative midway between the outlets. When the initial beach fill is included, the shoreline advances a minimum of 50 ft between the outlets and up to 150 and 240 ft with the 150,000 yd³/yr and 300,000 yd³/yr of backpassing, respectively. After 50 years, the shoreline advances west of the 6 mi marker when only 150,000 yd³/yr of backpassing occurs (Figure 115). The 300,000 yd³/yr backpassing combined with the initial fill creates the widest beach along Reaches 3 and 4 after 50 years. If the sand is backpassed to more than four locations through adjustable outlets, the shoreline advance will be more uniform. The shoreline still erodes less than 2 mi west of the seawall, but the rest of the shoreline accretes between 100 and 450 ft. Although

300,000 yd³/yr is backpassed from near San Luis Pass, the shoreline near the inlet does not retreat as much as the Reach 3 backpassing scenarios. The reason this happens is because the sand is backpassed to two locations along Reach 4. The final outlet along Reach 4 is very close to Reach 5. Since longshore transport moves from east to west along the west end, the model shows that the sand moves from Reach 4 and deposits on Reach 5.

Figure 114. Total shoreline change after 10 years of backpassing along Reaches 3 and 4.

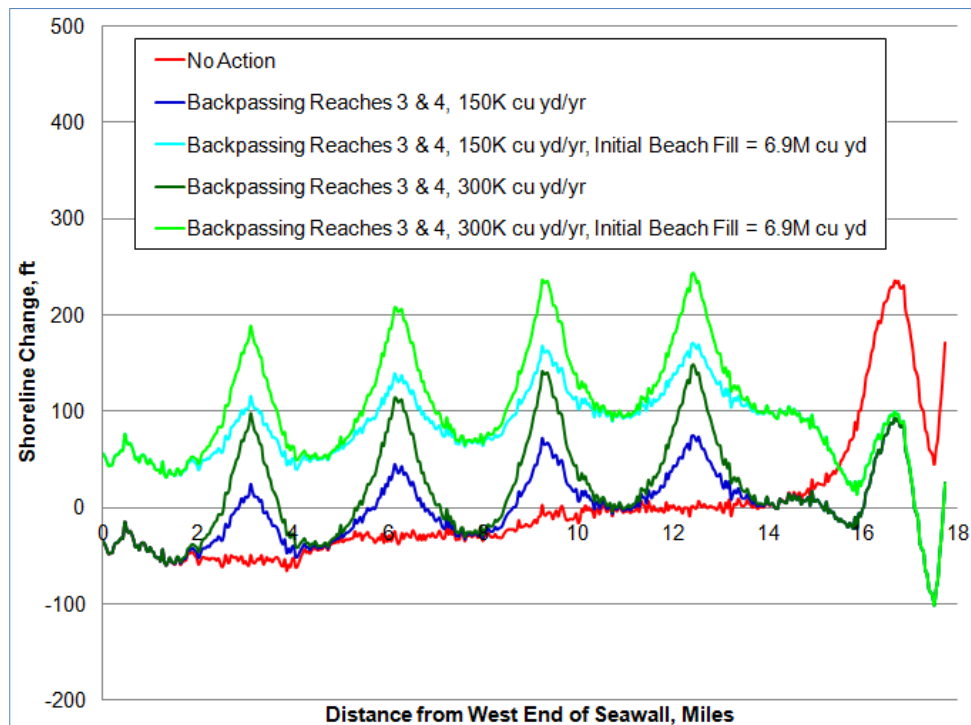
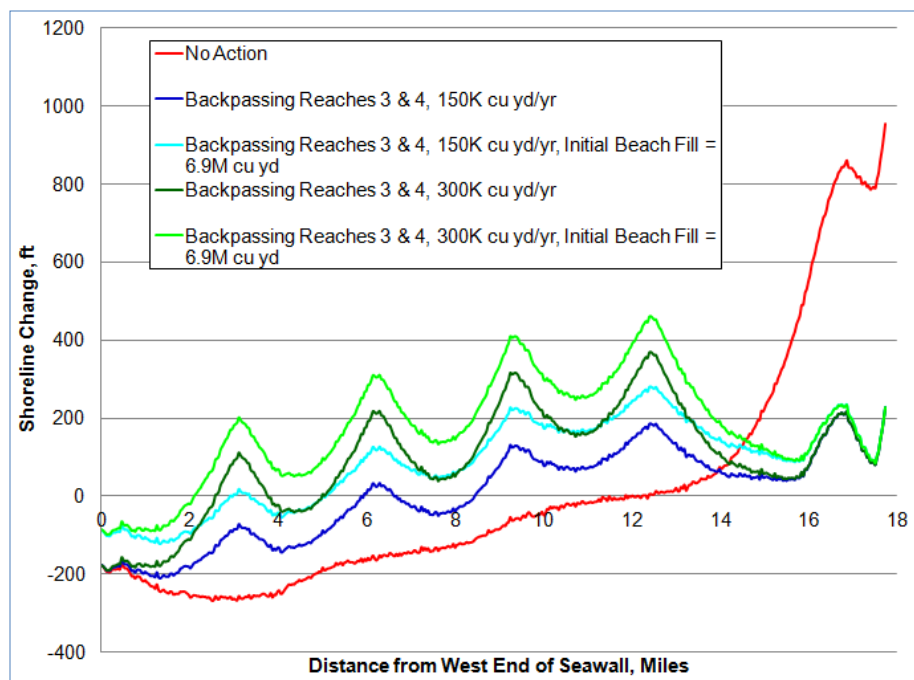


Figure 115. Total shoreline change after 50 years of backpassing along Reaches 3 and 4.



9 Conclusions

This report presents alternatives for a long-term sand management plan for Galveston Island, Texas. Widening the beaches of Galveston Island and developing a systematic strategy for managing sand resources will become the basis of a revivalism plan to enhance tourism and better protect the island from storms.

Specific alternatives for each reach are discussed in Chapter 2. The main option is a large-scale initial beach fill with backpassing plants in place to renourish the beaches on a semi-continuous basis. As an alternative if there are funding issues, limited sand, or other restrictions, smaller, more localized beach fills are also included in the plan. In order to obtain sand for beach nourishment, sediment management alternatives were investigated at East Beach and San Luis Pass.

9.1 Beach Fill

A comprehensive beach fill along reaches 1-5 (Figure 3) with a dune 100 ft wide and a beach/berm 200 ft wide will require about 13 million yd³ of sand. With advance fill of 50 percent, the total volume would be about 19,500,000 yd³. The GenCade modeling (described in Chapter 8) demonstrated that initial fill would be maintained by backpassing. Backpassing alone (without initial fill) of only 100,000 yd³/yr would eventually result in shoreline advance, but only after passage of decades.

9.2 Sand sources at East Beach, Galveston Island

The first option is to continue mining sand from Big Reef. Big Reef has been mined for decades. Permits are already in place, and a logical procedure would be to continue mining the aerial part of the reef using trucks and land-based equipment. An analysis determined that up to 1,800,000 yd³ could be available if specific areas are excavated to a depth of 5.5 yd.

A second option is to excavate an offshore deposition basin parallel to the beach in about 16 ft water depth. A basin 3000×150 yd and only 2 yd deep would yield 900,000 yd³ from initial construction and trap about 90,000 yd³ of sand annually (based on the sediment budget and assuming 50 percent trapping efficiency).

The third option would be to reduce sand transmission through the south jetty. If a 450-m section of the jetty extending from the current shoreline out to the east were sealed, up to 170,000 yd³/yr of sand would accumulate in a fillet.

A fourth option is to reduce Aeolian transport across the bare sand on East Beach, Big Reef, and the USACE dredge material disposal area. Sand fences could trap about 60 - 80,000 yd³ of sand in a year, while planting vegetation instead could trap up to 60,000 yd³ a year.

9.3 Sand sources at San Luis Pass

A groin placed perpendicular to the shoreline near the opening to San Luis Pass could trap littoral material, which would then be available for use in beach fill elsewhere and would reduce sand carried into the flood shoal. The groin should be placed near the west end of the island, possibly about at the junction of littoral cells Cells1_10 and Cells1_09 . Based on that study and assuming a trapping efficiency of 50 percent, 500 ft groin could trap about 130,000 yd³ of sand annually.

9.4 Recommendations

Determining exactly how much material moves onshore near East Beach needs to be evaluated in greater detail, using sediment tracers, side-scan sonar, bedload traps, or other methods to track seabed transport. The possible movement of sand from the Ocean Dredged Material Disposal Site (ODMDS) to Galveston Island is not well known. These data will help verify the sediment budget and identify the source(s) of the sediment.

We recommend that a repetitive beach profiling program be initiated. It would be beneficial to reoccupy the profile stations used in the Texas A&M 2002 profiling effort.

Wind-blown transport needs to be re-evaluated across East Beach and on Big Reef. A field study using sand traps could help verify if the calculation procedure used in this study correctly determined the magnitude of transport.

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APPENDIX A: Dredging summary, Galveston Ship Channel

Tables A1-A5 summarize dredging volumes from the Galveston entrance channel, Anchorage Area, boat slip, Inner and Outer Bar Channels, and Big Reef. Table A6 provides a summary of the dredging volumes. Data from before 2010 was extracted from an internal database maintained by SWG. Post-2010 data was from a spreadsheet supplied by SWG.

Table A1. Dredging volumes from Galveston entrance channel.

Channel	DSSStation	USStation	Notes	EndDate	Vol (yd ³)
Entrance and extended entrance			W9126G-13-C-0041	1-Dec-13	1,269,000
Entrance and extended entrance			W912HY-12-C-0023	1-Nov-12	175,000
Entrance and extended entrance			W912HY-11-C-0016	1-Dec-11	1,758,151
Entrance channel	74+000	40+000		24-Apr-12	1,809,495
Entrance and extended entrance			W912HY-08-C-0026	1-Jan-10	2,809,652
Entrance channel	66+000	23+000		24-May-10	2,262,000
Entrance channel	82+00	32+600		22-Aug-06	2,347,991
Entrance channel	51+000	37+000		28-Jun-03	3,627,241
Entrance channel	56+000	36+000		31-Mar-97	1,457,011
Entrance channel	56+000	36+000		25-Aug-93	1,751,450
Entrance channel	56+000	35+000		5-Dec-90	1,563,000
Entrance channel	51+000	30+675		30-Sep-89	58,938
Entrance channel	56+000	30+675	Est.: 2/3 of 1,038,946 yd ³	4-Oct-88	692,631
Entrance channel	56+000	30+675		31-Jul-86	1,656,469
Entrance channel	56+000	30+675		25-Jul-84	2,909,507
Entrance channel	56+000	30+675		5-Aug-80	972,296

	56+000	30+675		7-Sep-79	2,530,951
				25-Mar-77	
Total:					25,579,288
Years:					36.69
Annual dredging yd ³ :					697,226

Table A2. Dredging volumes from anchorage area.

Channel	DSSStation	USStation	Notes	EndDate	Vol (yd ³)
Anchorage area	17+400	12+000		31-Mar-97	603,695
Anchorage area	15+400	11+969		25-Aug-93	296,160
Anchorage area	19+400	11+969		5-Dec-90	1,261,000
Anchorage area	16+800	11+969.76		4-Oct-88	
Anchorage area	19+800	11+970		5-Aug-80	408,300
Anchorage area	19+800	16+000		9-Jul-78	1,130,462
				25-May-68	
Total (assume input from Bolivar Peninsula):					3,699,617
Years:					28.85
Annual dredging yd ³ :					128,242

Table A3. Dredging volumes from boat slip.

Channel	DSSStation	USStation	Notes	EndDate	Vol (yd ³)
Boat slip USACE	0+03	3+30		3-Aug-03	30,200
Boat slip USACE	0+00	3+30		6-Apr-98	19,142
Boat slip USACE	0+06	3+85		29-Jul-93	21,452
Boat slip USACE	0+30	3+30		30-Sep-89	44,502
Boat slip USACE	0+00C	3+85		7-Oct-85	40,473
Boat slip USACE	0+30	3+65		12-Apr-82	25,088
Boat slip USACE	0+55	3+80		9-Jul-78	7,213
Boat slip USACE	0+55	3+80		1-Jun-74	11,700
Boat slip USACE	0+55	3+80		11-Sep-70	7,696
				2-Jun-69	

Total:	207,466
Years:	34.17
Annual dredging yd ³ :	6,072

Table A4. Dredging volumes from inner and outer bar channel.

Channel	DSSStation	USStation	Notes	EndDate	Vol (yd ³)
Inner bar channel			W9126G-13-C-0041	1-Dec-13	882,300
Outer and inner bar chan.			W912HY-12-C-0023	1-Nov-12	600,000
Outer and inner bar chan.			W912HY-11-C-0016	1-Dec-11	194,375
Inner bar channel	22+569.69	15+600.00		24-Apr-12	2,007,620
Inner bar channel	20+000	8+031		22-Jul-10	1,939,568
Outer and inner bar chan.	23+000	0+000		24-May-10	779,000
Outer and inner bar chan.			W912HY-08-C-0026	1-Jan-09	2,042,695
Inner bar channel	0+000	10+000		24-Sep-06	144,463
Outer and inner bar chan.	25+000	4+649.75		31-Mar-97	464,826
Inner bar channel	14+225	14+150		6-May-96	8,653
Inner bar channel	21+912.37	4+649.75		30-Jul-95	691,683
Outer and inner bar chan.	25+000	4+649.79		25-Aug-93	845,012
Outer and inner bar chan.*	29+400	0+200	Est.: 1/3 of 1,038,946 yd ³	5-Dec-90	792,838
Outer and inner bar chan.	30+675	4+649		4-Oct-88	345,969
Outer and inner bar chan.	30+675	4+649		31-Jul-86	556,099
Outer and inner bar chan.	30+675	4+649		25-Jul-84	1,577,898
Outer and inner bar chan.	30+675	5+600		5-Aug-80	198,282

				7-Sep-79	
Total:					9,345,093
Years:					34.23
Annual dredging yd ³ :					272,976

Table A5. Dredging volumes from Big Reef.

Channel	DSSStation	USStation	Notes	EndDate	Vol (yd ³)
Big Reef (misc. removals pre-Hurricane Ike – not listed individually)				1-Jun-08	178,731
				1-Mar-85	
Total:					178,731
Years:					23.25
Annual dredging yd ³ :					7,687

Table A6. Dredging summary.

Location	Vol (yd ³)
Sand vol.: boat slip, Inner and Outer Bar Channel, Big Reef	286,735
Percentage sand (68 samples from SWG dredge database):	86%
Sand entering via S. jetty and Aeolian transport (yd ³ /yr):	246,592

Note: Strikeout represents data from SWG database not used; superseded with additional data from SWG.

APPENDIX B: Dredging and placement data, Galveston seawall and Big Reef

Table B1 lists beach fills and placements along Galveston Island and sand removal from Big Reef.

Table B1. Dredging summary.

Project	Year	Vol (yd ³)	Length (ft)	Source
Galveston Seawall - San Luis Hotel	3/1/1985	15,000	1500	Giardino et al. (1987)
Veneer and minor fills - 1999 to 2008 volume estimates based on a \$7.00/yd ³ cost estimate and was placed fronting the major hotels-undetermined length	1999	9613	unknown	Park Board
	2000	33,074	unknown	Park Board
	2001	5,823	unknown	Park Board
	2002	3,887	unknown	Park Board
	2003	32,418	unknown	Park Board
	2004	5,321	unknown	Park Board
	2005	461	unknown	Park Board
	2006	43,767	unknown	Park Board
	2007	18,499	unknown	Park Board
	6/1/2008	10,868	unknown	Park Board
Post-Ike fill (2009-2010) - Big Reef	6/1/2010	565,108	14 th to 61st	HDR (via John Lee, Jr.)
Beach nourishment - Galveston Seawall	1992 nearshore berm - (dredged from channel)	500,000	6,000	Shiner Moseley
	1995 (dredged from offshore)	710,000	19,000	City of Galveston (Engineering by CPE)

APPENDIX C: Data tabulation for sediment budget cells

Table C1 lists the fluxes and volume changes for each cell discussed in the text. Values are in English units (yd^3/yr) $\times 1000$.

Table C1. Galveston North Fillet cells.

Sediment Budget, Galveston Island

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VERSION 3b. Last update: Sep. 18, 2014

Nomenclature:

Units: 1000 yd^3/yr

Source 1 = bluffs, river influx, wind

Sink 1 = wind-blown loss

Source or sink 2 = offshore

Source or sink 3 = other (inlet, channel, trap)

LST1 = right (east) side of cell

LST2 = left (west) side of cell

Yellow cells = beach; blue cells = channel, inlet

ΔV = beach change (erosion or growth)

Placement = beach fill; Removal = dredging

Cell	Variable	Expect. value yd^3	Low value yd^3	High value yd^3	Notes, source
Galv. North Fillet	Q_{source1}				
Cell 1_1	Q_{sink1}				
34,100 ft	Q_{source2}	-5.5	-4.0	47.8	Offshore flux - used to balance cell
	Q_{sink2}				
	Q_{source3}				
	Q_{sink3}				
	$Q_{\text{source-LST1}}$	225.5	169.1	281.9	From Cell 9 to N (from 2006 sed. budget; not updated). Assume - = 75%, + = 125%
	$Q_{\text{sink-LST1}}$				
	$Q_{\text{source-LST2}}$				
	$Q_{\text{sink-LST2}}$	110.3	110.3	110.3	Sand to anchorage area, through jetty and boat gap.
	Placement				
	Removal				
	DeltaV	109.7	54.8	219.3	Based on translating 2002 profiles 1.12 m/year end-point rate. Assume - = 50%, + = 200%

	Residual	0.0	0.0	0.0	
	Q _{source1}				
Galv. Entrance Chan.	Q _{sink1}				
Cell 1_4	Q _{source2}	0.0	0.0	0.0	Assume no offshore source
	Q _{sink2}				
	Q _{source3}	697.226	697.2 26	697.2 26	From Galveston Bay, Bolivar Roads. Assume + = 125%
	Q _{sink3}				
	Q _{source-LST1}				
	Q _{sink-LST1}				
	Q _{source-LST2}				
	Q _{sink-LST2}				
	Placement				
	Removal	697.226	697.2 26	697.2 26	1979-2013 maintenance dredging.
	DeltaV				
	Residual	0.0	0.0	0.0	

	Q _{source1}	366.6	366.6	366.6	Fine grain from Galveston Bay
Anchorage Area	Q _{sink1}				
Cell 1_2	Q _{source2}				
	Q _{sink2}	348.6	348.6	348.6	To Cell 1_4 Entrance Channel
	Q _{source3}	110.3	110.3	110.3	Sand from Cell 1_1 via N. jetty (based on mean sand content of 86% for samples in inner and outer bar channels, using 1953-1997 samples).
	Q _{sink3}				
	Q _{source-LST1}				
	Q _{sink-LST1}				
	Q _{source-LST2}				
	Q _{sink-LST2}				
	Placement				
	Removal	128.2	128.2	128.2	1978-97 dredging.
	DeltaV				
	Residual	0.0	0.0	0.0	

	Q _{source1}	388.8	388.8	388.8	Fine grain material from Galveston Bay
Inner and Outer Bar	Q _{sink1}				
Cell 1_3	Q _{source2}				
	Q _{sink2}	348.6	348.6	348.6	To Cell 1_4 Entrance Channel
	Q _{source3}	246.6	246.6	246.6	Sand from Cell 1_5 via S. jetty and Aeolian (based on mean sand content of 86% for samples in inner and outer bar channels, using 1953-1997 samples)
	Q _{sink3}				
	Q _{source-LST1}				

	Q _{sink} -LST1				
	Q _{source} -LST2				
	Q _{sink} -LST2				
	Placement				
	Removal	286.7	286.7	286.7	1980-2012 dredging from channel, boat slip (R = 6.07 yd ³ /yr), Big Reef (R = 7.69 yd ³ /yr).
	DeltaV				
	Residual	0.0	0.0	0.0	

East Beach	Q _{source} 1				
Cell 1_5	Q _{sink} 1				
20,300 ft long	Q _{source} 2	355.7	286.2	487.2	From offshore - only way to balance cell and account for fillet growth.
	Q _{sink} 2				
	Q _{source} 3				
	Q _{sink} 3	246.6	246.6	246.6	Sand to Cell 1_3 via S. jetty and Aeolian
	Q _{source} -LST1				
	Q _{sink} -LST1				
	Q _{source} -LST2	41.2	35.5	59.9	From Cell 1_6
	Q _{sink} -LST2	0.0	0.0	0.0	Assume all littoral transport moves to east
	Placement				
	Removal				
	DeltaV	150.3	75.1	300.5	Based on translating 2002 profiles +11.25 ft/yr. (BEG long-term shoreline change through 2007). Assume - value = 50%, + = 200%
	Residual	0.0	0.0	0.0	

Galv. Sea Wall	Q _{source} 1				
Cell 1_6	Q _{sink} 1				
35,300 ft long	Q _{source} 2				
	Q _{sink} 2				
	Q _{source} 3				
	Q _{sink} 3				
	Q _{source} -LST1				
	Q _{sink} -LST1	41.2	35.5	59.9	Assume 50% sed. moves to east
	Q _{source} -LST2				
	Q _{sink} -LST2	41.2	35.5	59.9	Assume 50% sed moved to west
	Placement	59.7	59.7	74.7	1985-2008 placements (exclude 2009 post-Ike fill), data from John Lee., Jr., Coastal Strategies Group, LLC. Additional placements possibly not recorded, assume + value = 125%.
	Removal				
	DeltaV	-22.6	-11.3	-45.2	Based on translating 2002 profiles - 0.72 ft/yr. (BEG 85-year shoreline change through 2007 for original part of the seawall). Assume - value = 50%, + = 200%

	Residual	0.0	0.0	0.0	
Galv State Park	Q _{source1}				
Cell 1_7	Q _{sink1}				
49,500 ft long	Q _{source2}				
	Q _{sink2}				
	Q _{source3}				
	Q _{sink3}				
	Q _{source-LST1}	41.2	35.5	59.9	From Cell 1_6
	Q _{sink-LST1}	0.0	0.0	0.0	Assume no east movement
	Q _{source-LST2}				
	Q _{sink-LST2}	166.3	105.6	299.0	To Cell 1_8
	Placement	15.0	15.0	18.8	Placements at Sunny Beach, Sands of Kahana, Spanish grant, and Bermuda Beach. Additional placements possibly not recorded, assume + value = 125%.
	Removal				
	DeltaV	-110.2	-55.1	-220.4	Based on translating 2002 profiles - 3.39 ft/yr. (BEG long-term shoreline change through 2007). Assume - value = 50%, + = 200%
	Residual	0.0	0.0	0.0	
Cell 1_8	Q _{source1}				
18,700 ft long	Q _{sink1}				
	Q _{source2}				
	Q _{sink2}				
	Q _{source3}				
	Q _{sink3}			299.0	
	Q _{source-LST1}	166.3	105.6	42	From Cell 1_7
	Q _{sink-LST1}	0.0	0.0	0.0	Assume no east movement
	Q _{source-LST2}				
	Q _{sink-LST2}	191.3	120.6	345.1	To cell 1_9
	Placement	5.0	5.0	6.3	Placement at Sea Isle. Assume possible unrecorded placement = 125%
	Removal				
	DeltaV	-19.9	-10.0	-39.8	Based on translating 2002 profiles - 1.59 ft/yr. (BEG long-term shoreline change through 2007). Assume - value = 50%, + = 200%
	Residual	0.00	0.00	0.00	
West Beach	Q _{source1}				
Cell 1_9	Q _{sink1}				
23,800 ft long	Q _{source2}				
	Q _{sink2}				
	Q _{source3}				
	Q _{sink3}				

	Q _{source} -LST1	191.3	120.6	345.1	From Cell 1_8
	Q _{sink} -LST1	0.0	0.0	0.0	Assume no east movement
	Q _{source} -LST2				
	Q _{sink} -LST2	251.6	159.3	453.1	To cell 1_10
	Placement	17.0	17.0	21.3	Placement at Terramar Beach and Pointe San Luis
	Removal				
	DeltaV	-43.4	-21.7	-86.8	Based on translating 2002 profiles - 2.74 ft/yr. (BEG long-term shoreline change through 2007). Assume - value = 50%, + = 200%
	Residual	0.0	0.0	0.0	

San Luis Pass E.	Q _{source} 1				
Cell 1_10	Q _{sink} 1				
5,000 ft long	Q _{source} 2				
	Q _{sink} 2				
	Q _{source} 3				
	Q _{sink} 3	240.1	153.5	430.0	Into San Luis Pass flood shoal
	Q _{source} -LST1	251.6	159.3	453.1	From Cell 1_9
	Q _{sink} -LST1	0.0	0.0	0.0	Assume no east movement
	Q _{source} -LST2				
	Q _{sink} -LST2	0.0	0.0	0.0	Assume no west movement (all material into inlet)
	Placement				
	Removal				
	DeltaV	11.6	5.8	23.2	2002 profile G002 translated 3.68 ft. Prof. G001 not useable.
	Residual	0.0	0.0	0.0	

San Luis Pass	Q _{source} 1				
Flood Shoal	Q _{sink} 1				
Cell 1_11	Q _{source} 2				
	Q _{sink} 2				
	Q _{source} 3	240.1	153.5	429.9 7	From open coast Cell 1_10
	Q _{sink} 3				
	Q _{source} -LST1				
	Q _{sink} -LST1				
	Q _{source} -LST2	?	?	?	Unknown input from cell south of pass
	Q _{sink} -LST2				
	Placement				
	Removal				
	DeltaV				
	Residual	240.1	153.5	430.0	INCOMPLETE, need flood shoal growth data

APPENDIX D: Aeolian transport methodology

Chapter III-4 of the *Coastal Engineering Manual* (Hsu and Weggel 2002) provides a methodology for computing wind-blown transport. The procedure is lengthy and requires building a spreadsheet to complete the calculations. A portion of the chapter is quoted in Text Box D1, and the following paragraphs describe how the procedure was applied to East Beach and Big Reef. All calculations were done in metric units.

1.1.1 Text Box D1

III-4-4. Procedures for Calculating Wind-Blown Sand Transport

The steps for calculating wind-blown sand transport on beaches follow.

- a. Obtain hourly average wind speed and direction data. (Wind data tabulated at intervals less frequent than 1 hr may be used in lieu of hourly data; however, hourly data are preferable.)
- b. Obtain daily precipitation data and monthly evaporation records from a nearby National Weather Service (NWS) station. (These data are available in "Climatological Data" summaries published monthly for each state by the National Climatic Data Center (NCDC), Asheville, NC).
- c. Obtain the density and median grain size of the beach sand at the study site.
- d. Compute the critical shear velocity u_{*t} for the mean grain diameter using Equation 4-20.
- e. Compute the critical wind speed at the 2-m height U_{2mt} using Equation 4-8 with the value of u_{*t} computed under Step 4 above. (This is the wind speed measured at the 2-m height that can initiate sand transport.)
- f. Shear velocity u_* is relatively independent of height up to a height of about 50 m above ground level; therefore, Equation 4-7 can be used to compute the critical wind speed at any height above the ground using the U_{2mt} and u_{*t} . (For example, let $Z_1 = 2$ m, $U_{Z_1} = U_{2mt}$, $Z_2 =$ the height at which the available wind measurements were taken, and solve for $U_{Z_2t} =$ the critical wind velocity at the Z_2 height.) Only wind speeds in excess of the computed U_{Z_2t} will result in sand transport.
- g. If wind speeds exceed the critical value and there was no precipitation on a given day, compute the potential sand transport rate using Equation 4-16 or Equation 4-18.
- h. If there was precipitation on a given day, the amount of precipitation should be compared with the amount of evaporation. If evaporation exceeds precipitation, compute the potential sand transport rate using Equation 4-16 or 4-18. (If daily evaporation data are not available, daily evaporation can be estimated by dividing monthly evaporation by the number of days in the month.)

Step a. Hourly wind and other observations were available from two National Oceanic and Atmospheric Administration (NOAA) sites near East Beach.

- Dec. 12, 1996 - Dec. 29, 2008: Pleasure Pier at Galveston, Station 8778710, located offshore of the seawall. Before 2009, meteorology data could be downloaded from the “tidesandcurrents.noaa.gov” web page:
http://tidesandcurrents.noaa.gov/data_menu.shtml?stn=8771510%20Galveston%20Pleasure%20Pier,%20TX&type=Meteorological+Observations (accessed Jan. 2009). NOAA removed the meteorology instruments on July 20, 2011, and the meteorology data is no longer available. We previously saved hourly data year-by-year as ASCII text files and imported each year into Microsoft® Office Excel 2003 spreadsheets.
- Jan. 1, 2009 – Dec. 31, 2010: Pleasure Pier at Galveston, Station 8778710. NOAA provided the data by special request because the NOAA web page was not operating correctly.

Step b. Precipitation and evaporation data are available online from the National Climatic Data Center at site:

<http://www.ncdc.noaa.gov/data-access/land-based-station-data/data-publications> (accessed February 4, 2014).

The user needs to select “Climatological Data (CD)” and proceed to the next page, where he selects the state of interest and then month of interest. The reports are available free to users with .gov or .mil addresses. The reports are in the form of Adobe® PDF files. Each month report for the State of Texas is about 95 pages long.

The Galveston National Weather Service (NWS) station only reported data intermittently was therefore unsuitable for the analysis. The closest NWS station with both rainfall and evaporation data was the Beaumont Research Center, operated by Texas A&M University, Index 0613, Division 08, County Jefferson. It is located at 94°18′ W, 27° 08′ N. Days when rainfall exceeded evaporation were coded as “Y” in the spreadsheet, while all other days were dry or “N”. Note that “Y” or “N” applied to an entire 24-hour day.

Step c. The median grain size used for the analysis was 0.116 mm, based on the average of four surface samples collected on profile lines G051 and G058 in 2002 by Texas A&M University.

- Line G051: $B_2 = 0.119$; $I_2 = 0.119$; $W_2 = 0.119$; Ave. = 0.118
- Line G058: $B_2 = 0.106$; $I_2 = 0.12$; $W_2 = 0.117$; Ave = 0.114

Use a density of 2.65 gm/cm³ for quartz sand.

Step d. The critical shear velocity for 0.116 mm quartz sand was 0.185 m/sec.

Step e. The critical shear at the 2-m height was 4.21 m/sec, using the results from Step d above. This is computed from the roughness relationship $U^* = 0.044 U_{2m}$ from Hsu (1977), applicable to bare beach sand.

Step f. Z_2 , the height at which the available wind measurements were taken, was set at 9.0 m. The anemometer height at Pleasure Pier was 11.5 m above the water, with the assumption that this referred to MLLW. This equals about 11 m above MSL. We then assumed that the average elevation of the dry sand on East Beach and Big Reef was 2 m above MSL. Therefore U_{z2t} , the threshold for sand movement, was 4.90 m/sec. A test was made with assumption that East Beach was only 1 m above MSL and Z_2 set at 10.0 m. The resulting transport for 2007 was only about 4 percent less than using $Z_2 = 9.0$ m.

Table D1 is a list of coefficients and calculated parameters used in the analysis.

Table D1. Galveston Aeolian transport parameters.

Parameter	Value
D = median sand size, mm	0.116
U_{*1} = Initiation of sand transport, m/sec	0.185
U_{2mt} = Threshold wind speed at 2-m height, m/sec	4.21
U_{9mt} = threshold wind speed at 9-m measurement height, m/sec	4.9
K = dimensionless aeolian sand transportation coef., gm/cm-s	0.000116
q_v = volumetric sand transport = $1.026 \times 10^{-10} U_{9m}^3$ in cm ³ /cm-sec	1.03E-10
q = transport = $1.631 \times 10^{-10} U_{9m}^3$ in gm/cm-sec	1.63E-10

Θ = jetty azimuth in deg	9
Length of south jetty crossing bare sand beach (m)	720
Wind velocity and direction station	NOAA Sta.8771510 Galveston Pleasure Pier
Precipitation and evaporation measurement station	Beaumont Research Ctr.
Time zone	GMT

Step g. The spreadsheet was coded so that sand transport was only calculated if $U_{z2t} > 4.90$ m/sec and rainfall = N.

Step h. This step was simplified for this setting. During many days with precipitation, total rainfall was one inch or more, much greater than the evaporation. Therefore, days were either wet or were essentially dry, and using Equations 4-16 or 4-18 was an extra calculation not necessary here. These would be useful in a setting like the Pacific Northwest, where rain falls in the form of drizzle for many days and daily rainfall might be about the same as the evaporation.

Step i. Wind direction was rotated 180° to show the direction to which the wind was blowing. The angle theta (Θ) for this portion of the jetty was 9° from true north. Therefore, the north-south component of the wind carrying sand across the jetty was $\cos \Theta$.

Step j. The length of bare (non-vegetated) sand crossed by the south jetty was 720m. This was used as a multiplier factor for hourly transport across jetty q_v (m^3/hr).

Step k. Hourly transport was summed to tabulate monthly values. Then monthly values were summed to produce annual statistics.

The following figures are annual plots of wind-blown sand transport. Units are in metric (m^3) as per the original computations.

Figure D1. Galveston Big Reef 1997.

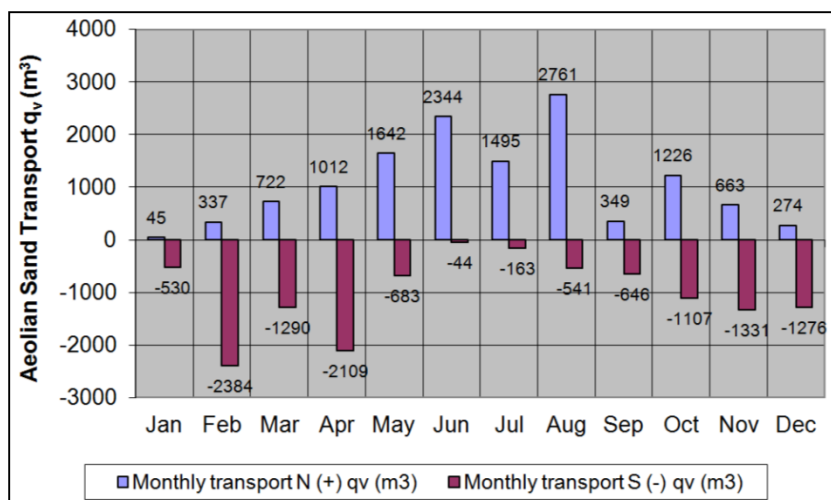


Figure D2. Galveston Big Reef 1998.

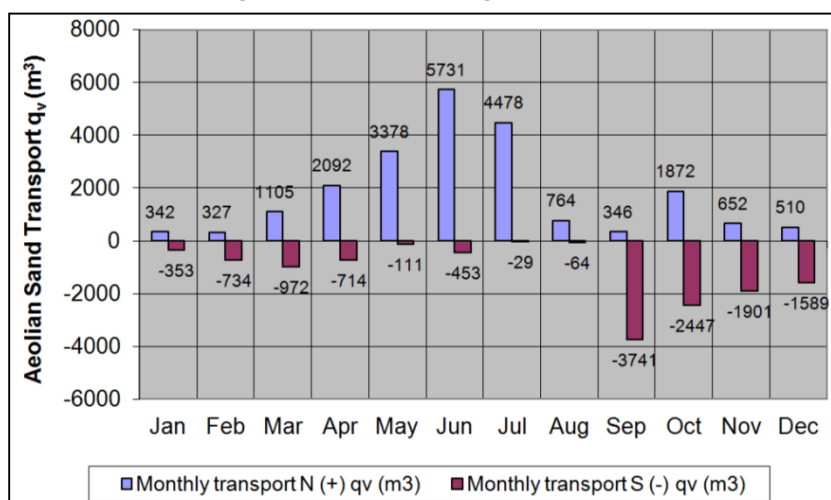


Figure D3. Galveston Big Reef 1999.

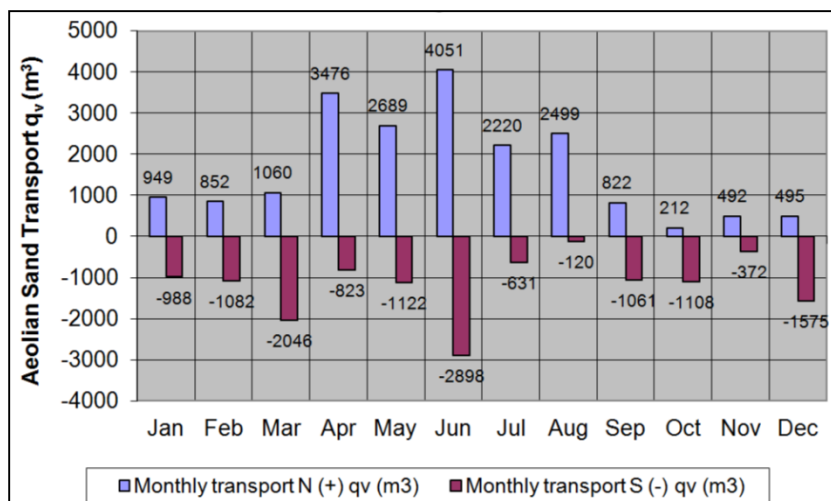


Figure D4. Galveston Big Reef 2000.

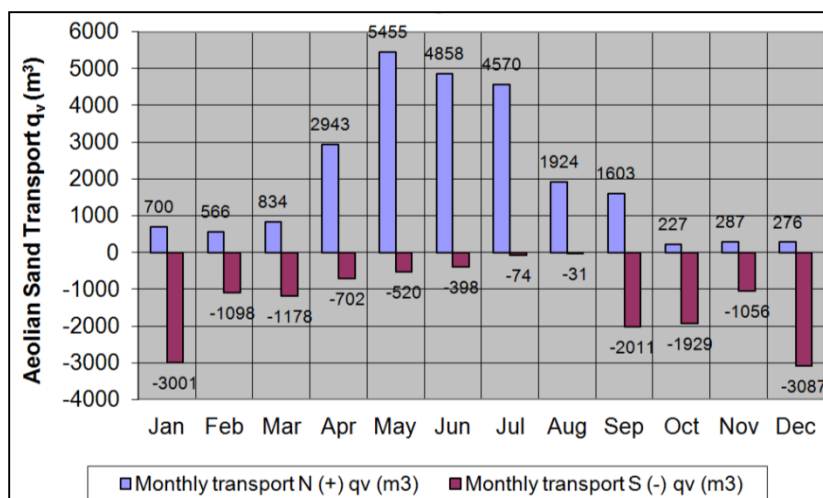


Figure D5. Galveston Big Reef 2001.

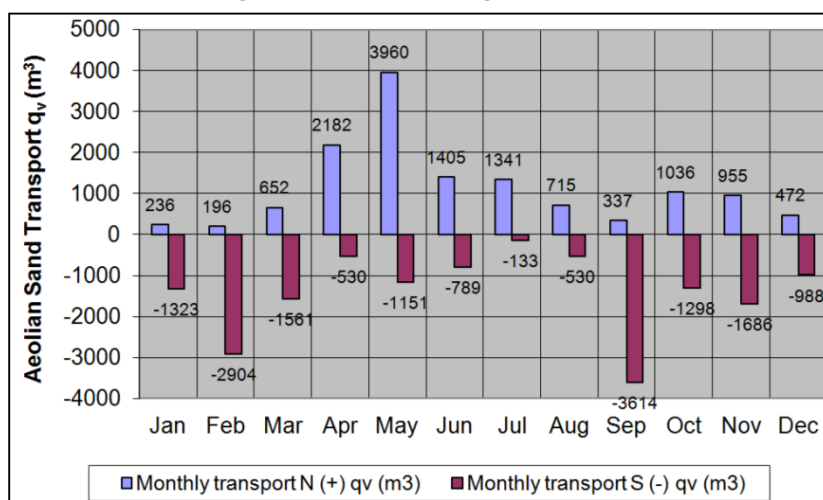


Figure D6. Galveston Big Reef 2002.

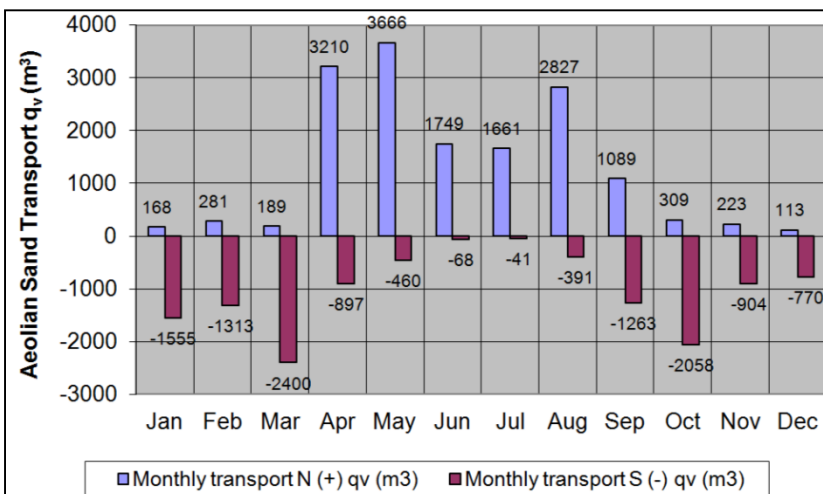


Figure D7. Galveston Big Reef 2003.

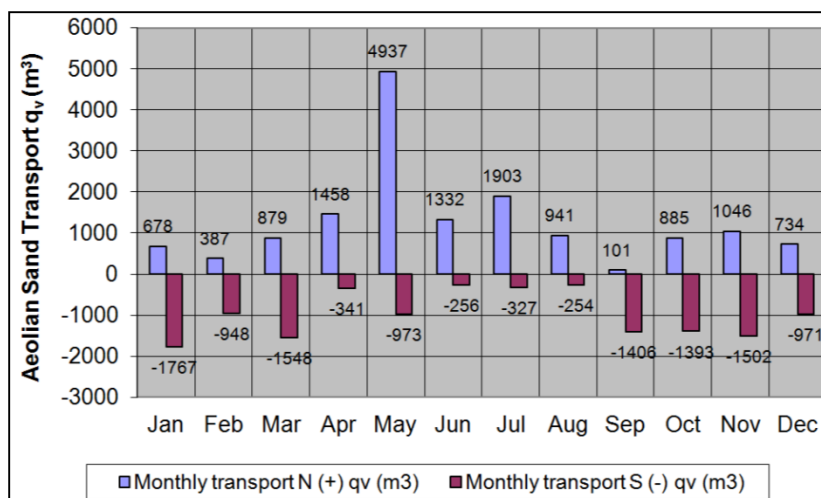


Figure D8. Galveston Big Reef 2004.

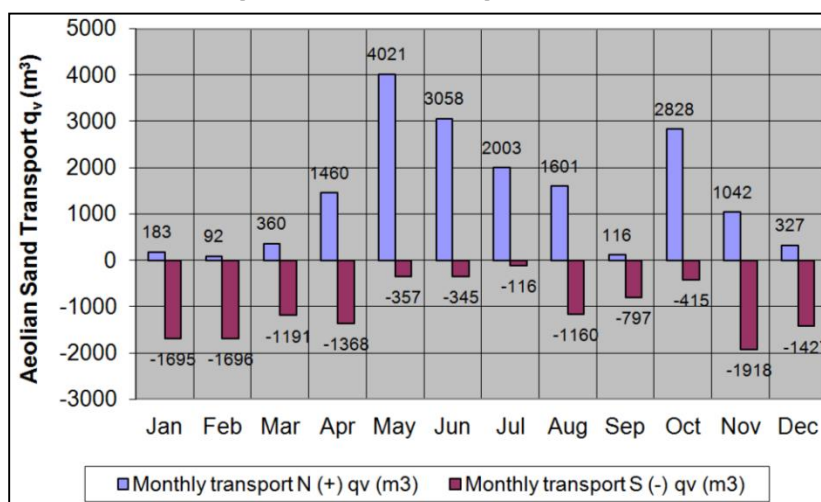


Figure D9. Galveston Big Reef 2005.

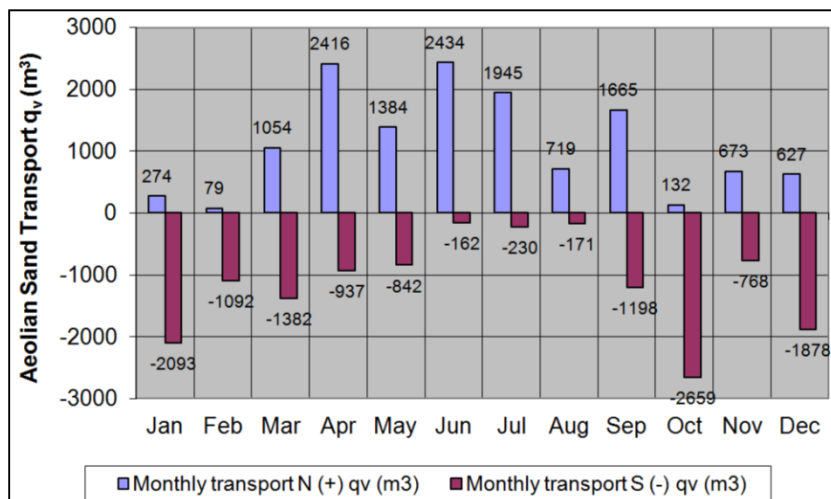


Figure D10. Galveston Big Reef 2006.

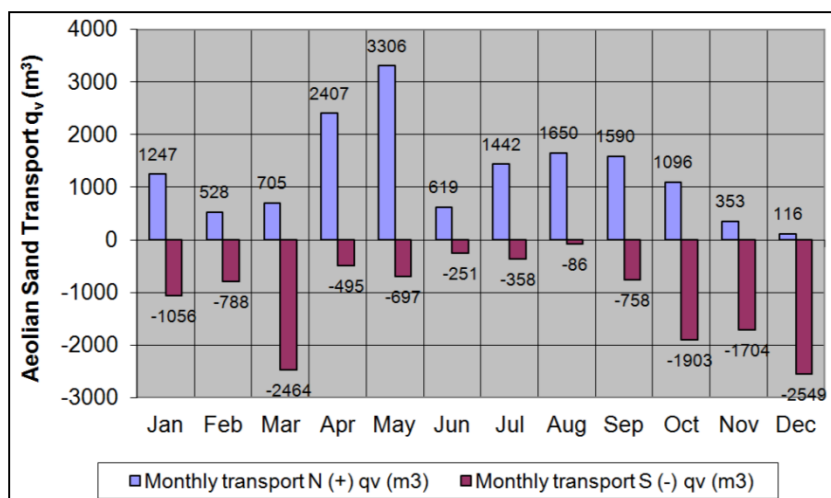


Figure D11. Galveston Big Reef 2007.

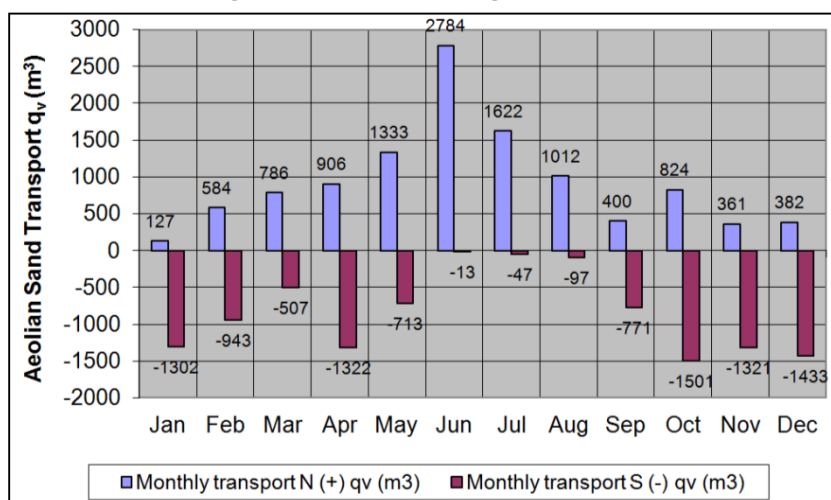


Figure D12. Galveston Big Reef 2008.

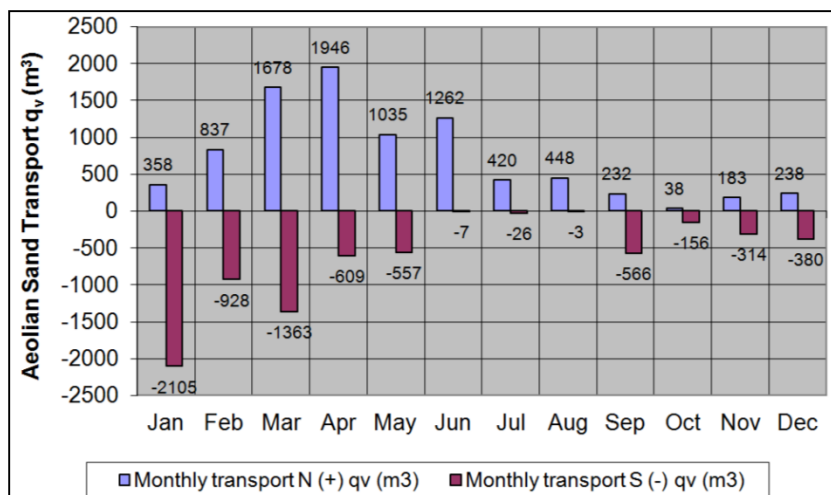


Figure D13. Galveston Big Reef 2009.

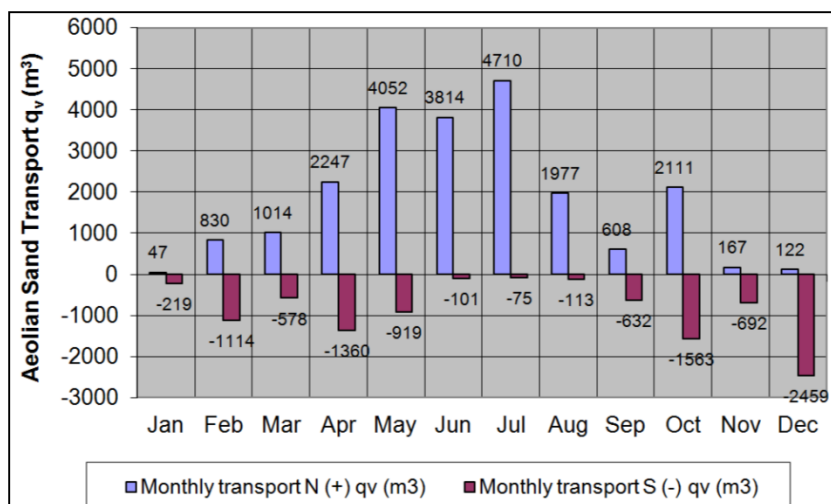
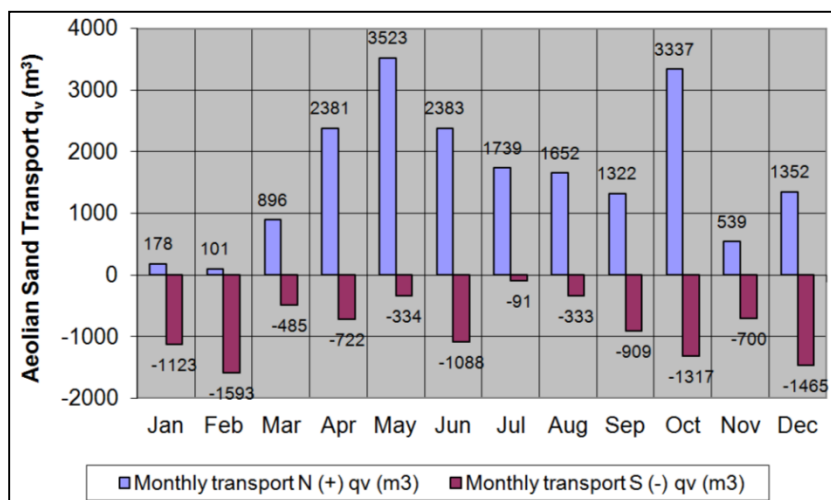


Figure D14. Galveston Big Reef 2010.



APPENDIX E: Beach Fill Volumes

Table E1 lists calculations used to determine the amount of sand needed to complete a proposed beach fill along the Galveston Seawall. Table E2 lists volumes for proposed 300-ft-wide beach along the entire island, divided into Park Board reaches. Overfill is estimated at 50 percent.

Table E1. Beach fill volumes for seawall (Reaches 1 and 2).

	Option 1 (dune and 200-ft berm/beach, 270 ft wide total)			Option 2 (200 ft berm/beach only)		
Texas A&M profile no.	Total volume (yd ³ /ft)	Profile dist. (ft)	Sand vol (yd ³)	Total volume (yd ³ /ft)	Profile dist. (ft)	Sand vol (yd ³)
50	219.56	2607	572,400			
49	92.66	2607	241,600	135.84	2607	354,100
48	100.86	2607	262,900	11.86	2607	30,900
47	112.86	2607	294,200	18.57	2607	48,400
46	88.96	2607	231,900	29.30	2607	76,400
45	94.06	2607	245,200	7.42	2607	19,300
44	36.06	2607	94,000	11.85	2607	30,900
43	107.66	2607	280,700	0.00	2607	0
42	222.36	2607	579,700	24.35	2607	63,500
41	229.66	2607	598,700	138.65	2607	361,500
40	214.76	2607	559,900	145.68	2607	379,800
39	227.86	2607	594,000	130.64	2607	340,600
38	223.76	2607	583,300	143.41	2607	373,900
37	175.66	2607	457,900	138.92	2607	362,200
Total:			5,596,400			2,691,000

Table E2. Beach fill volumes for comprehensive fill (Reaches 1 to 5).

Profile no.	Zero dist. on profile	X for BM AP	Beach fill vol. for transl ated profil e below zero (yd ³ /ft)	Temp late vol abov e zero (yd ³ /ft)	200 2 prof ile abo ve zero (yd ³ /ft)	Abo ve zero vol. nee ded (yd ³ /ft)	Tot vol (yd ³ /ft)	Prof ile dist. (ft)	Sand vol Option 1 (yd ³)	Sand vol (yd ³)
Reach 1										
044-050 (summarized from Table E1)									1,942,200	560,000
Reach 2										
037-043 (Summarized from Table E1)									3,654,200	2,131,600
Reach 3										
026-036 averaged	230	70	54.5	59.2 59	29. 8	29.4 6	83. 96	300 00	2,518,800	2,518,800
Reach 4										
007-025 averaged	230	70	52.3	59.2 59	26. 3	32.9 6	85. 26	517 00	4,407,900	4,407,900
Reach 5										
002-006 averaged	580		0	59.2 59	20. 9	38.3 6	38. 36	123 00	471,800	471,800
Total for all reaches:									12,994,900	10,090,100
Advance nourishment (assume 50%):									6,497,500	5,045,100
Total vol. including advance:									19,492,400	15,135,200