Storm-Induced Beach Change (SBEACH)
High-Frequency Storm Erosion
Model Study for Bay County

Division of Water Resource Management

Florida Department of Environmental Protection

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1. Background

Since 2009, high-frequency storm tide studies have been conducted by the Beaches and Shores Resource Center (BSRC) of Florida State University and the Department of Environmental Protection's (DEP's) Division of Water Resource Management (DWRM) for the 24 Coastal Construction Control Line (CCCL) studied counties. Hydrographs with 15- and 25-year return intervals were developed for the application of dune erosion models. Due to increased usage of the Storm-Induced Beach Change (SBEACH) by coastal engineers for coastal projects in Florida, DEP contracted with the BSRC to conduct the model calibration and application on a county-by-county basis. A total of eight counties were completed: Walton, Okaloosa, Brevard, St. Johns, Volusia and Indian River by Leadon and Nguyen (2009 and 2010); and Sarasota and Palm Beach by Wang and Manausa (2013). Since 2014, the SBEACH calibration study has been conducted by DWRM's Engineering, Hydrology and Geology Program (EHG); Lee and Franklin were completed by Wang and Manausa (2015 and 2016) before the current Bay County study. The SBEACH model, Version 4.03, for high-frequency storm event is used in verification for armoring projects and shore/dune protection project permit applications.

The SBEACH model developed by the U.S. Army Corps of Engineers (USACE) is an empirically based numerical model for predicting short-term profile response to storms. The SBEACH model calculates beach profile changes with emphasis on beach and dune erosion and bar formation and movement. It is a cross-shore sediment transport model, so the longshore processes are considered to be uniform and neglected in the calculation of profile changes. The model was initially formulated using data from prototype-scale laboratory experiments, and further developed and verified based on field measurements and sensitivity testing (Larson and Kraus, 1989).

To accurately apply the SBEACH model for a high-frequency storm event, it is essential to have the model calibrated in the project area under similar storm conditions. This requires detailed pre- and post-storm beach profile surveys that represent a storm's effects on cross-shore beach change, and coincident information regarding the wind, wave, and water level conditions. This study presents eroded dune and beach profiles due to high-frequency storm events with return intervals of 15 years and 25 years in Bay County using the latest version of the SBEACH model. All data resources for calibration and input files required to run the SBEACH model are documented.

2. Model Calibration

Searches for available surveyed beach profiles associated with a tropical storm or hurricane for Bay County resulted in a data set with sufficient completeness and quality for model calibration. A set of beach profiles in Bay County was surveyed before and after Hurricane Ivan of 2004. The model calibration became possible with the BSRC's 2-D Storm Surge Model, and the measured storm tides on the open coast.

2.1 Storm Data

Hurricane Ivan developed from a large tropical wave that moved off the west coast of Africa on August 31, 2004. It continued to develop to a tropical depression around 1800 UTC September 2, and became Tropical Storm Ivan at 0600 UTC September 3. Ivan moved on a generally westward motion and steadily strengthened, becoming a hurricane at 0600 UTC September 5. Ivan reached the Category 5 strength three times in Caribbean Sea before it entered the Gulf of Mexico early on September 14 at Category 4 strength (Figure 1).

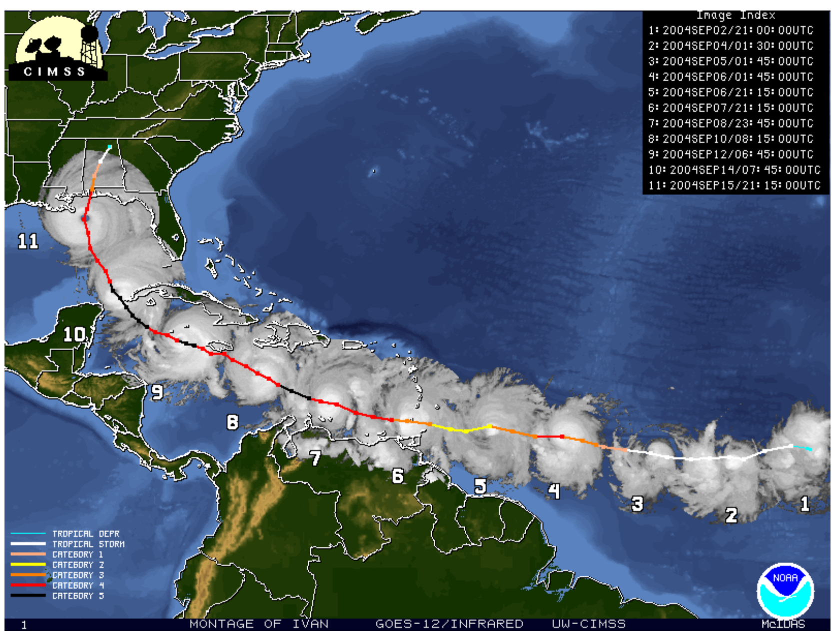

Figure 1. *Hurricane Ivan Track (Source: CIMSS, UW-Madison).*

As Ivan neared the northern U.S. Gulf coast, it weakened only slowly. It made landfall as a 121-mile-per-hour (Category 3) hurricane at approximately 1:50 a.m. CDT (0650 UTC) on September 16, just west of Gulf Shores, Alabama. By this time, the eye diameter had increased to 40-50 n mi., which resulted in some of the strongest winds occurring over a narrow area near the south Alabama-western Florida panhandle border. The winds of Ivan are presented in the wind swath map show in Figure 2. The data was prepared and provided by the Hurricane Research Division (HRD) at the Atlantic Oceanographic and Meteorological Laboratory (AOML) of the National Oceanographic and Atmospheric Administration (NOAA).

The graph in Figure 3 depicts the best track central barometric pressure and wind speed history for Ivan, based on data obtained from Tropical Cyclone Report of Hurricane Ivan, National Hurricane Center (Stewart, 2005). Wind speed dropped and central pressure rose dramatically right after landfall.

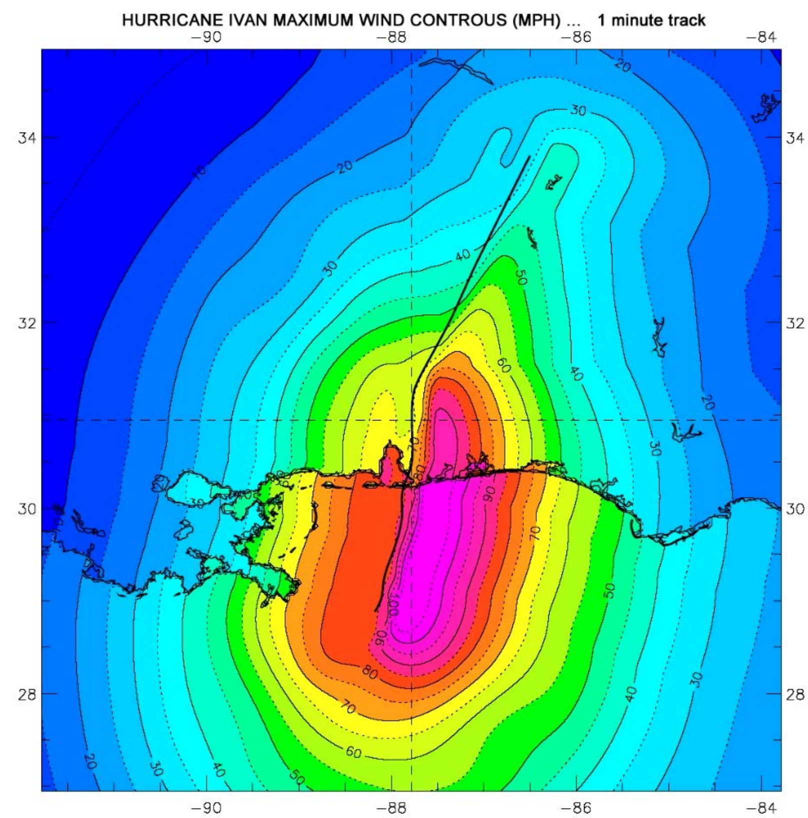

Figure 2. *Surface Wind Fields Associated with Hurricane Ivan at Landfall.*

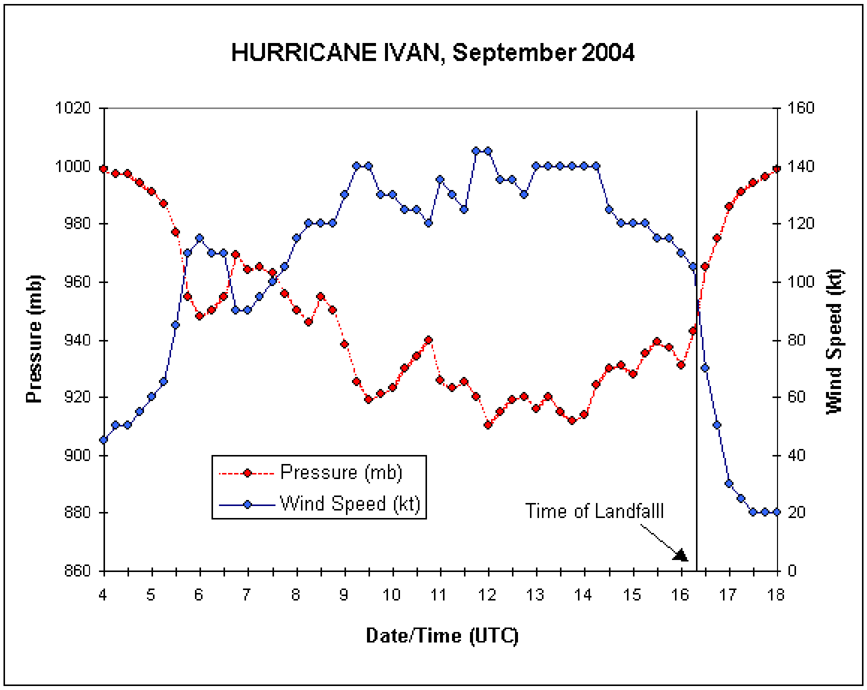

Figure 3. *Best Track Pressure and Wind Speed for Hurricane Ivan, September 4-18, 2004.*

2.1a Storm Tide Data

The URS Group, Inc., was contracted by the Federal Emergency Management Agency (FEMA) to collect and survey Coastal High-Water Marks (CHWMs) in the Ivan impacted areas. Only the interior High-Water Mark (HWM) data from beach areas was selected to evaluate the storm tide associated with Hurricane Ivan (Figure 4). To verify those measured HWM data and to provide the additional areas with predicted storm tides, the 2-D Storm Surge Model was employed to calculate the total storm tide, i.e., surge generated from barometric pressure and wind stress plus dynamic wave setup and astronomical tide. Hurricane track, pressure deficit, and radius to the maximum wind (RMW) of Ivan for 72 hours were input to the 2-D Storm Surge Model. The model then ran and calculated the total storm tide for 10 locations in Panhandle area. Figure 5 displays the results of model calculated total storm tides and the measured HWM. The 2-D Storm Surge Model calculated peak storm tide by Hurricane Ivan agrees closely with the measured HWM.

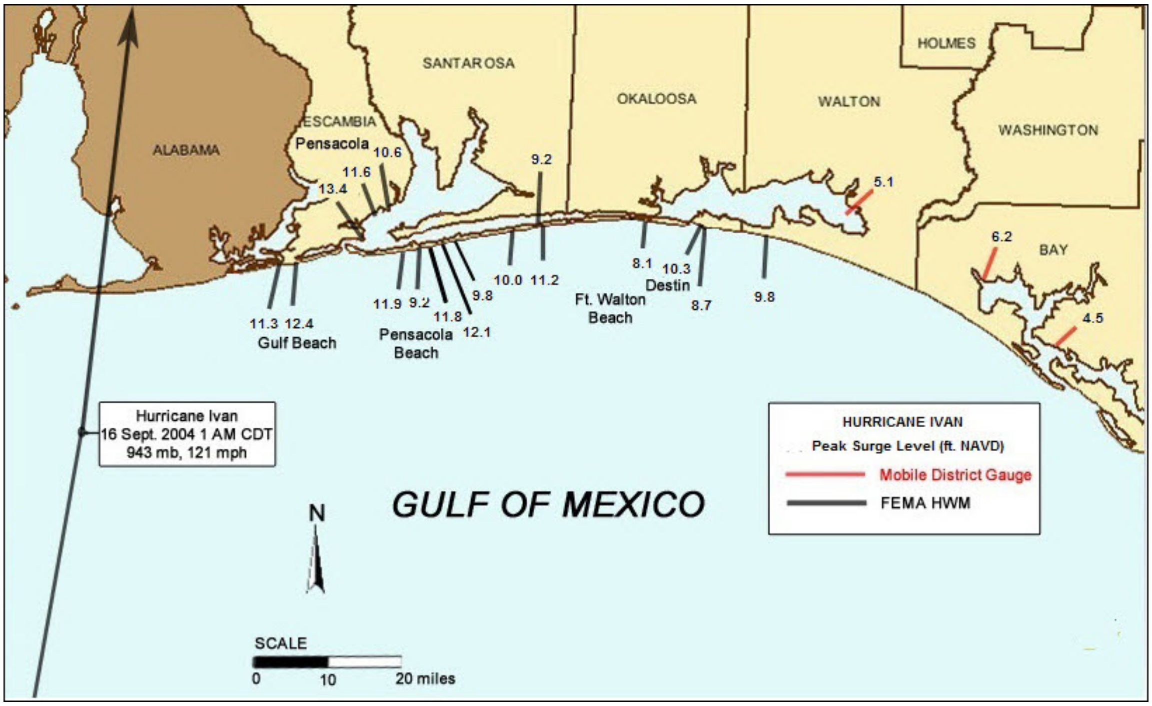

Figure 4. *Surveyed Peak Surge Levels Along the Panhandle Area for Hurricane Ivan.*

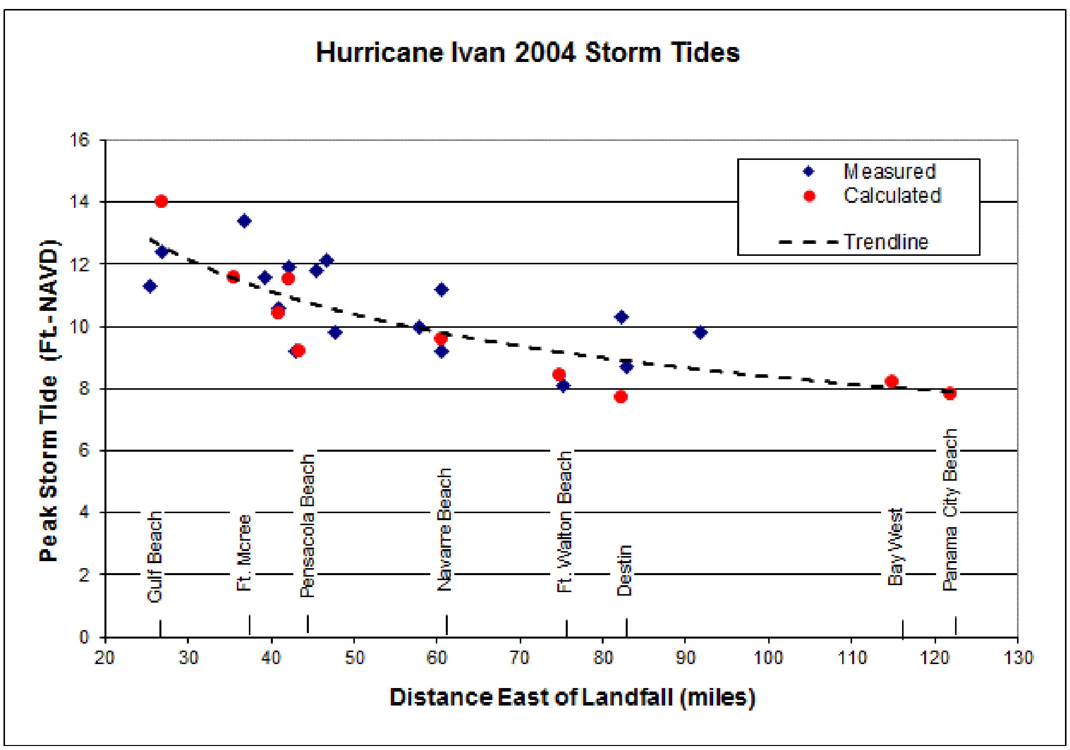

Figure 5. *Peak Surge Levels in Panhandle Area for Hurricane Ivan.*

Based on the 2-D Storm Surge calculated, peak storm tide, and the trendline in Figure 5, the peak storm tide for the western Bay county is about 8.0 ft. above NAVD. The tide gauge at Panama City Beach Pier during Ivan recorded a peak storm tide of 5.8 ft. above NAVD (Figure 6). Since the gauge is located 830 feet offshore from the monument R-40, the recorded storm tide should only include partial wave setup. By comparing the measured HWM and the calculated total storm tides with the Total Storm Tide Values for Various Return Periods listed in Table 1, it shows that Hurricane Ivan generated total storm tides ranging between 30 and 50 years return period for the western Bay County area. Therefore, Hurricane Ivan was selected as a high-frequency storm, and the hydrograph measured from the Panama City Bach Pier is adjusted and applied for the SBEACH Model calibration.

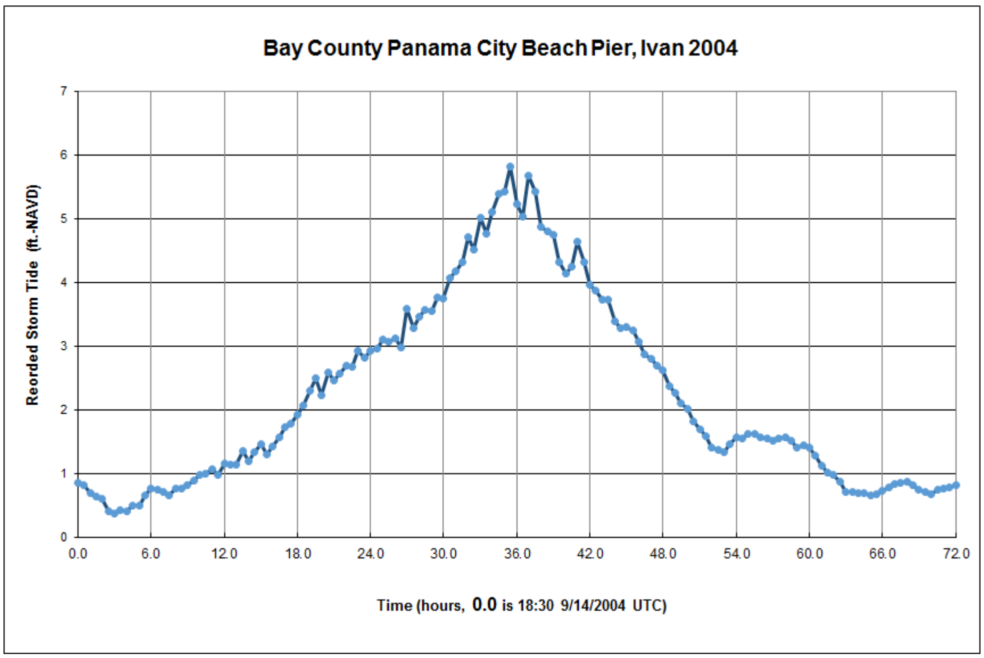

Figure 6. *Storm Tide Recorded at Panama City Beach Pier during Hurricane Ivan, 2004.*

***Table 1**. Total Storm Tide Values* (ft.-NAVD) for Various Return Periods*

Return Period, TR (years)	West Profile	Middle Profile	East Profile
50	8.5	8.7	8.8
30	7.3	7.3	7.4
25	6.9	7.0	7.0
20	6.4	6.4	6.4
15	5.7	5.6	5.7
10	4.6	4.6	4.5
5	2.1	2.2	2.2

**Includes contributions of: wind stress, barometric pressure, dynamic wave set-up and astronomical tide.*

2.1b Wind and Wave Data

Measured wave data for Hurricane Ivan was available from the National Data Buoy Center (NDBC) Station 42039, which is located approximately 100 miles south-southwest of the Panama Beach City pier at a depth of 270 m. Significant wave height, dominant wave period, and mean wave direction values from the buoy data were transformed from the buoy location to a 40-foot depth offshore of Panama City Beach (Leadon and Nguyen, 2009). The wave data at the 40-foot water depth coincide with general seaward depth limits of the profile survey depths and was used in the SBEACH Model. A plot of the deep-water wave data recorded by NDBC Station 42039 is shown in Figure 7. Transformed wave conditions established at the 40-foot depth used as input wave conditions for Ivan in SBEACH Model are shown in Figure 8.

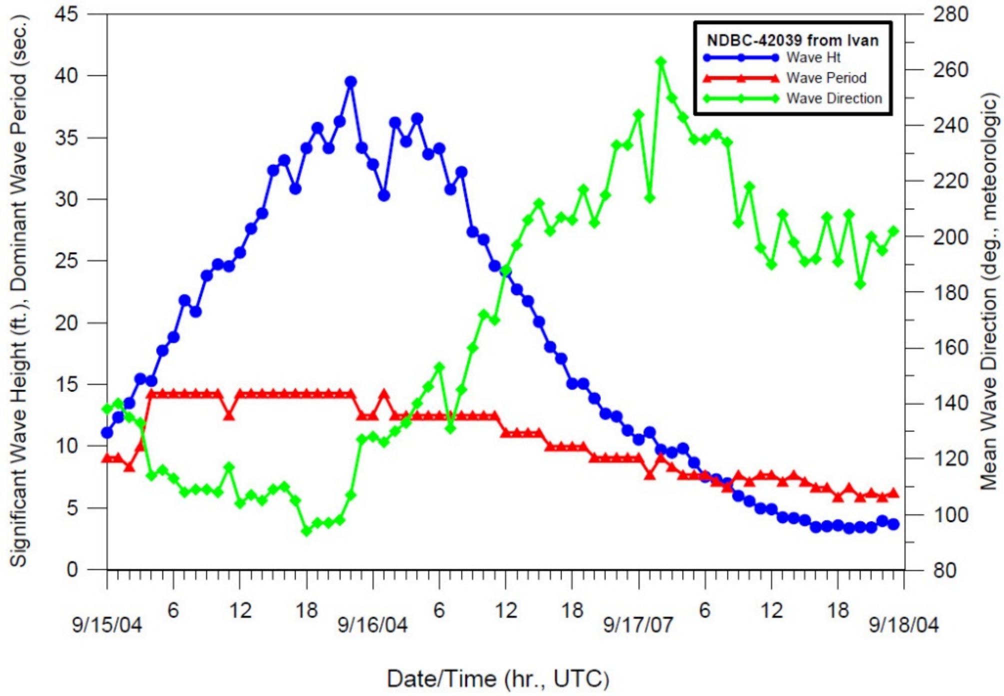

Figure 7. *Deep Water Wave Conditions for Hurricane Ivan at NDBC Buoy 42039. (Leadon and Nguyen, 2009)*

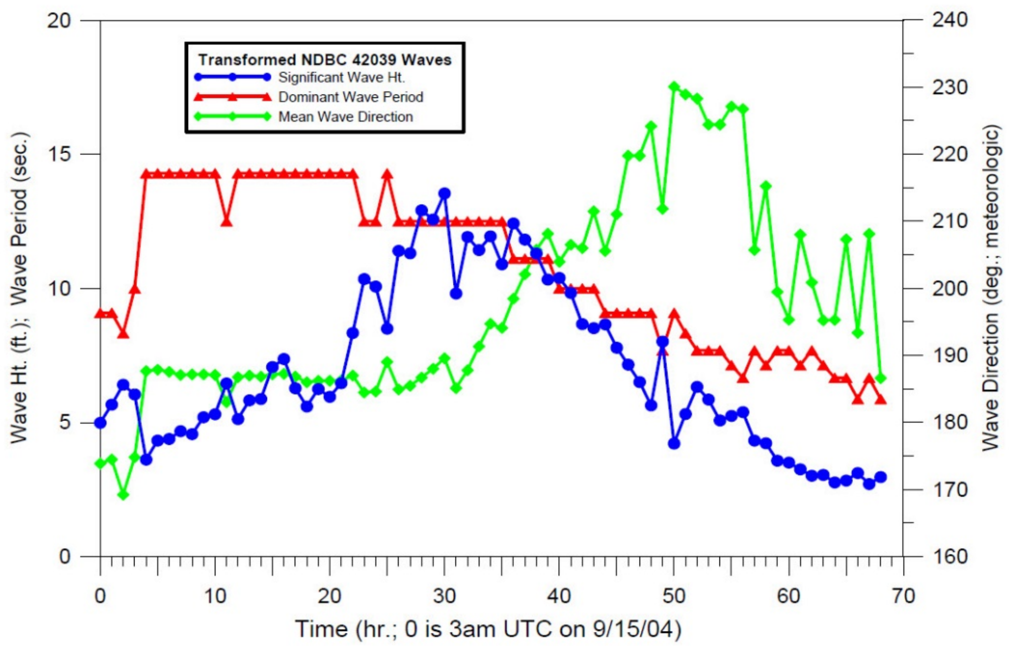

Figure 8. *Transformed NDBC Buoy Wave Conditions at 40 ft. depth for Hurricane Ivan. (Leadon and Nguyen, 2009)*

2.1c Hydrographic Survey Data

Costal Planning and Engineering, Inc., and the University of Florida conducted Pre-and Post-Ivan surveys for Bay County in June 2004 and October 2004, respectively. A total of 50 profiles from R-1 to R-50, all of which are located at the windward side of Hurricane Ivan and show consistent erosion, were selected for the model calibration. The map in Figure 9 shows the location of the profiles selected for the SBEACH model calibration and the peak storm tide calculated with the 2-D Storm Surge Model.

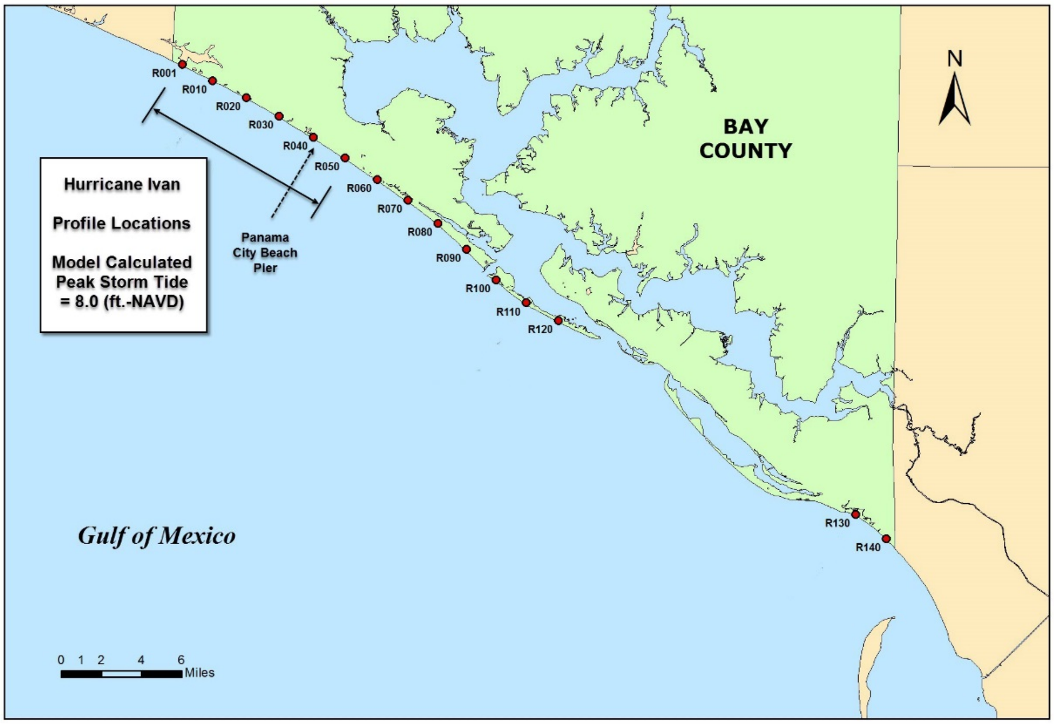

Figure 9: *Locations of Profiles and the Calculated Peak Storm Tide Used in SBEACH Calibration.*

2.2 Model Input Parameters

The SBEACH model's primary input information includes profile, storm, and sediment data. Profile data is selected based on the segment of shoreline being modeled. Mean grain size of the beach material is one of the primary sediment data required. Other inputs include model parameters, such as grid size, time step, and the transport rate coefficient.

The beach profiles were represented in the model using a constant grid scheme with grid cell spacing of five feet in order to generate a detailed result. Each reach was approximately 2,500 feet long, and had about 500 cells measuring five feet across, well below the 1,000-cell limit allowed by the SBEACH model. Sediment data was obtained from the beach sediment survey in the Florida's northwest coast (Daniel et al, 2011). For the model calibration area, R-1 to R-50 of Bay County, carbonate material averaged 2.2 percent of the sample sediments and the average mean grain size was 0.339 mm.

The default values for SBEACH are shown in Table 2. A series of model runs were conducted within the range of recommended values to achieve the best fit between measured and SBEACH calculated erosion profiles.

Table 2. *Listing of SBEACH Input Parameters*

Parameters	Unit	Default Value	Range of Recommended Values
Transport rate coefficient, K	m^4 /N	1.75 e^{-006}	0.25 e^{-006} - 2.5 e^{-006}
Overwash transport parameter		0.005	0.002 - 0.008
Coefficient for slope dependent term, ε	m^2/s	0.002	0.001 - 0.005
Transport rate decay coeff. multiplier, λ	m^{-1}	0.5	0.1 - 0.5
Landward surf zone depth	ft.	1.0	0.5 - 1.6
Effective grain size (mean D_{50})	mm	0.35	0.15 – 1.0
Maximum slope prior to avalanching	degree	45	15 - 90 deg.
Water temperature	degree, C	20	0 - 40

2.3 Model Calibration Results

The sensitivity evaluation resulted in initially setting most of the model input parameters at or near the default values as described above. Wind speed and direction, available as options during the model input, were not included due to their insignificant effect in the model results. For each SBEACH run, the hydrographs measured from the Panama City Beach pier gauge were entered; the SBEACH model then calculated and added the wave setup internally to reach the desired final water level. The hydrographs were then adjusted for the 50 selected profiles, such that the peak water elevation outputs from SBEACH were in agreement with the peak storm tide values calculated by the 2-D Storm Surge Model for Hurricane Ivan.

The average measured versus the SBEACH calculated erosion distance of the 50 profiles for contours from three to 14 feet above NAVD 88 were used as the principle basis for determining the calibration parameters setting. A wave height of 10 feet and wave period of 12 seconds, which are the average values from the Ivan data as shown in Figure 8, were selected for model parameters. Starting with the default values, a series of values for each calibration parameter were tested. The transport rate coefficient, K, the transport rate decay coefficient, the coefficient for slope dependent term, ε, and the maximum slope prior to avalanching were found to be significant to the calibration results, so they were adjusted individually until reasonable agreement with the measured erosions were achieved.

The final parameter values summarized in Table 3 were determined as those providing the best presentation of measured erosions for the 50 selected profiles. Figure 5 shows comparisons of average contour recessions between the measured and SBEACH model computed for Hurricane Ivan based on the final model parameters described above. The SBEACH model predicted erosions with the calibrated parameters came to a close agreement with the measured ones, especially for contours between three and eight feet, which were impacted the most by the given 8-foot storm tide. Plots of pre-storm, post-storm, and SBEACH model predicted profiles, with the final calibration parameters for each of the 50 profiles, are presented in Appendix A.

Table 3. *SBEACH Model Calibration Parameters for Bay County*

Parameters	**Unit**	**Values**
Transport rate coefficient, *K*	m^4 /N	2.5 e^{-006}
Overwash transport parameter		0.005
Coefficient for slope dependent term, ε	m^2/s	0.005
Transport rate decay coeff. multiplier, λ	m^{-1}	0.5
Landward surf zone depth	ft.	1.0
Effective grain size (mean D_{50})	mm	0.339
Maximum slope prior to avalanching	degree	20
Water temperature	degree, C	27
Wave Input Conditions		
Wave Height, H	ft.	10
Wave Period, Tp	Sec.	12
Wave Direction, α	degree	0 (shore-normal)

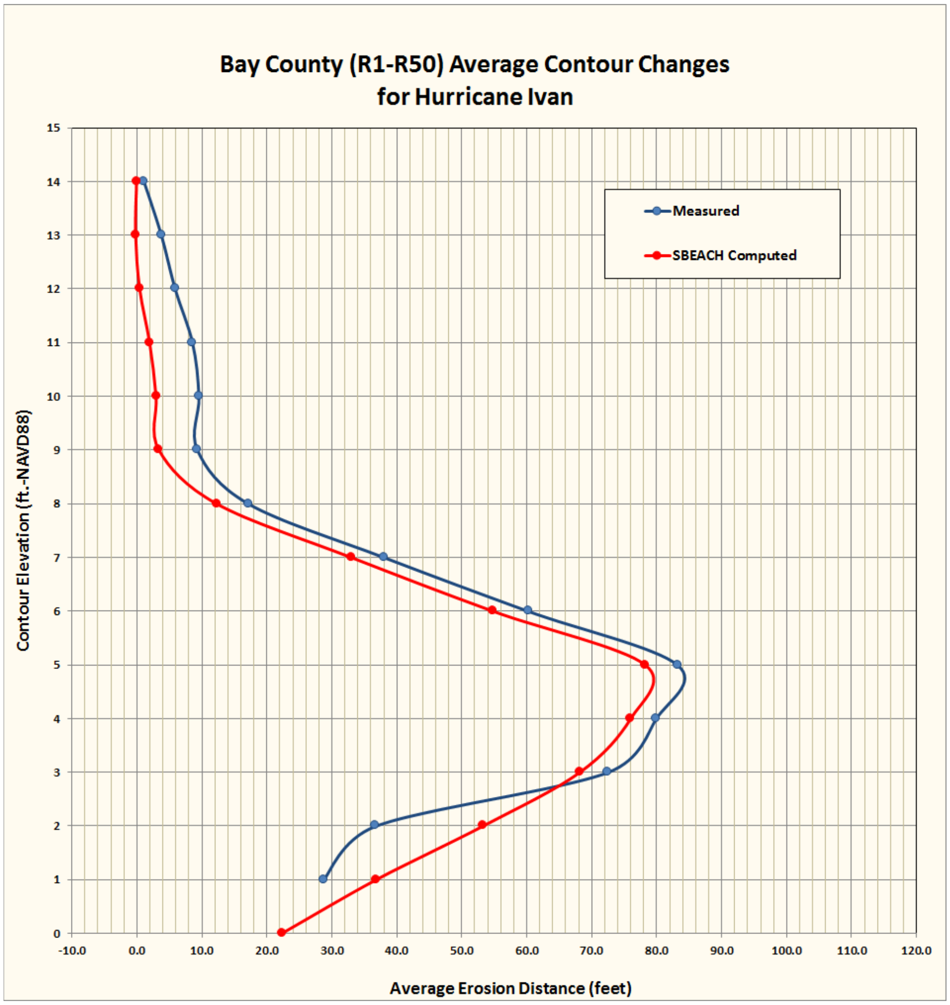

Figure 10: *Comparisons of Average Contour Changes Between Measured and SBEACH Model Computed for Hurricanes Ivan.*

3. Bay County SBEACH Application

3.1 Model Configuration

Configuration of the SBEACH model in Bay County for high-frequency storm erosion will be primarily based on the model calibration results, as shown in Table 3 of the previous section. County-wide sediment data was obtained from the beach sediment survey in the Florida's northwest coast and Keys (Daniel et al, 2011). Figure 11 presents the mean grain size distribution throughout Bay County. The wave height was set as ten feet, which was averaged from the wave heights applied in the other counties for a typical high frequency storm, as listed in Table 4. A ten-foot wave height with a twelve-second wave period were chosen as reasonable approximations for a generic high-frequency storm that would impact this area. Bay County storm tides developed by Wang (2015) for 15- and 25-year storms are shown in Table 5.

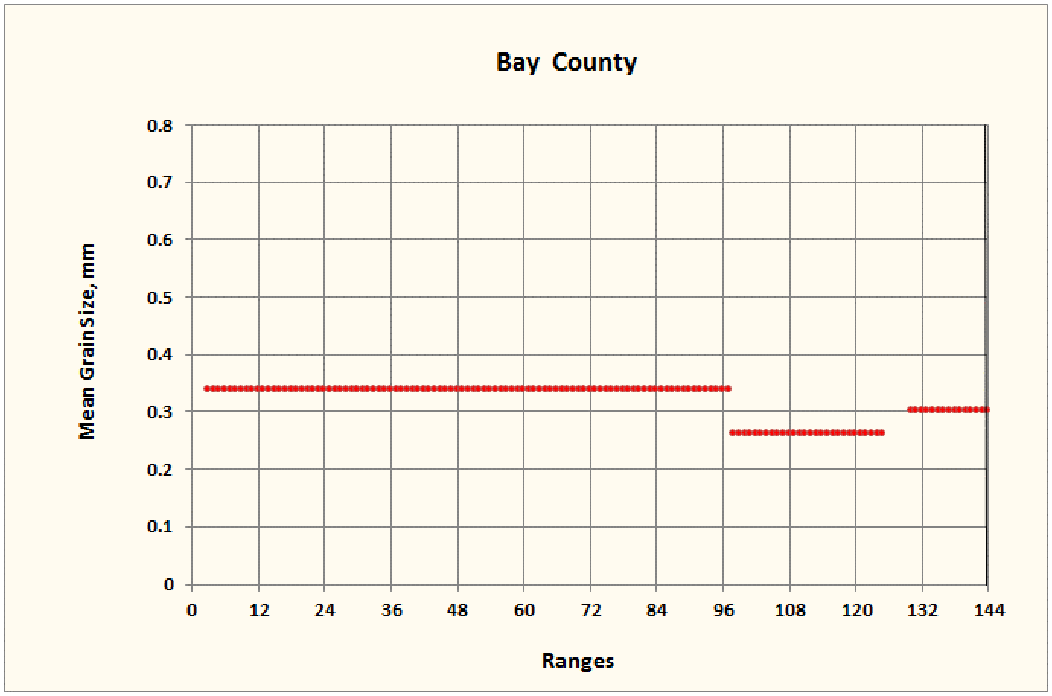

Figure 11: *Sediment Data Distributions in Bay County.*

Table 4. *Wave Heights Used in Florida Counties for SBEACH Applications*

County	Wave Height (ft.)	Reference
Brevard	12	Leadon and Nguyen, 2010
Indian River	12	Leadon and Nguyen, 2010
Palm Beach	15	Wang and Manausa, 2013
Pensacola Beach, Escambia	10	Olson Associates, 2014
St. Johns	10	Leadon and Nguyen, 2010
Sarasota	7	Wang and Manausa, 2013
Volusia	10	Leadon and Nguyen, 2010
Walton	10	Leadon and Nguyen, 2009

Table 5. *High-Frequency Storm Tides Level* (ft.-NAVD) for Bay County*

Ranges	15-year Return Period	25-year Return Period
R-1 to R-40	5.7	6.9
R-41 to R-100	5.6	7.0
R-101 to R-144	5.7	7.0

* *Includes contributions of: wind stress, barometric pressure, dynamic wave set-up and astronomical tide.*

As mentioned in the Model Calibration Results (Section 2.3), only the hydrographs without wave setup were applied since the SBEACH model calculated and added the wave setup internally to reach the final water level. The final model output water levels did not always agree with the desired 15- or 25-year storm tides at first run; therefore, the input hydrographs were then adjusted so the resultant SBEACH model peak water levels were equivalent to the predicated storm tides for each profile. Recommended Reach and Storm input values to be used in 15- and 25-year storm erosion calculations by SBEACH are listed in Appendix B. Time series values for the adjusted hydrographs without wave setup for each reach are shown in Figures 12 and 13 and are tabulated in Appendix C.

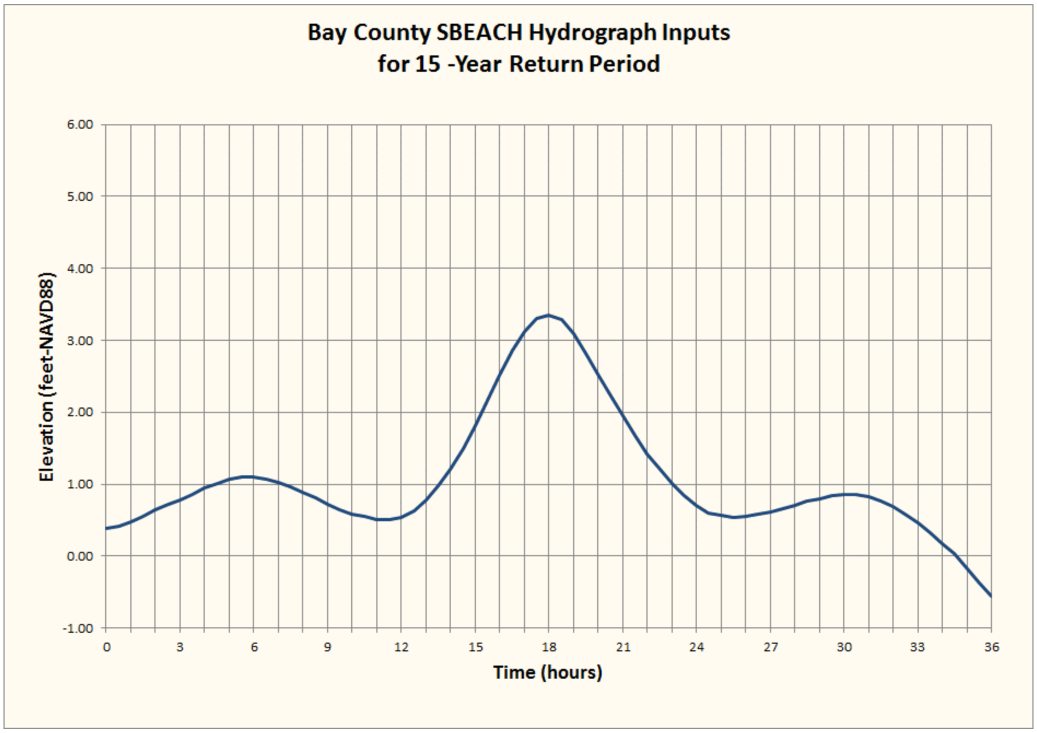

Figure 12: *15-year Hydrographs for Bay County Profiles in SBEACH Application.*

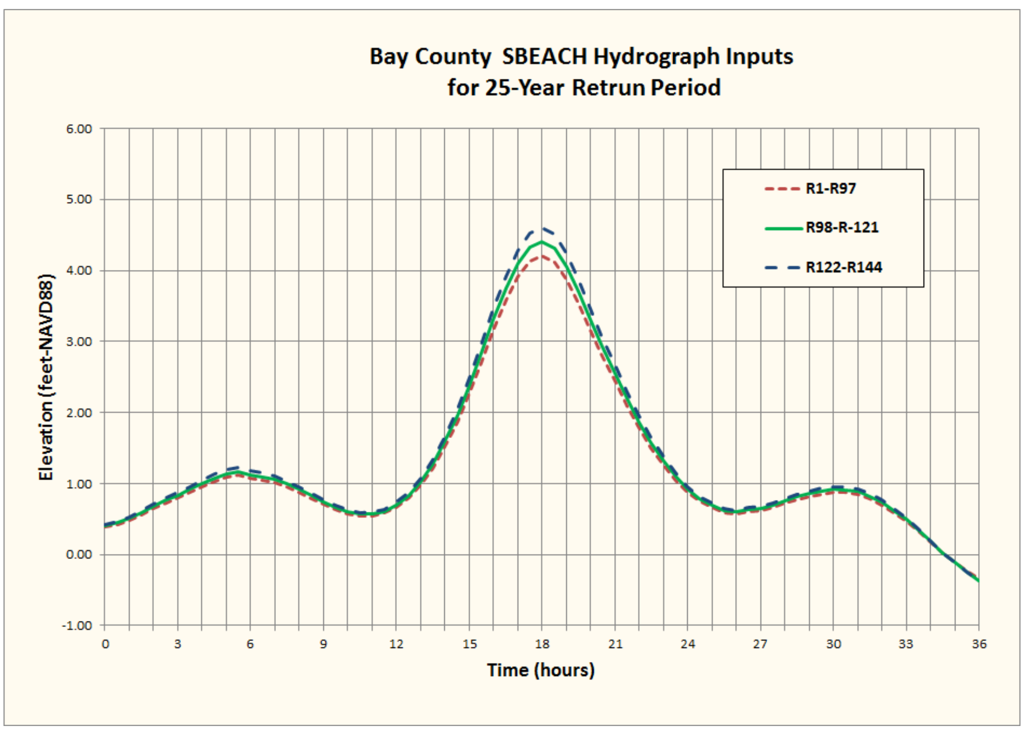

Figure 13: *25-year Hydrographs for Bay County Profiles in SBEACH Application.*

3.2 Model Application and Results

Representative plots of surveyed profiles and their associated eroded profiles generated from SBEACH for the 15- and 25-year return periods for Bay County are provided in Appendix D. The most updated profiles available for Bay County at present for SBEACH application are listed in Table 6.

Table 6. *Profiles Used in SBEACH Application for Bay County*

Range	Beach Profile Date	Offshore Profile Date
1-97	May 2016	May 2016
98-144	Aug. - Sept. 2008	Aug. - Sept. 2008

The plots in Appendix D are shown in the NAVD 88 vertical datum. The map in Figure 14 below depicts the DEP profile range locations along the Bay County shoreline.

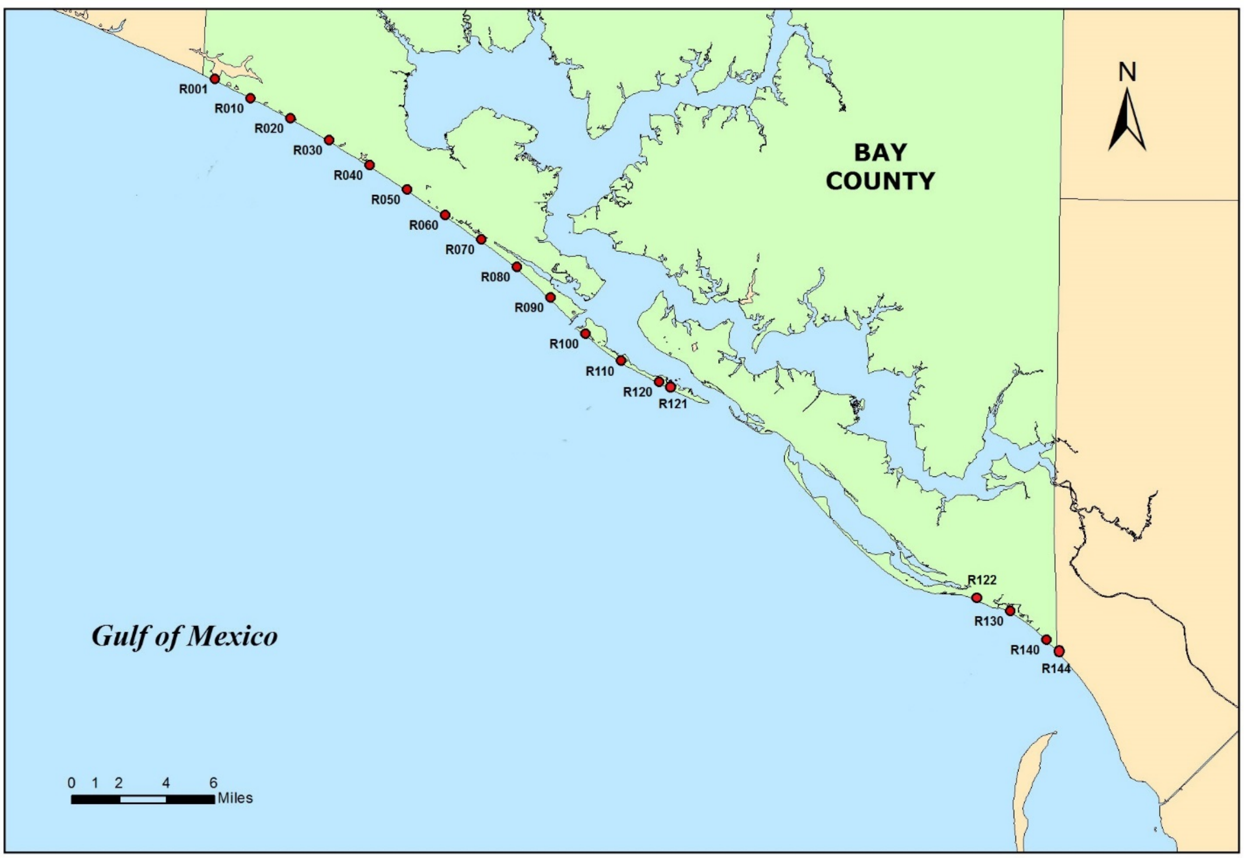

Figure 14: *DEP Profile Range Locations Along the Bay County Shoreline.*

References

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8. Wang, S.Y., "Inclusion of Tropical Storms for the Combined Total Storm Tide Frequency Restudy for Bay County", Engineering, Hydrology & Geology Program, Division of Water Resource Management, Florida Department of Environmental Protection, June 2015.

9. Wang, S. Y. and Manausa, M., “SBEACH High-Frequency Storm Erosion Model Study for Sarasota County, Final Report”, Beaches and Shores Resource Center, Florida State University, March 2013.

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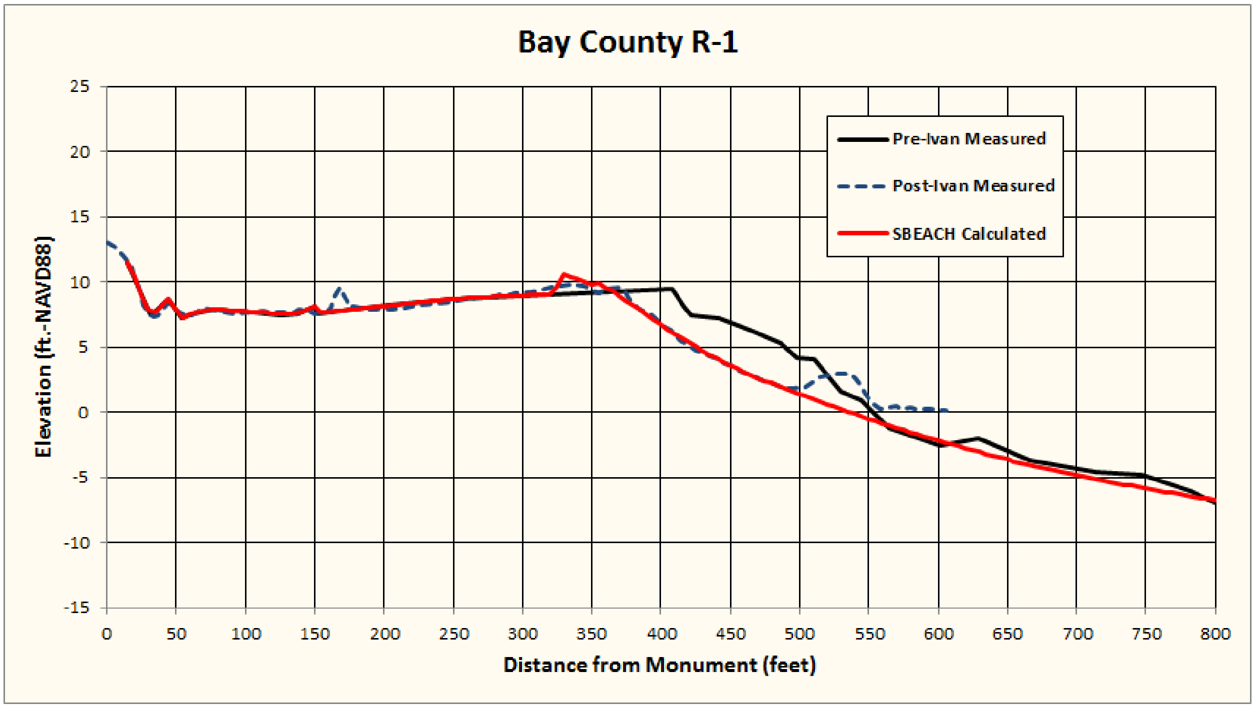
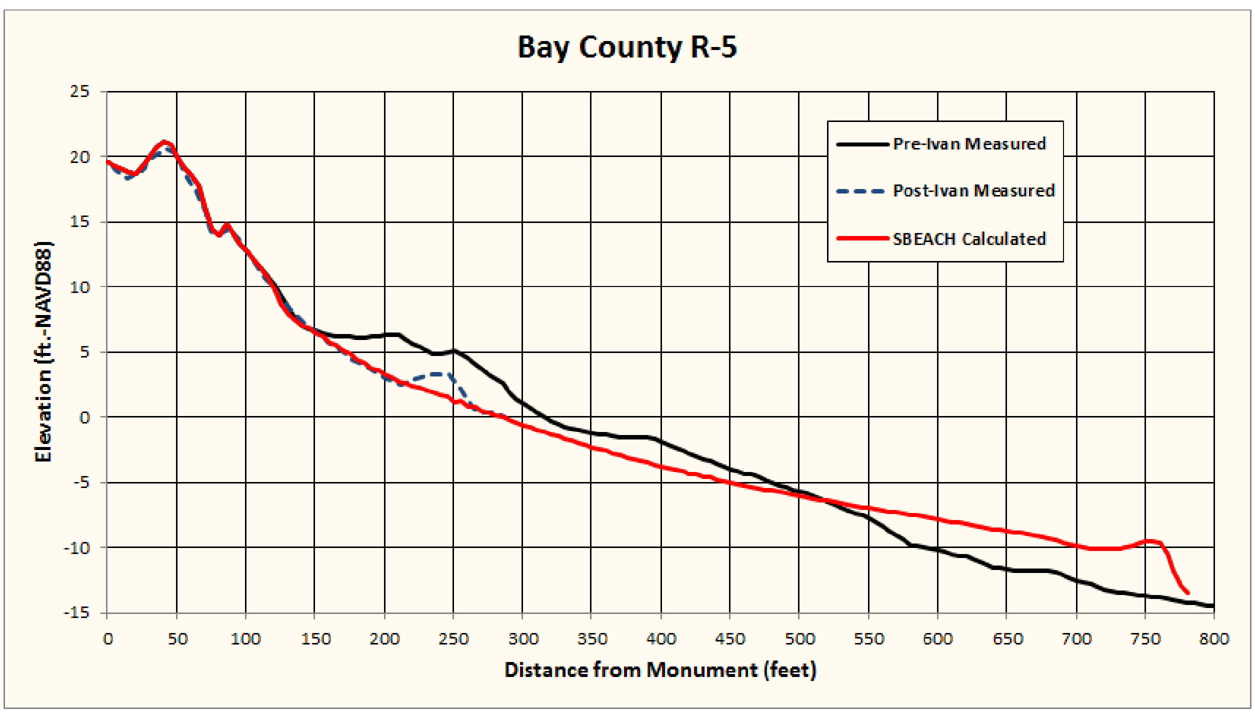
11. Wang, S. Y. and Manausa, M., “SBEACH High-Frequency Storm Erosion Model Study for Lee County”, Engineering, Hydrology & Geology Program, Division of Water Resource Management, Florida Department of Environmental Protection, June 2015.

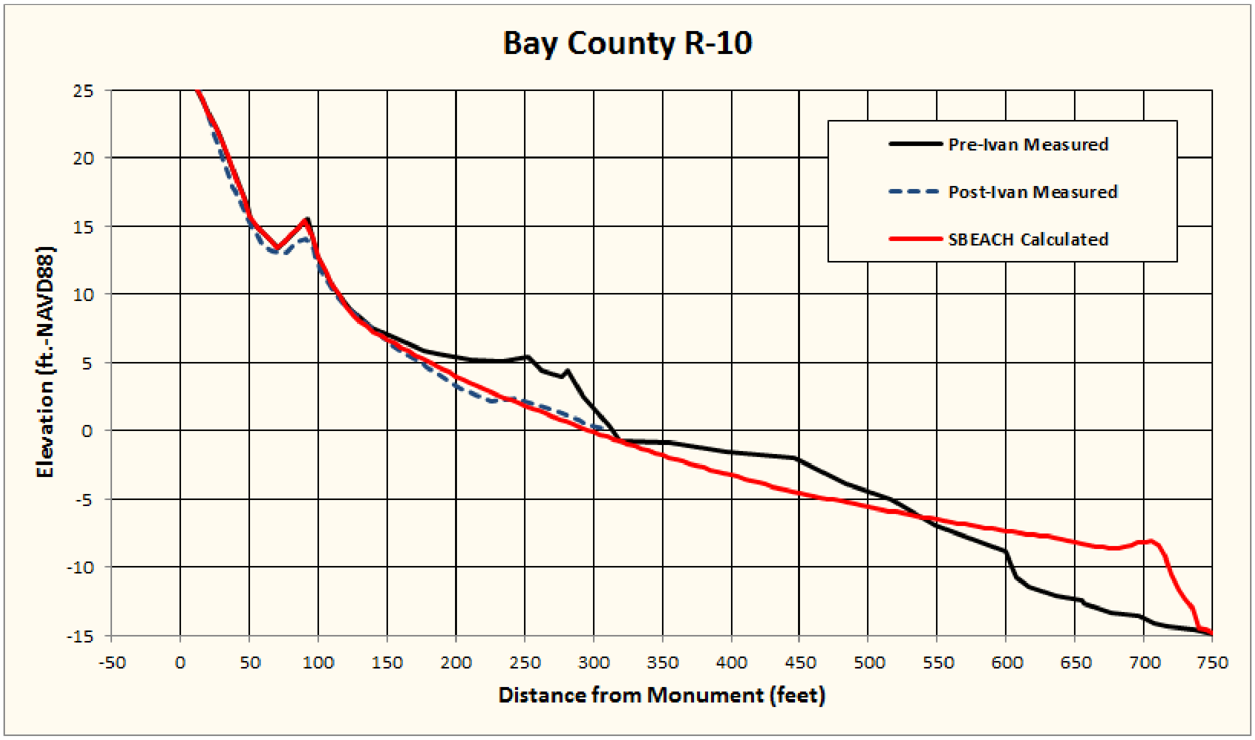
12. Wang, S. Y. and Manausa, M., “SBEACH High-Frequency Storm Erosion Model Study for Franklin County”, Engineering, Hydrology & Geology Program, Division of Water Resource Management, Florida Department of Environmental Protection, June 2016.

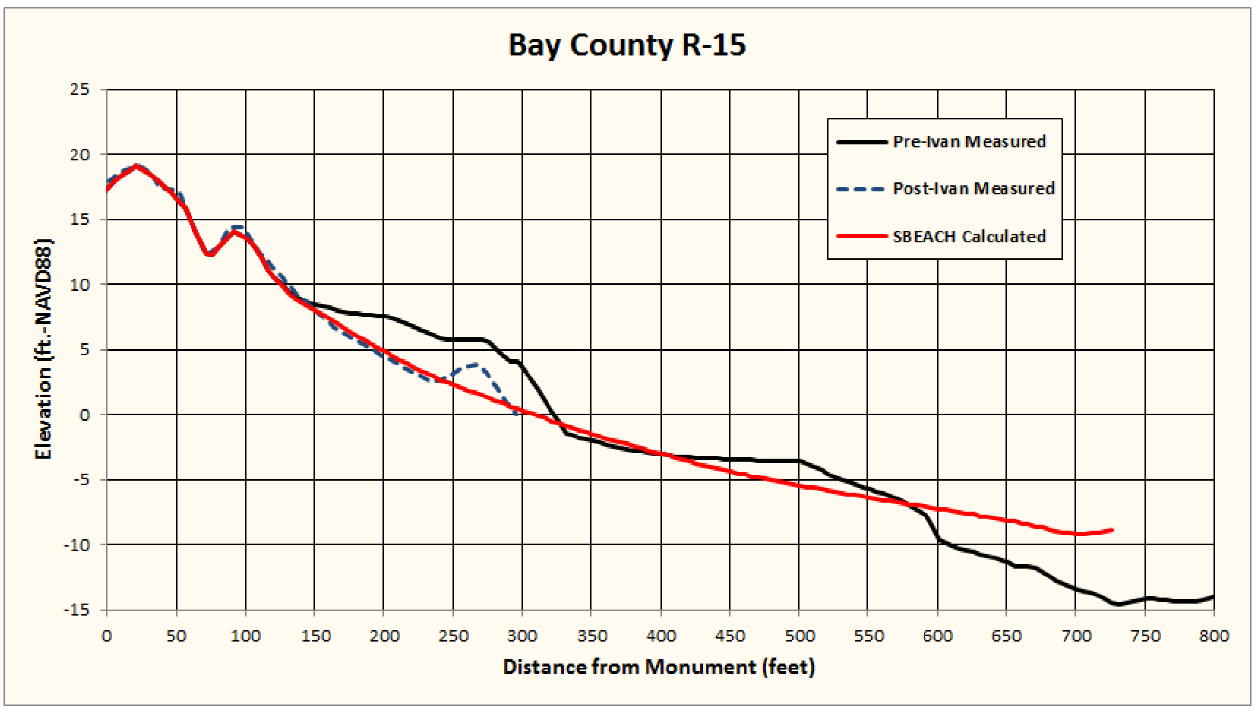
Appendix A

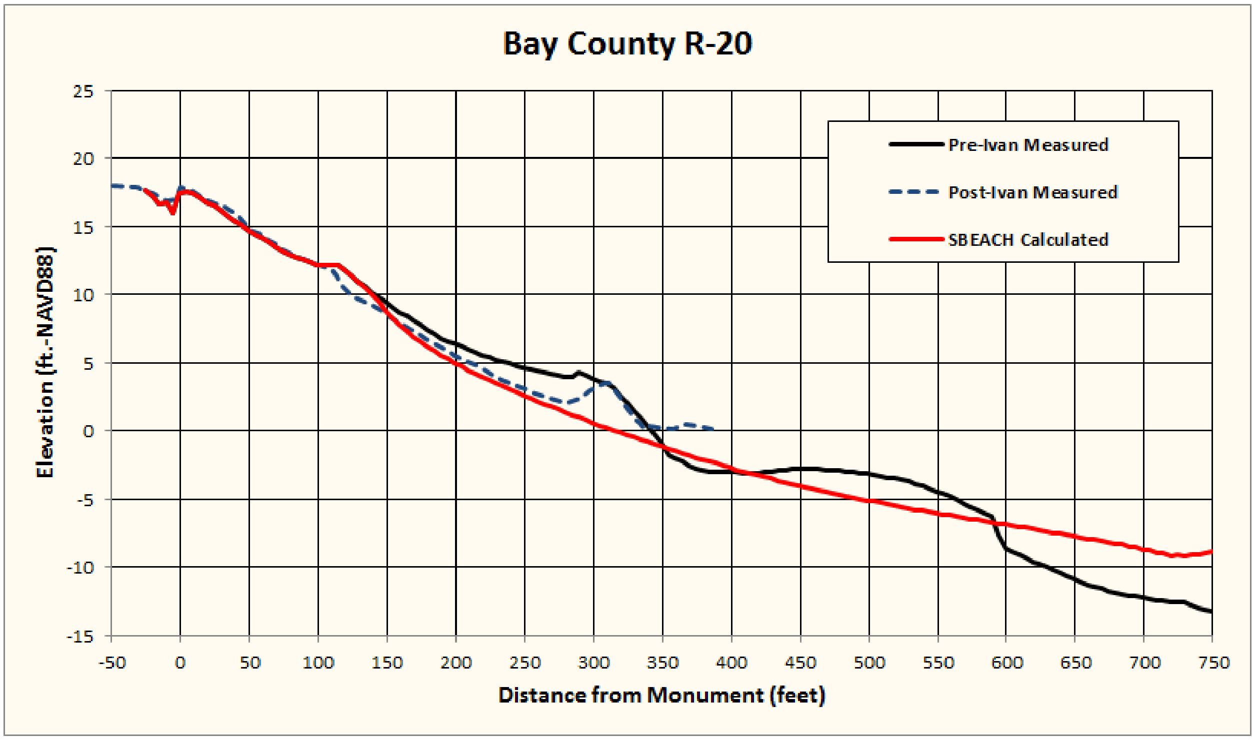
SBEACH Calibration Profiles for Bay County

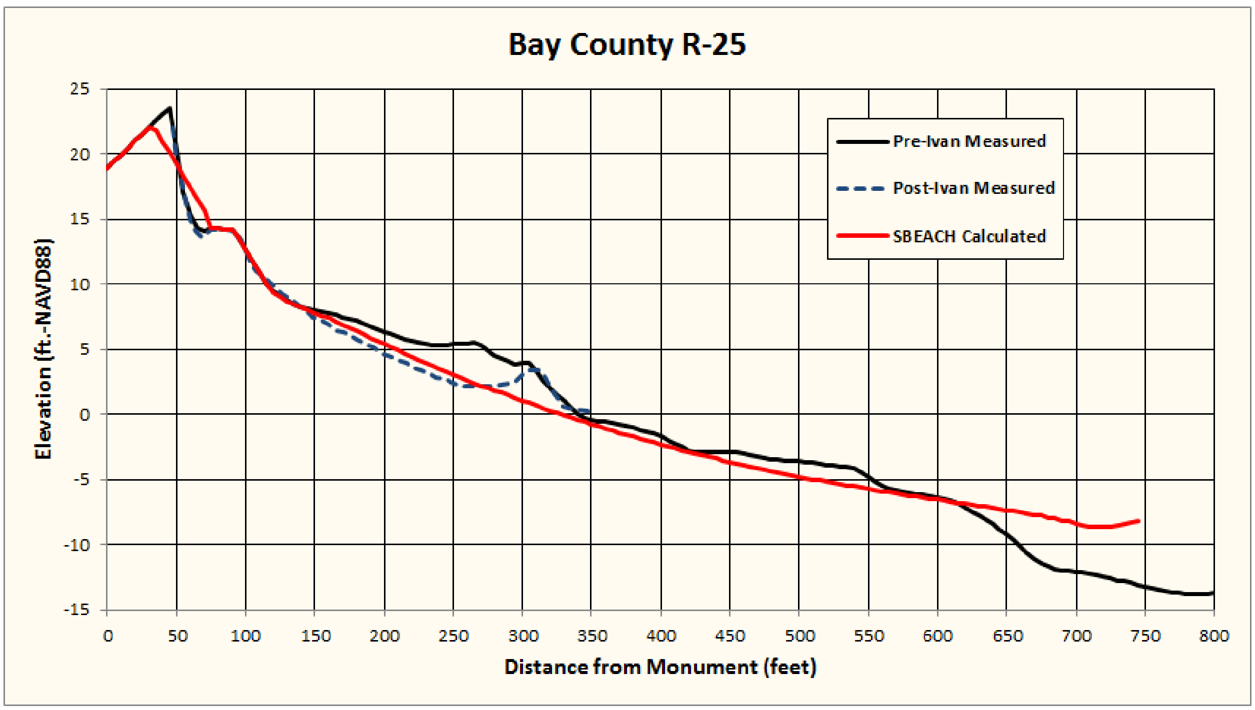


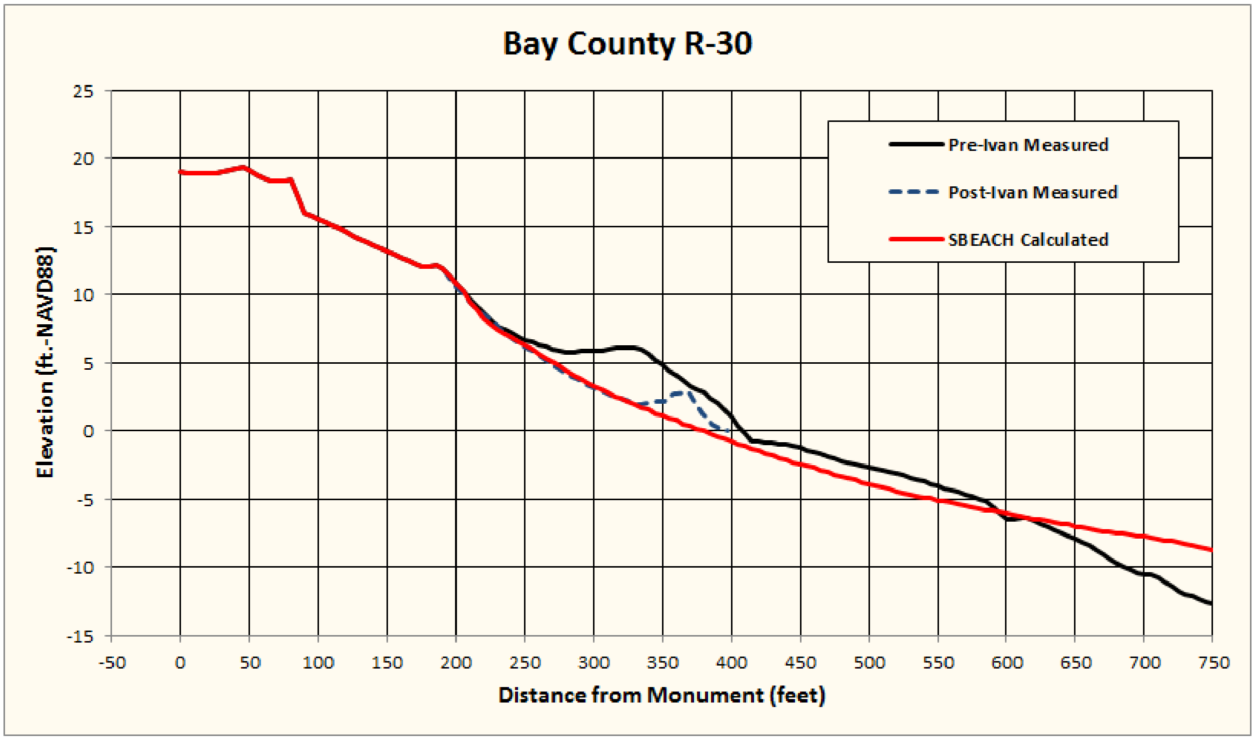


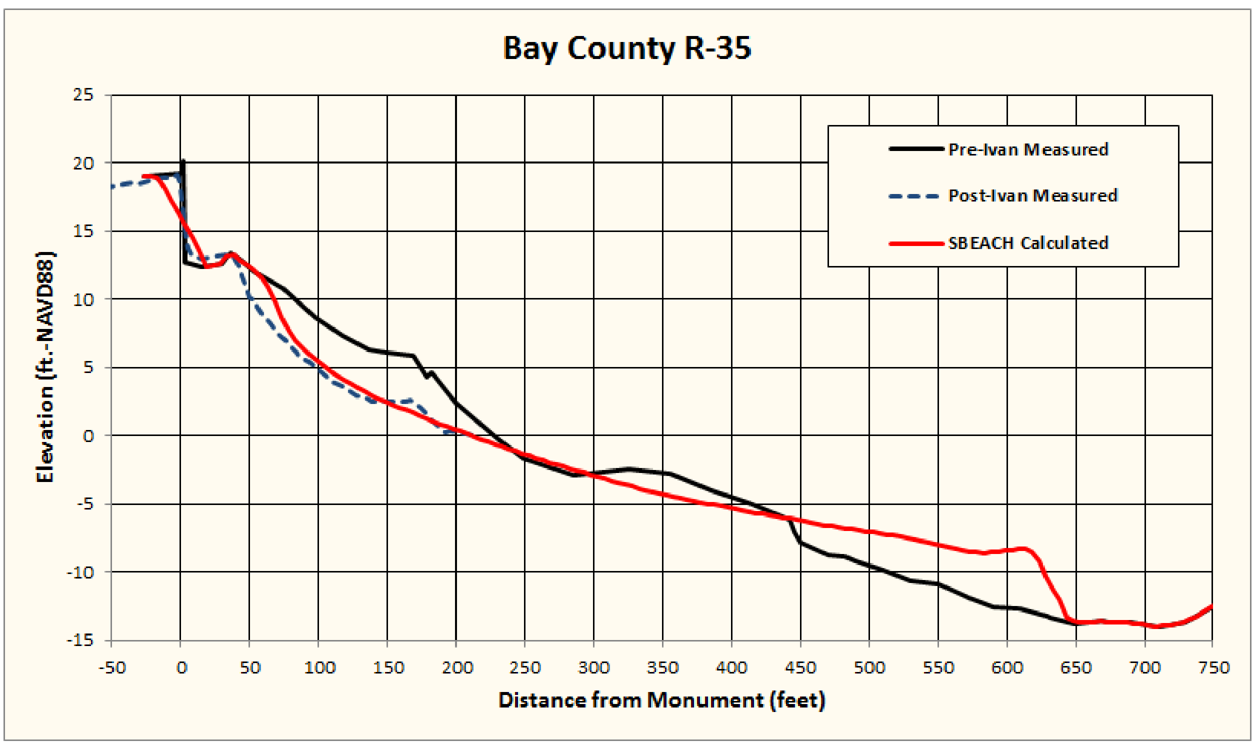

Bay County R-10
Pre-Ivan Measured
Post-Ivan Measured
SBEACH Calculated
Elevation (ft.-NAVD88)
25
20
15
10
5
0
-5
-10
-15
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Distance from Monument (feet)


Bay County R-15
Pre-Ivan Measured
Post-Ivan Measured
SBEACH Calculated
Elevation (ft.-NAVD88)
25
20
15
10
5
0
-5
-10
-15
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance from Monument (feet)


Bay County R-20
Pre-Ivan Measured
Post-Ivan Measured
SBEACH Calculated
Elevation (ft.-NAVD88)
25
20
15
10
5
0
-5
-10
-15
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Distance from Monument (feet)


Bay County R-25
Pre-Ivan Measured
Post-Ivan Measured
SBEACH Calculated
Elevation (ft.-NAVD88)
25
20
15
10
5
0
-5
-10
-15
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance from Monument (feet)


Bay County R-30
Pre-Ivan Measured
Post-Ivan Measured
SBEACH Calculated
Elevation (ft.-NAVD88)
25
20
15
10
5
0
-5
-10
-15
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Distance from Monument (feet)


Bay County R-35
Pre-Ivan Measured
Post-Ivan Measured
SBEACH Calculated
Elevation (ft.-NAVD88)
25
20
15
10
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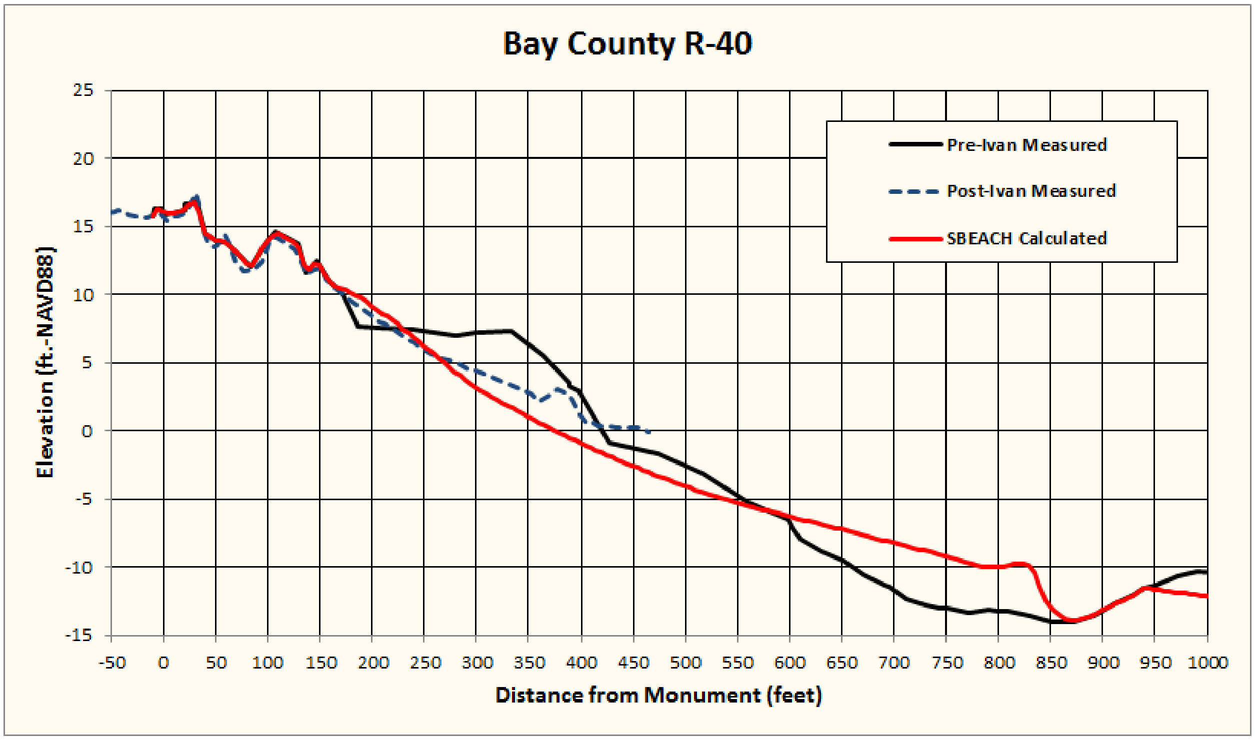
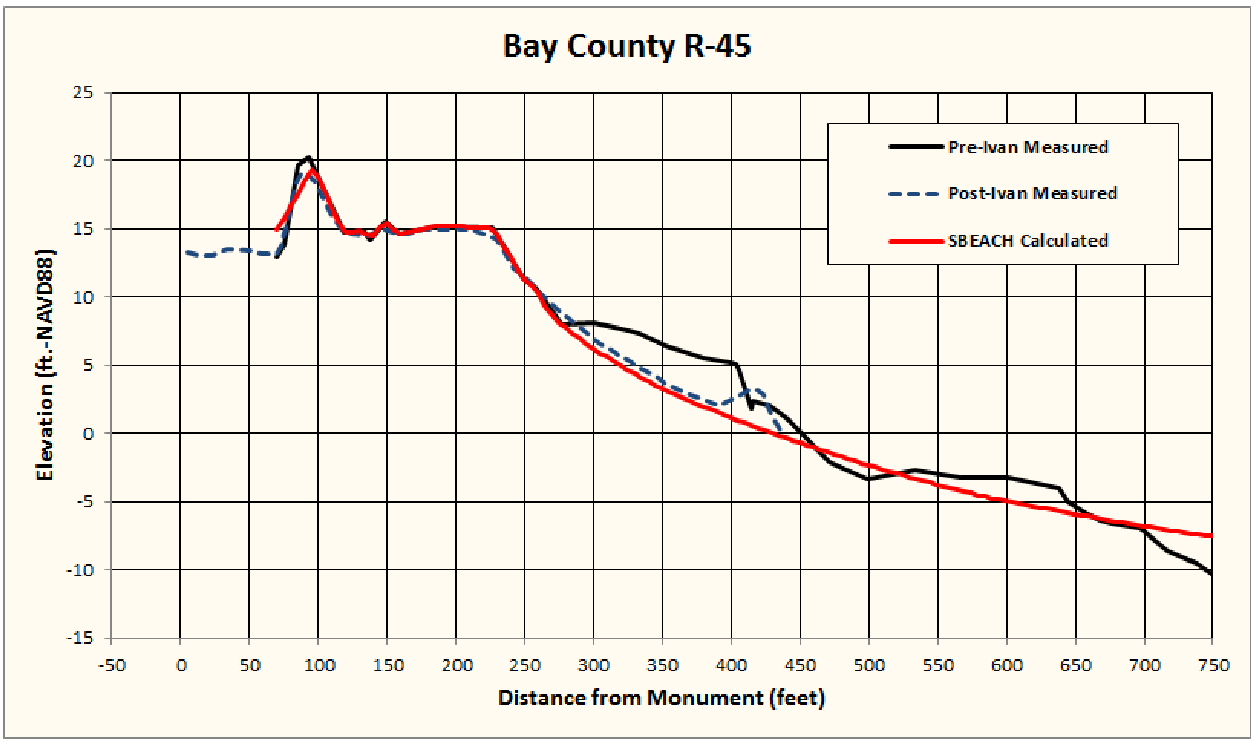
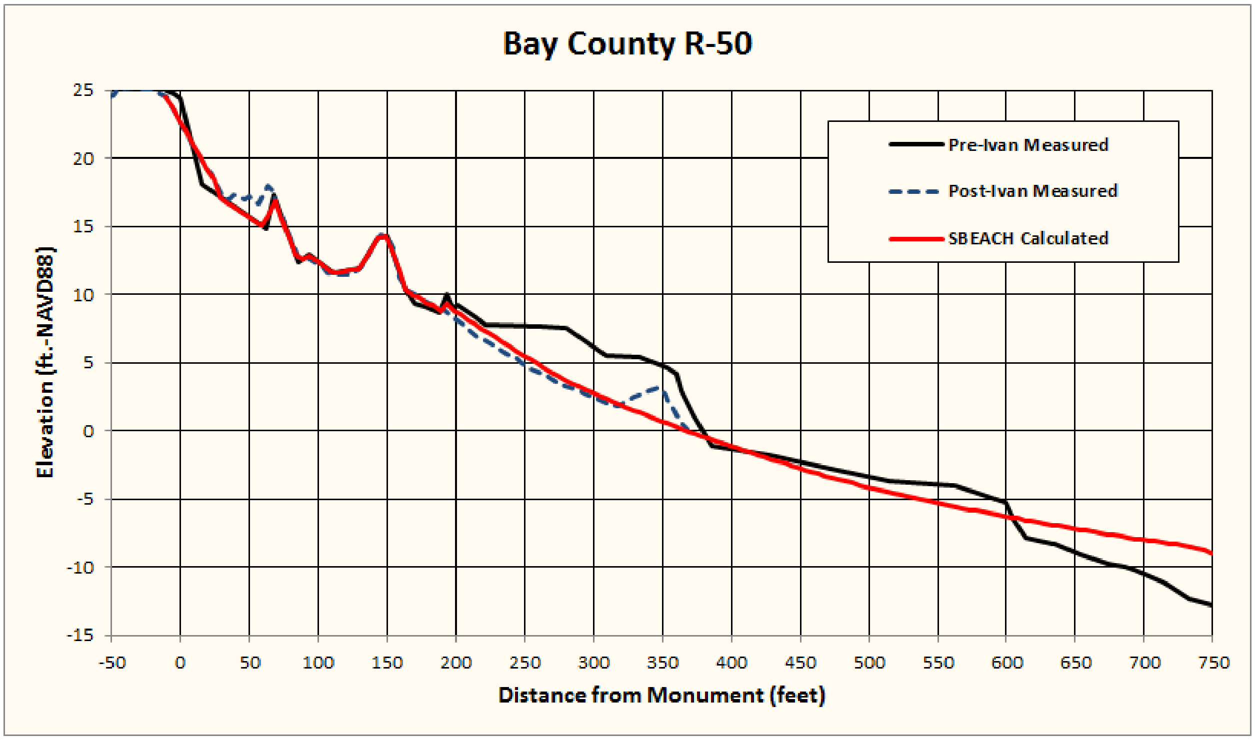
0
-5
-10
-15
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Distance from Monument (feet)


Bay County R-40
Elevation (ft.-NAVD88)
Distance from Monument (feet)
Pre-Ivan Measured
Post-Ivan Measured
SBEACH Calculated
25
20
15
10
5
0
-5
-10
-15
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000


Bay County R-45
Elevation (ft.-NAVD88)
Distance from Monument (feet)
Pre-Ivan Measured
Post-Ivan Measured
SBEACH Calculated
25
20
15
10
5
0
-5
-10
-15
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750


Bay County R-50
Elevation (ft.-NAVD88)
Distance from Monument (feet)
Pre-Ivan Measured
Post-Ivan Measured
SBEACH Calculated
25
20
15
10
5
0
-5
-10
-15
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750

Appendix B

Recommended SBEACH Input Values

Final SBEACH Input Settings for 15- and 25-year storm erosions in Bay County.

For all Storm Tide Hydrographs – Use 15- and 25-year hydrographs without wave setup adjusted proportionally to peak elevation shown for each range location segment shown below; storm duration for all cases is 36 hrs. All elevations listed below are in NAVD 88 vertical datum. All wave input depth values were set as deep water with no wave randomization. All storm time steps were set at five minutes. Water temperature is set at 27 degrees. Grid cell width is five feet.

Range Segments	**R1 – R144**
Transport Rate Coefficient, *K*	2.5 e^{-006}
Overwash Transport Parameter	0.005
Coefficient for Slope Dependent Term, ε	0.005
Transport Rate Decay Coeff. M ultiplier, λ	0.1
Landward Surf Zone Depth (ft.)	1.0
Maximum Slope Prior to Avalanching	20
Constant Wave Height (ft.)	10
Constant Wave Period (sec.)	12
15-year Hydrograph Peak Elevation (ft.)	5.7
25-year Hydrograph Peak Elevation (ft.)	7.0

Range	**Mean Grain Size (mm)**
3 - 97	0.339
98 - 125	0.261
130 - 144	0.302

Appendix C

Adjusted 15- and 25-year Hydrograph Tables for Bay County

Bay County – Adjusted 15-year Hydrograph (ft.-NAVD) for SBEACH

Time (hour)	R1 – R144
0.00	0.38
0.50	0.42
1.00	0.48
1.50	0.55
2.00	0.64
2.50	0.72
3.00	0.78
3.50	0.86
4.00	0.94
4.50	1.01
5.00	1.06
5.50	1.09
6.00	1.09
6.50	1.06
7.00	1.03
7.50	0.96
8.00	0.89
8.50	0.81
9.00	0.72
9.50	0.64
10.00	0.59
10.50	0.55
11.00	0.50
11.50	0.50
12.00	0.53
12.50	0.64
13.00	0.78
13.50	0.97
14.00	1.21
14.50	1.49
15.00	1.81
15.50	2.16
16.00	2.52
16.50	2.86
17.00	3.13
17.50	3.30
18.00	3.36
18.50	3.29

Time (hour)	R1 – R144
19.00	3.09
19.50	2.82
20.00	2.53
20.50	2.23
21.00	1.95
21.50	1.67
22.00	1.42
22.50	1.20
23.00	1.01
23.50	0.84
24.00	0.70
24.50	0.60
25.00	0.57
25.50	0.55
26.00	0.55
26.50	0.59
27.00	0.61
27.50	0.65
28.00	0.71
28.50	0.76
29.00	0.80
29.50	0.83
30.00	0.86
30.50	0.85
31.00	0.83
31.50	0.77
32.00	0.69
32.50	0.58
33.00	0.46
33.50	0.32
34.00	0.18
34.50	0.03
35.00	-0.18
35.50	-0.38
36.00	-0.56

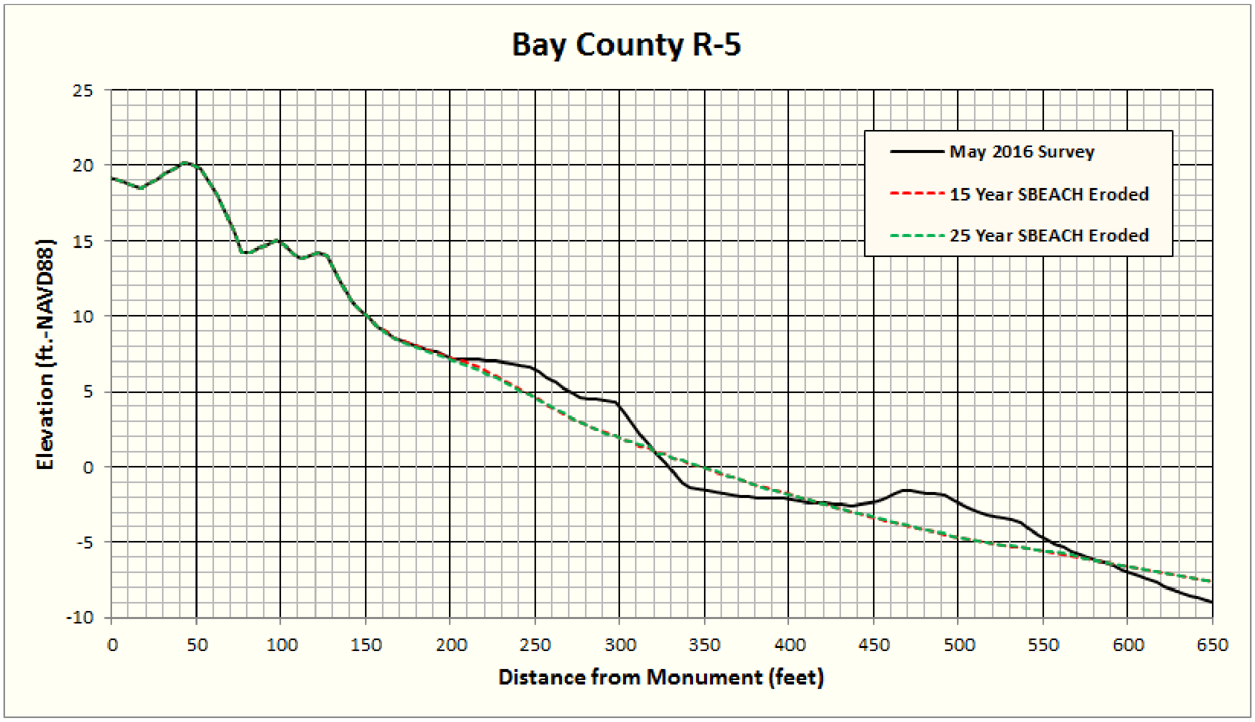
Bay County - Adjusted 25-year Hydrograph (ft.-NAVD) for SBEACH

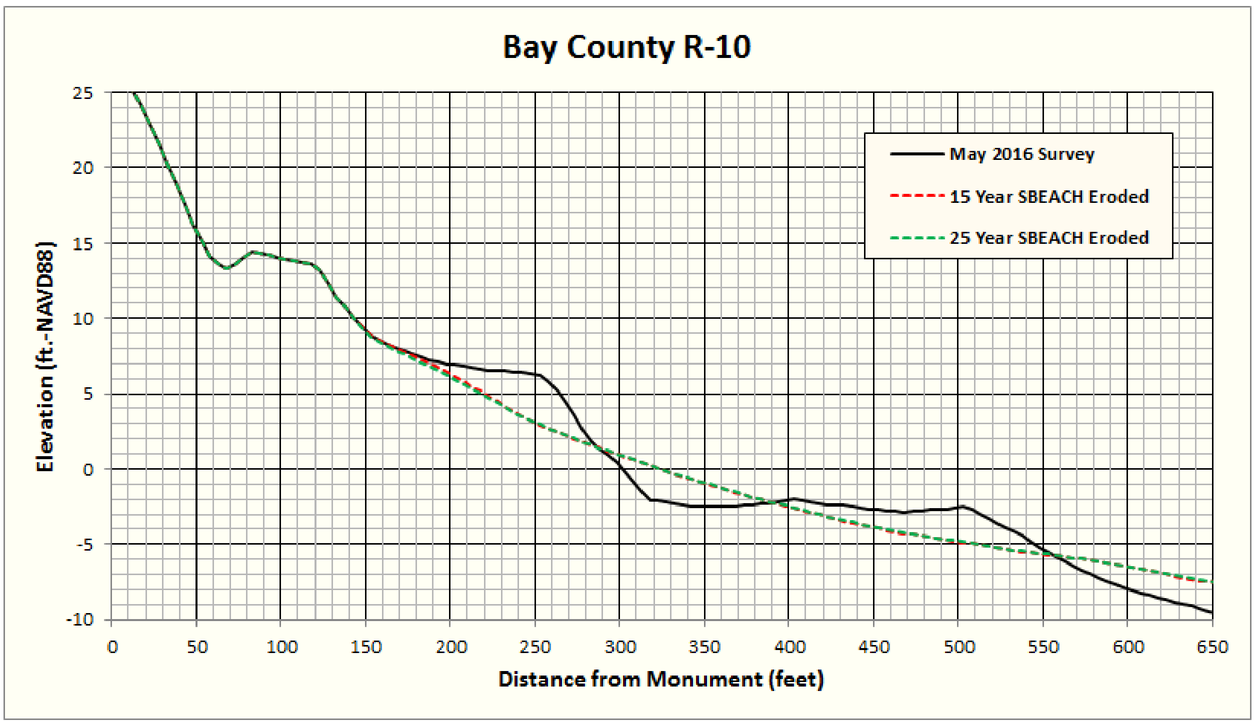
Time (hour)	R1 – R97	R98 - R121	R122 – R144
0.00	0.39	0.41	0.43
0.50	0.43	0.45	0.47
1.00	0.49	0.51	0.53
1.50	0.56	0.59	0.62
2.00	0.65	0.69	0.72
2.50	0.73	0.77	0.80
3.00	0.80	0.84	0.87
3.50	0.88	0.92	0.96
4.00	0.96	1.01	1.05
4.50	1.03	1.08	1.13
5.00	1.09	1.14	1.19
5.50	1.12	1.17	1.22
6.00	1.07	1.13	1.18
6.50	1.04	1.10	1.14
7.00	1.01	1.06	1.11
7.50	0.95	0.99	1.04
8.00	0.88	0.92	0.96
8.50	0.79	0.83	0.87
9.00	0.70	0.74	0.77
9.50	0.63	0.66	0.69
10.00	0.58	0.61	0.63
10.50	0.54	0.57	0.59
11.00	0.55	0.57	0.60
11.50	0.58	0.61	0.64
12.00	0.67	0.70	0.73
12.50	0.80	0.84	0.87
13.00	0.98	1.03	1.07
13.50	1.22	1.28	1.33
14.00	1.51	1.59	1.66
14.50	1.86	1.95	2.04
15.00	2.27	2.38	2.48
15.50	2.71	2.84	2.96
16.00	3.16	3.31	3.46
16.50	3.58	3.76	3.92
17.00	3.91	4.10	4.29
17.50	4.13	4.33	4.53
18.00	4.20	4.41	4.60
18.50	4.12	4.32	4.51
19.00	3.87	4.06	4.24
19.50	3.53	3.70	3.87
20.00	3.16	3.32	3.46
20.50	2.79	2.92	3.05

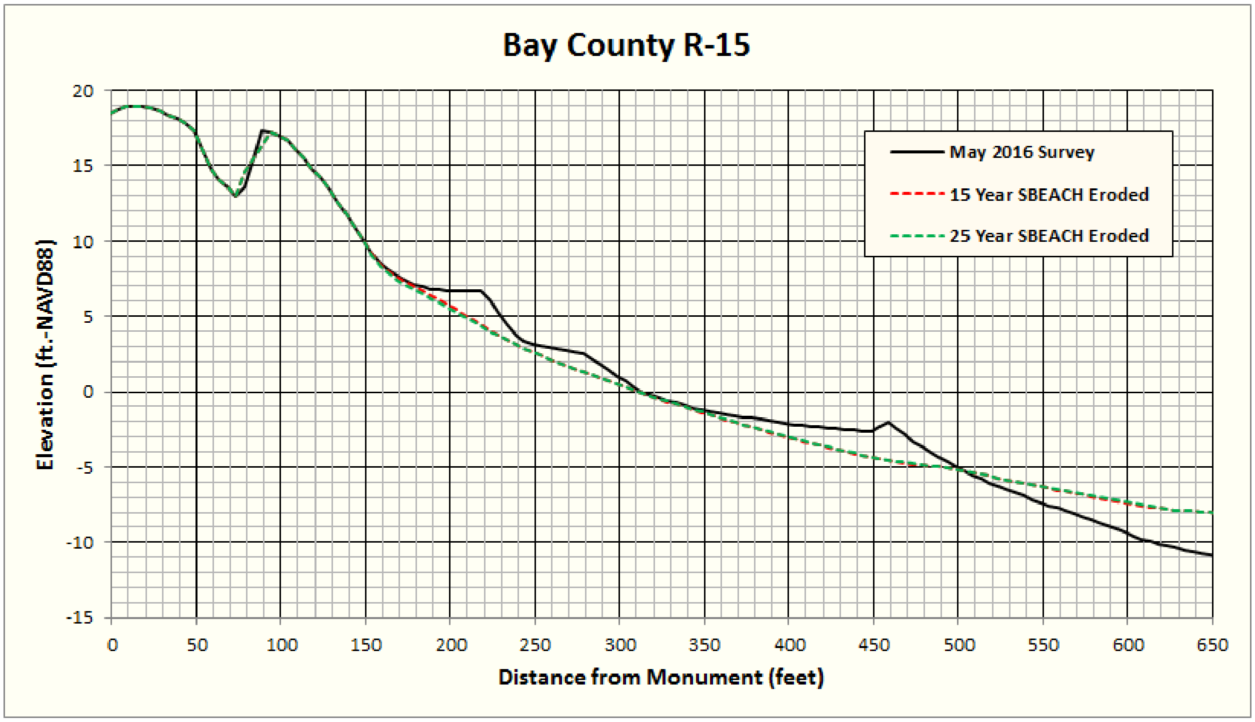
Time (hour)	**R1 – R97**	**R98 - R121**	**R122 – R144**
21.00	2.44	2.55	2.67
21.50	2.10	2.20	2.29
22.00	1.78	1.87	1.95
22.50	1.51	1.58	1.65
23.00	1.26	1.33	1.38
23.50	1.05	1.10	1.15
24.00	0.88	0.92	0.96
24.50	0.75	0.79	0.82
25.00	0.66	0.69	0.72
25.50	0.59	0.62	0.65
26.00	0.57	0.60	0.63
26.50	0.60	0.63	0.66
27.00	0.62	0.65	0.68
27.50	0.67	0.70	0.73
28.00	0.72	0.75	0.79
28.50	0.77	0.81	0.85
29.00	0.82	0.86	0.89
29.50	0.85	0.89	0.93
30.00	0.88	0.92	0.96
30.50	0.87	0.91	0.95
31.00	0.85	0.89	0.93
31.50	0.79	0.82	0.86
32.00	0.70	0.74	0.77
32.50	0.59	0.62	0.65
33.00	0.47	0.49	0.51
33.50	0.32	0.34	0.35
34.00	0.18	0.19	0.20
34.50	0.03	0.03	0.03
35.00	-0.11	-0.12	-0.12
35.50	-0.23	-0.25	-0.25
36.00	-0.34	-0.37	-0.37

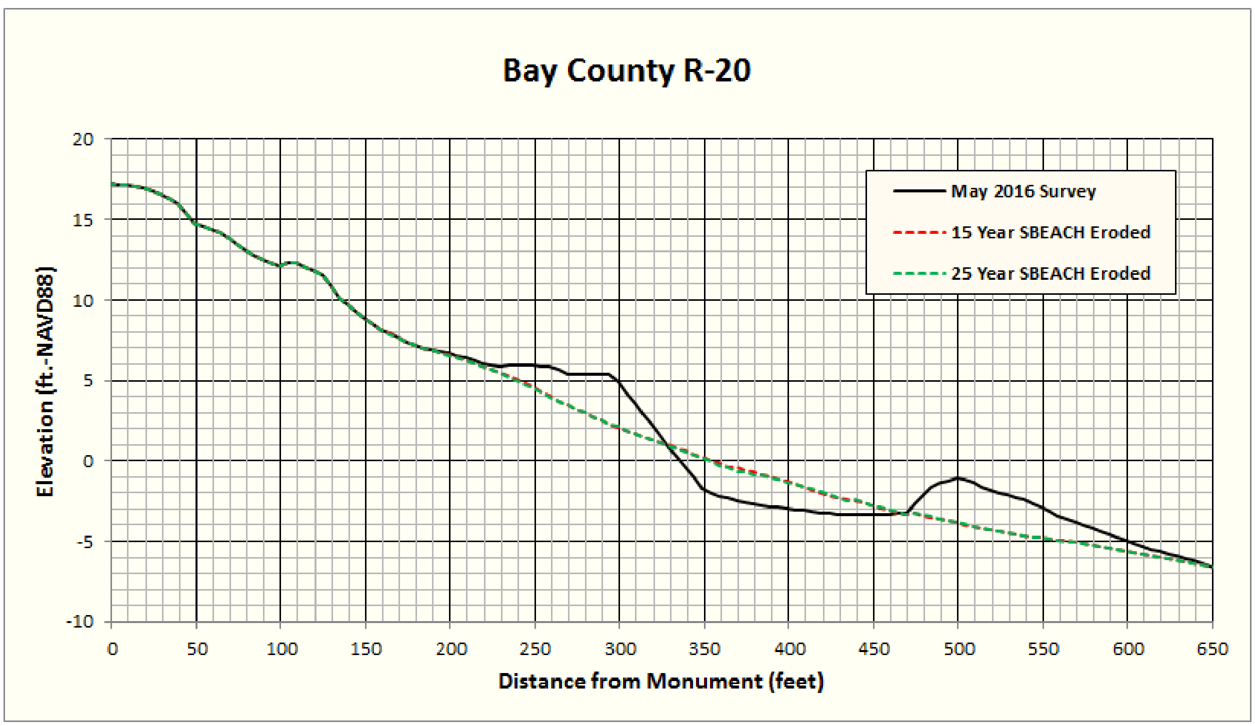
Appendix D

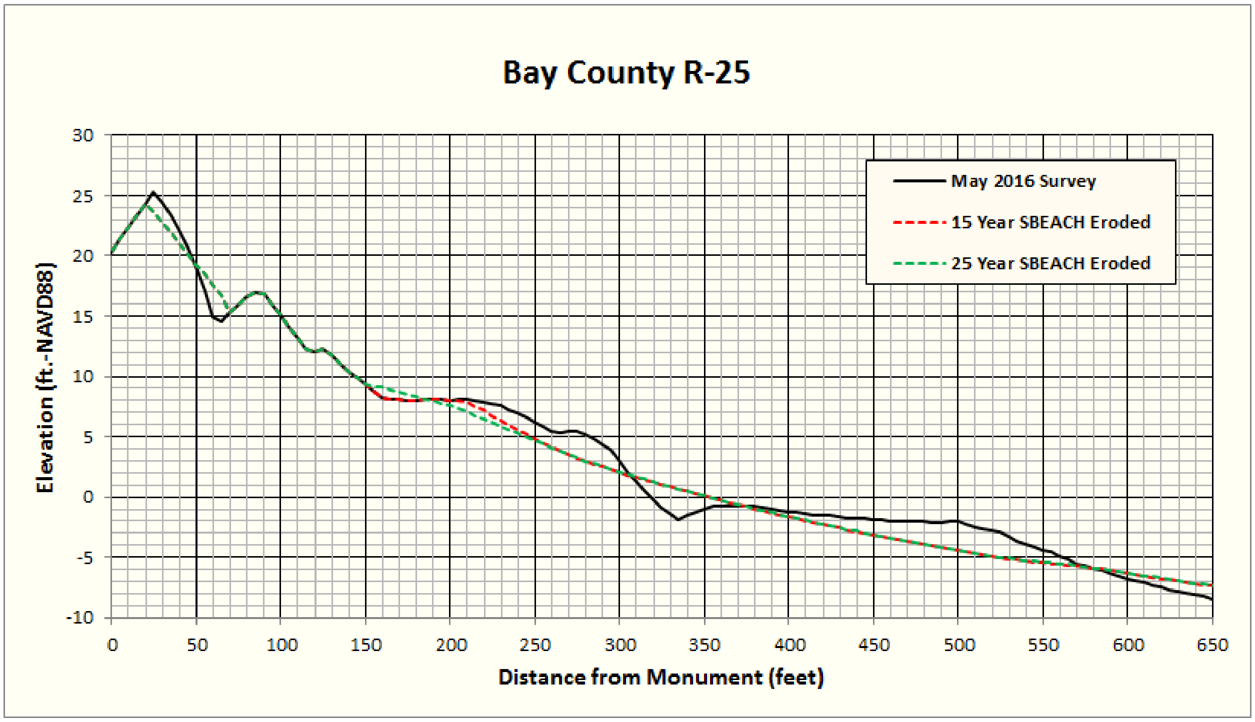
Bay County SBEACH 15- and 25-year Storm Erosion Profiles

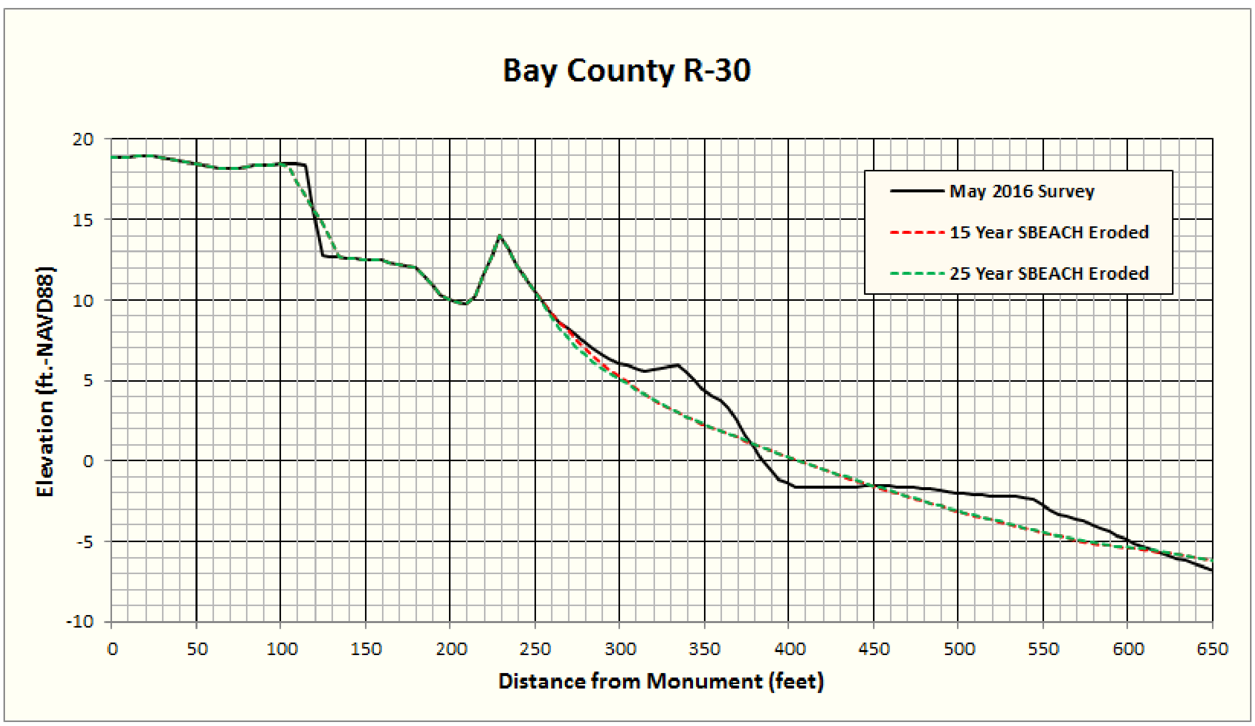


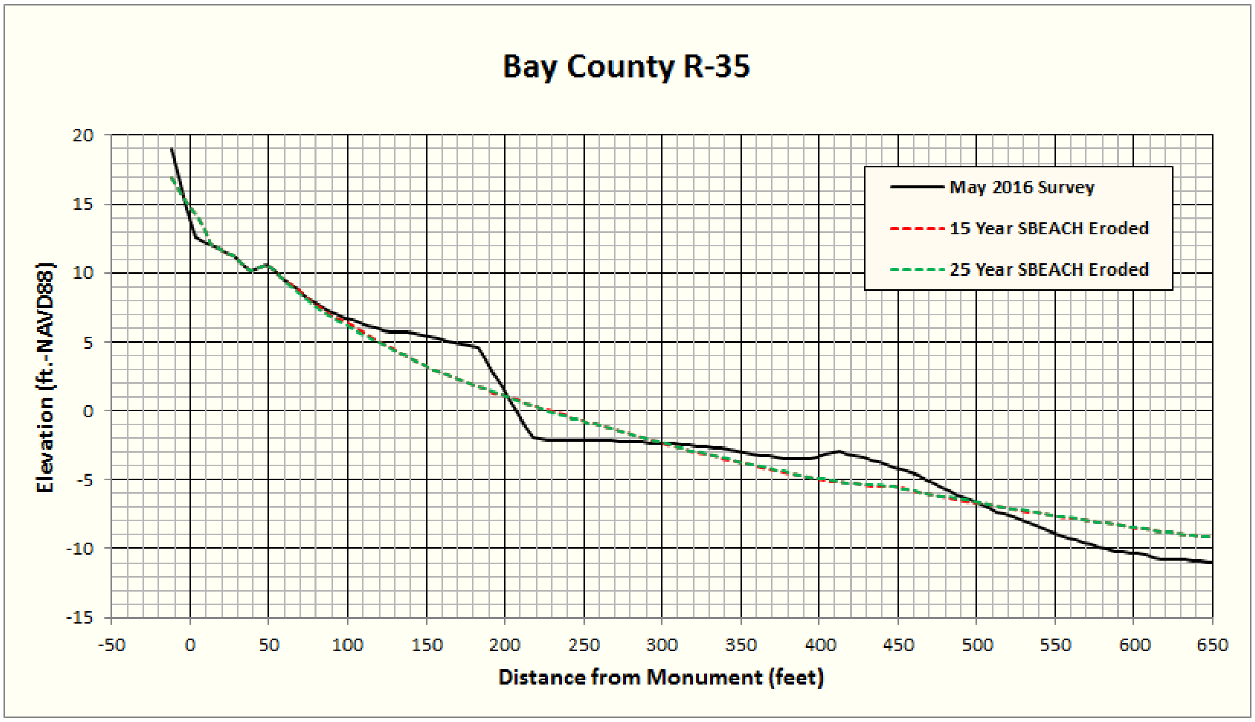


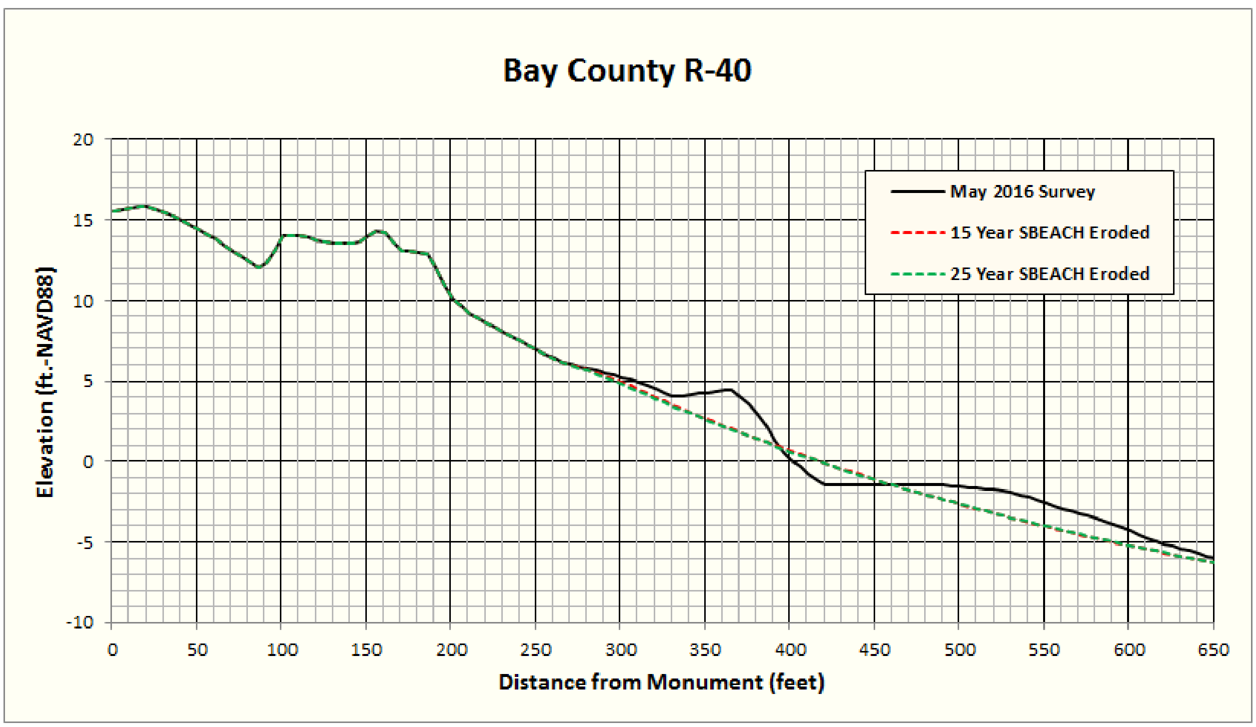

Bay County R-15
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
20
15
10
5
0
-5
-10
-15
0
50
100
150
200
250
300
350
400
450
500
550
600
650
Distance from Monument (feet)

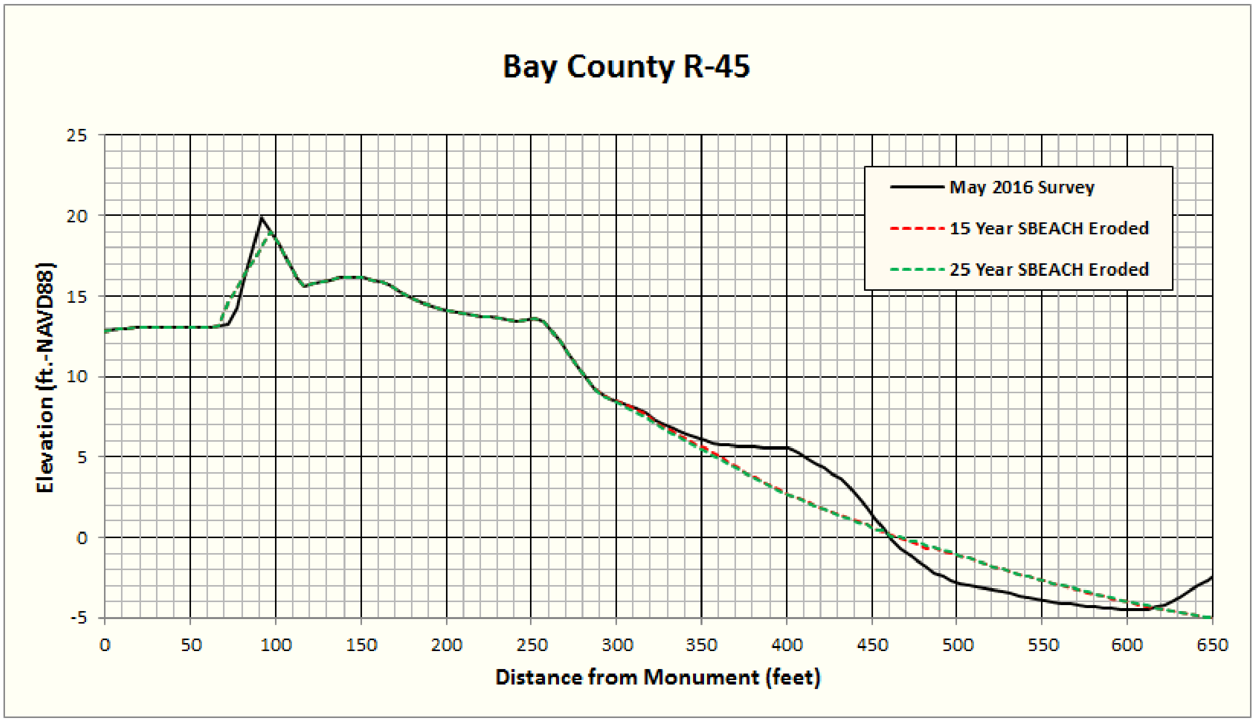

Bay County R-20
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
20
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
450
500
550
600
650
Distance from Monument (feet)

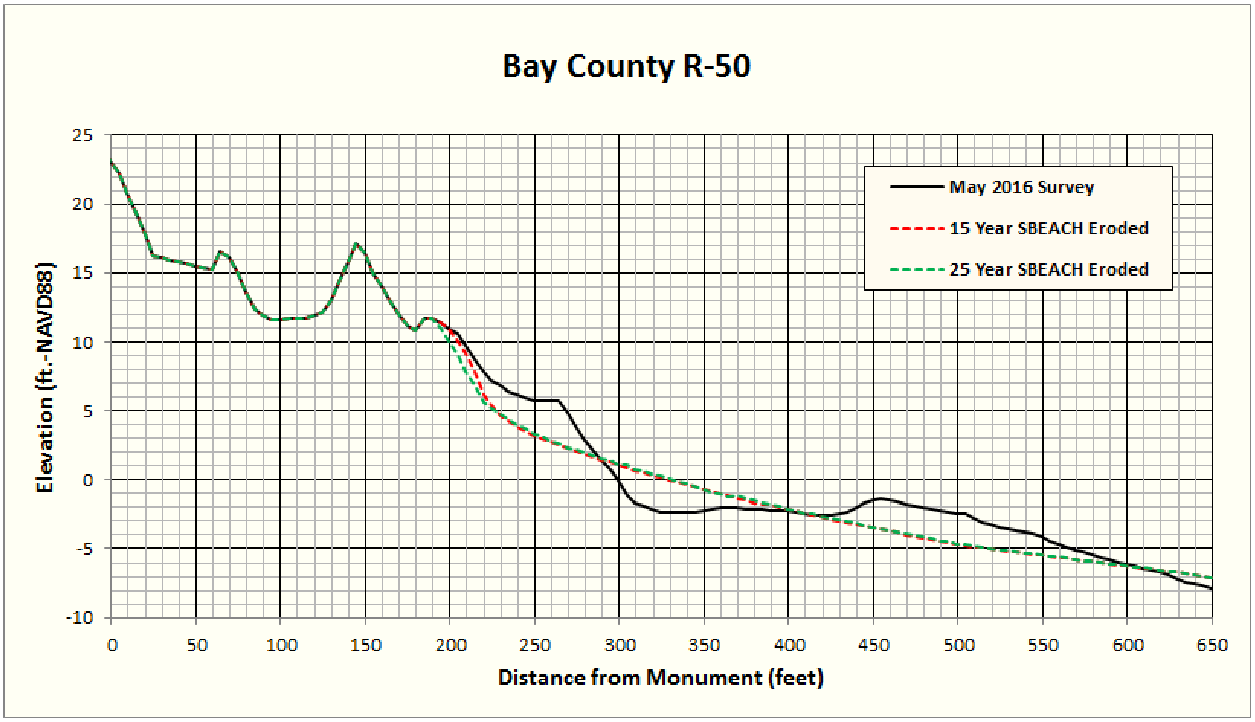

Bay County R-25
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
30
25
20
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
450
500
550
600
650
Distance from Monument (feet)

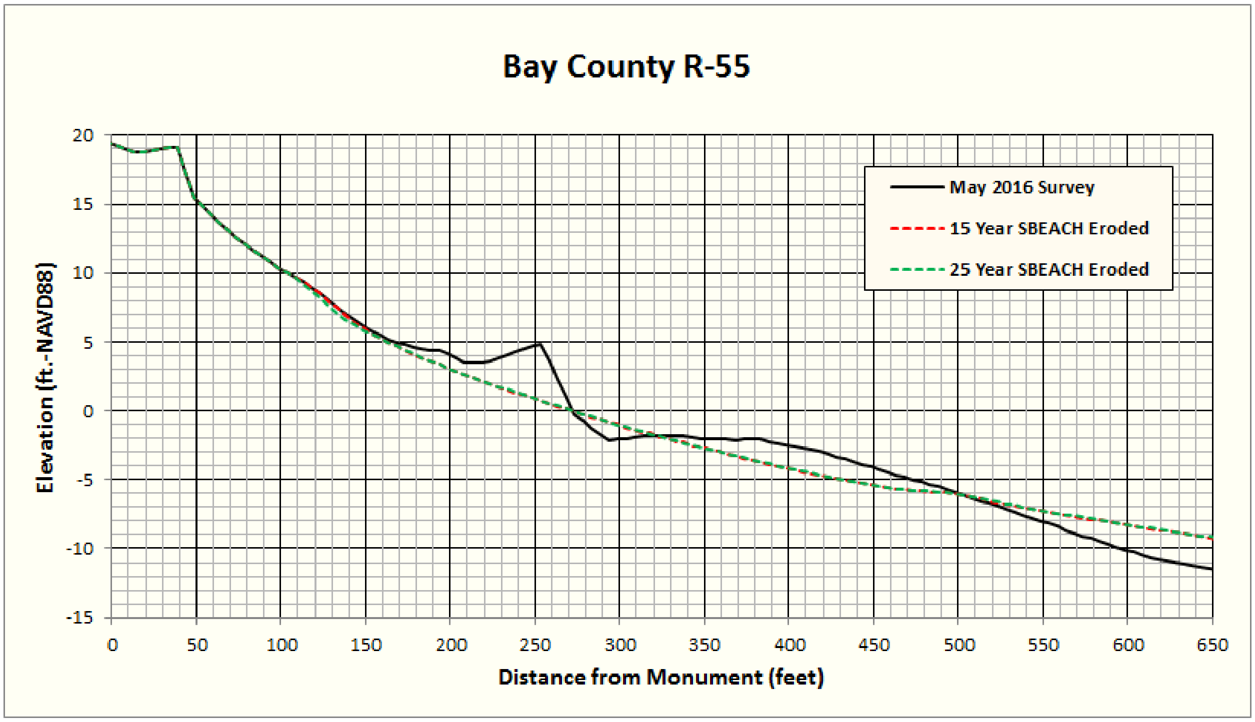

Bay County R-30
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
20
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
450
500
550
600
650
Distance from Monument (feet)

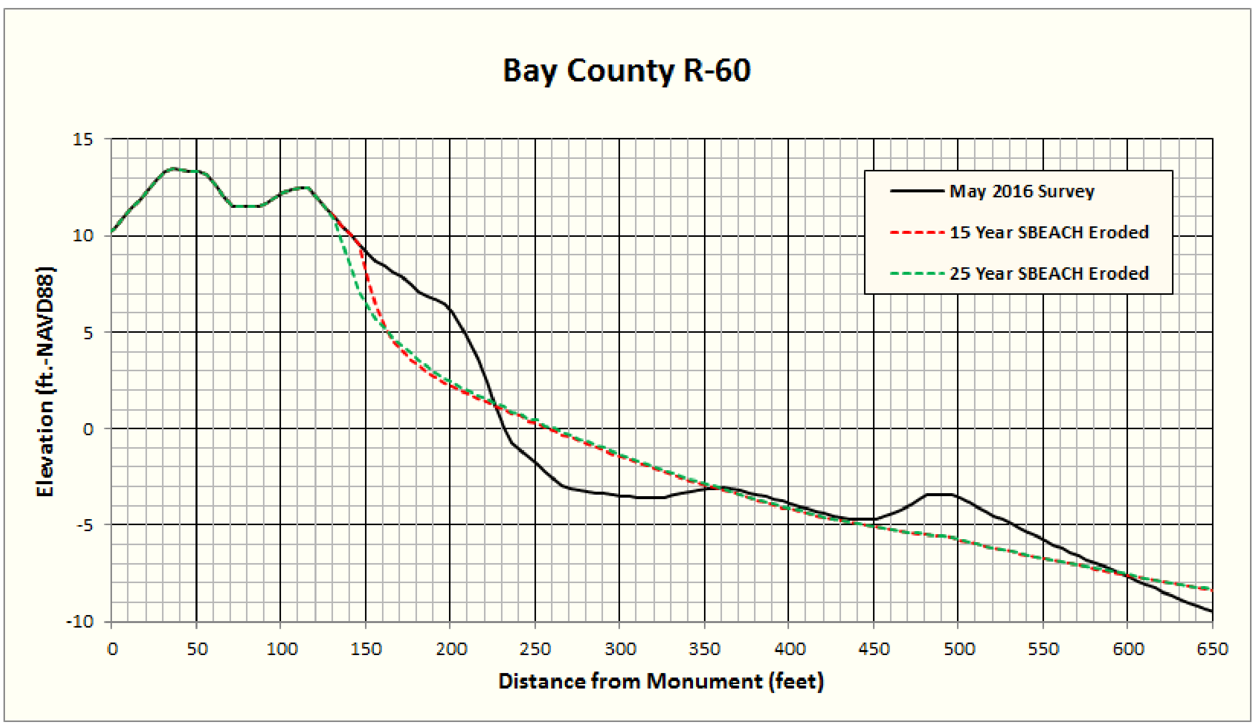

Bay County R-35
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
Distance from Monument (feet)
20
15
10
5
0
-5
-10
-15
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650

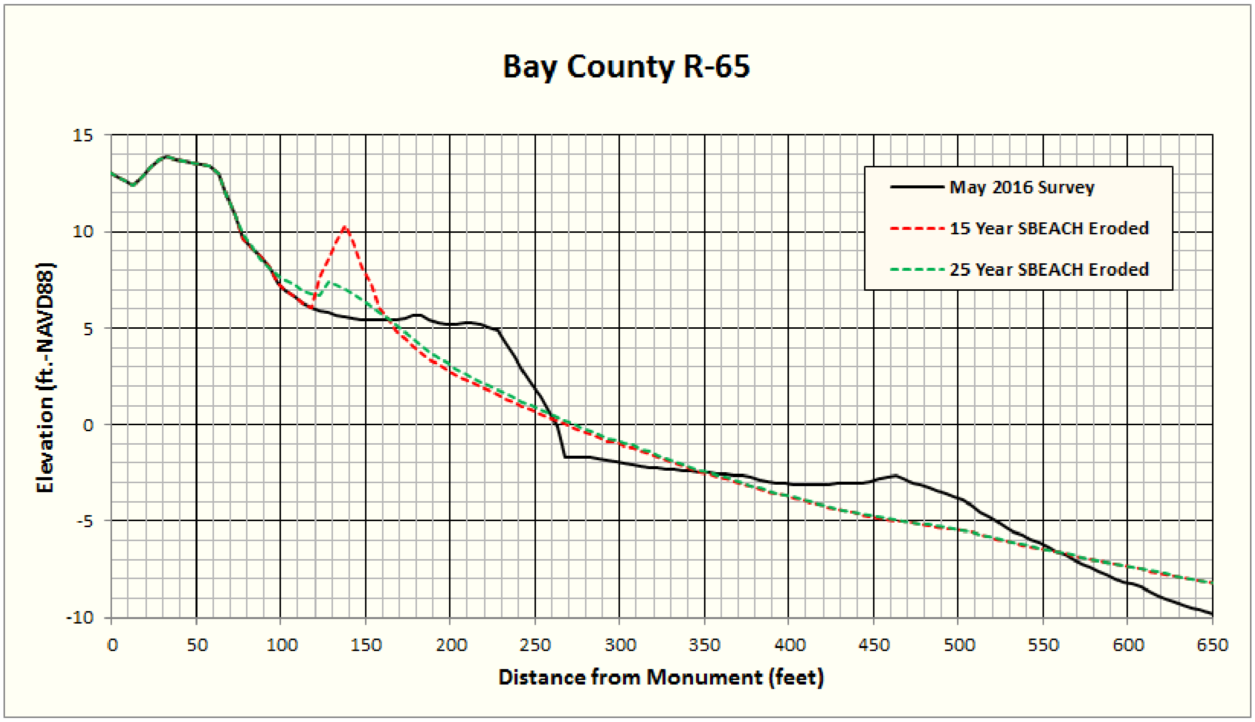

Bay County R-40
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
Distance from Monument (feet)
20
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
450
500
550
600
650

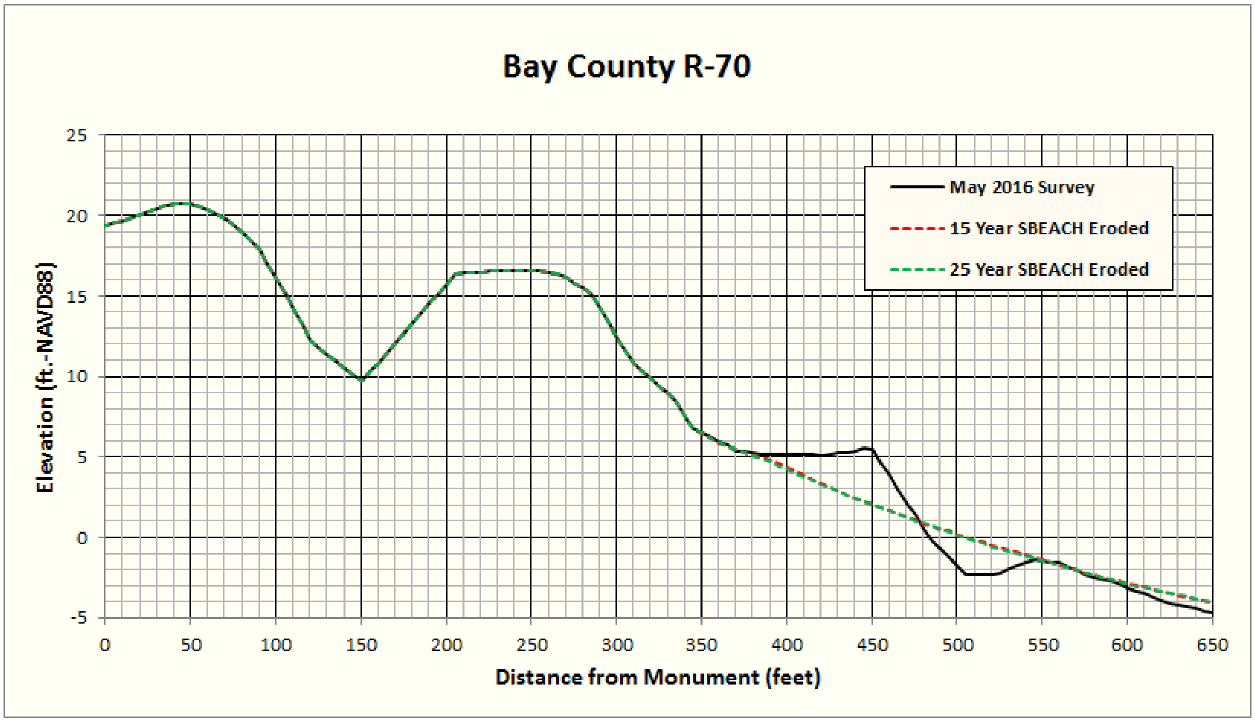

Bay County R-45
Elevation (ft.-NAVD88)
Distance from Monument (feet)
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
25
20
15
10
5
0
-5
0
50
100
150
200
250
300
350
400
450
500
550
600
650

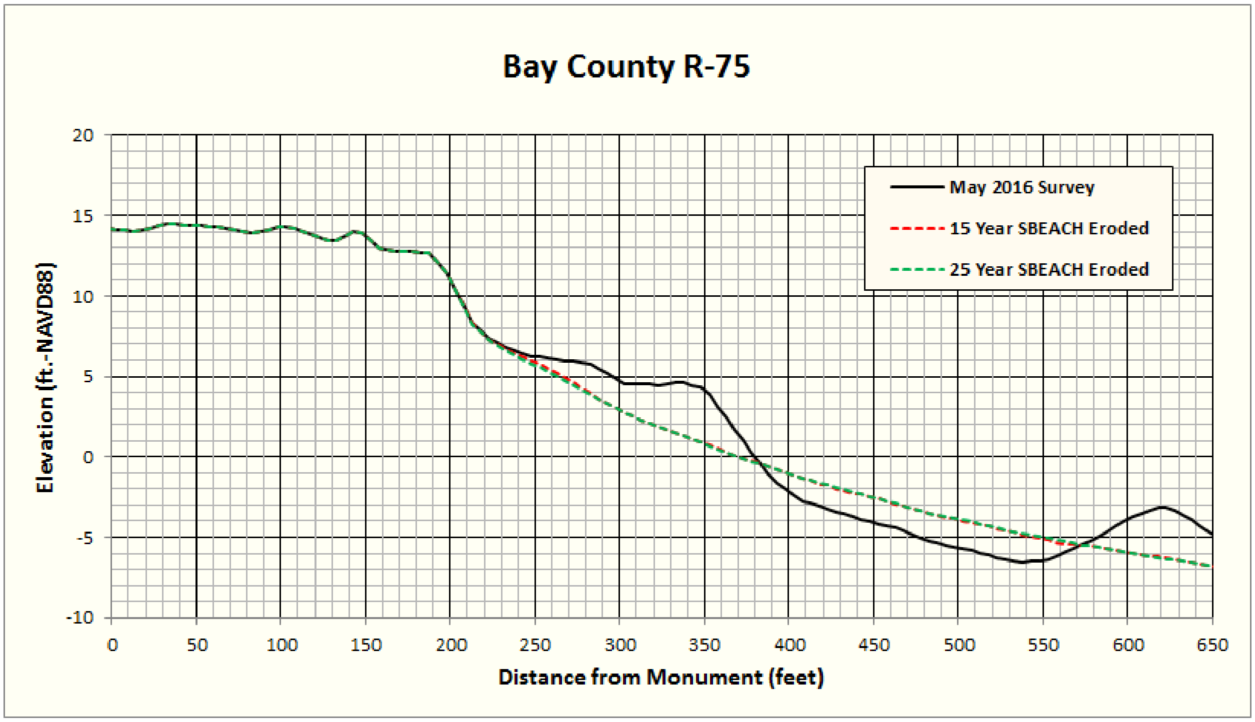

Bay County R-50
Elevation (ft.-NAVD88)
Distance from Monument (feet)
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
25
20
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
450
500
550
600
650

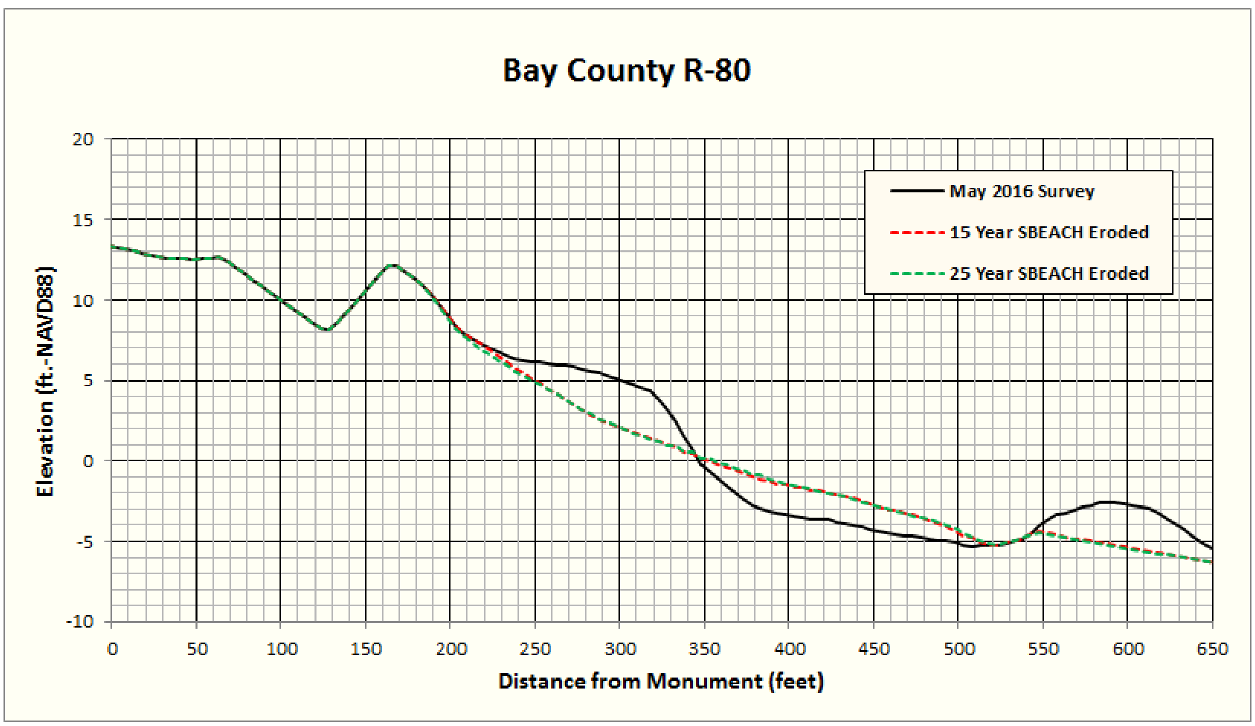

Bay County R-55
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
20
15
10
5
0
-5
-10
-15
0
50
100
150
200
250
300
350
400
450
500
550
600
650
Distance from Monument (feet)

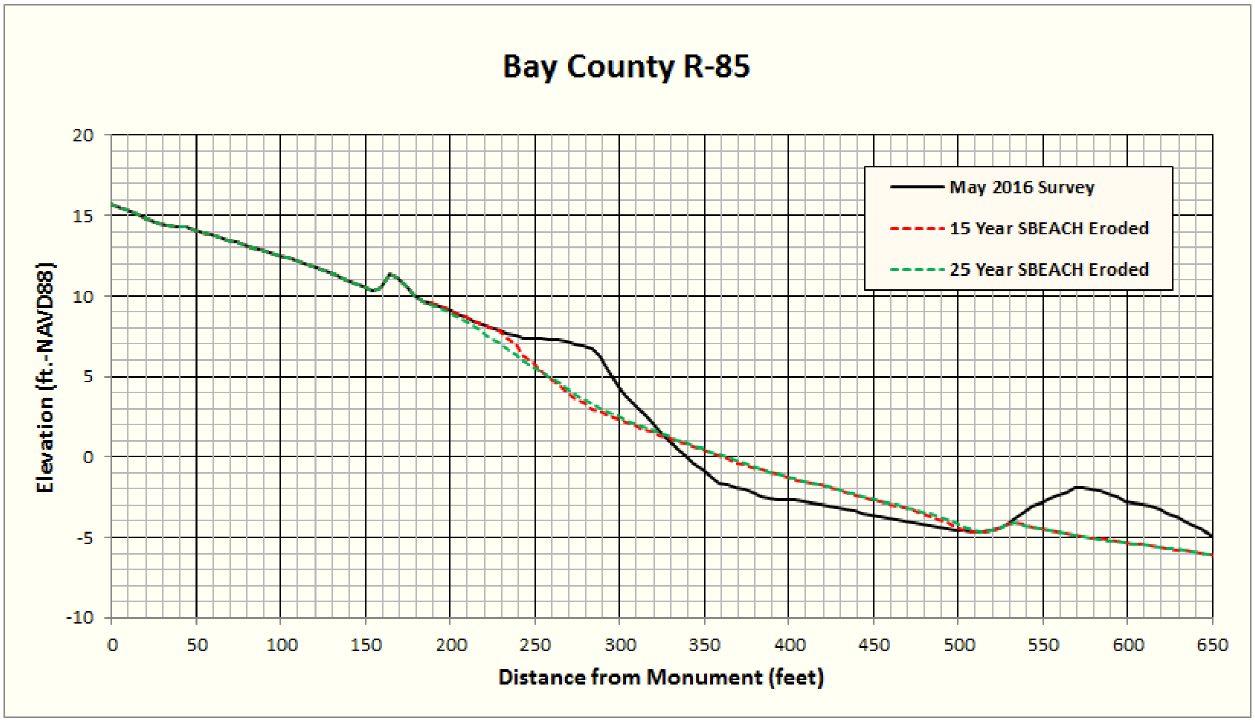

Bay County R-60
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
450
500
550
600
650
Distance from Monument (feet)

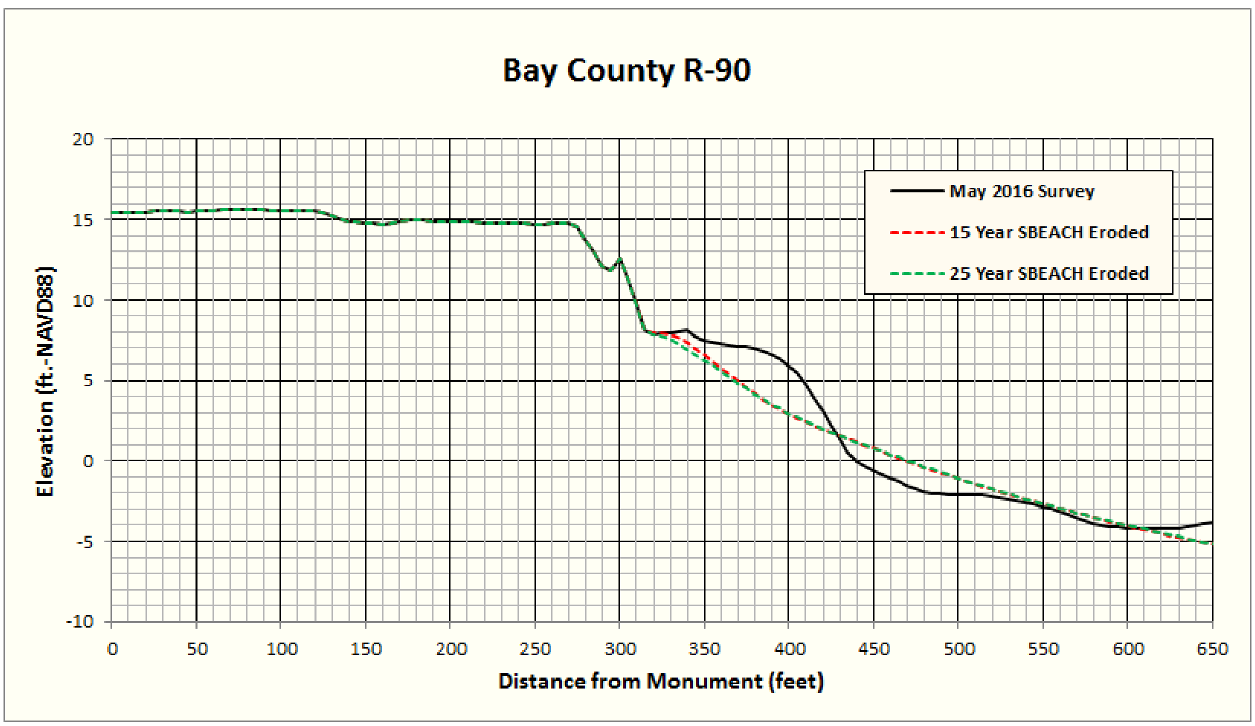

Bay County R-65
15
10
5
0
-5
-10
Elevation (ft.-NAVD88)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
Distance from Monument (feet)
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded

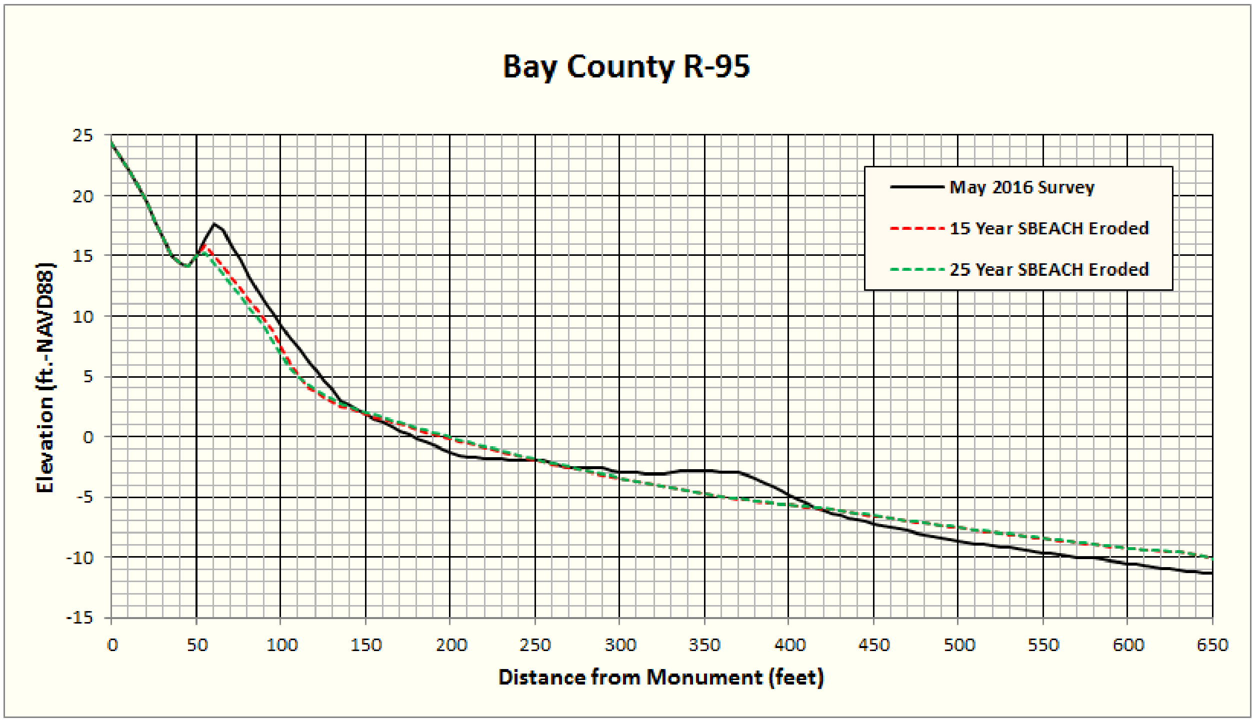

Bay County R-70
25
20
15
10
5
0
-5
Elevation (ft.-NAVD88)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
Distance from Monument (feet)
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded

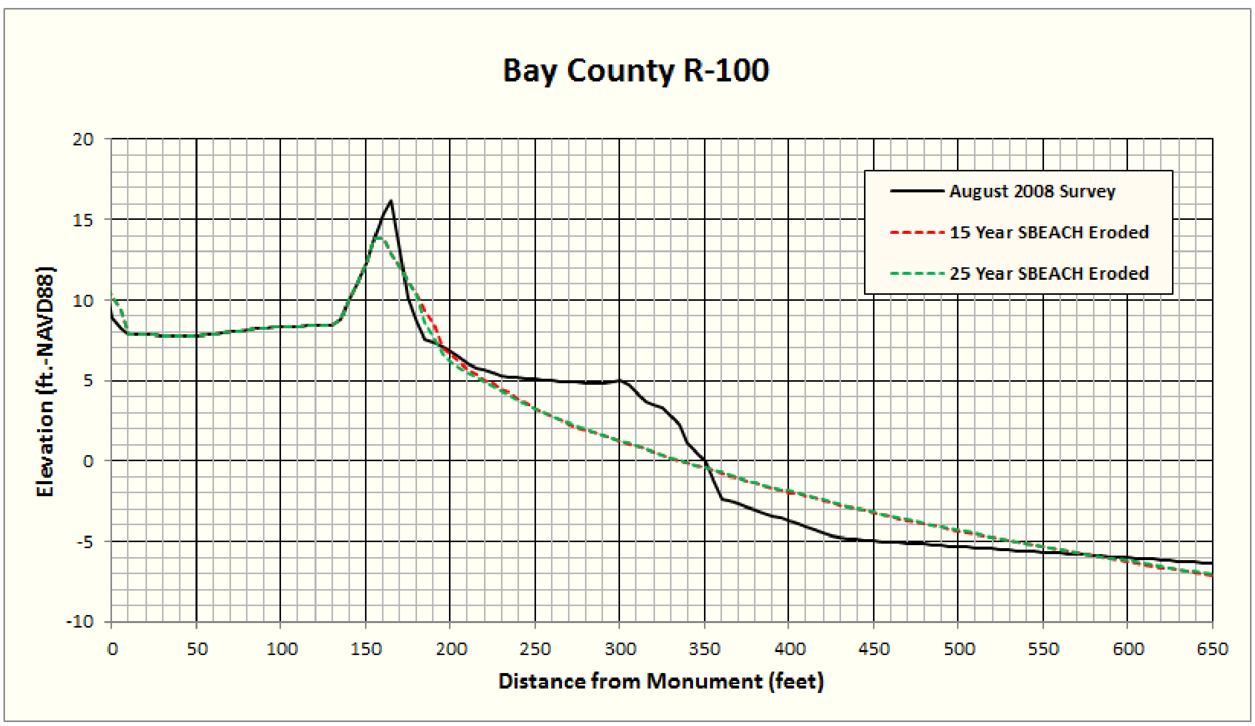

Bay County R-75
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
Distance from Monument (feet)

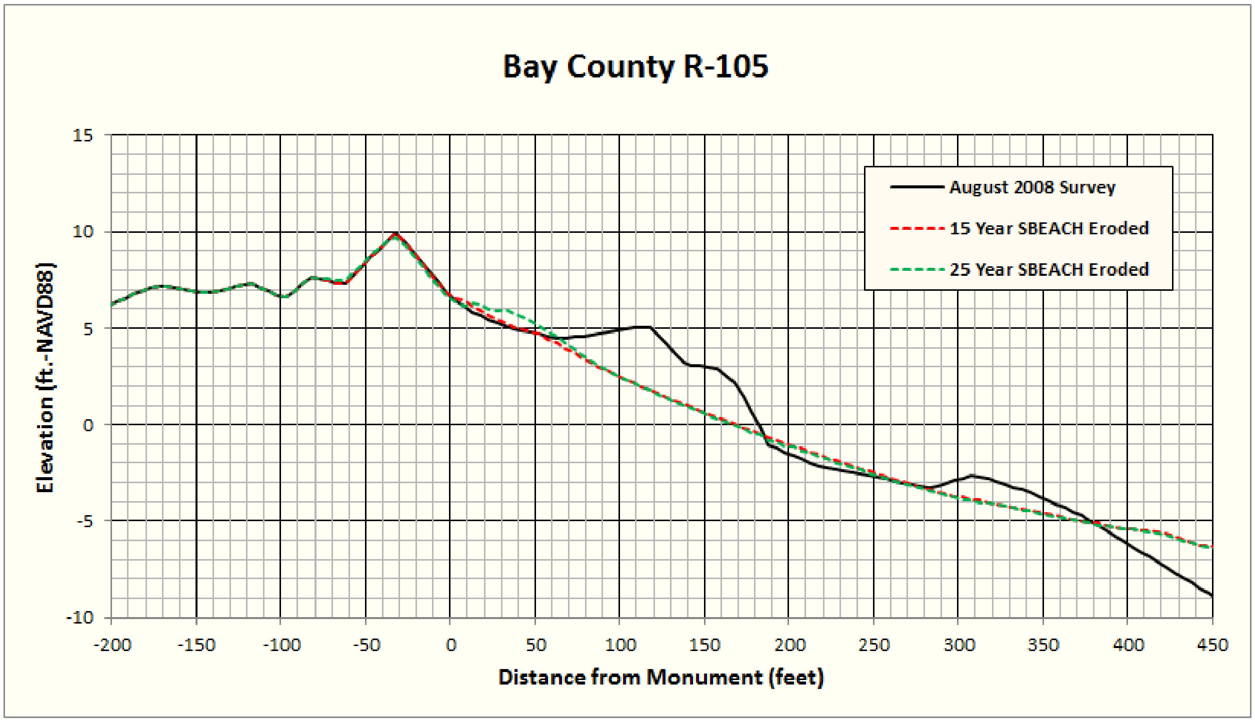

Bay County R-80
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
Distance from Monument (feet)

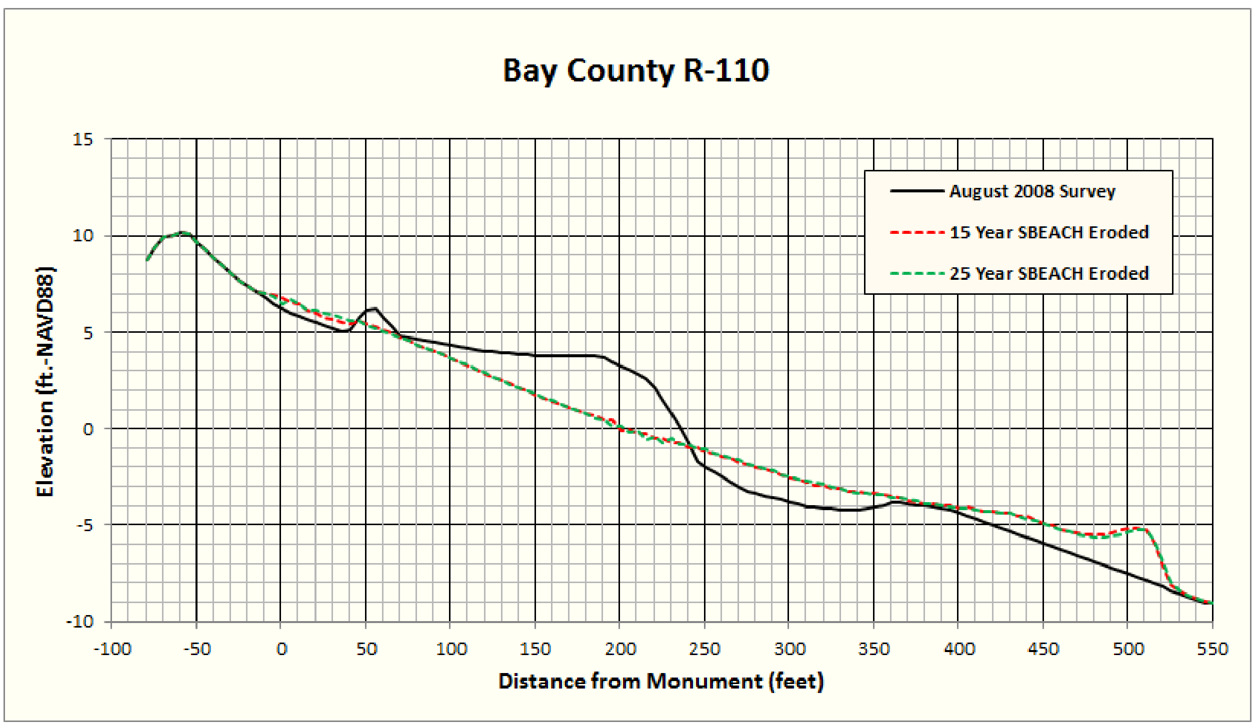

Bay County R-85
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
Distance from Monument (feet)
20
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
450
500
550
600
650

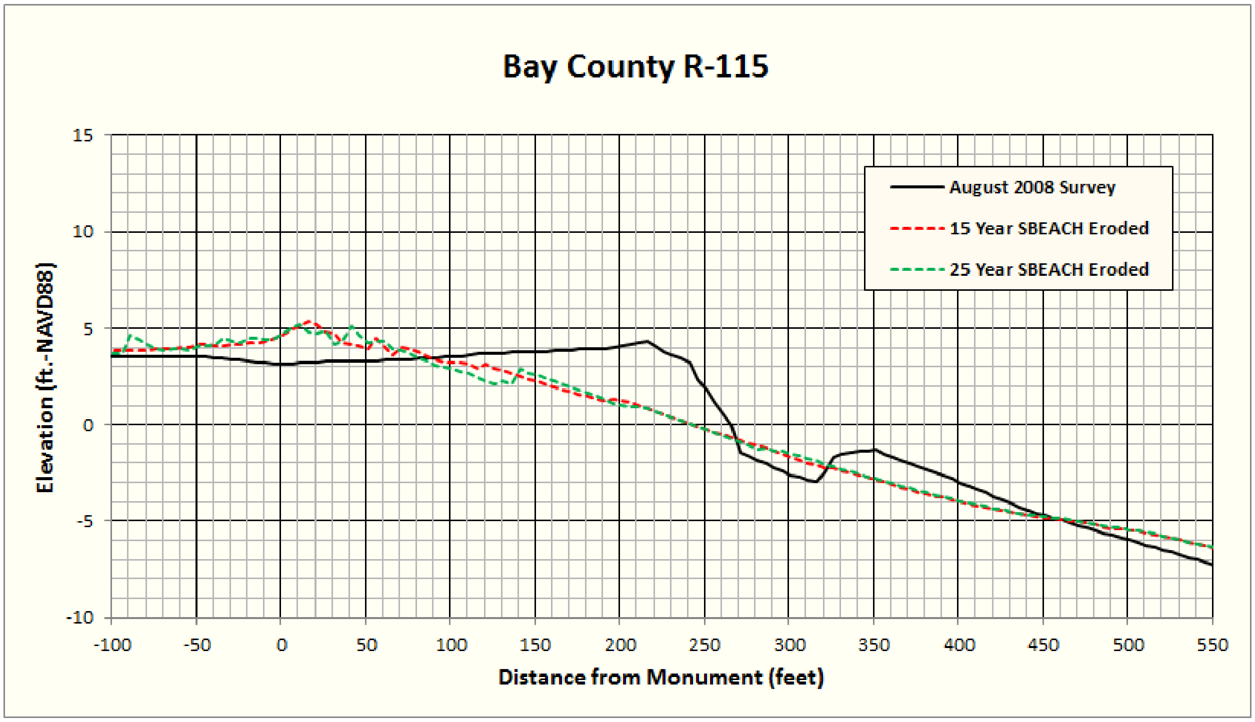

Bay County R-90
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
Distance from Monument (feet)
20
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
450
500
550
600
650

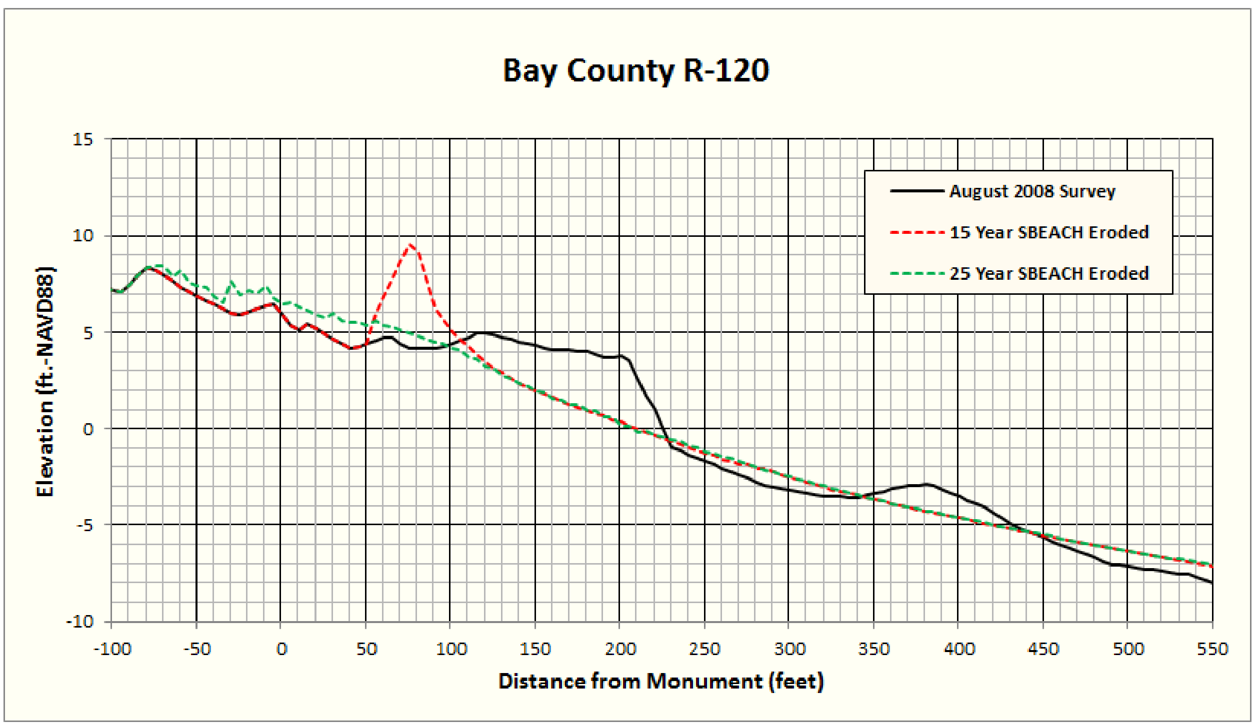

Bay County R-95
Elevation (ft.-NAVD88)
Distance from Monument (feet)
May 2016 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
25
20
15
10
5
0
-5
-10
-15
0
50
100
150
200
250
300
350
400
450
500
550
600
650

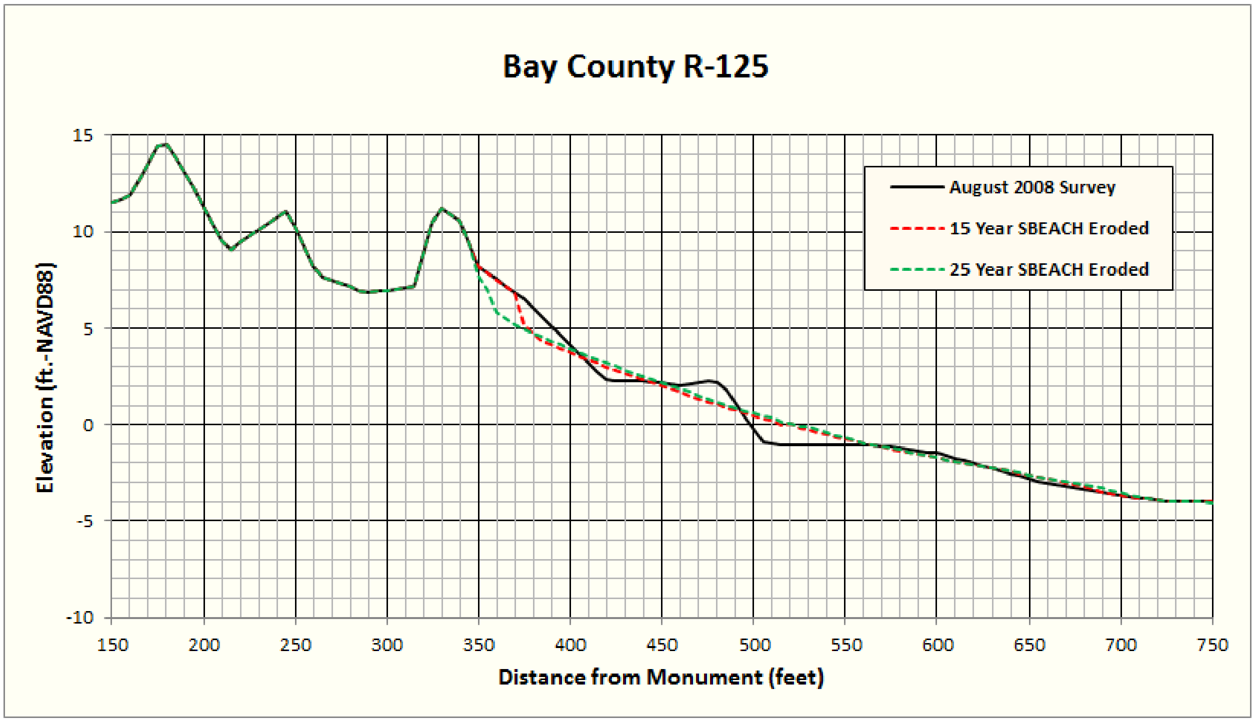

Bay County R-100
Elevation (ft.-NAVD88)
Distance from Monument (feet)
August 2008 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
20
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
450
500
550
600
650

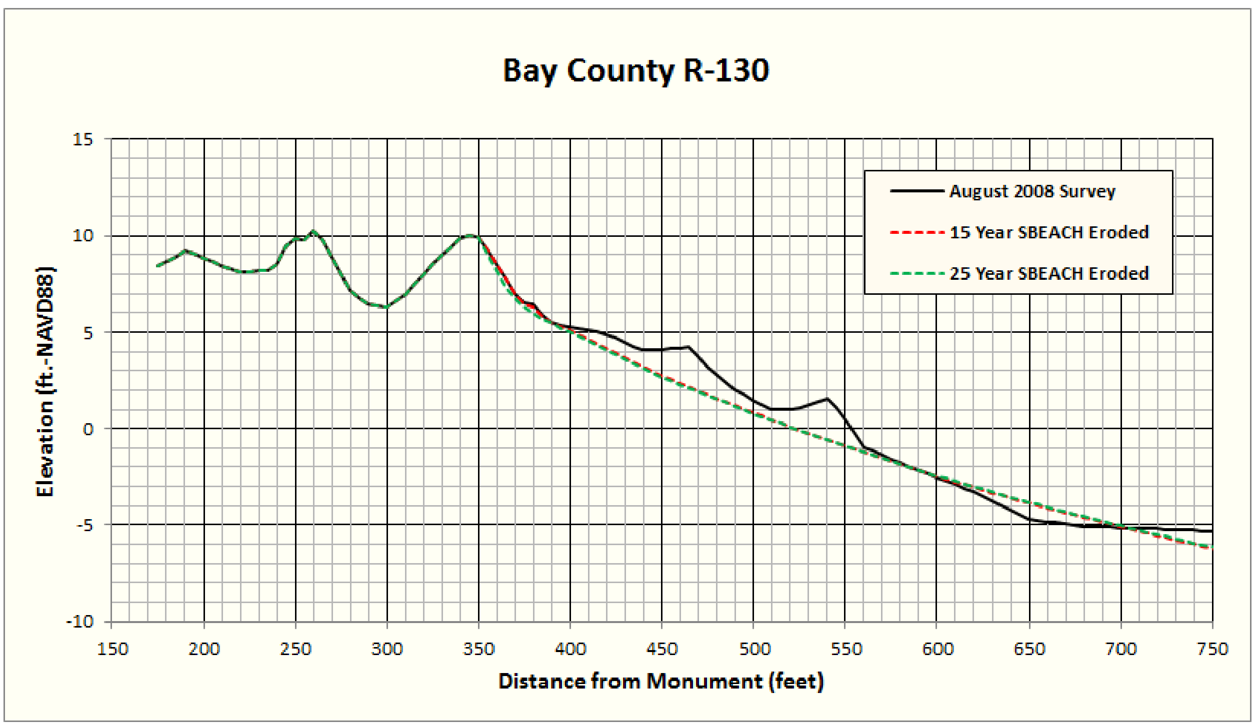

Bay County R-105
Elevation (ft.-NAVD88)
Distance from Monument (feet)
August 2008 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
15
10
5
0
-5
-10
-200
-150
-100
-50
0
50
100
150
200
250
300
350
400
450

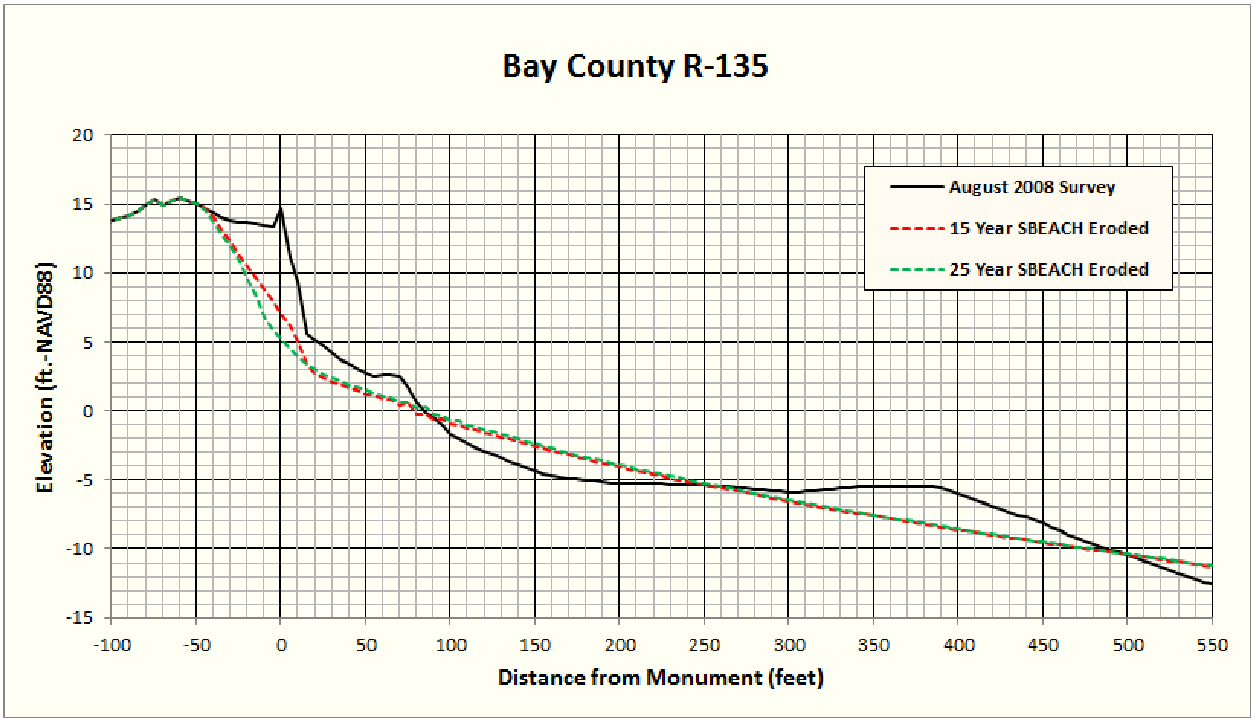

Bay County R-110
Elevation (ft.-NAVD88)
Distance from Monument (feet)
August 2008 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
15
10
5
0
-5
-10
-100
-50
0
50
100
150
200
250
300
350
400
450
500
550

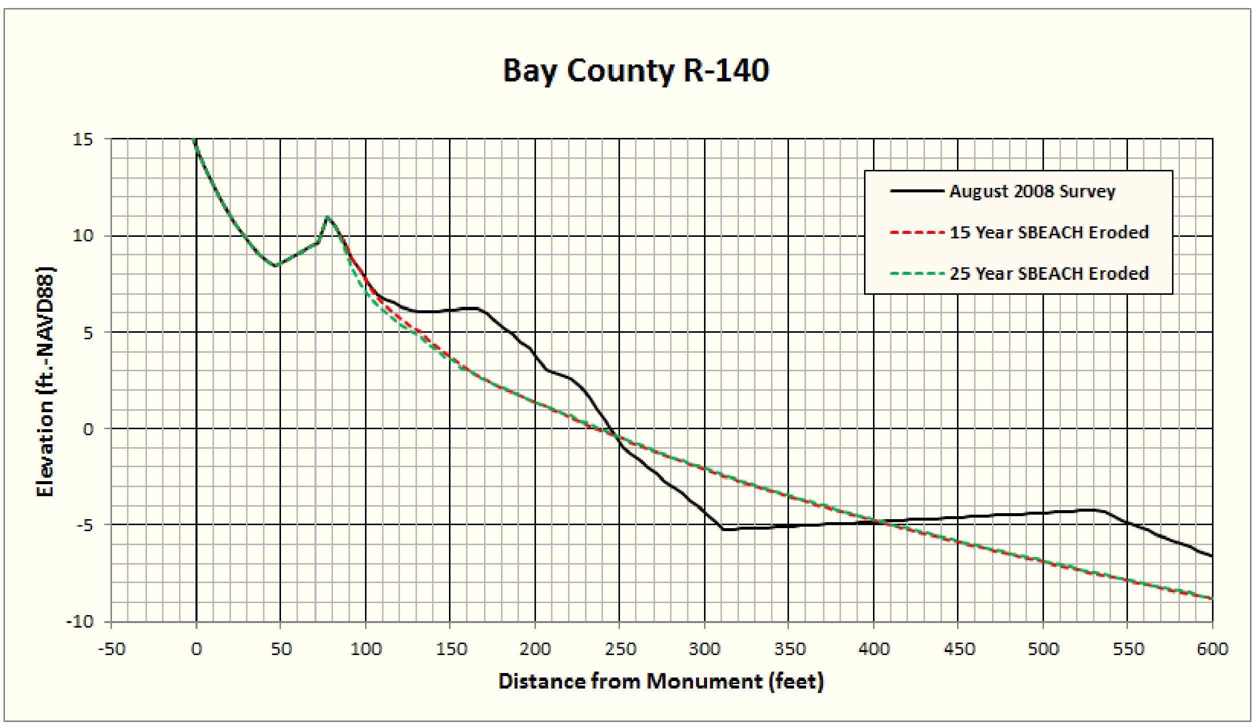

Bay County R-115
August 2008 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
Distance from Monument (feet)
15
10
5
0
-5
-10
-100
-50
0
50
100
150
200
250
300
350
400
450
500
550

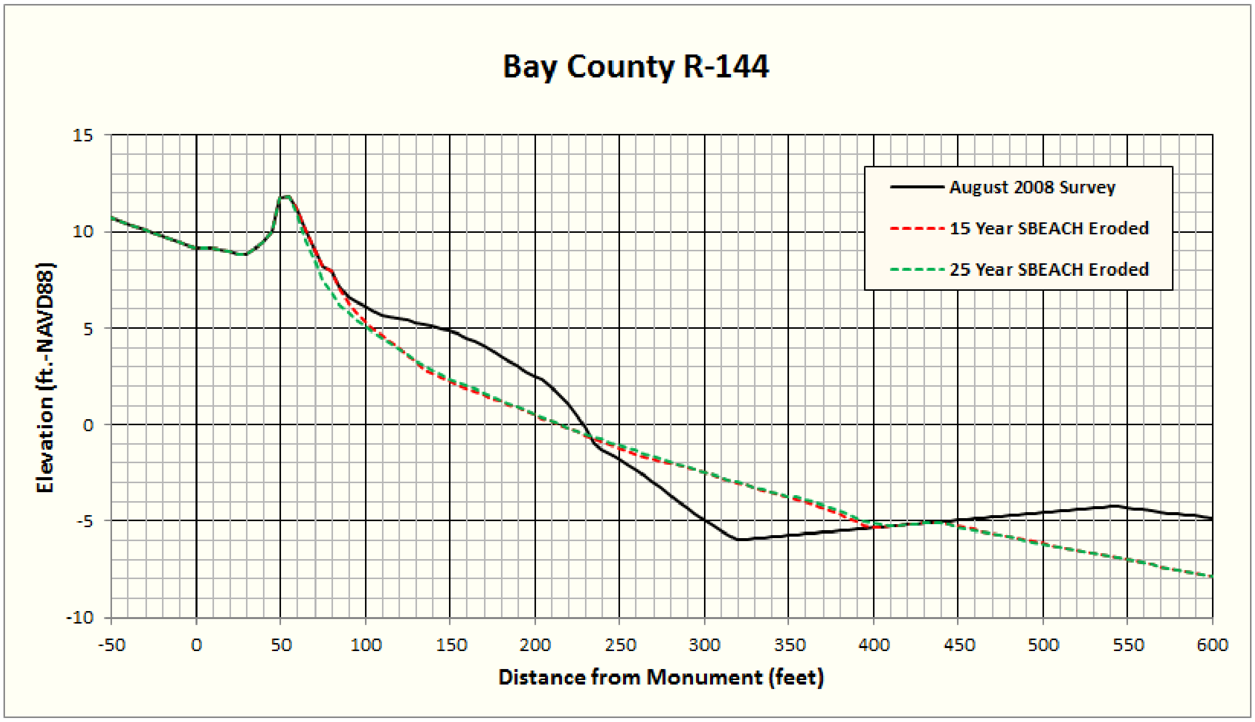

Bay County R-120
August 2008 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
Distance from Monument (feet)
15
10
5
0
-5
-10
-100
-50
0
50
100
150
200
250
300
350
400
450
500
550


Bay County R-125
15
10
5
0
-5
-10
150
200
250
300
350
400
450
500
550
600
650
700
750
Elevation (ft.-NAVD88)
Distance from Monument (feet)
August 2008 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded


Bay County R-130
15
10
5
0
-5
-10
150
200
250
300
350
400
450
500
550
600
650
700
750
Elevation (ft.-NAVD88)
Distance from Monument (feet)
August 2008 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded


Bay County R-135
August 2008 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
Distance from Monument (feet)
20
15
10
5
0
-5
-10
-15
-100
-50
0
50
100
150
200
250
300
350
400
450
500
550


Bay County R-140
August 2008 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
Distance from Monument (feet)
15
10
5
0
-5
-10
-50
0
50
100
150
200
250
300
350
400
450
500
550
600


Bay County R-144
August 2008 Survey
15 Year SBEACH Eroded
25 Year SBEACH Eroded
Elevation (ft.-NAVD88)
15
10
5
0
-5
-10
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
Distance from Monument (feet)