Post-storm Data Collection Surveys
Hurricane and Tropical Storm Harvey
Galveston Island, Texas

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Executive Summary

Because of the impacts of Hurricane Harvey on the beachfront of Galveston Island in August of 2017, the City of Galveston requested post-storm data collection surveys be conducted by Atkins North America, Inc. (Atkins) to document potential beach erosion impacts. For the post-storm survey, three existing engineered beaches were chosen for assessment: Dellanera Beach, Babe's Beach, and the Historic Galveston Beach Stretch. Dellanera beach is situated between the western terminus of the Galveston seawall to Dellanera Park. Babe's Beach extends from the west end of 61st Street's rock groin to 75th Street fronting the seawall. The Historic Galveston Beach Stretch extends from 12th Street to 61st Street fronting the seawall. All three beach areas have experienced losses of beach sand volume due to erosion over time and are part of an ongoing 4-year monitoring survey to document sediment movement during normal and extreme weather events.

Hurricane Harvey made landfall as a Category 4 hurricane near Rockport, Texas on August 25, 2017, with maximum sustained winds of 130 mph; however, the effects of the storm extended further north and east including the Houston-Galveston area. Hurricane Harvey continued to batter the upper-Texas coastline for approximately 6 days from August 25–30, 2017, as the storm system meandered through South Texas before continuing a path back in to the Gulf of Mexico and making a second landfall near Cameron, Louisiana. Harvey brought strong winds, heavy rains, and a significant storm surge to Galveston Island; resulting in increased beach sand erosion across the entire island.

Post-storm surveys of the three engineered beaches were conducted over a 45-day period in the months of October and November 2017. Surveys were completed utilizing the same methodology as those conducted during the previous monitoring surveys. For beach monitoring, Atkins field teams performed two primary tasks:

1. Collection of terrestrial/topographic survey data
2. Collection of bathymetric survey data from the beach-water interface out to the depth of closure.

Both tasks were meant to assess post storm conditions within the three survey areas. The terrestrial/topographic data collected will be used to compare the existing shore-face to the previous monitoring survey profiles for volume changes whereas the bathymetric surveys will be compared to previous off-shore surveys to determine sediment movement and/or loss in the swash zone out to the depth of closure.

The post-storm surveys indicate volumetric changes in beach sand across all three engineered beaches. Both Dellanera and Babes beach each experienced more than 100,000 cubic yards (CY) of beach sand loss due to Harvey. On the Historic Galveston Beach Stretch, Harvey impacts resulted in the loss of more than 216,000 CY of beach sand that was placed in this location during the 2017 sand nourishment project. The post-storm surveys conducted by Atkins in 2017 present a clear depiction of the immediate impacts to Galveston's shoreline during Hurricane Harvey.

1. INTRODUCTION

Post-storm data collection surveys were conducted by Atkins North America, Inc. (Atkins) in select locations along Galveston Island's beaches to identify potential erosion impacts caused by Hurricane and Tropical Storm (TS) Harvey between August 25 and 30, 2017. Three engineered beaches located along Galveston Island were chosen for the post-storm survey effort including Dellanera Beach, Babe's Beach, and the Historic Galveston Beach Stretch (Figures 1-1 through 1-3). The Historic Galveston Beach Stretch extends from 12th Street to 61st Street fronting the seawall. Babe's Beach extends from the west end of 61st Street's rock groin to 75th Street fronting the seawall. Dellanera Beach is situated between the western terminus of the Galveston seawall to Dellanera Park.

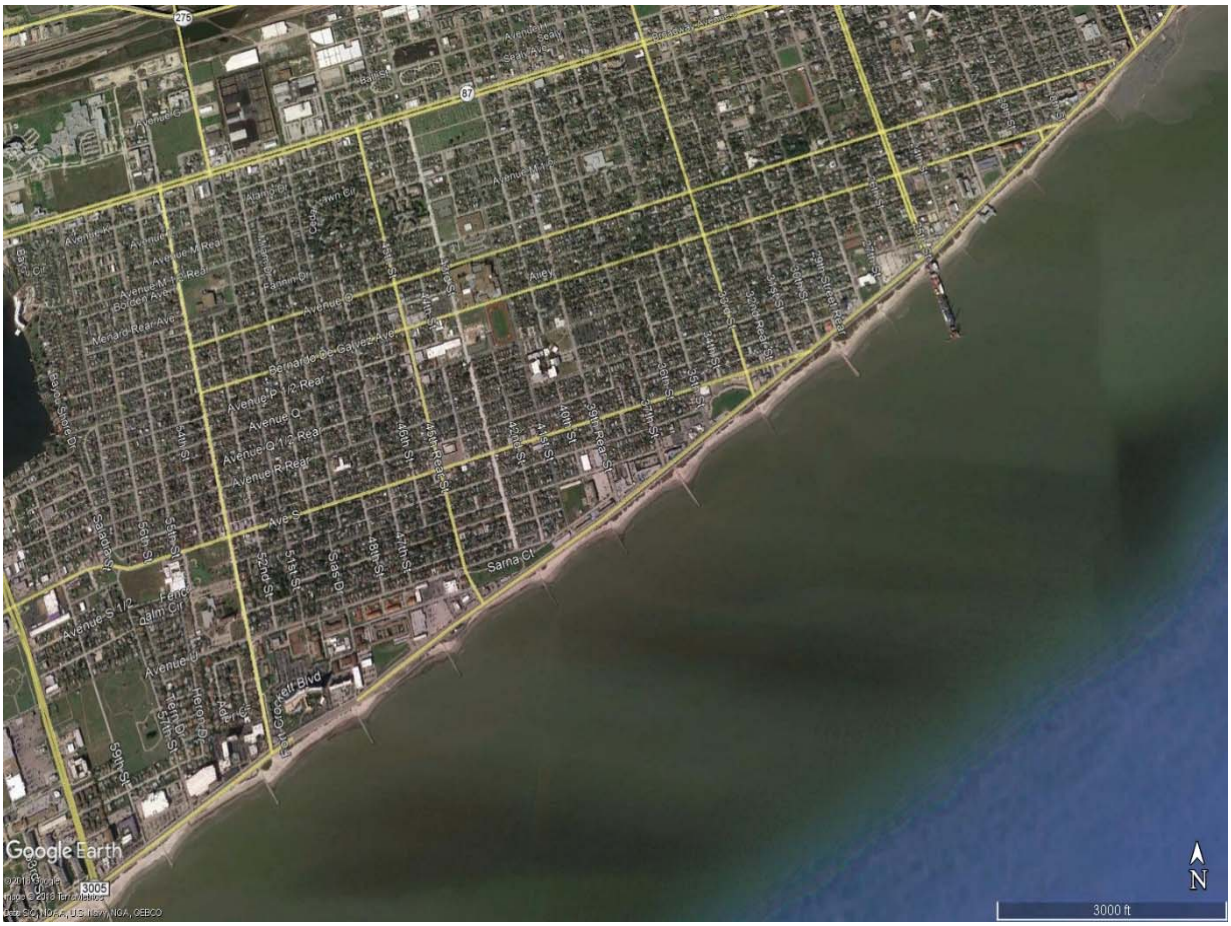


Figure 1-1: Galveston's Historic Seawall Beach (base image: Google Earth)

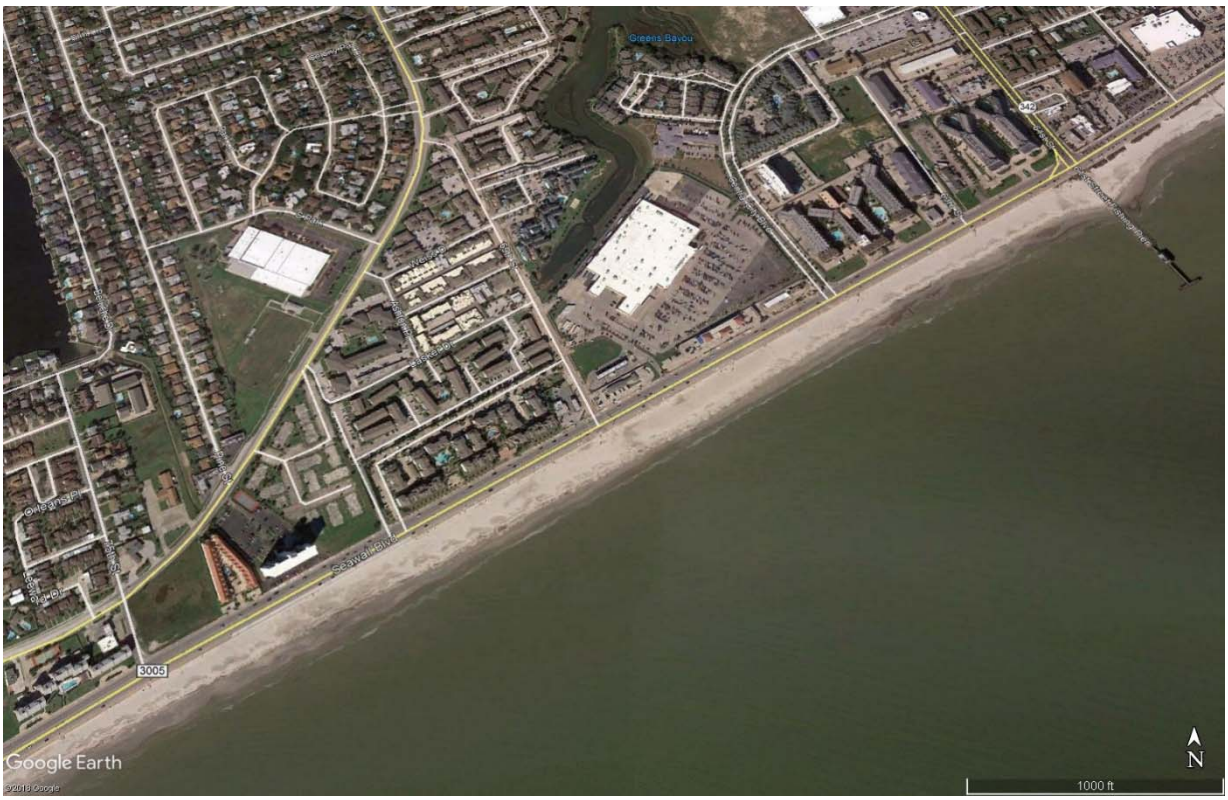


Figure 1-2: Babe's Beach (base image: Google Earth)

Figure 1-3: Dellanera Beach (base image: Google Earth)

The three beaches are currently associated with a 4-year-long monitoring study, which provides a robust assemblage of pre-storm characterization data. Per the Federal Emergency Management Agency's (FEMA) Public Assistance Program and Policy Guide (PAPPG), replacement of sand on beaches (i.e., nourishment) is only eligible under conditions listed in 44 CFR § 206.226(j)(2)(i) and 44 CFR § 206.226(j)(2)(ii). The amount of sand eligible for replacement is limited to the amount lost as a result of an incident (i.e., a major storm event). Such losses are to be assessed and documented to determine the eligible volume of sand for replacement. Therefore, the report herein documents pre- and post-storm beach conditions and resulting 2017 changes in sand volume for potential FEMA assistance and future need- or grant-related beach projects. All collected data will also be made available to the City of Galveston, the Texas General Land Office (GLO), and the Galveston Park Board of Trustees.

The purpose of this technical report is to identify and quantify sediment loss within the three engineered beach areas (Dellanera Beach, Babe's Beach, and the Historic Galveston Beach Stretch) utilizing data collection surveys conducted pre- and post-Hurricane Harvey. Data from surveys performed within these areas during the four-year monitoring event along the entire Galveston Island shoreline is also included in this report. The following sections of this report will provide background and physical setting of the project (Section 1), describe Hurricane Harvey's path and associated storm conditions along Galveston (Section 2), discuss data collection survey methods (Section 3), and conclude with a summary of Atkins' findings from the data collection (Section 4).

1.1. Background

Beach erosion is an ever-present issue for Galveston Island. Noting that the landward migration of coastal shorelines is a naturally-occurring event, the process has been stifled over the past several decades due to an increase in upland development and the construction of coastal protection structures such as the seawall and a series of riprap groins that impede the long-shore drift of sediment. Such anthropogenic impairments have resulted in increased beach erosion. Policies have been adopted by the State of Texas (Open Beaches Act, Dune Protection Act, Title 31 Texas Administrative Code [TAC] § 15.17; Natural Resources Code [NRC] §33.607; General Land Office's Texas Coastal Management Plan [CMP]) and the City of Galveston (Dune Protection and Beach Access Plan, Erosion Response Plan) to help mitigate and prevent excessive human-induced beach erosion; generally resulting in a minimization of impacts to Galveston's beaches caused by human activities. However, beach erosion can be exacerbated during major storm events (i.e., hurricanes and tropical storms). Such events have resulted in a cumulative negative effect through the continued loss of beach area.

Galveston Island has experienced three direct hits from major storm systems since the year 2000 (TS Allison, Hurricane Ike, and Hurricane Harvey). The island has also experienced lesser impacts from five others (TS Grace, Hurricane Claudette, Hurricane Rita, Hurricane Humberto, and Hurricane Eduardo) that either made landfall further north and east or south and west along the Texas coast (National Weather Service [NWS], 2018). Tropical Storm Allison crossed Galveston Island as a strong TS on June 5, 2001; bringing 60 mph winds and over 20 inches of rain before moving out of the Houston/Galveston area on June 10. Ike made landfall on Galveston Island on September 13, 2008 as a Category 2 hurricane with maximum sustained winds of over 100 mph. The storm produced one of the greatest storm surges, ranging between 15 and 20 feet, along the Texas coast. In 2017, Texas experienced Hurricane Harvey. A Category 4 hurricane that made two landfalls (first as a Hurricane and secondly as a TS). Although, impacts to Galveston Island beaches were not as significant as those encountered with Hurricane Ike, the island did experience strong wind and surge conditions over the extended time period that resulted in sediment loss.

1.2. Survey Locations and Physical Setting

Galveston Island is a sandy barrier island located in Galveston County along Texas' upper coast along the Gulf of Mexico. The barrier island sits approximately 41 miles north and east of Freeport, Texas and approximately 46 miles southeast of Houston, Texas. The island is approximately 27 miles long and about three miles wide at its widest point; resulting in an island encompassing an approximately 64 square mile area. The island is situated between two large tidal inlets, the San Luis Pass to the south and west, and Bolivar Roads to the north and east. Its beaches are managed and maintained by the City of Galveston, the Galveston Park Board, and the Texas General Land Office (GLO).

The three engineered beaches surveyed both pre- and post-Hurricane Harvey are all located along the Gulf side of Galveston Island from a beach area adjacent to 12th street to approximately ½ mile west of the Galveston Island Seawall's western terminus. Galveston's Historic Seawall Beach is located between 12th Street and 61st Street fronting the Galveston seawall (Figure 1-4). Babe's Beach is located immediately west of the 61st Street rock groin to 75th Street fronting the Galveston seawall (Figure 1-5). Dellanera Beach is located from the Galveston Island Seawall's western terminus, extending west approximately ½ mile to Dellanera Park (Figure 1-6). Over time, all locations have experienced significant losses of beach sand volume due to erosion.

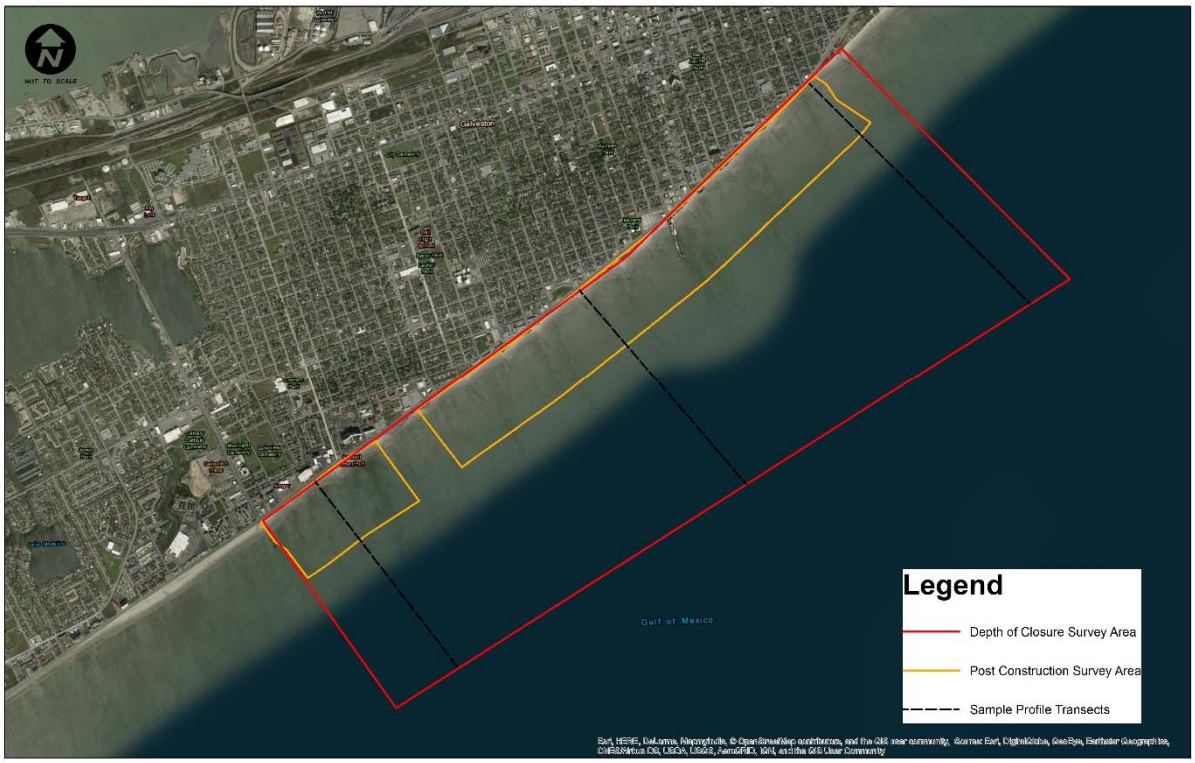


Figure 1-4: Galveston's Historic Seawall Beach depth of closure survey area (base image: Google Earth)

Figure 1-5: Babe's Beach depth of closure survey area (base image: Google Earth)

Figure 1-6: Dellanera Beach depth of closure survey area (base image: Google Earth)

Galveston Island's beaches are continually exposed to the wind and wave climates of the Gulf of Mexico as well as the daily semi-diurnal tide levels and associated tide currents. Mean tide range based on various tidal stations around Galveston Island is approximately 1.0 to 1.5 feet. Typical tidal datums as reported by the National Oceanographic and Atmospheric Administration's (NOAA) Tides and Currents collected from multiple tidal stations around Galveston Island are illustrated in Table 1. Historically, Galveston's Gulf shoreline was subject to coastal processes and sediment transports via the Longshore Current. However, these naturally-occurring events have been impeded by a rock groin system established and associated with Galveston's seawall that disrupts waves and longshore currents; trapping the movement of shoreline sediments. Beach areas located along Galveston Island's western end past the seawall and groin system continue to be affected and shaped by natural events; and therefore, are considered more dynamic than those areas along Galveston's east end. It should be noted that the natural processes previously described may be exacerbated as human development continues along the western end of Galveston Island. To counter the loss of Galveston Island's beaches due to erosion, several nourishment and restoration projects have occurred since the mid-1990s.

Table 1: Tidal datum for tidal stations proximal to the three survey areas (information provided by NOAA Tides & Currents, accessed January 2018)

Station ID	8771341	8771416	8771450	8771510	8771510
Station Name	Galveston Bay Entrance (North Jetty)	Galveston Bay Entrance (South Jetty)	Galveston Pier 21	Galveston Pleasure Pier	San Luis Pass
Mean Higher-High Water (MHHW)	10.78	9.67	5.79	5.54	5.39
Mean High Water (MHW)	10.66	9.47	5.7	5.34	5.32
NAVD88	0	0	4.52	4.11	0
Mean Sea Level (MSL)	10.08	8.7	5.21	4.61	4.91
Mean Tide Level (MTL)	10.08	8.71	5.2	4.62	4.87
Mean Low Water (MLW)	9.5	7.94	4.68	3.89	4.43
Mean Lower-Low Water (MLLW)	9.11	7.53	4.38	3.5	4.24

Note: All station records are in reference to standard (STND) datum.

1.3. Annual Beach Monitoring Surveys

For the purposes of monitoring beach conditions, Atkins has established a series of survey events to document beach conditions and Galveston's yearly sand volume loss. Since April 2014, Atkins has been performing monitoring surveys (known as the "Coastal Survey Plan [CSP]") which focuses on the 28.2 miles of existing beach from the shorelines of the Bolivar Roads inlet to the shorelines of the San Luis Pass on Galveston Island; and include the three beaches identified earlier in this section. These monitoring events are meant to:

1. Provide data to the City of Galveston, Galveston Park Board of Trustees, and City of Jamaica Beach for their annual Beach Maintenance Permits;
2. Provide documentation of beach conditions for potential FEMA assistance; and
3. Provide stakeholders with valuable long-term information regarding shoreline erosion, as well as a "snapshot" of contemporary beach conditions.

Monitoring of Galveston's beaches was performed continuously for approximately 28 days on a yearly basis beginning April 2014 and ending around the same time in 2017. During the monitoring events terrestrial data was collected from the landward beach face to the shoreline through wading depth. Bathymetric data was collected from wading depth to the estimated depth of closure.

1.4. Beach Nourishment & Dune Restoration

As previously described above, beach nourishment has been a constant working solution to beach erosion in Texas since the mid-1990s. Since that time, methods for such projects have improved. Between December 2014 and March 2017, three significant beach nourishment and restoration efforts were completed on Galveston Island including the nourishments of the shoreline associated

with the historic Galveston Seawall. Efforts to restore Galveston's beaches, specifically, Dellanera Beach, Babe's Beach, and the Historic Seawall Beach are described below. A typical design drawing for each is illustrated in Figures 1-7; 1-8, and 1-9.

2015 Dellanera Beach Nourishment & Dune Restoration

Prior to the Hurricane Ike 2015 FEMA nourishment and dune restoration project completed by the City of Galveston, the Galveston Park Board, and the GLO, Dellanera Beach had undergone nourishment efforts in some fashion ten times since the year 2000; primarily in the form of hauling sand from an upland borrow site and/or the replacement of sand encasements for geotextile tube core dunes. The City of Galveston, Galveston Park Board, and GLO 2015 efforts included working with local and state officials to establish support for the project, sand source identification under added pressure due to Galveston Island's "sand starved" status and city ordinances restricting excavation activities on the island, and a compressed project timeline. The $4.9 million Dellanera Beach Nourishment and Dune Restoration Project in 2015 resulted in the placement of approximately 113,500 CY of sand to construct approximately 2,100 feet of beach and a protective dune structure.

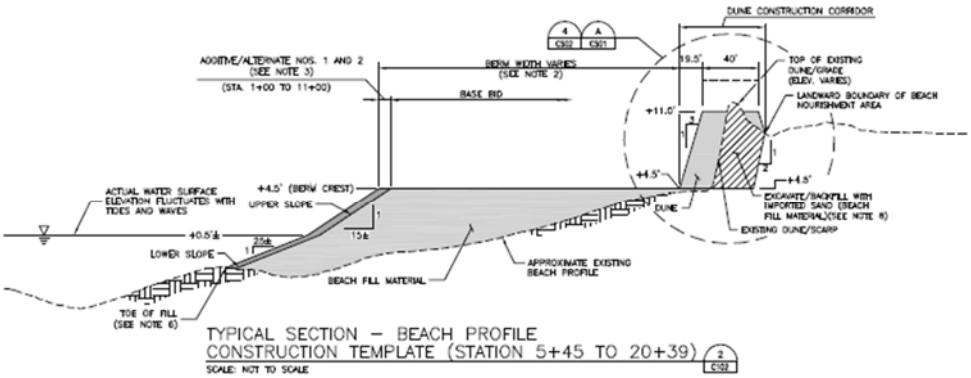


Figure 1-7: Representation of Dellanera's beach nourishment and restoration design (HDR Engineering Inc, 2013)

2015 Babe's Beach Restoration

The Babe's Beach Habitat Restoration project was coordinated and executed with support from the GLO, City of Galveston, U.S. Army Corps of Engineers and the Galveston Park Board of Trustees. Placement activities began on September 3, 2015 and concluded in November of 2015 using a hopper dredge resulting in placement of 4,980 LF (just over 629,000 CY) of sand; restoring an approximate 300-foot-wide beach. The restoration has resulted in approximately 34 acres of coastal beach and dune habitat for native species, enhanced recreational opportunities for residents and visitors, and provides protection against undermining of the Galveston Seawall and additional storm surge protection. This area west of 61st Street is the newest engineered beach area along Galveston's shoreline.

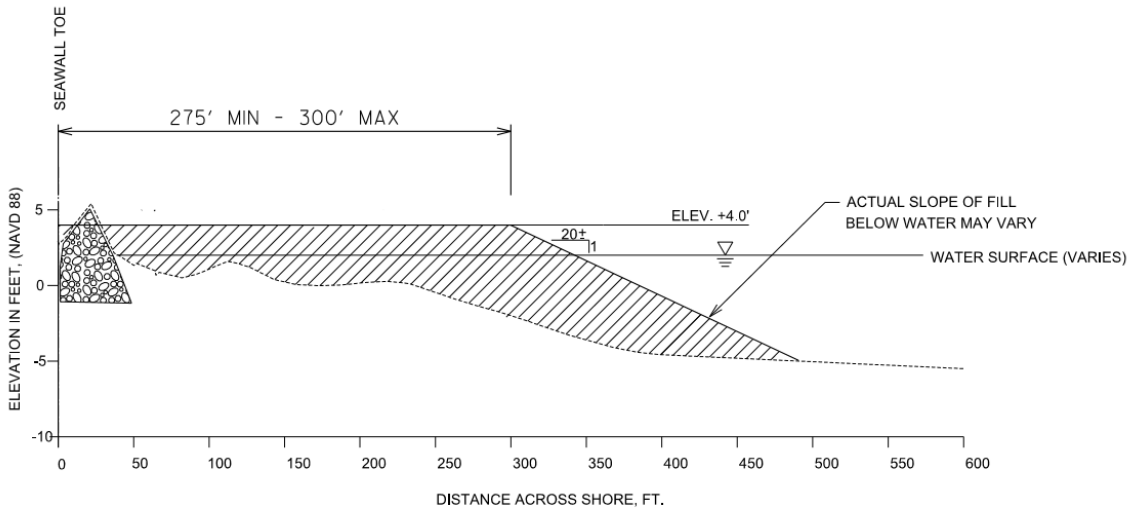


Figure 1-8: Representation of Babe's beach nourishment and restoration design (USACE, 2015)

2017 Historic Seawall Beach Restoration

Beaches along the Galveston Seawall have been regularly receiving sand for beach nourishment purposes since 1985, generally hauled to the area by trucks; however, this area had not experienced a major restoration effort until 1992 and 1995. In 1995 it was determined that Galveston's weak tourism economy was directly related to the lack of a wide recreational beach fronting the seawall. During the 1995 restoration event, approximately 710,000 CY of sand was placed along the seawall. In 2008, due to Hurricane Ike the Historic Seawall Beach required the emergency placement of approximately 565,000 CY of sand to re-establish the beach fronting the original sections of the seawall. In late 2016, another nourishment project was given the green-light to begin dredging and placement activities for the purpose of enhancing the public beach. Dredging and placement concluded in March of 2017 with the placement of approximately 1.2 million CY of sand along 3.69 miles of beach along the seawall.

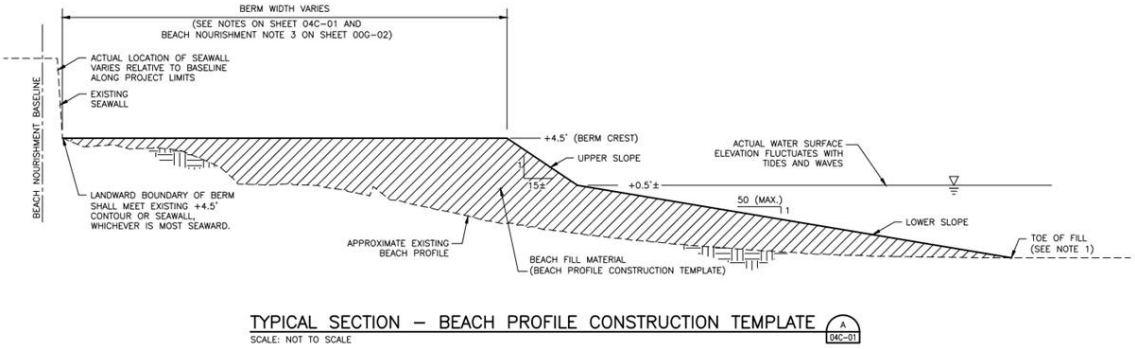


Figure 1-9: Representation of Historic Galveston Seawall beach nourishment and restoration design (HDR Engineering Inc, 2017)

2. HURRICANE HARVEY (2017)

Hurricane Harvey (Figure 2-1) made landfall as a Category 4 hurricane near Rockport, Texas, on August 25, 2017, with maximum sustained winds of 130 mph (National Hurricane Center [NHC], NOAA, 2017). Figure 2-2 illustrates the track of Hurricane Harvey from development to first land fall in the United States as well as its second landfall as a tropical storm. The system began as tropical storm Harvey upon entering the Caribbean Sea, West of the Lesser Antilles Islands (e.g., St. Lucia, St. Vincent and the Genedines, and Grenada), on August 18. Continuing a west-northwesterly path across the Yucatan Peninsula, tropical storm Harvey eventually made its way in to the Gulf of Mexico where it wavered between a tropical storm and a tropical depression before quickly increasing in strength to a Category 1 hurricane on August 24.

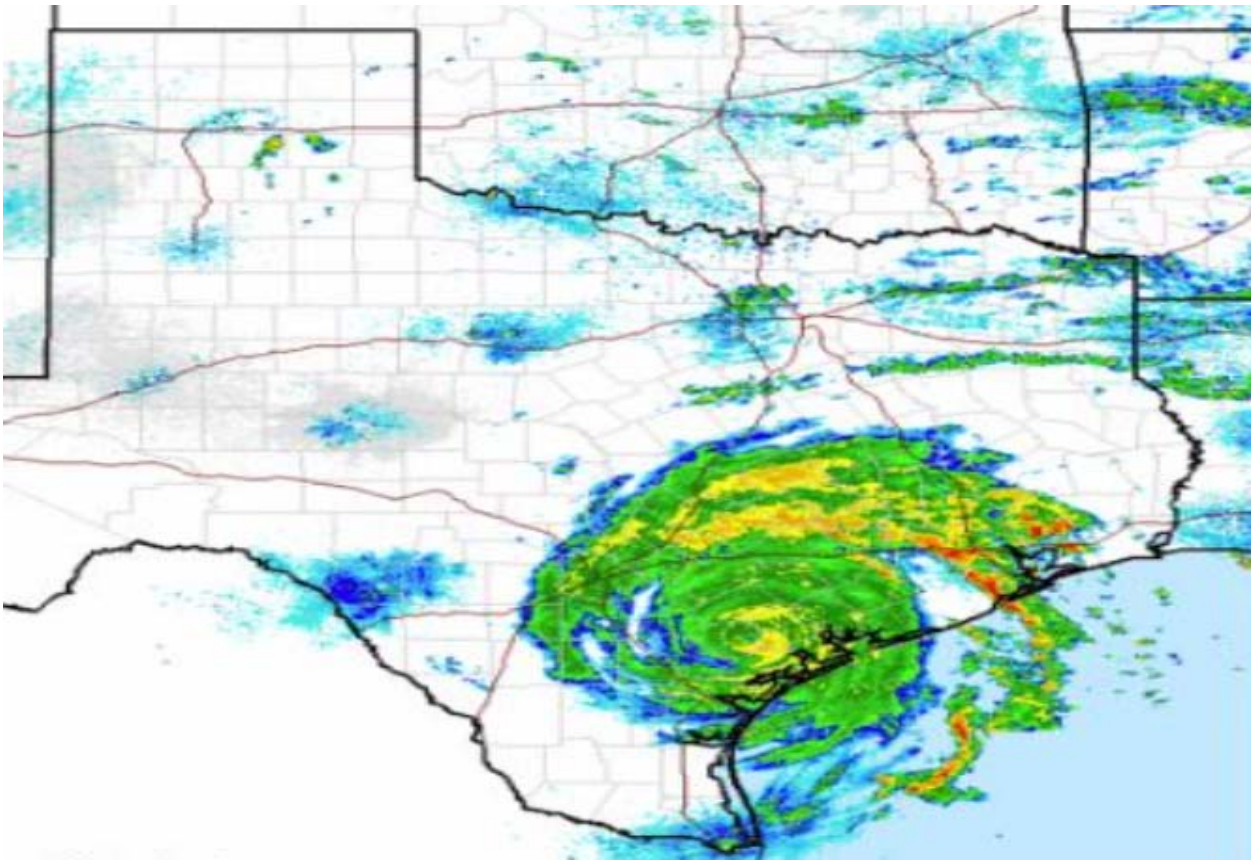


Figure 2-1: Radar image of Hurricane Harvey after it made first landfall near Rockport, TX (National Weather Service [NWS], NOAA, 2018)

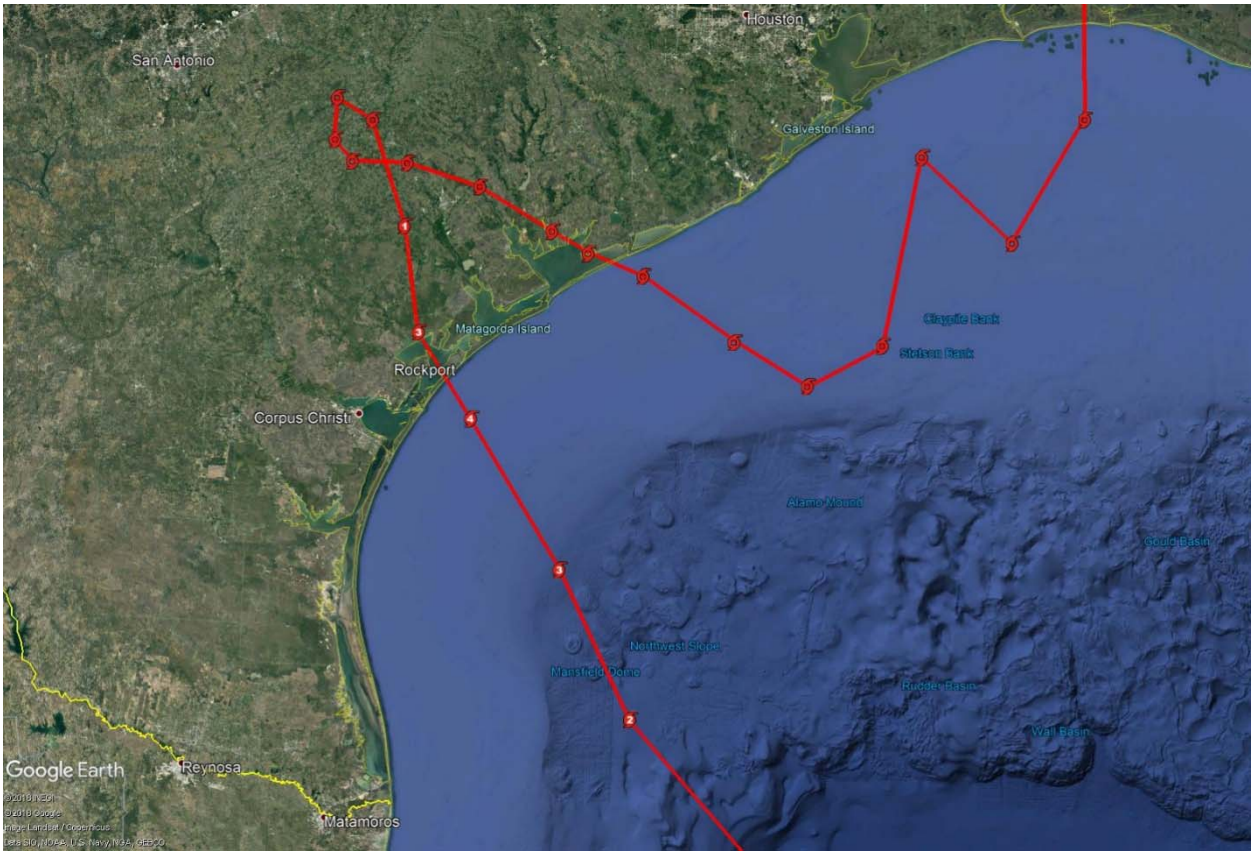


Figure 2-2: Storm track of Hurricane Harvey within the Gulf of Mexico with reference to the location of Galveston Island, TX (track: NHC, NOAA; base image: Google Earth)

Now Hurricane Harvey, the storm continued a north-northwesterly path towards the Texas Gulf Coast; increasing its sustained windspeed from 80 mph to 130 mph within 2 days. The storm continued its path to the north-northwest into Texas as it lost intensity and its movement stalled on August 27 over an area approximately 50 miles northwest of Victoria, Texas. Harvey made its way back out into the Gulf of Mexico by August 28 before turning to the northeast; making a second landfall near Cameron, Louisiana as a tropical storm with sustained winds around 45 mph. Figure 2-3 shows the track of tropical storm Harvey in the vicinity of Galveston Island, Texas. Harvey continued to the northeast through Louisiana as a tropical storm; decreasing rapidly to a tropical depression before continuing through the Midwest as a low-pressure system.

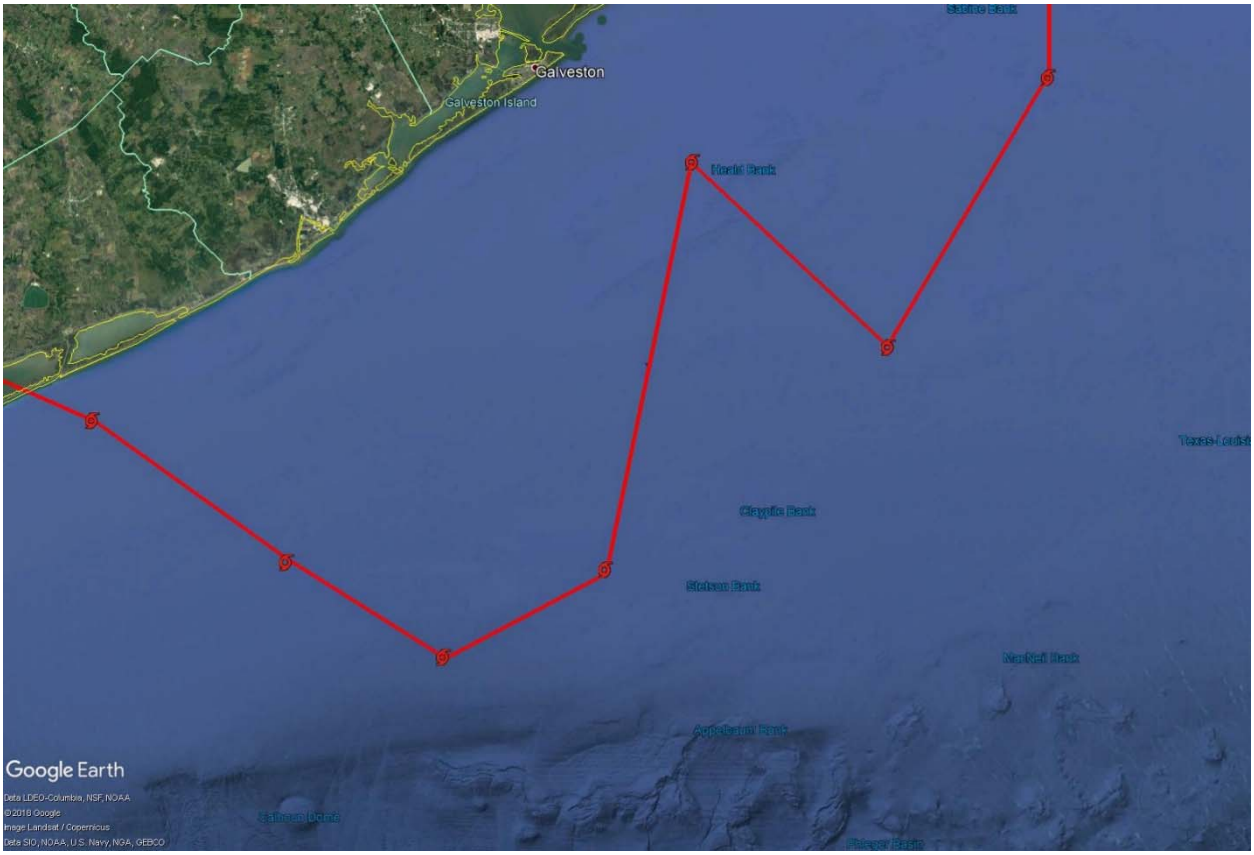


Figure 2-3: Storm track of Tropical Storm Harvey within the within the vicinity of Galveston Island, TX (track: NHC, NOAA; base image: Google Earth)

Storm Conditions on Galveston Island Beaches

Although the storm did not result in damages similar to Hurricane Ike in 2008, Galveston Island did experience the effects of then Tropical Storm Harvey for approximately 6 days – from August 25 through August 30, 2017 – in the form of heavy precipitation, increased winds, and a moderate storm surge. Data collected from nearby meteorological stations San Luis Pass (LUIT2) and Galveston Bay Entrance North Jetty (GNJT2) identified average sustained wind speeds upwards of 20 miles per hour (mph). Data from both meteorological stations are illustrated in Figure 2-4. It should be noted that land-based meteorological stations such as the Sholes International Airport (Station KGLS) recorded average windspeeds of approximately 24 mph with gusts up to approximately 36 mph for the six-day period between August 25 and August 29, 2017.

Data collected at Station 42035 located approximately 22 nautical miles East of Galveston, Texas indicated wave height ranging from approximately 6 to 12-feet mean higher high water (MHHW) (Figures 2-5). Additionally, tidal gauges at Pier 21 (Station 8771450) on Galveston Island, Texas and along the North jetty of the Galveston Bay entrance (Station 8771341) measured an associated storm surge averaging 1 to 2.5 feet MHHW during the storm event (Figures 2-6 and 2-7). The combination

of consistently strong winds and the associated storm surge resulted in increased wave action along Galveston's beaches over 5 days; thus, resulting in increased erosion.

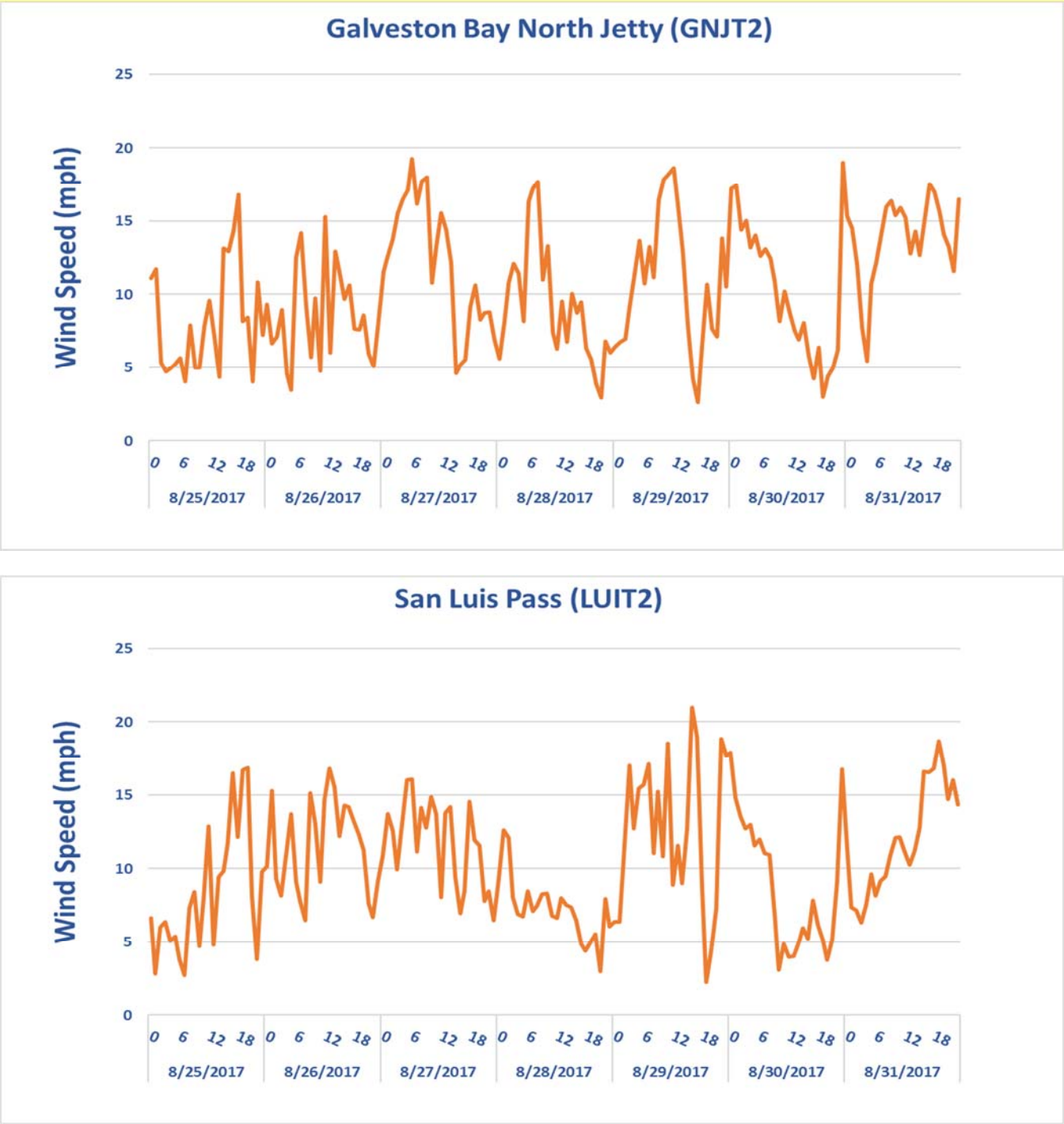


Figure 2-4: Time series of wind speed measured by hour at meteorological stations located nearshore (GNJT2 and LUIT2) and offshore (Station 42035) in the vicinity of Galveston Island, Texas

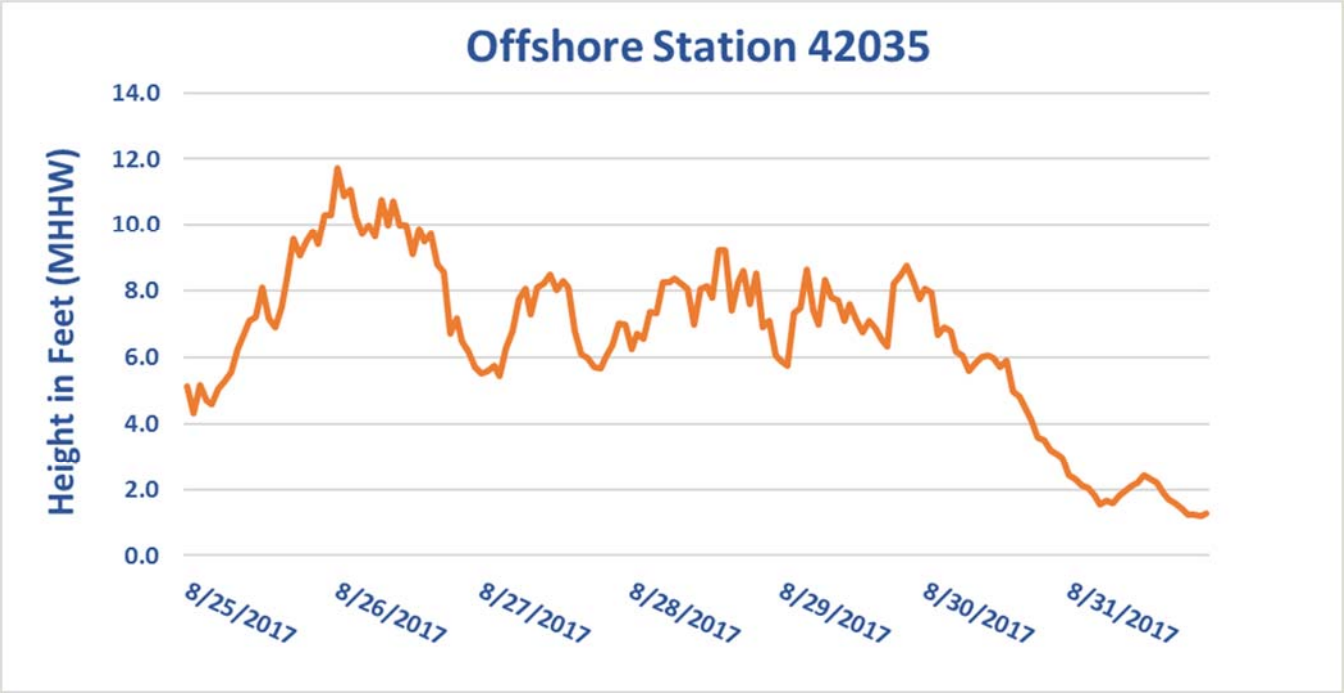


Figure 2-5: Time series of wave height (feet) measured at the nearest offshore meteorological station (42035) located 23 NM to the East of Galveston Island, Texas (National Data Buoy Center, NOAA, 2018)

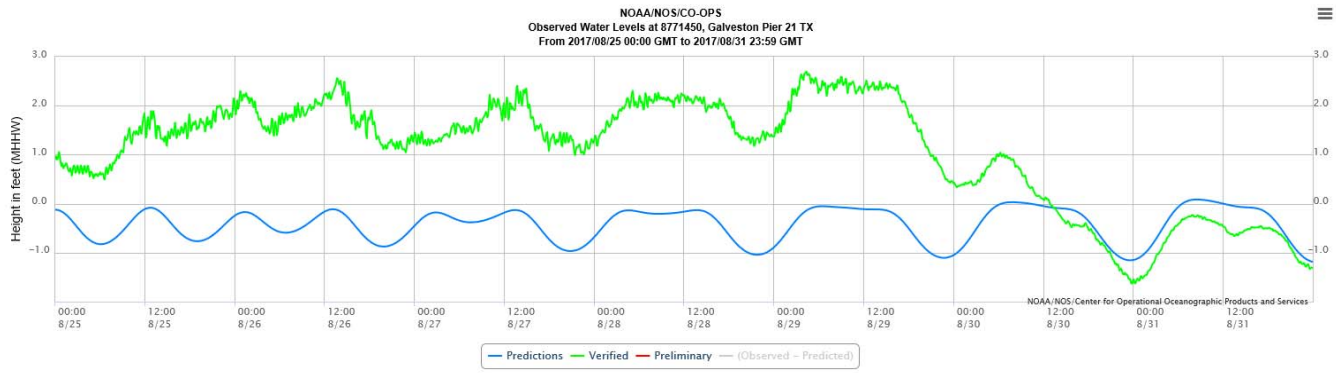


Figure 2-6: Time series of verified and predicted water level height in feet (MHHW) measured at Pier 21 (Station 8771450) on Galveston Island, Texas from August 25 to August 31, 2017 (Tides and Currents, Center for Operational Oceanographic Products and Services, NOAA, 2018)

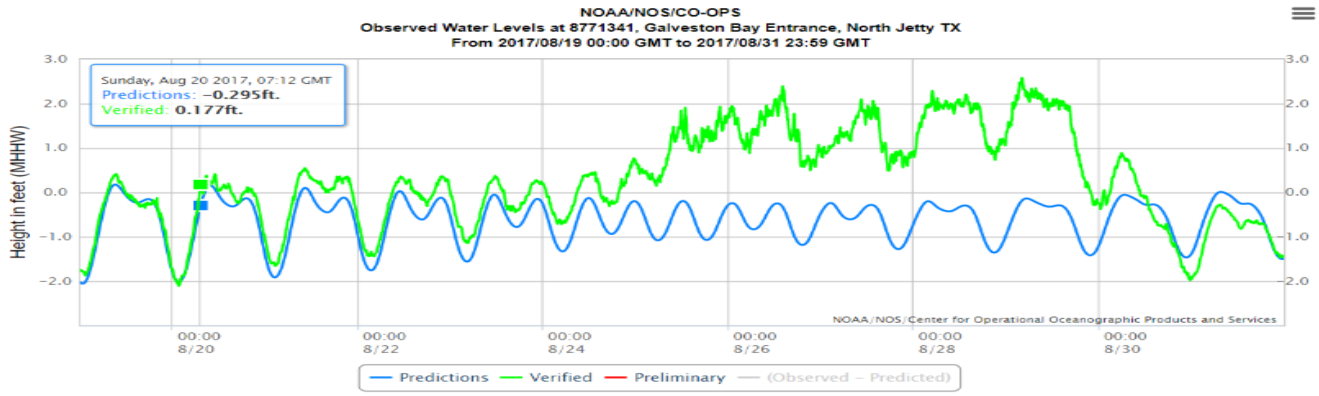


Figure 2-7: Time series of verified and predicted water level height in feet (MHHW) measured at the Galveston Bay Entrance, North Jetty, TX (Station 8771341) from August 20 to August 30, 2017 (Tides and Currents, Center for Operational Oceanographic Products and Services, NOAA, 2018)

3. SURVEY METHODS

Impacts from Hurricane Harvey occurred approximately four months after the 2017 beach monitoring surveys for the CSP concluded. In accordance with the currently established (and completed) CSP, Atkins was requested by the City of Galveston to perform additional surveys for the previously mentioned engineered beaches described in Section 1 to provide a post-storm "snapshot" of contemporary beach conditions. The surveys were conducted over a 45-day period in the months of October and November. Surveys were completed utilizing the same methodologies as those conducted during the previous monitoring surveys - methods used for post-storm surveys reflect those performed during the monitoring surveys and are consistent with established industry "best practices" for topo- and hydrographic surveying analyses. Such efforts were conducted to provide an additional post-storm "snapshot" of contemporary beach conditions.

For annual beach monitoring, Atkins field teams completed two primary tasks: 1) the collection of terrestrial/topographic survey data and 2) the collection of bathymetric survey data. Both tasks were meant to assess existing conditions within the three survey areas and for the entire 28.2 mile stretch of Galveston Island– terrestrial/topographic data collected will be used to analyze conditions of the existing shoreface; whereas bathymetric surveys will provide the basis for collecting data to the depth of closure by providing high-resolution data along the shoreline. Additionally, coordinates used for the project are based on the Texas Coordinate System, South Central Zone, NAD83 (Grid) coordinates and elevations are based on the North American Vertical Datum of 1988 (NAVD88) as collected by static GPS network observations referencing CORS Stations TXGA, TXAG, and TXLM on NGS monuments designated: AW7078, AW0590, AW0443, AW5710, AW0611, AW5708, AW0634, AW0637, AW0644, and AW5710. The coordinates and elevations from the static network (Figure 3-1) have been used through the duration of the 4-year beach monitoring surveys and this post storm survey (Table 2).

Table 2: Static network coordinates and elevations used during monitoring surveys and the post storm survey

Monument ID	Northing	Easting	Elevation
AW5710	13,602,086.97	3,210,358.58	5.36
AW7078	13,692,841.25	3,326,346.26	4.60
AW0443	13,685,782.54	3,299,911.67	14.37
AW0611	13,661,803.55	3,289,868.45	14.94
AW0590	13,676,792.27	3,310,374.26	14.44
AW5708	13,645,727.10	3,264,124.36	6.40
AW0634	13,628,077.25	3,242,217.25	9.18
AW0644	13,602,952.81	3,211,628.02	8.63
AW0637	13,621,154.13	3,233,204.36	8.38
AW0518	13,659,038.39	3,281,584.12	4.54

3.1. Terrestrial/Topographic Surveys

Within all three survey areas the Leica C-10 high-definition (HD) scanner (Figure 3-2) was used to collect shoreface profile data on the dry beach surface. The scanner was stationed at a maximum of 400-foot intervals along to beach, collecting dense point cloud data. The point cloud data was then registered to project control through Leica Cyclone software and exported in 3D Points File (.pts) format. TopoDOT software was then used to extract elevations on a 3-foot grid for the creation of a detailed digital terrain model (DTM).

Figure 3-1: Example of a typical Leica C-10 high-definition scanner

Using Real Time Kinematic (RTK) Global Positioning System (GPS) Atkins field staff complemented the terrestrial survey data with additional survey points in areas around dunes and in the swash zone of the beach (out to -3-feet depth).

3.2. Bathymetric Surveys

Atkins field teams employed a 30-foot Scully's aluminum boat equipped with Reson 7125 Multi-beam bathymetry system (Figure 3-2) to collect seafloor elevation measurements to assess depth of closure (24-foot water depth). Depth of Closure is considered the maximum depth that wave energy will influence sediment motion on the seabed. The depth of closure survey provides complete data coverage from the roughly 6-foot water depth to the depth of closure as estimated in previous studies performed along Galveston Island and agreed to with project partners. Additional equipment used

for bathymetric data collection included differential GPS unit, RTK, sound velocity profiler, and a heave compensator. During the survey, field teams completed between one and three 1,000-foot survey transects (depending on the survey area) perpendicular to the shoreface to relate Wading Depth information and create a comprehensive dataset.

Figure 3-2: Example of typical multi-beam and single-beam survey

3.3. Collected Field Data

Field data collected using terrestrial laser scanning, GPS observations, single-beam transects, and multi-beam system were processed independently and Quality Assurance/Quality Control measures were taken to check the accuracy of all data-sets.

Once all data sets were checked, DTMs were created with AutoCAD Civil3D for each data set and areas of overlap were checked for consistency. The various DTM's surfaces were then merged into one comprehensive DTM for each of the three project areas. This procedure is the same that was used for the 4-year monitoring period and allows for accurate comparison.

4. SUMMARY OF FINDINGS

Atkins utilized AutoCAD Civil3D to import DTM's from the post storm surveys, 4-year monitoring period surveys, and those provided by others from post construction. The Volume Dashboard tool, within AutoCAD Civil3D, was then used to create volume surfaces and allow for volume comparison between each dataset.

Atkin's post-storm surveys show a loss in beach sand volume across all three engineered beaches (Table 3). Both Dellanera and Babes Beach experienced more than 100,000 CY of beach sand loss due to Harvey. On Historic Galveston Seawall Beach, Harvey impacts resulted in the loss of more than 216,000 CY of beach sand that was placed in this location during the 2017 nourishment effort.

Table 3: Depth of Closure survey results for Dellanera and Babe's beach

DEPTH OF CLOSURE SURVEYS (2016 VS. 2017 POST-STORM)[1]		
Beach	**Total Area (Acres)**	**Volume Lost (CY)**
Dellanera	342.57	118,668
Babes Beach	737.06	101,387

[1] Surveys conducted by Atkins.

On Historic Galveston Seawall Beach, measurements were derived from comparing the post construction template (2017) with the Post-Harvey depth of closure survey trimmed to the construction template limits, a subset of the total beach monitoring area. Harvey impacts resulted in the loss of more than 216,000 CY of beach sand that was placed in this location during the 2017 nourishment effort (Table 4).

Table 4: Survey results for Historic Galveston Seawall beach based on 2017 post-construction template area

2017 POST-CONSTRUCTION[1] VS. 2017 ATKINS POST-STORM		
Beach	**Total Area (Acres)**	**Volume Lost (CY)**
Historic Seawall	830.34	216,342

[1] Data provided by other Hydroterra Technologies LLC.

Profiles were used to compare the surfaces and evaluate how the sand appears to be moving in each of the nourishment areas. For the depth of closure survey comparison between 2016 and 2017 (Post Storm) in Dellanera (Figures 4-1 and 4-2), accumulation of sand was observed in the near-shore portion of the survey while having volume loss from the beach/shore interface towards depth of

closure. At Babes Beach (Figures 4-3 and 4-4), there was general loss of sand along the beach face and movement of sand near depth of closure, which resulted in the overall net loss.

While comparing depth of closure surveys in 2016 and 2017 (Post Storm) at the Historic Seawall (Figures 4-5 and 4-6), large gains throughout the survey area are observed from the 2017 nourishment project as would be expected. To analyze the effects of Harvey to the Historic Seawall area, post-construction survey data was provided by Hydroterra and compared to our 2017 Post Storm Survey (Figure 4-7). The comparison profiles indicate a substantial loss along the beach face and movement of sand out to approximately –12-feet (NAVD88), which resulted in the observed overall net loss.

In conclusion, the impacts of Hurricane Harvey to the three engineered beaches showed a net decrease in sand volume. The losses incurred are somewhat typical after experiencing wind and wave energy associated with a tropical storm system. The ongoing monitoring program provides sufficient background data to adequately and confidently compare pre-storm, post-nourishment, and post-storm areas for volume assessment.

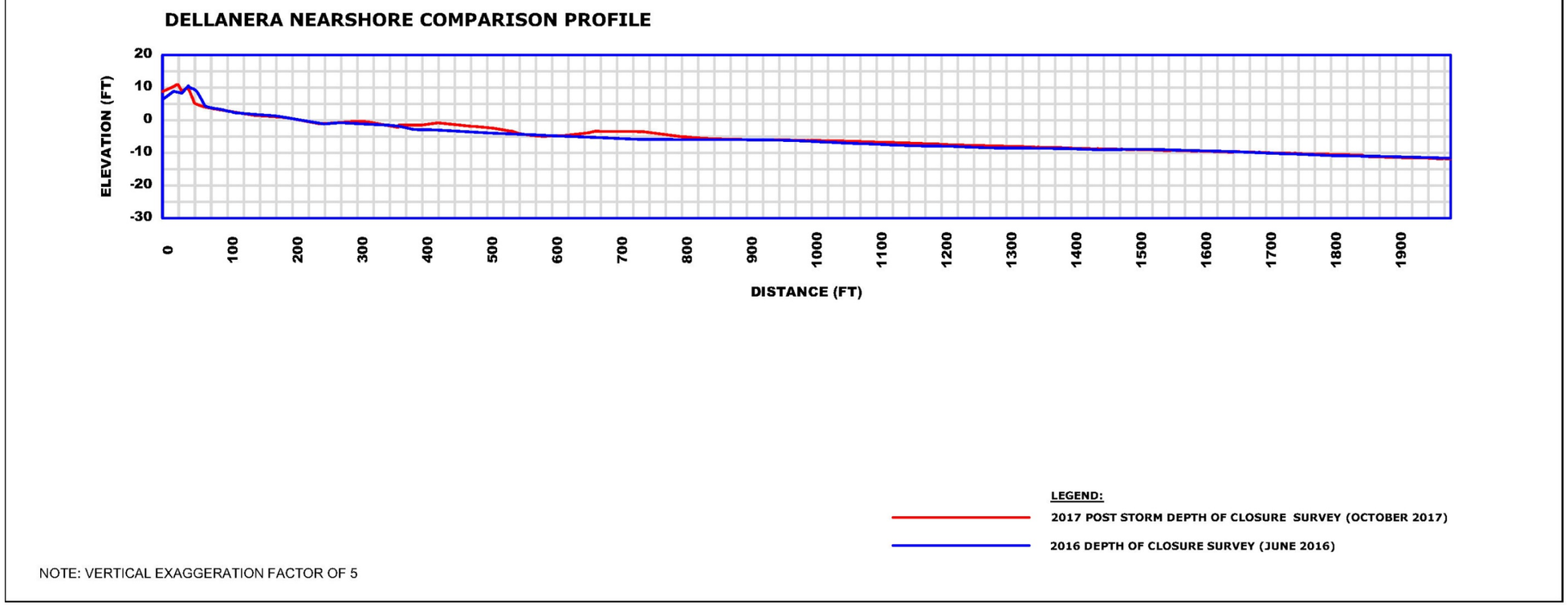
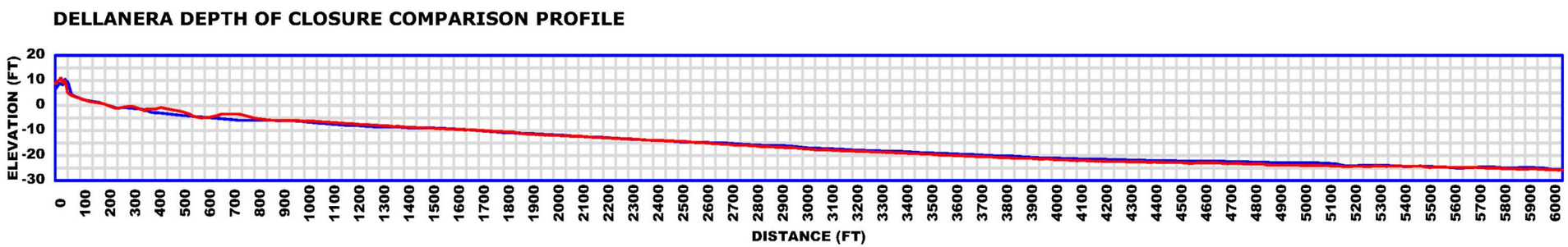


Figure 4-1: Dellanera Nearshore Comparison Profile (Depth of Closure)



LEGEND:

2017 POST STORM DEPTH OF CLOSURE SURVEY (OCTOBER 2017)

2016 DEPTH OF CLOSURE SURVEY (JUNE 2016)

NOTE: VERTICAL EXAGGERATION FACTOR OF 10

Figure 4-2: Dellanera Comparison Profile (Depth of Closure)

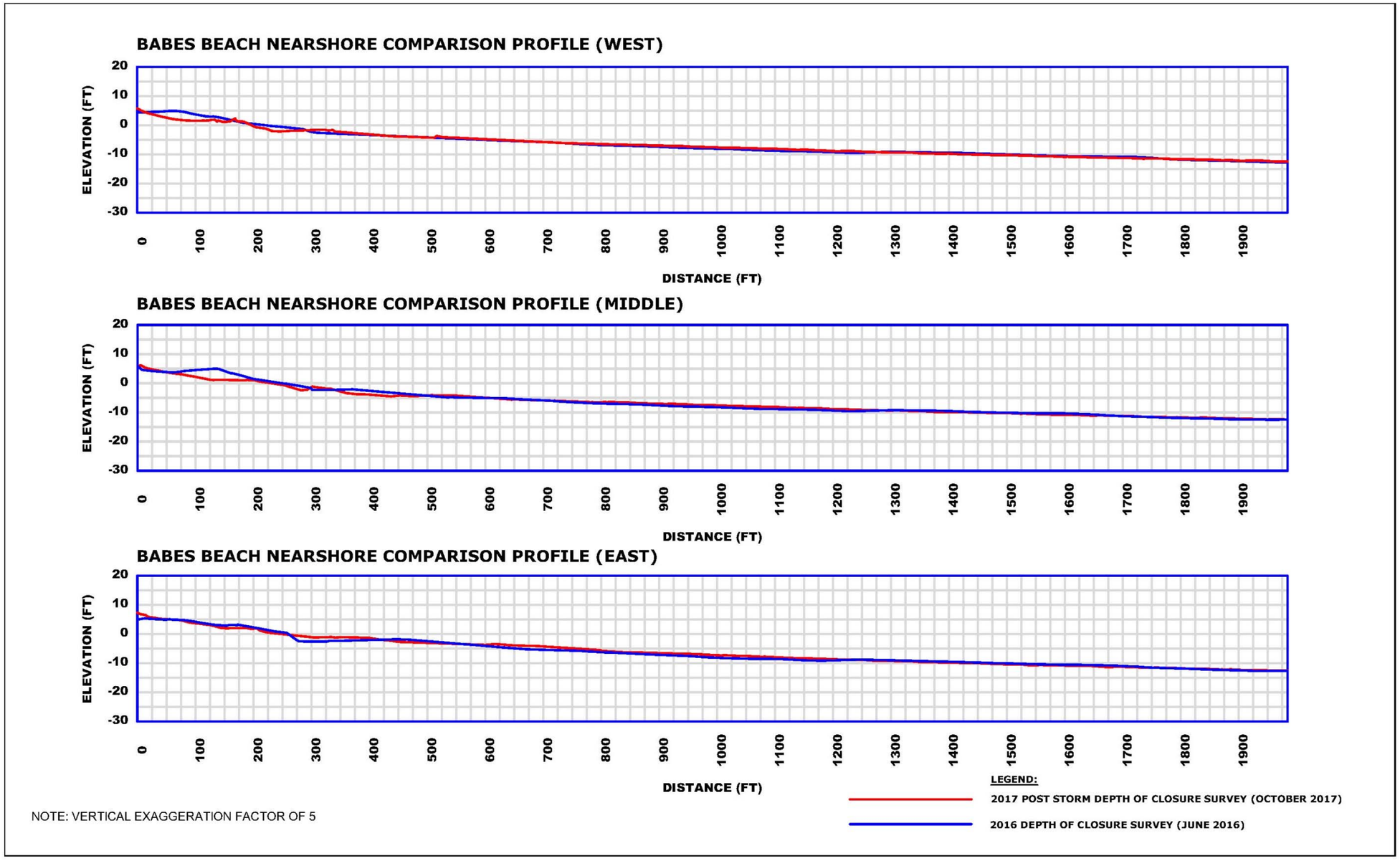


Figure 4-3: Babes Beach Nearshore Comparison Profile

Figure 4-4: Babes Beach Depth of Closure Comparison Profile (West, Middle, and East)

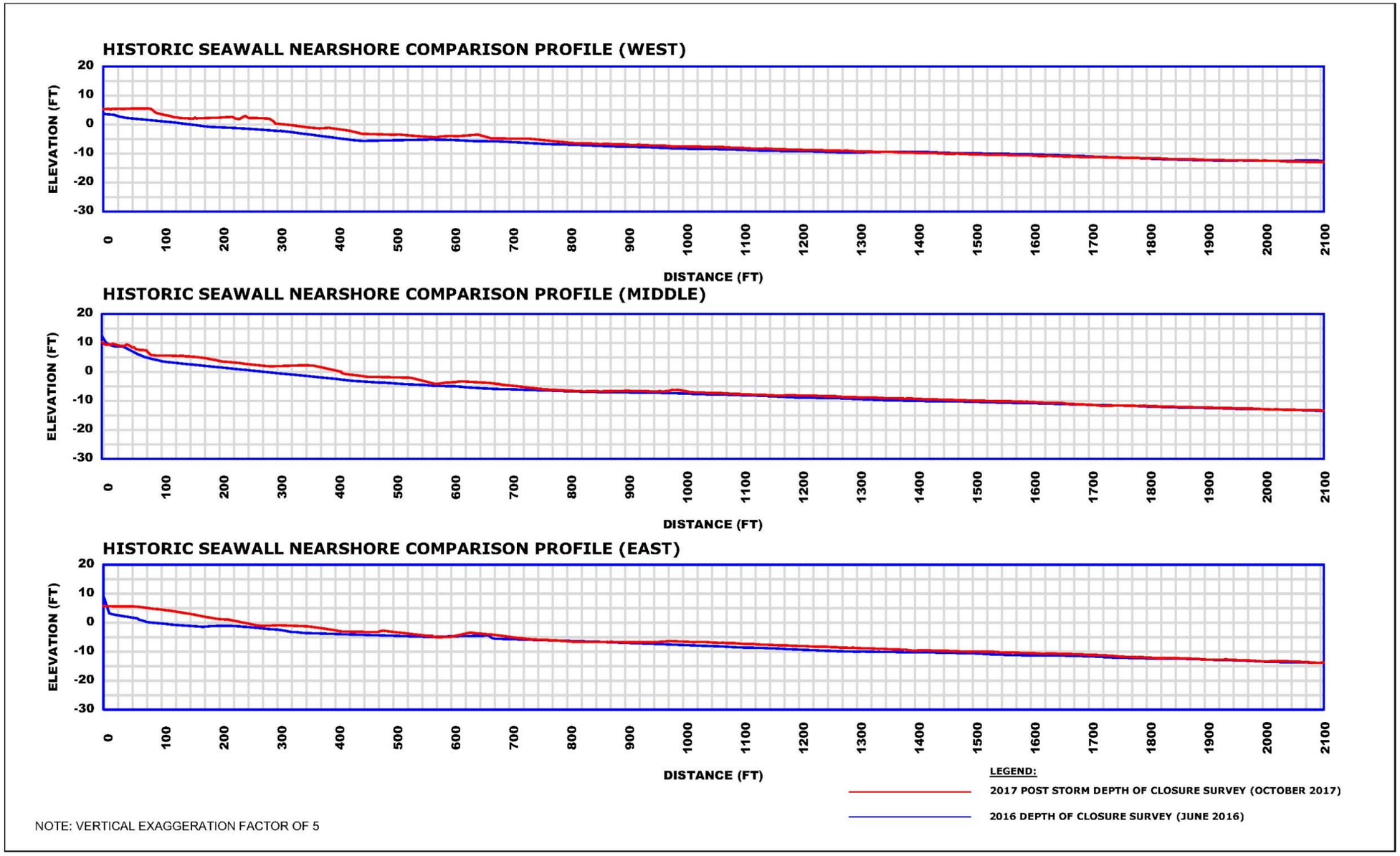


Figure 4-5: Historic Seawall Nearshore Comparison Profile (Depth of Closure)

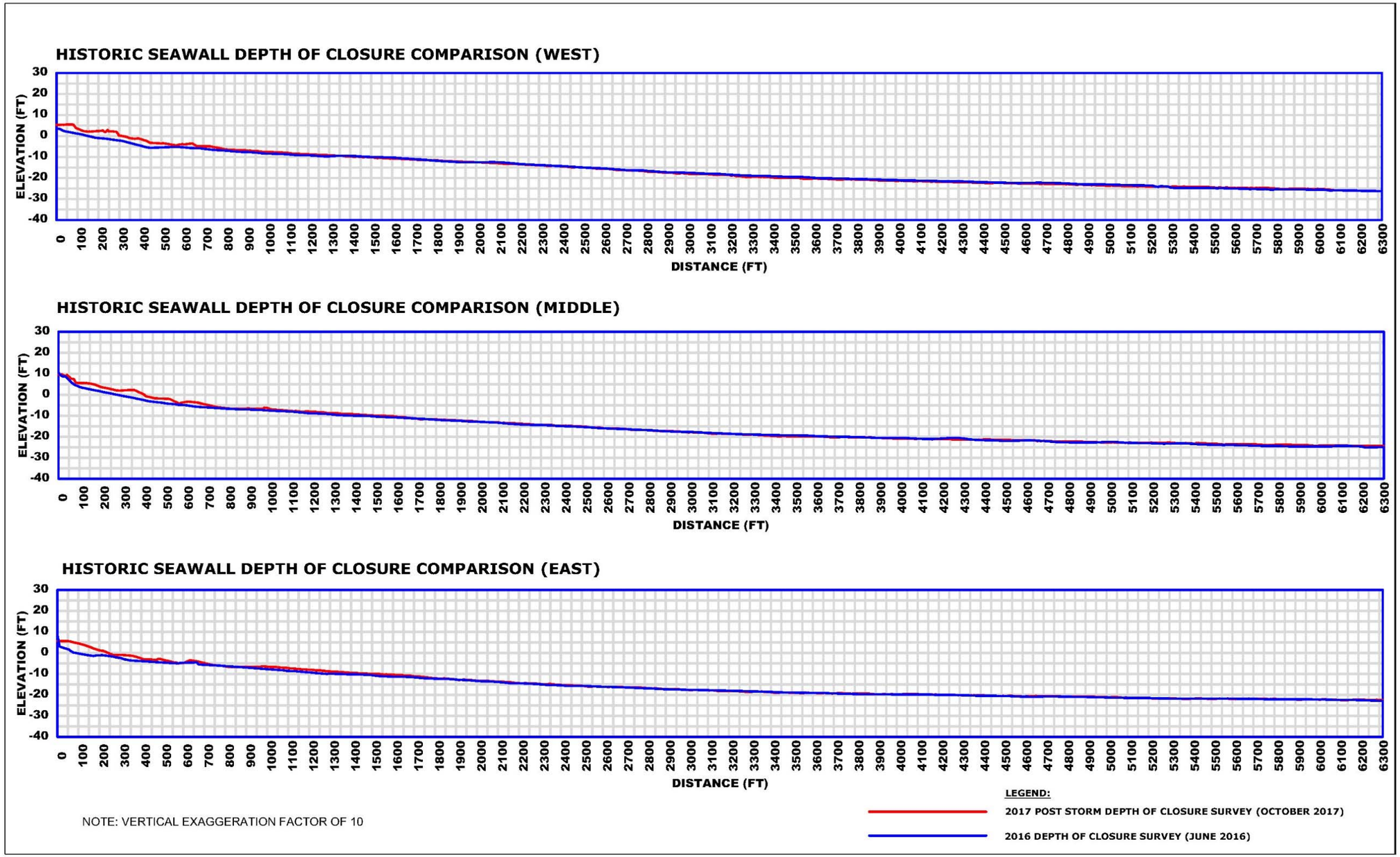


Figure 4-6: Historic Seawall Comparison Profile (West, Middle, and East)

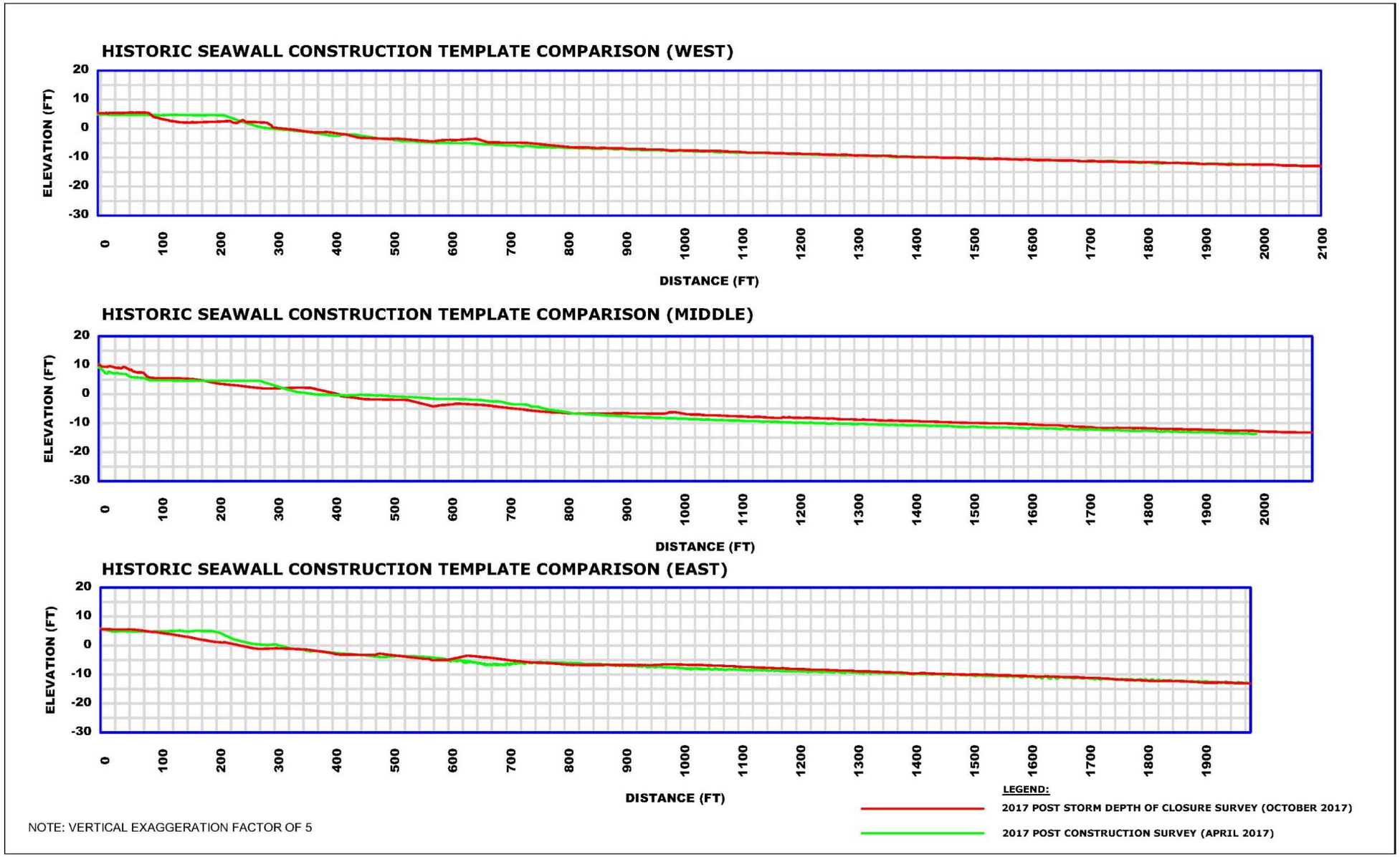


Figure 4-7: Historic Seawall Construction Template Comparison Profile (West, Middle, and East)

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