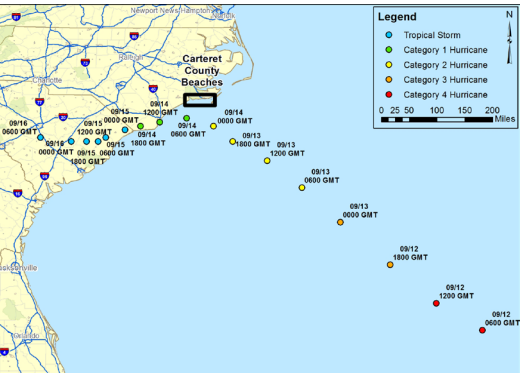
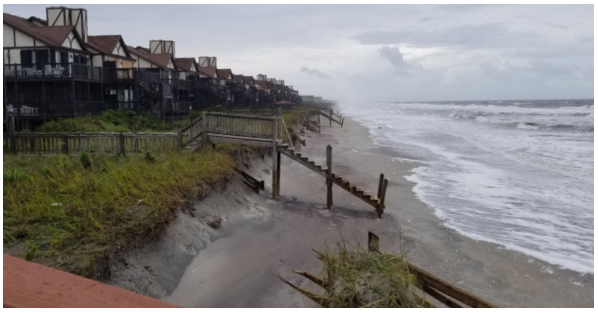
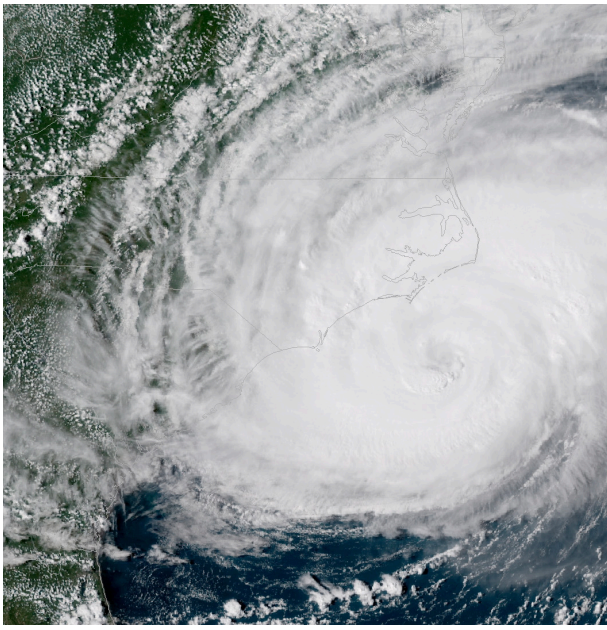
BOGUE BANKS BEACH AND NEARSHORE MAPPING PROGRAM

HURRICANE FLORENCE POST-STORM IMPACT EVALUATION

FINAL REPORT | JANUARY 2019







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geodynamics
COMPLEX COASTAL CHANGE MADE CLEAR

Executive Summary

Comprehensive surveying of the Bogue Banks shoreline began in 1999 to develop the Bogue Banks Beach Restoration Project. In Spring 2004, the Bogue Banks Beach and Nearshore Mapping Program was initiated to assess beach conditions and form strategies for future beach nourishment projects. Bear Island and Shackleford Banks were added to the program in October 2004 and May 2005, respectively. Currently, surveys are performed annually during the spring/summer timeframe along all three islands. In addition, after large storm events surveying is performed along Bogue Banks to assess damages. The most recent regular (pre-storm) monitoring survey was completed during March 2018 by Geodynamics. Geodynamics conducted a post-storm survey on September 19 through September 26, 2018 immediately following the passage of Hurricane Florence. For this storm impact evaluation, the March 2018 survey was compared with the September 2018 survey. The profile data have been used to compute shoreline change at MHW (+1.5 ft NAVD88) and volume change above MHW, -5 ft NAVD88 (wading depth), -12 ft NAVD88 (outer bar), -20 ft NAVD88 (approximate closure), and -30 ft NAVD88.

Trends to be noted along a majority of the shoreline were volume losses above MHW, -5 ft NAVD88, -12 ft NAVD88, and -20 ft NAVD88. Profile plots showed there was significant erosion of the incipient dune, berm, and beachface down to approximately -4 ft NAVD88. Beyond this, there was a small recovery of material down to approximately -10 ft NAVD88 followed by formation of a large trough where the offshore bar was previously located and then capture of eroded material well offshore, seaward of the typical offshore bar location with much of it beyond depth of closure. Key statistics were computed for defined regions along the Bogue Banks shoreline between the pre- and post-storm survey profiles including:

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Inlet-Ocean (Transects 1-11)	11,488	-47.6	-24.3	-278,605	-28.7	-330,138	-36.1	-414,817	-9.2	-105,694	21.0	241,260
Emerald Isle-West (Transects 12-25)	18,288	-25.7	-20.2	-368,746	-28.6	-523,728	-40.3	-736,750	-36.1	-660,896	11.7	213,575
Emerald Isle-Central (Transects 26-36)	15,802	-34.6	-20.8	-329,442	-23.6	-372,360	-35.2	-556,272	-41.4	-654,711	1.0	15,325
Emerald Isle-East (Transects 37-48)	13,220	-27.8	-19.2	-254,290	-22.3	-295,149	-35.8	-472,897	-43.8	-579,021	-7.2	-95,539
Indian Beach-Salter Path (Transects 49-58)	12,850	-25.4	-19.4	-249,575	-19.4	-249,199	-34.6	-444,810	-37.1	-477,032	-10.2	-130,771
Pine Knoll Shores (Transects 59-76)	23,878	5.5	-14.6	-348,827	-13.4	-319,234	-24.1	-575,901	-20.4	-487,867	-3.4	-80,610
Atlantic Beach (Transects 77-102)	26,176	-20.9	-13.2	-346,529	-12.0	-312,956	-16.8	-439,261	-4.0	-103,931	21.5	563,222
Fort Macon State Park (Transects 103-112)	6,691	-10.7	-9.4	-62,734	-4.9	-32,506	14.1	94,297	51.3	343,207	64.8	433,471
Beaufort Inlet (Transects 112B-116)	2,000	-91.1	-9.2	-18,447	-15.5	-30,999	-15.6	-31,213	-8.6	-17,151	0.2	365
Bogue Inlet-Channel (Transects 117-120)*	2,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Reach Length	Weighted Avg	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total
FEMA Engineered Beach (Transects 1-76)	**95,527**	**-22.2**	**-19.2**	**-1,829,485**	**-21.9**	**-2,089,808**	**-33.5**	**-3,201,448**	**-31.0**	**-2,965,222**	**1.7**	**163,240**
Oceanfront (Transects 1-112)	**128,393**	**-21.4**	**-17.4**	**-2,238,748**	**-19.0**	**-2,435,271**	**-27.6**	**-3,546,411**	**-21.2**	**-2,725,946**	**9.0**	**1,159,933**

*Note: Due to the dynamic nature of Bogue Inlet, shoreline and volume calculations were not performed

Given the overall loss in material above -20 ft NAVD88 (depth of closure) of -3,040,389 cy along the portions of the shoreline currently eligible for FEMA reimbursement (Transects 7

– 76), the County will be seeking financial aid to replace sand on the beach. Additionally, the post-storm monitoring efforts put forth as part of the Master Beach Nourishment Plan, which totaled $119,800, are reimbursable under FEMA disaster declarations for Carteret County.

The following table presents a summary of losses incurred by town. It is expected that Emerald Isle (Bogue Inlet – Ocean, Emerald Isle – West, Emerald Isle – Central, and Emerald Isle – East) will seek reimbursement for 2,075,490 cy. Indian Beach and Salter Path are grouped as one management reach during monitoring and will seek reimbursement for 477,032 cy total (416,536 cy in Indian Beach and 60,496 cy in Salter Path). Pine Knoll Shores will seek reimbursement for 487,867 cy of material.

Reach (Transects)	Volume Lost Above -20 ft NAVD88 (cy)
Emerald Isle (Transetcs 7-48)	-2,075,490
Indian Beach-Salter Path (Transects 49-58)	-477,032
Pine Knoll Shores (Transects 59-76)	-487,867
Engineered Beach (Transects 7-76)	**-3,040,389**

There is a small portion of oceanfront State owned land in Indian Beach/Salter Path, totaling approximately 2,750 feet of shoreline. If sand lost on this portion of the beach is removed from the total losses, the Indian Beach/Salter Path reimbursement claim will be reduced to 374,947 cy (314,451 cy in Indian Beach and 60,496 cy in Salter Path).

It should be noted that the background erosion rates in the FEMA engineered beach portion of Bogue Banks are relatively small and currently range from +1.10 cy/ft/yr of accretion to -2.42 cy/ft/yr of erosion. Therefore, given the small timeframe between the pre-storm surveys in March 2018 and post-storm surveys in September 2018, it is unlikely that there was significant measurable background erosion.

As noted, there are inevitable margins of uncertainty associated with hydrographic survey data that may reduce the accuracy of volumetric change analyses. Therefore, it is essential to thoroughly review the beach and bathymetric profiles using various analytical techniques and general engineering judgment to assure that results are not falsely interpreted. The findings presented in this report have undergone quality control by two senior coastal engineers.

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1.0 Objective

Hurricane Florence made landfall on the North Carolina coast, just south of Wrightsville Beach, on September 14, 2018, as a Category 1 hurricane. However, storm conditions impacted the North Carolina coast for several days before and after the hurricane made landfall. As a direct result of the hurricane, the beaches of Bogue Banks, including all reaches of the County and local municipality sponsored (non-federal) engineered beach project, experienced large changes in the beach profile, creating significant erosion of the beach and incipient dune along with moderate escarpment of the primary dune. In most cases, material was transported offshore, well beyond the depth of closure, culminating in significant volume losses above MHW (+1.5 ft NAVD88), -5 ft NAVD88, -12 ft NAVD88, and -20 ft NAVD88. The federal government has declared Hurricane Florence as a federal disaster within Carteret County, authorizing FEMA Categories A through G public assistance. The objective of this report is to document field inspections and survey data collected immediately following Hurricane Florence and to describe impacts and estimate damages to the engineered beaches of Carteret County by comparison of post-storm profile surveys with pre-storm surveys conducted in March 2018.

Federal Category B public assistance applies to "Emergency Protective Measures" and is intended to assist public authorities with any measures taken to ensure hurricane preparedness within the authority's jurisdiction. Federal Category G public assistance applies to "Parks, Recreational, and Other Facilities" and is intended to assist with damages sustained during the hurricane to those facilities within the authority's jurisdiction, including beaches. A primary intent of this report is to document the pre- and post- storm conditions of the Bogue Banks oceanfront to quantify the storm protection that was lost during the hurricane, satisfying the monitoring and maintenance requirements for the FEMA engineered beach. Please note that the County's planning, monitoring, and previous communication with FEMA denotes the engineered beach as the volume of sand between the top of the dune out to -12 ft NAVD88 (see **Figure 4-1**).

2.0 Recent History of Engineered Beach Nourishment and Monitoring in Carteret County

The Carteret County Shore Protection Office, in coordination with Bogue Banks municipalities, oversees and coordinates the design, monitoring, and maintenance, including initial nourishment and planned renourishments, of a public "engineered beach" project along 18.1 miles of Bogue Banks, including Emerald Isle, Indian Beach/Salter Path, and Pine Knoll Shores. The remaining portions (≈6.2 miles) of Bogue Banks (Atlantic Beach and Fort Macon) are either provided protection (beach nourishment) under the Dredged Material Management Plan (DMMP) of Morehead City Harbor Federal Navigation Project or are areas not eligible for federal expenditures for beach nourishment.

The Bogue Banks Beach and Nearshore Mapping Program (BBBNMP), sponsored by Carteret County, formally began in June 2004 as a continuation of a monitoring program initiated in 1999 for assessing beach conditions and forming strategies for the Bogue Banks Beach Restoration Project (Phases I, II, and III). Bear Island was first surveyed and added to the BBBNMP in October 2004 while Shackleford Banks was added in May 2005.

Initial construction of the engineered beaches by Carteret County commenced in 2002 (Phase I) and was completed in 2005 (Phase III). Since May 2005, surveys along Bogue Banks, Bear Island, and Shackleford Banks have been performed annually during the spring/summer timeframe. In addition, Bogue Banks is also surveyed after large storm events to quantify damage done to the beach and support the municipalities' requests for FEMA reimbursement for losses to the engineered beach (Emerald Isle, Indian Beach/Salter Path, and Pine Knoll Shores). The most recent annual survey was completed in March 2018 by Geodynamics LLC (Geodynamics), and a post-storm survey was conducted in September 2018 immediately following the passage of Hurricane Florence. This report documents the data sources, methods, and results of a survey evaluation performed to compare the September 2018 post-storm survey with the prior March 2018 survey.

A beach maintenance plan has been in effect since 2003-2004, with triggers for beach renourishment initially established if the average volume in any reach from the top of the dune to -12 ft NAVD88 drops below 225 cy/ft or if the percent fill remaining in any reach from the Bogue Banks Beach Restoration Project which placed sand on Indian Beach/Salter Path and Pine Knoll Shores (Phase I-2002), Emerald Isle Central and Emerald Isle East (Phase II-2003), and Emerald Isle West and Bogue Inlet (Phase III-2005) falls below 50% of the original fill amount. The triggers for beach nourishment were adjusted in 2015 with submission of a revised FEMA engineered beach plan which is discussed later in the document.

The robust maintenance plan has included multiple additional nourishment projects since the Bogue Banks Restoration Project was constructed. Additional sand was added to the beaches within Phases I, II, and III of the Bogue Banks Beach Restoration Project following Hurricane Isabel (2003, with renourishment completed in 2004), Hurricane Ophelia (2005, with renourishment completed in 2007) and Hurricane Irene (2011, with renourishment completed in 2013). In March 2004, a small FEMA sponsored renourishment project was constructed in Emerald Isle (156,000 cy). In January – March 2007, as a result of Hurricane Ophelia which impacted the Bogue Banks area in 2005, FEMA approved and provided funding to place a total of 1,229,836 cy of material on the beach on various stretches of Emerald Isle (648,447 cy), Indian Beach/Salter Path (319,113 cy), and Pine Knoll Shores (262,276 cy). In February – March 2013, as a result of Hurricane Irene which impacted the Bogue Banks area in 2011, FEMA approved and provided funding for a portion of the project (including mobilization/demobilization and approximately 270,000 cy of fill) to place a total of 965,011 cy of material on the beach on various stretches of Emerald Isle (649,790 cy) and Pine Knoll Shores (315,221 cy). In addition, the USACE placed material on Atlantic Beach and Fort Macon in 2011 (1,347,300 cy), 2014 (1,107,585 cy), and 2017 (621,000 cy) as part of the USACE Interim Operation Plan for the Morehead City Harbor Dredged Material Management Plan (DMMP) which is located outside the current engineered beach.

Table 2-1 summarizes the historical nourishment projects in the study area by management reach along with the funding source (please note that Local includes towns, county, and State). **Table 2-2** presents the total placement by management reach for all the projects combined. Management reaches within the engineered beach portion of Bogue Banks have been highlighted in yellow.

Table 2-1. Nourishment Volumes by Project & Management Reach

Year	Project	Management Reach	Nourishment Volume (cy)	Funding Source
2002	County Phase 1	Pine Knoll Shores	1,276,586	Local
2002	County Phase 1	Indian Beach/Salter Path	456,994	Local
2002	USACE Disposal	Fort Macon	209,348	USACE
2003	County Phase 2	Emerald Isle - Central	1,016,946	Local
2003	County Phase 2	Emerald Isle - East	850,780	Local
2004	USACE Section 933	Indian Beach/Salter Path	582,735	Local/USACE
2004	USACE Section 933	Pine Knoll Shores	116,547	Local/USACE
2004	FEMA Post Isabel	Emerald Isle - Central	57,408	FEMA
2004	FEMA Post Isabel	Emerald Isle - East	98,592	FEMA
2005	Brandt Island Pump Out	Atlantic Beach	2,390,000	USACE
2005	USACE Disposal	Fort Macon	530,729	USACE
2005	County Phase 3	Bogue Inlet - Ocean	173,919	Local
2005	County Phase 3	Emerald Isle - West	516,949	Local
2007	USACE Section 933	Pine Knoll Shores	507,939	Local/USACE
2007	FEMA Post Ophelia	Emerald Isle - West	304,037	FEMA
2007	FEMA Post Ophelia	Emerald Isle - Central	114,942	FEMA
2007	FEMA Post Ophelia	Emerald Isle - East	229,468	FEMA
2007	FEMA Post Ophelia	Indian Beach/Salter Path	319,113	FEMA
2007	FEMA Post Ophelia	Pine Knoll Shores	262,276	FEMA
2007	USACE Disposal	Fort Macon	184,828	USACE
2008	AIWW Tangent B Disposal	Pine Knoll Shores East	148,393	USACE
2011	USACE Disposal	Atlantic Beach	799,504	USACE
2011	USACE Disposal	Fort Macon	547,196	USACE
2013	FEMA Post Irene	Emerald Isle - West	198,190	Local/FEMA
2013	FEMA Post Irene	Emerald Isle - Central	83,635	Local/FEMA
2013	FEMA Post Irene	Emerald Isle - East	367,965	Local/FEMA
2013	FEMA Post Irene	Pine Knoll Shores	315,221	Local/FEMA
2014	USACE Disposal	Atlantic Beach	522,518	USACE
2014	USACE Disposal	Fort Macon	585,067	USACE
2015	USACE Disposal	Fort Macon	150,000	USACE
2017	USACE Disposal	Atlantic Beach	621,000	USACE
TOTAL			***14,538,825***	

Table 2-2. Nourishment Volumes by Management Reach (cy)

Management Reach (Transects)	Nourishment Volume (cy)
Bogue Inlet - Ocean (1-11)	173,919
Emerald Isle West (12-25)	1,019,176
Emerald Isle Central (26-36)	1,272,931
Emerald Isle East (37-48)	1,546,805
Indian Beach/Salter Path (49-58)	1,358,842
Pine Knoll Shores (59-76)	2,626,962
Atlantic Beach (77-102)	4,333,022
Fort Macon (103-112)	2,207,168
TOTAL	***14,538,825***

Carteret County has completed development of a programmatic Environmental Impact Statement (EIS) which essentially outlines the nourishment needs (quantity, location, and timeframe) and sediment resources for Bogue Banks for the next 50 years. One environmental permit, which has been obtained from review of the EIS, is now available to cover all nourishment actions for the next 50 years, eliminating the time-consuming process of permitting each individual project and allowing for placement of sand as needed. The annual monitoring efforts will decide the exact timing and extents of future nourishment projects by tracking the average profile volume in each management reach as compared to nourishment triggers that define the minimum profile volumes required to provide an equal level of protection along the Bogue Banks shoreline. As part of the development of the programmatic EIS, the Bogue Banks Master Beach Nourishment Plan was developed (M&N 2014). This engineering study revised the volumetric triggers for each management reach (from the original 225 cy/ft), based on the profile volume from the foredune (landward most crest of primary dune) to the outer bar (above -12 ft NAVD88) to provide equal protection along the Bogue Banks oceanfront. Based on the engineering analysis and historical and expected future funding levels, it was determined that Carteret County would be able to maintain protection from a 25-yr storm event. Detailed SBEACH modeling (1-D cross-shore) was used to determine the amount of material above -12 ft NAVD88 that is needed to provide a 25-yr event level of protection in each management reach. This is different for each reach depending on existing dune height, berm width, offshore slope, etc. **Table 2-3** presents the management reaches and newly developed nourishment triggers. Documentation of this effort and the update to the FEMA engineered beach to include all oceanfront areas of Emerald Isle, Indian Beach/Salter Path, and Pine Knoll Shores was submitted to FEMA in June 2015 (M&N 2015a, M&N 2015b, M&N 2015c).

Table 2-3. Master Beach Nourishment Plan Triggers

Reach (Profiles)	Management Reach Length (ft)	Nourishment Trigger (cy)
Bogue Inlet (1-11)*	11,488	235
Emerald Isle West (12-25)*	18,288	266
Emerald Isle Central (26-36)*	15,802	211
Emerald Isle East (37-48)*	13,220	221
Indian Beach/Salter Path (49-58)*	12,850	224
Pine Knoll Shores (59-76)*	23,878	211
Atlantic Beach (77-102)	26,176	254
TOTAL	**121,702**	
AVERAGE		**233**
		weighted

*Highlighted Areas Denote Updated FEMA Engineered Beach Reaches

3.0 Pre- and Post-Storm Survey Data Collection

Geodynamics conducted a survey of Bogue Banks in March 2018 as part of the annual monitoring for the BBBNMP. The profile lines and origins used in previous BBBNMP monitoring studies

were also used for the March 2018 survey. In addition, topographic mobile laser scanning was introduced in March 2018 for a portion of Bogue Banks ranging from Transect 27 to Transect 82 (Emerald Isle through Pine Knoll Shores), covering the seaward face of the dune from approximately +14 ft NAVD88 to the water line at approximately 0 ft NAVD88. Most recently, Geodynamics conducted a post-storm survey September 19 - 26 after the passage of Hurricane Florence. All of the profile lines and origins used in the BBBNMP monitoring program were used for the post-storm survey and the topographic mobile laser scanning was performed. **Figure 3-1** shows the location of the profile lines and origins applied by Geodynamics for the BBBNMP survey in March 2018 and the post-storm survey in September 2018. As shown, lines were stationed from west to east along Bogue Banks. The survey data was provided in ASCII (xyz), Excel (xyz), Shapefile (GIS), and Free Format (BMAP) formats allowing for compatibility with multiple programs. The survey was referenced in NAD 1983 State Plane North Carolina (feet) with a vertical datum of NAVD 1988.

Several steps were taken by Geodynamics to ensure the accuracy of the survey data. The march 2018 and post-storm survey (September 2018) represent a continuation of previous surveys conducted for the Carteret County Shore Protection Office using high-density singlebeam sonar and topographic survey of Bogue Banks. These surveys meet the requirements specified in the NOS (National Ocean Service) Hydrographic Surveys Specifications and Deliverables (April, 2007), the OCS (Office of Coast Survey) Field Procedures Manual for Hydrographic Surveying (June 2008) and the criteria for Navigation and Dredging Support Hydrographic Surveys as outlined in the U.S. Army Corps of Engineers Hydrographic Surveying Manual, EM 1110-2-1003 (EM 1110-2-1003 January 2002). Detailed survey equipment, methods, and post-processing, and quality control procedures are provided in the standalone post-storm survey report by Geodynamics presented in **Appendix A**.

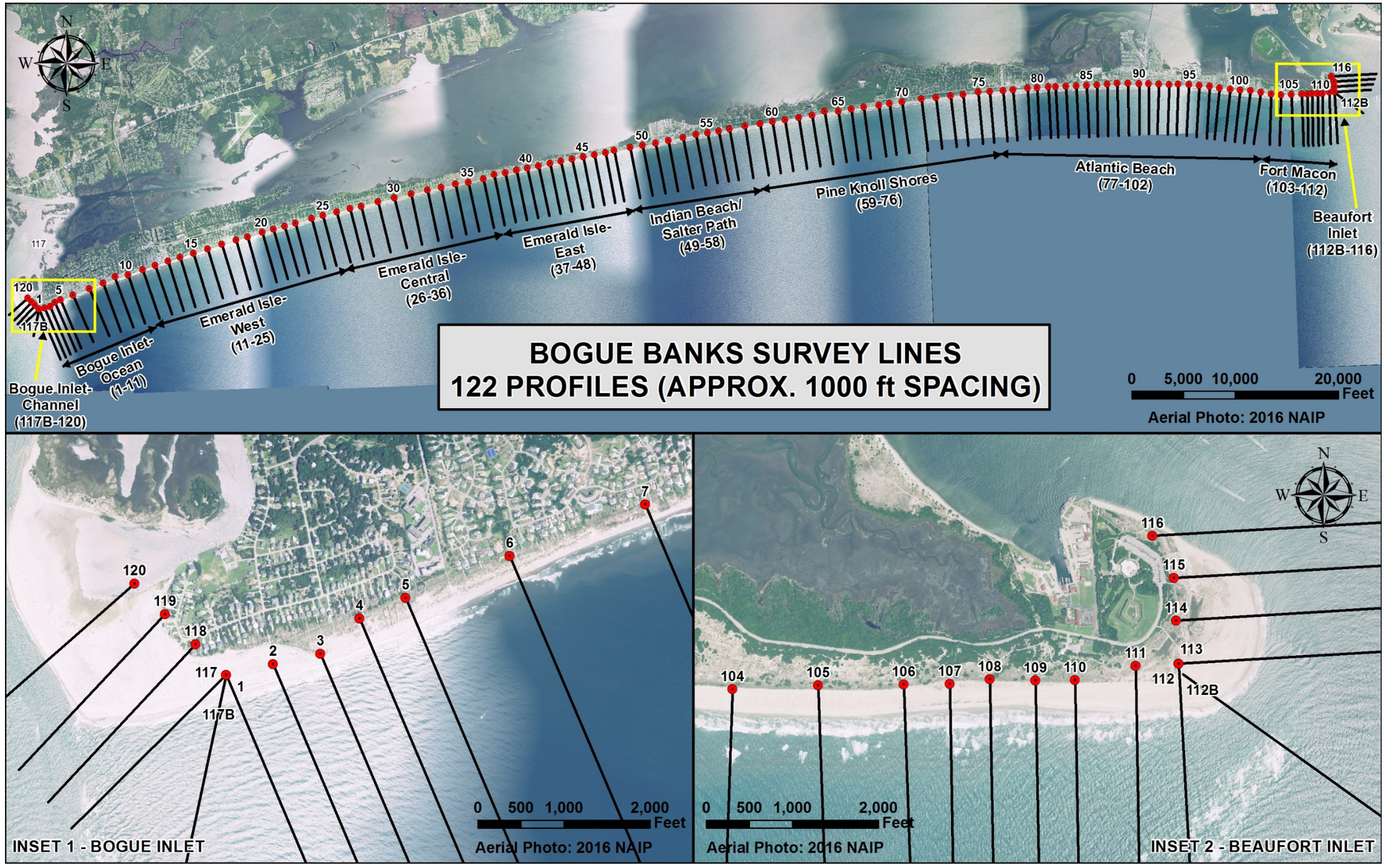


Figure 3-1. BBBNMP and Post-Storm Profile Line Locations – Bogue Banks

4.0 Survey Evaluation Methods

4.1. Shoreline and Volume Change

Survey comparisons and respective analysis were performed using Beach Morphology Analysis Package (BMAP). BMAP is a program developed by the USACE to analyze morphologic and dynamic properties of beach profiles.

All survey data sources were imported into ArcGIS, in xyz format, and displayed to compare the coverage of each set of data. Free Format files containing the March 2018 and post-storm (September 2018) beach profiles being used for the comparison were then imported into Beach Morphology Analysis Package (BMAP). Using BMAP, two indicators of beach profile change were calculated for each transect.

First, shoreline change designated at the mean high water (MHW) contour, defined as +1.5 ft NAVD88, was calculated at each transect between the March 2018 and September 2018 profiles. The resulting value represents the shoreline change (ft) over the time period between surveys.

Then, representative volume changes were calculated at each transect between March 2018 and September 2018. Volume changes were calculated for five different extents across the profile, in order to better understand the processes occurring onshore and offshore of the Bogue Banks beach area. Calculations included volume change above MHW (+1.5 ft NAVD88), above -5 ft NAVD88 (wading depth/recreational beach), above -12 ft NAVD88 (outer bar), above -20 ft NAVD88 (approximate closure), and above -30 ft NAVD88. For those profiles which did not extend to -30 ft NAVD88, volume calculations were performed above -30 ft out to the extent of the shortest survey. As with the shoreline change, the results represent volume change (cy/ft) over the period of time between surveys. In addition, the volume changes were converted to cumulative changes (cy) over the entire shoreline. This was done by applying the average end area method to the unit volume changes (cy/ft) computed at each transect and summing the total volume changes over the entire shoreline. The resulting value indicated the total loss or gain of material between survey periods based on the applicable profile extents.

Volume changes calculated for portions of the profiles above MHW are representative of changes in the amount of material in the dune system and on the subaerial beach. These areas are highly influenced by the impact of storm activity. Volume comparisons for portions of the profiles above -5 ft NAVD88 (approximate wading depth) are representative of changes in the portion of the beach used for recreation. Volume comparisons above -12 ft NAVD88 help to track sand movement to and from the outer sand bar and are ultimately used in decision making for future beach nourishment projects. Volume comparisons above -20 ft NAVD88 allow for the tracking of sand movement offshore to the approximate depth of closure while reducing the amount of uncertainty associated with the survey data by eliminating changes beyond this depth related to the vertical margin of uncertainty in the hydrographic survey data. Finally, volume comparisons above -30 ft NAVD88 allow the complete tracking of sand movement offshore. However, hydrographic survey measurement accuracy may impact these calculations. This is a comprehensive way to assess the impact of storm activity on the subaerial beach and dune system

as well as track the movement of sand offshore and quantify total gains and losses in the entire system. **Figure 4-1** presents a graphic showing the various calculation lenses.

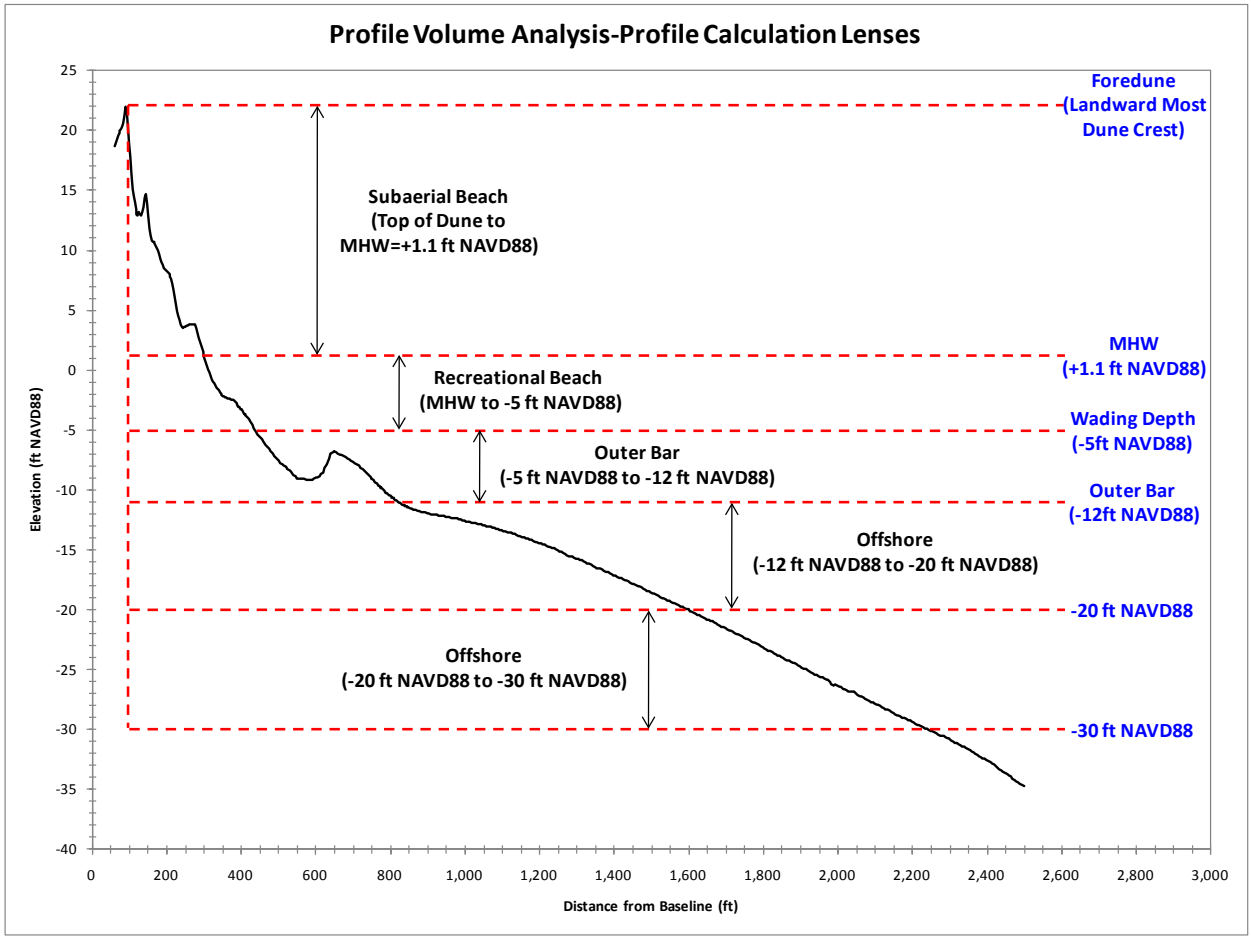


Figure 4-1. Profile Calculation Lenses

Upon inspection of recent survey data, it appears the depth of closure is approximately -20 ft NAVD88. **Figure 4-2** through **Figure 4-5** show example historical annual profiles from 2008 – 2018 for various locations along the engineered beach portion of Bogue Banks in Emerald Isle, Indian Beach/Salter Path, and Pine Knoll Shores. As can be seen, the profiles typically merge together seaward of the offshore bar between -16 ft NAVD88 and -20 ft NAVD88. Therefore, for volume change calculation purposes, the depth of closure is assumed to be -20 ft NAVD88.

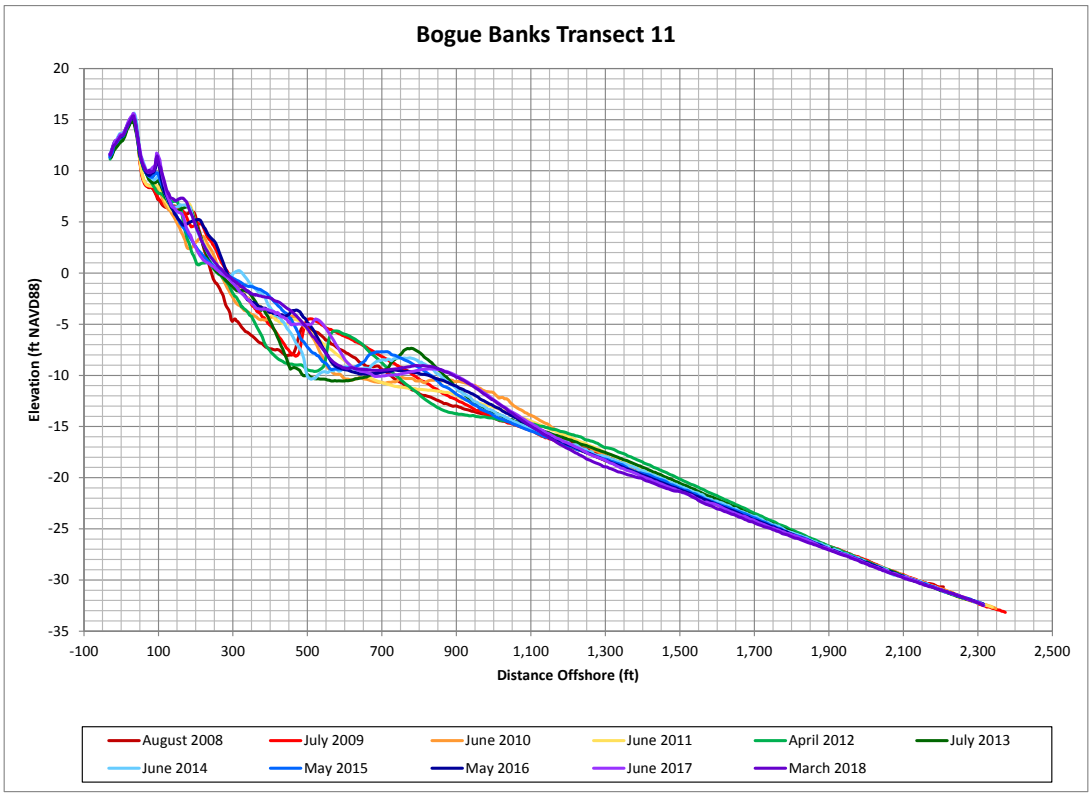


Figure 4-2. Example Historical Profiles (Bogue Inlet – Ocean)

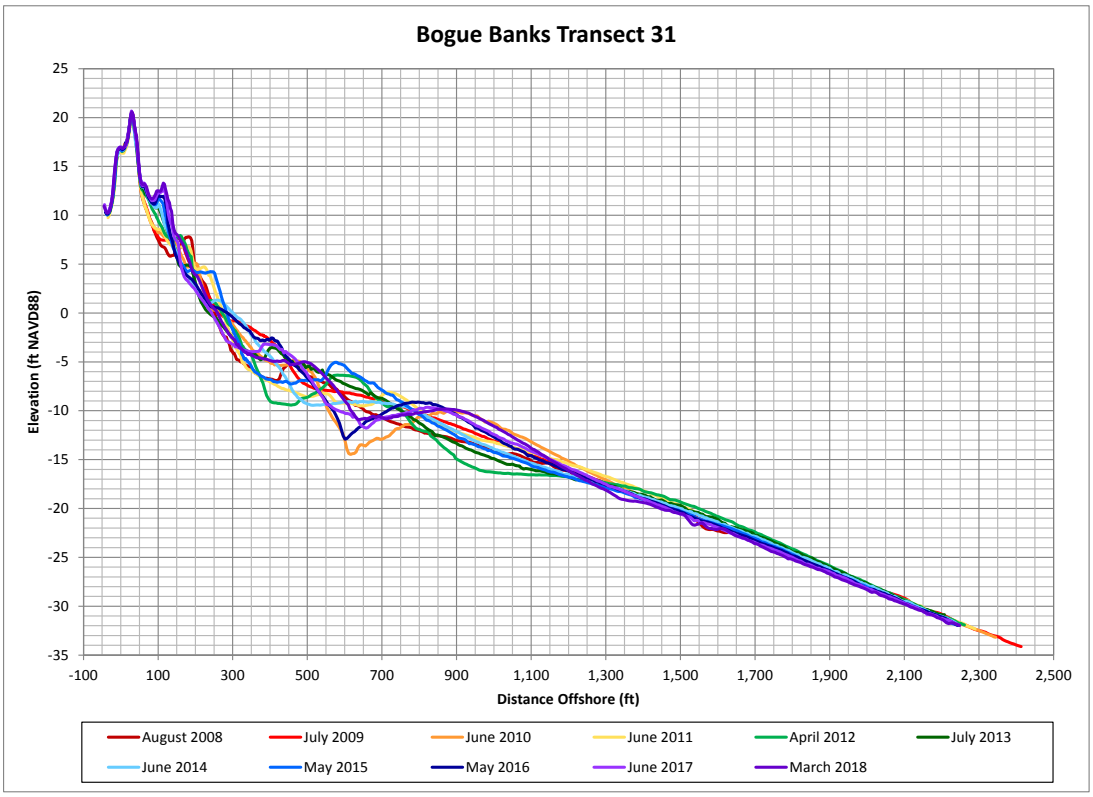


Figure 4-3. Example Historical Profiles (Emerald Isle – Central)

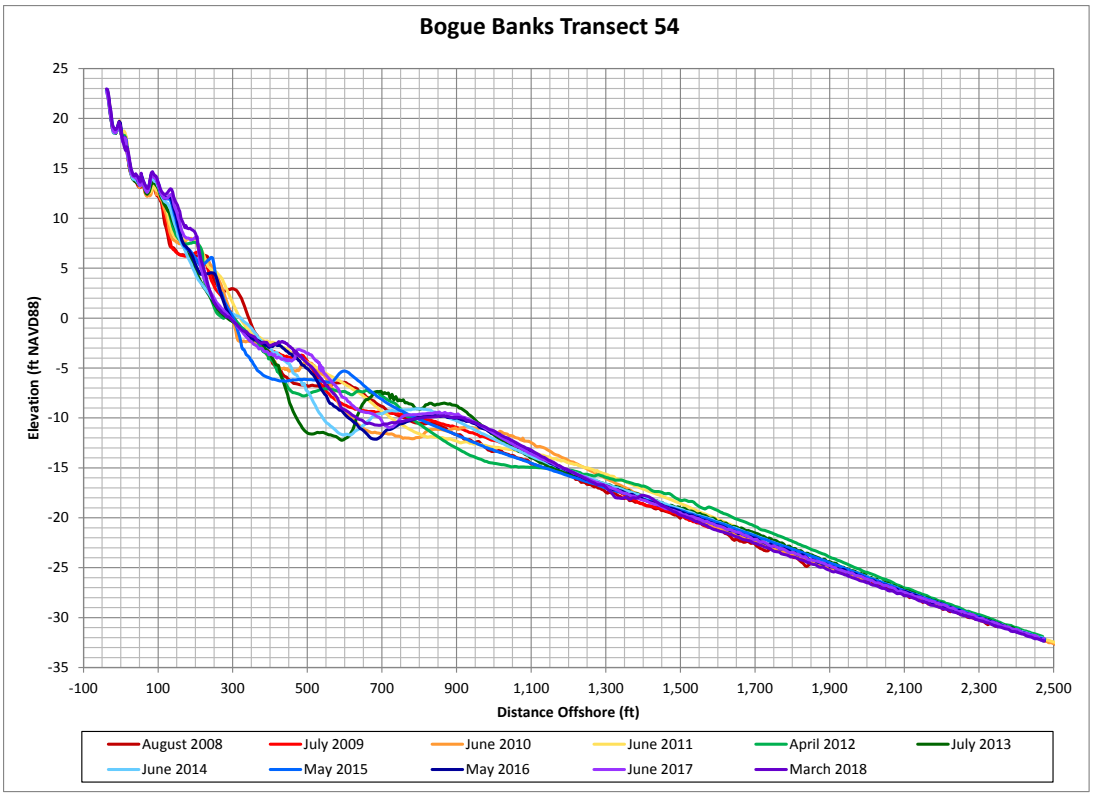


Figure 4-4. Example Historical Profiles (Indian Beach/Salter Path)

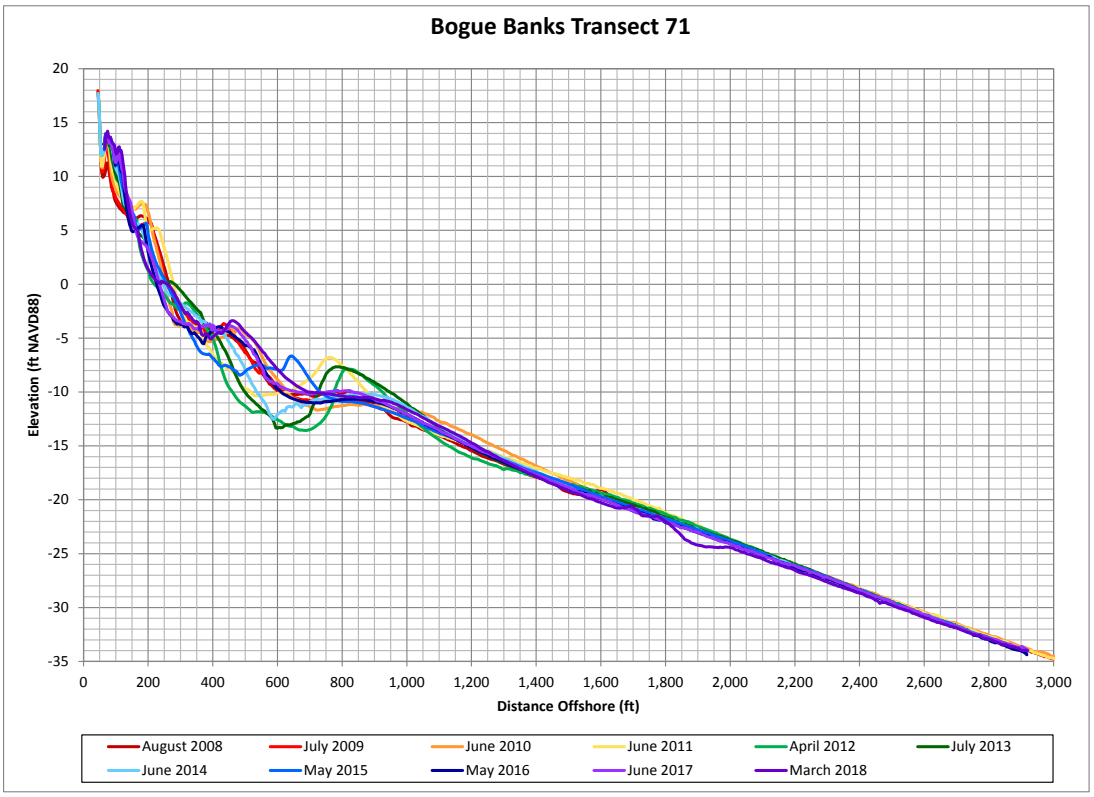


Figure 4-5. Example Historical Profiles (Pine Knoll Shores)

4.2. Mobile Laser Scanner Evaluation

Furthermore, an evaluation of the mobile laser scanning data was performed to assess for morphological features and storm induced changes not captured by the survey transects. High quality surfaces created from the March 2018 and September 2018 laser scanner data were "subtracted" to create a surface showing the elevation change between the two surveys.

4.3. Base of Dune Position Change

Additionally, an assessment of the change in position of the base of the dune along Bogue Banks from March 2018 to September 2018 was performed. The March 2018 and September 2018 dune base position was obtained from detailed surfaces created using a combination of profile data and mobile laser scanner data. The difference in position was calculated in GIS at each transect and plotted to determine any trends in seaward growth or landward erosion of the dune along the oceanfront shoreline.

4.4. Nourishment Trigger Assessment

Finally, in accordance with the Master Beach Nourishment Plan, a preliminary assessment of current conditions of the beach compared to the new nourishment triggers was completed as part of this report. The average profile volume above -12 ft NAVD88 was calculated for each management reach and plotted with respect to the nourishment triggers defined in the Master Beach Nourishment Plan to indicate which reaches have profile volumes close to their triggers and would be in need of nourishment in the near future.

5.0 Discussion of Hurricane Florence

Hurricane Florence made landfall on September 14, 2018 just south of Wrightsville Beach, NC where it slowed considerably for several days before moving away from the coast and into South Carolina. Hurricane Florence approached the North Carolina coast on a northwesterly track, turned slightly south as it made landfall, and then continued west into South Carolina as illustrated in **Figure 5-1.** The symbols in the figures indicate the National Hurricane Center's (NHC) published best track position for the hurricane, with time given in GMT. As seen in **Figure 5-1**, the hurricane track showed the center of the storm stayed well south of Carteret County, however, the most damaging quadrant of the storm was located to the northeast, corresponding to significant effects in Carteret County.

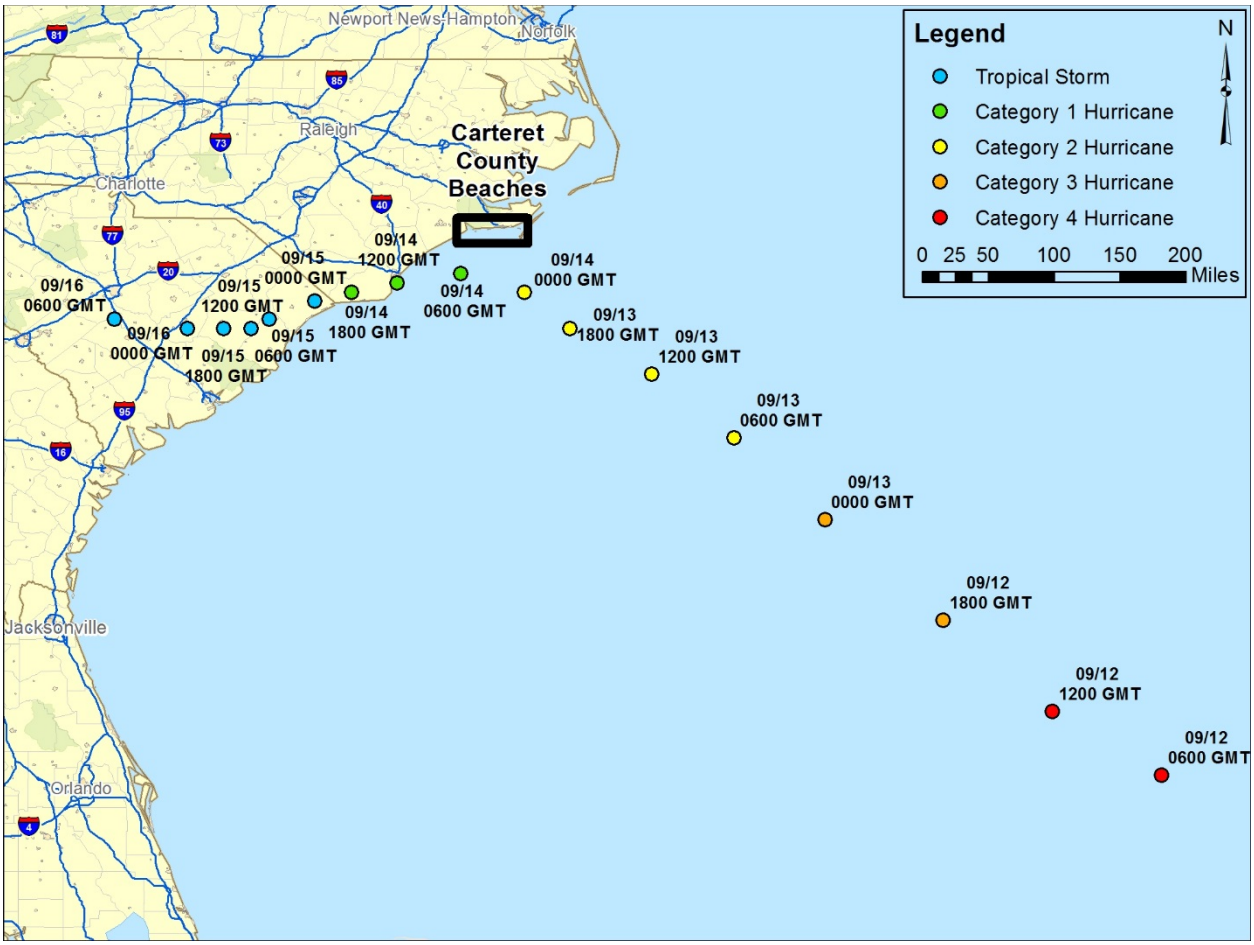


Figure 5-1. Hurricane Florence Track

Hurricane Florence was Category 4 hurricane at its strongest point as it approached the southern tip of the United States. The storm made landfall on the North Carolina coast as Category 1 hurricane. National Data Buoy Center buoy 41159 – Onslow Bay Outer measured wave conditions continuously through the approach and passage of Hurricane Florence while the Beaufort Tide Gage 8656483 measure water levels. **Figure 5-2** presents the locations of each of these data gages with respect to Bogue Banks.

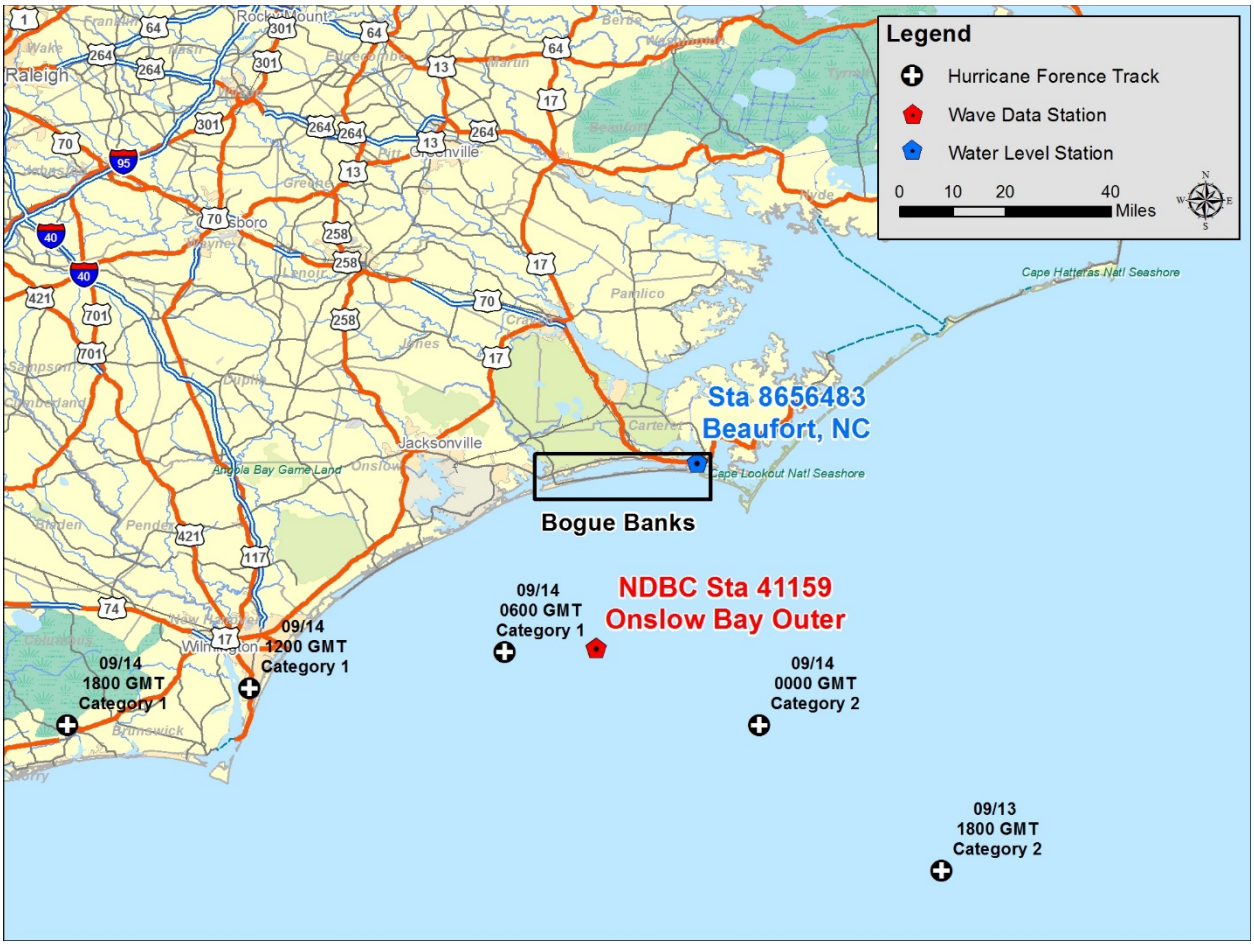


Figure 5-2. Wave Condition and Water Level Buoy Locations

The hurricane winds produced very large waves offshore, as indicated in **Figure 5-3** which charts the significant wave height (ft), wave period (sec), mean wave direction (deg), and water levels (ft NAVD88) during the storm. Offshore significant wave heights at buoy 41159 peaked at approximately H_s = 28 ft on September 13, 2018. However, elevated wave conditions (greater than 6 ft) existed from September 12 through September 17. The mean wave direction indicates waves primarily coming from the southeast for the duration of the storm, however, the angle of approach changed after the storm made landfall on September 14. Water levels measured at Beaufort indicate that Hurricane Florence caused a surge of approximately 3 ft above predicted tidal levels during two separate occasions on September 14, 2018. The peak water level of 5.148 ft NAVD88 constitutes a record high at the Beaufort tide gage and the next high tide measurement tied the previous record. Surge magnitudes on the oceanfront beaches of Bogue Banks are likely to have been slightly higher than indicated by the more sheltered Beaufort tide gage and wave setup effects would have been significant on the beaches. Lastly, it is also important to note that the wave periods experienced during Florence were higher than normal at the onset of the storm but decreased after the hurricane made landfall on September 14.

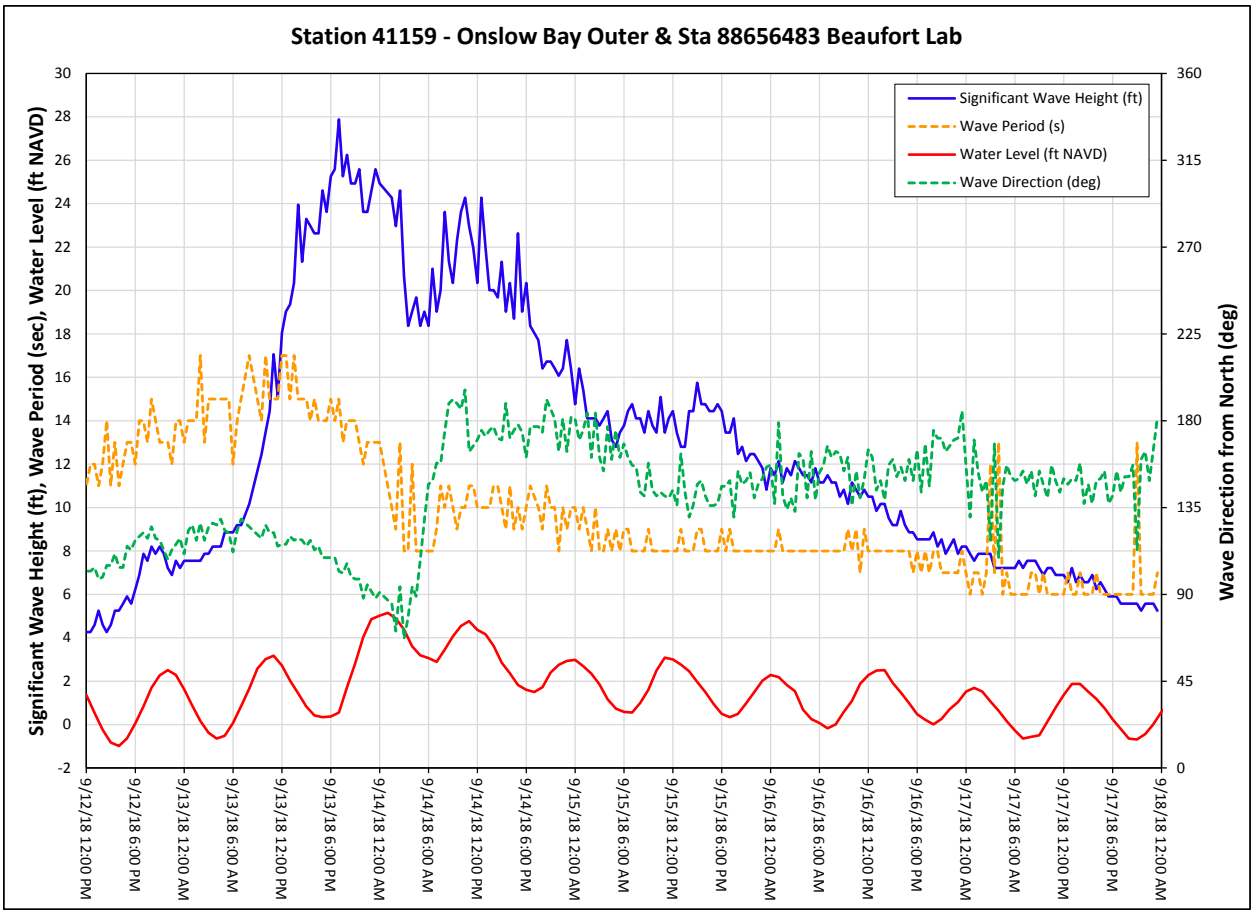


Figure 5-3. Measured Wave and Water Level Conditions During Hurricane Florence

Based on an analysis completed for the Bogue Banks Master Beach Nourishment Plan (M&N 2014), a 5-year storm event along Bogue Banks contains an offshore peak wave height of approximately 26.2 ft and a 10-year storm event contains an offshore peak wave height of approximately 31.2 ft. Therefore, in terms of wave height, Florence was somewhere between a 5 and 10-year event. It is estimated that a 5-year storm event contains a water level of approximately 4.8 ft NAVD88 and a 10-year storm event contains a water level of approximately 5.4 ft NAVD88. While the peak water level at Beaufort during Hurricane Florence was 5.15 ft NAVD88, falling in between the 5-year and 10-year event, the Beaufort tide gage is sheltered within the inlet and it is probable that water levels on the oceanfront were slightly higher. Analysis completed for the Bogue Banks Master Beach Nourishment Plan indicated that water levels at Atlantic Beach were, on average, 1.2 times the peak at Beaufort. Therefore, it is likely that water levels along the oceanfront reached almost 6.2 ft, making Florence somewhere between a 25-year event (water level = 5.6 ft) and a 50-year event (water level = 8.0 ft) in terms of water level.

While the magnitude of the storm was certainly large, the duration of the storm likely constituted a significant amount of the damage. The previous storm during which Bogue Banks experienced significant erosion was Hurricane Irene in 2011. **Figure 5-4** shows a comparison of wave and water level conditions between Hurricane Florence and Hurricane Irene. As can be seen, the duration of elevated significant wave heights (greater than 6 ft) for Hurricane Irene was around 55 hours whereas Hurricane Florence produced elevated significant wave heights for approximately

120 hours. In addition, water levels during Hurricane Florence peaked at a higher elevation for multiple tidal cycles.

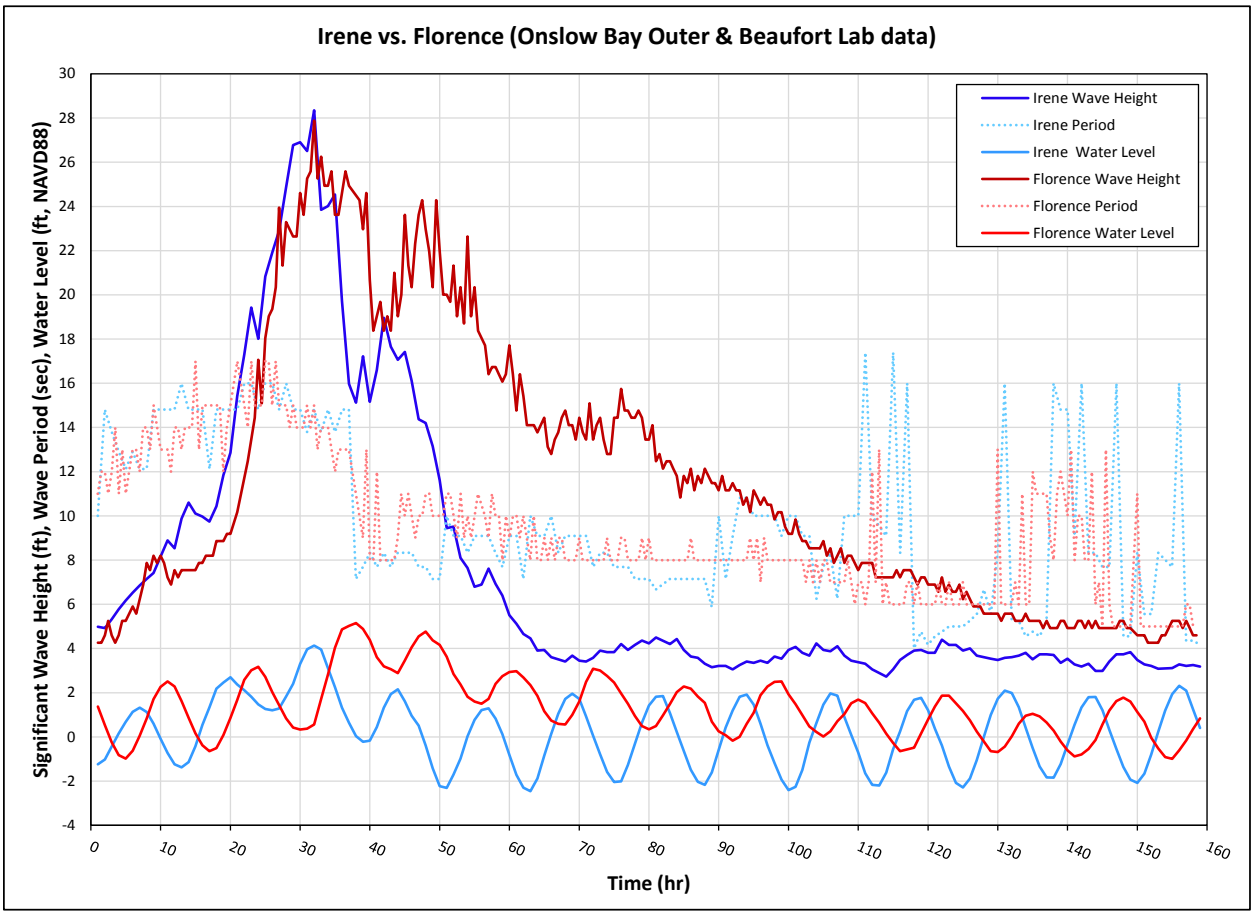


Figure 5-4. Comparison of Hurricane Irene and Hurricane Florence Wave and Water Level Conditions

6.0 Discussion of Post-Storm Survey Evaluation

6.1. Post-Storm Field Inspection

As Hurricane Florence approached, a pre-storm field inspection was conducted by the Carteret County Shore Protection Office (CCSPO) on September 10, 2018. After Hurricane Florence passed, a post-storm field inspection was completed by the CCSPO on September 16, 2018. Furthermore, Moffatt & Nichol staff conducted an additional post-storm field inspection on September 19 – 20, 2018. The field inspections consisted of photo and visual observations taken at key locations along Bogue Banks, a post-storm video of the oceanfront shoreline, and GPS survey points located the base of the dune escarpment used to track dune erosion. Links to the pre-Florence photos taken by the CCSPO can be found at http://www.carteretcountync.gov/gallery.aspx?AID=59 and links to the post-Florence photos taken by the CCSPO can be found at http://www.carteretcountync.gov/gallery.aspx?AID=60. Links to the pre- and post-storm photo comparisons completed by the CCSPO can be found at http://www.carteretcountync.gov/DocumentCenter/View/5213/Before-After-Florence-2018. A small briefing prepared by the CCSPO which describes some of the visual observations and

provides a pre- and post-storm comparison of photos at a few key locations along Bogue Banks along with a summary of post-storm photos and observations completed by the Moffatt & Nichol field investigation team can be found in **Appendix B**.

During the field investigation, it was evident that the berm and incipient dune had experienced significant erosion while the primary dune was also impacted, causing large escarpments along the seaward face of the dune. **Figure 6-2** and **Figure 6-3** present examples of the pre- and post-storm field comparison by the CCSPO, showing berm and incipient dune losses along with escarpment of the primary dune.

Figure 6-1. Example of Berm and Incipient Dune Loss – Ocean Reef, Emerald Isle (CCSPO)

Figure 6-2. Example of Berm and Incipient Dune Loss - Memorial Park, Pine Knoll Shores (CCSPO)

Primary dune escarpment varied in magnitude along Bogue banks anywhere from 2 – 3 ft up to 15 ft. It was prevalent in almost every location west of Transect 90, located in Atlantic Beach. Locations to the east of Transect 90 have historically been nourished by the USACE, most recently in 2017. These locations suffered a significant loss of the recently constructed berm but did not see escarpment of the dune like the remainder of the island. **Figure 6-3** presents the escarpment noted at various locations along Bogue Banks during the Moffatt & Nichol field inspection.

Figure 6-3. Example of Primary Dune Escarpment Along Bogue Banks (Moffatt & Nichol)

6.2. Beach Changes Attributed to Hurricane Florence

Shoreline and beach profile volume change trends are discussed in the following sections for the defined management reaches of Bogue Banks (**Figure 3-1**). For reference, the MHW shoreline position for March 2018 and Post-Florence (September 2018) was plotted on aerials and is presented in **Appendix C** along with the March 2018 and post-Florence mobile laser scanner DEM surfaces and March 2018 vs. September 2018 surface comparison. Profile comparison plots for individual transects which include the March 2018 and Post-Florence (September 2018) profiles are presented in **Appendix D**. The computed shoreline changes and volume changes at each individual transect for the time periods being covered are tabulated in **Appendix E**.

6.2.1. Bogue Inlet

The Bogue Inlet region is comprised of an oceanfront area located in Emerald Isle along the western terminus of Bogue Banks which covers Transects 1 through 11 (Bogue Inlet – Ocean) and an area along the eastern side of Bogue Inlet covering Transects 117 through 120 (Bogue Inlet – Channel) (see **Figure 3-1**). This area along the eastern side of Bogue Inlet is not within the bounds of the current engineered beach while the oceanfront area is. A summary of average shoreline and volume changes between March 2018 and September 2018 for the Bogue Inlet region are presented in **Table 6-1**.

Table 6-1. Average Shoreline and Volume Change for Bogue Inlet

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Inlet-Ocean (Transects 1-11)	11,488	-47.6	-24.3	-278,605	-28.7	-330,138	-36.1	-414,817	-9.2	-105,694	21.0	241,260
Bogue Inlet-Channel (Transects 117-120)*	2,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

*Note: Due to the dynamic nature of Bogue Inlet, shoreline and volume calculations were not performed

The Bogue Inlet – Ocean region experienced an overall average shoreline recession of -47.6 ft, with profiles nearest Bogue Inlet experiencing the largest losses (see shoreline change plot in **Appendix C**). Volume losses were experienced above MHW, -5 ft NAVD88, -12 ft NNAVD88, and -20 ft NAVD88. Overall, the Bogue Inlet - Ocean reach lost approximately -414,817 cy (-36.1 cy/ft) of material above -12 ft NAVD88 due to Hurricane Florence. Smaller losses above -20 ft NAVD88 (-105,694 cy) and gains above -30 ft NAVD88 (+241,260 cy) indicate the transport and capture of eroded material offshore, much of beyond the depth of closure. Profile plots in **Appendix D** show significant losses to the incipient dune and in some cases the primary dune as well as erosion of the berm and the beacface down to approximately -4 ft NAVD88. Beyond this, there is a small recovery of material down to approximately -10 ft NAVD88 followed by formation of a large trough where the offshore bar was previously located and then capture of material well offshore, seaward of the typical offshore bar location with much of it located beyond depth of closure. **Figure 6-4** shows a representative profile for the Bogue Inlet - Ocean region displaying the typical trends.

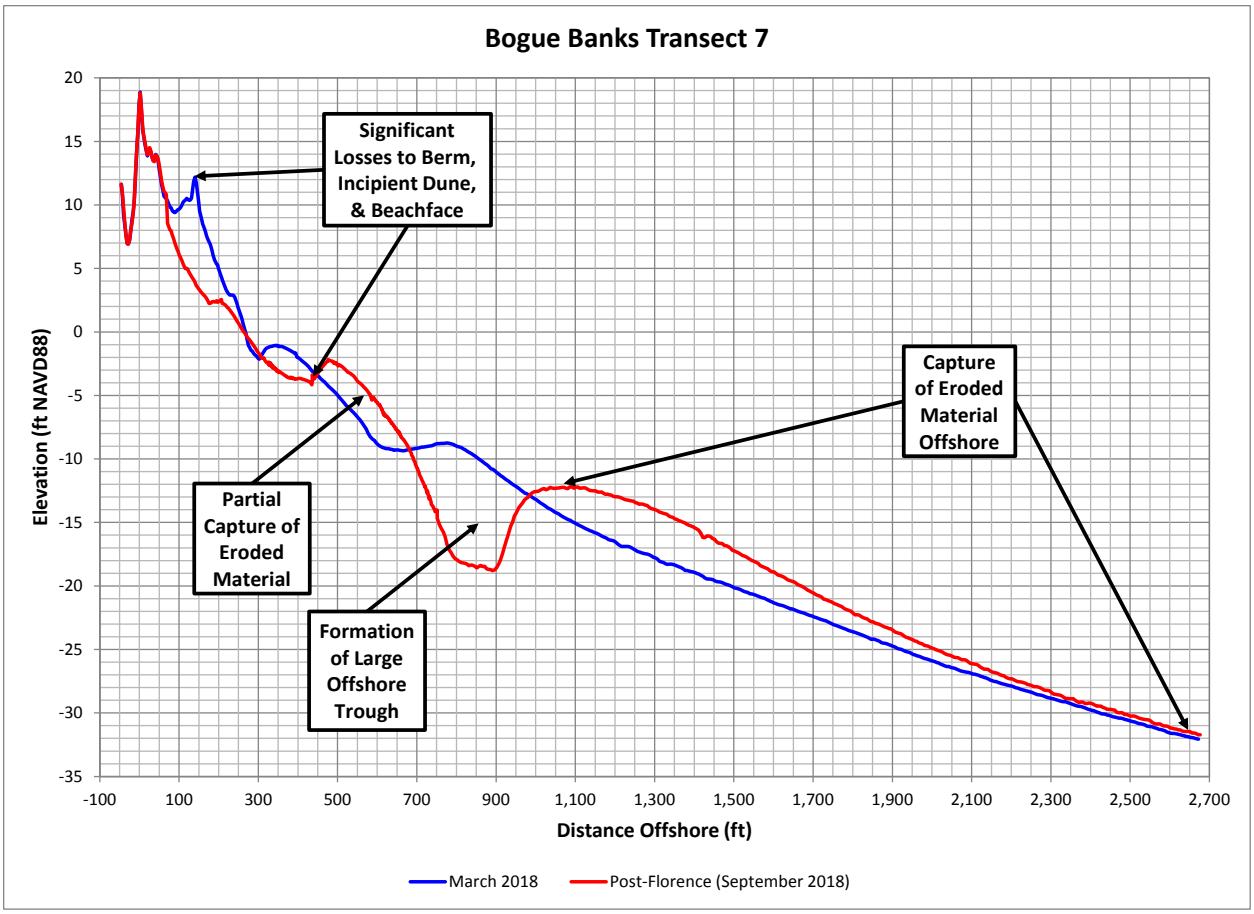


Figure 6-4. Bogue Inlet – Ocean Representative Profile

Figure 6-5 displays the unit volume change at each transect for the Bogue Inlet - Ocean region. As can be seen, losses above MHW, -5 ft NAVD88, and -12 ft NAVD88 are prevalent throughout the reach. Transects nearest Bogue Inlet experienced gains above -20 ft NAVD88 and -30 ft NAVD88, however, these gains diminish as distance from the inlet increases.

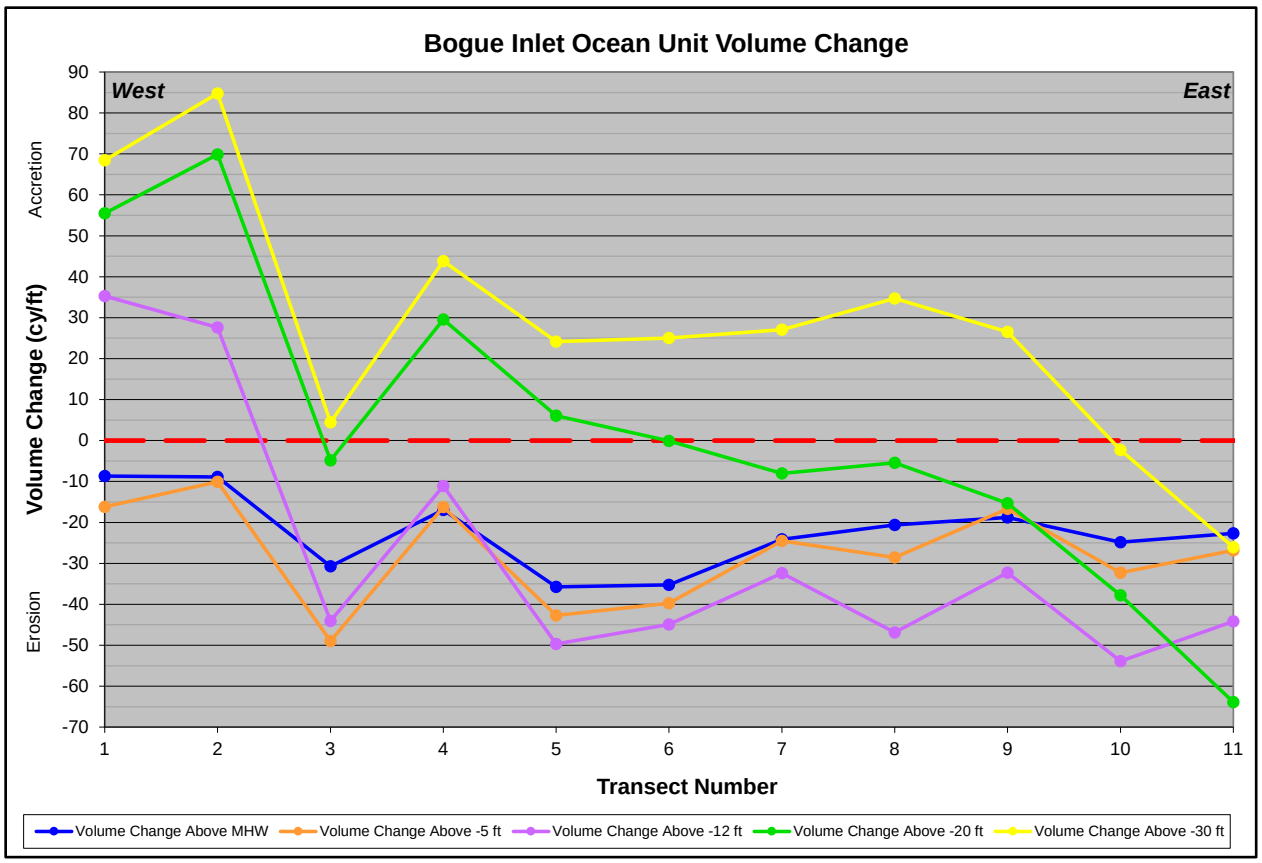
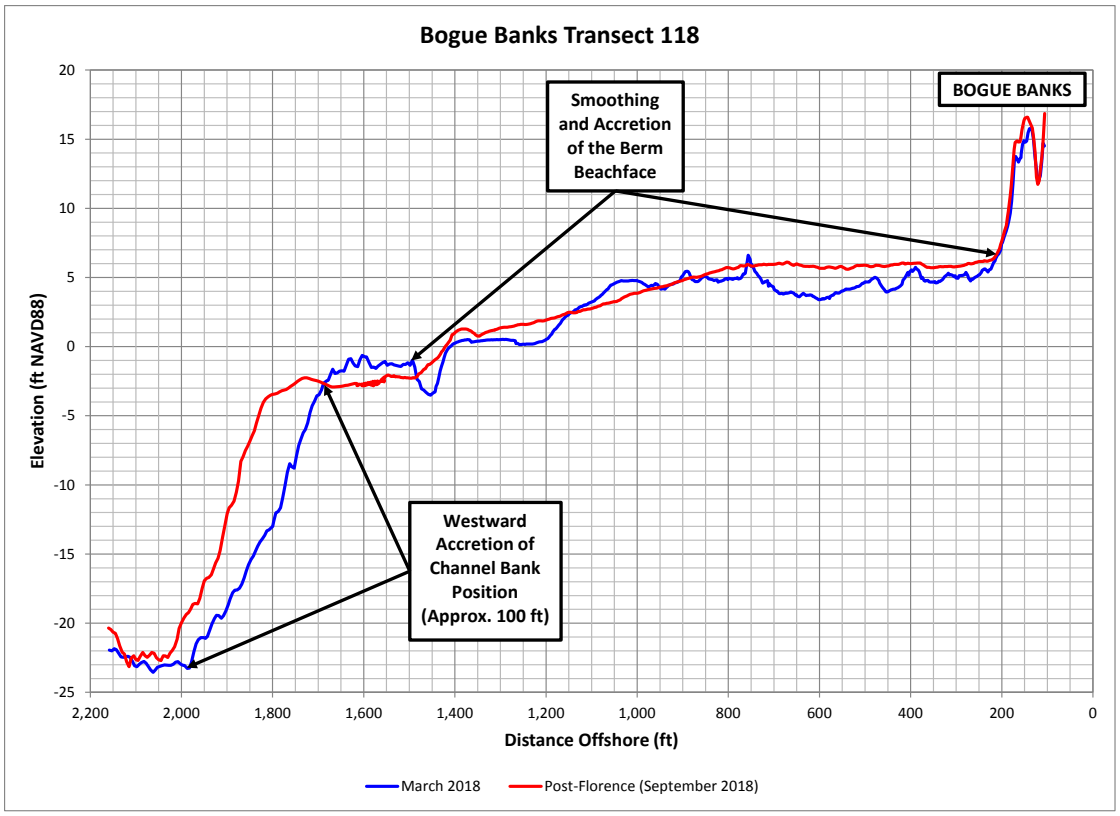


Figure 6-5. Bogue Inlet Ocean Unit Volume Change (March 2018 – September 2018)

The Bogue Inlet - Channel region is highly dynamic due to the inlet. The location of dry land changes so frequently that profiles along Bogue Inlet often do not line up properly from year to year. Therefore, analytical calculations were not performed at Transect 117 through 120. However, upon investigation of the profile plots in **Appendix D**, it appears that there was some significant westward accretion of the channel bank around the throat of the inlet (i.e. Transect 118) whereas the interior of the inlet experienced much less change in the channel position (i.e. Transect 120). **Figure 6-6** shows example profiles (Transect 118 and Transect 120) from Bogue Inlet which display the varied trends between the throat and interior of Bogue Inlet. In both locations, it does appear that the bottom of the channel shoaled slightly.



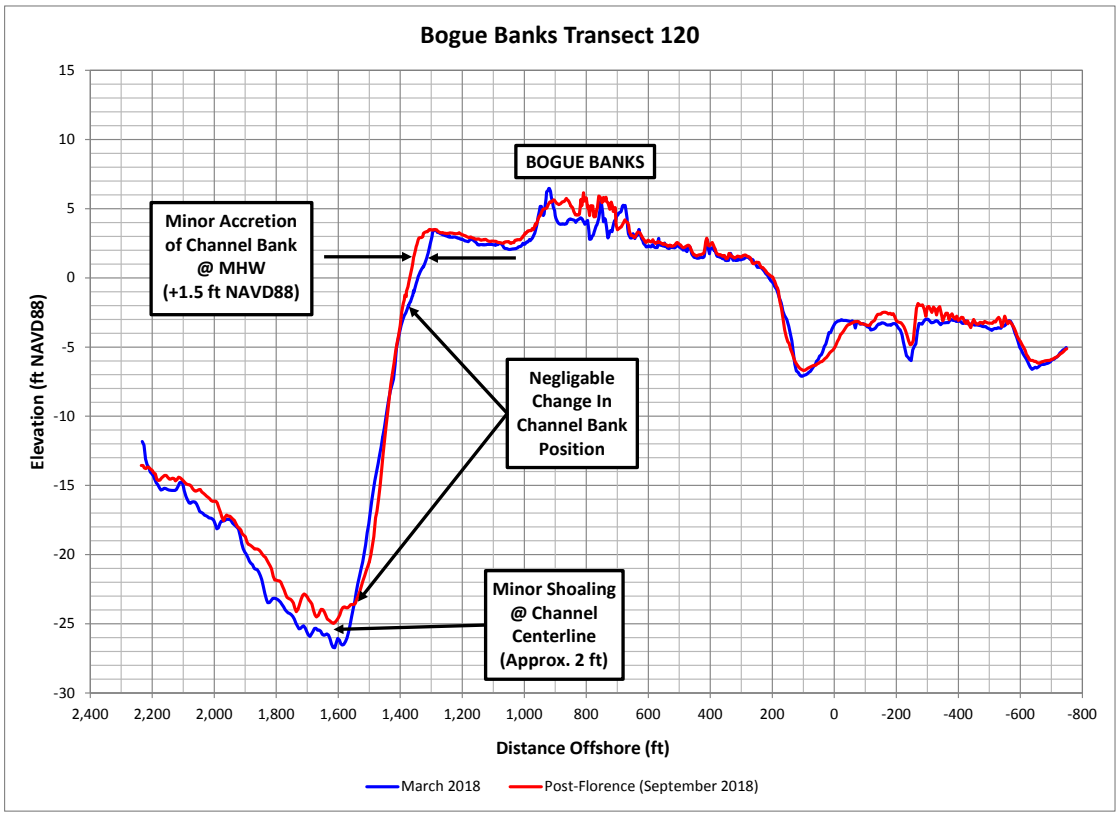


Figure 6-6. Example Bogue Inlet Transects

6.2.2. Emerald Isle

The Emerald Isle region covers Transects 12 through 48 of the Bogue Banks shoreline and is divided into three management reaches (see **Figure 3-1**): 1) Emerald Isle – West (Transects 12-25), 2) Emerald Isle – Central (Transects 26-36), and 3) Emerald Isle – East (Transects 37-48). Since monitoring began in 1999, this area has received a total of 3.84 million cy of nourishment material as a result of past local projects and FEMA post-storm work (Isabel, Ophelia, and Irene). A summary of average shoreline and volume changes between March 2018 and September 2018 for the Emerald Isle region are presented in **Table 6-2**.

Table 6-2. Average Shoreline and Volume Change for Emerald Isle

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Emerald Isle-West (Transects 12-25)	18,288	-25.7	-20.2	-368,746	-28.6	-523,728	-40.3	-736,750	-36.1	-660,896	11.7	213,575
Emerald Isle-Central (Transects 26-36)	15,802	-34.6	-20.8	-329,442	-23.6	-372,360	-35.2	-556,272	-41.4	-654,711	1.0	15,325
Emerald Isle-East (Transects 37-48)	13,220	-27.8	-19.2	-254,290	-22.3	-295,149	-35.8	-472,897	-43.8	-579,021	-7.2	-95,539
Emerald Ise - Total (Transects 12-48)	47,310	-29.3	-20.1	-952,478	-25.2	-1,191,236	-37.3	-1,765,919	-40.0	-1,894,628	2.8	133,361

The Emerald Isle region experienced an overall average shoreline recession of -29.3 ft. While the magnitude of shoreline recession varied throughout the reach, it was evident at almost every transect (see shoreline change plot in **Appendix C**). Overall, Emerald Isle experienced volume losses above MHW, -5 ft NAVD88, -12 ft NAVD88, and -20 ft NAVD88. Losses above -12 ft NAVD88 totaled -1,765,919 cy (-37.3 cy/ft) and were fairly consistent throughout the management reaches at 35 – 40 cy/ft. Volume gains experienced above -30 ft NAVD88 in Emerald Isle – West and Emerald Isle – Central and only minor volume losses in Emerald Isle – East indicate that eroded material was captured offshore, however, it was well below the depth of closure. As with Bogue Inlet - Ocean, profile plots in **Appendix D** show significant losses to the incipient dune and escarpment of the primary dune as well as erosion of the berm and the beach face down to approximately -4 ft NAVD88. Beyond this, there is a small recovery of material down to approximately -10 ft NAVD88 followed by formation of a large trough where the offshore bar was previously located and then capture of material well offshore, seaward of the typical offshore bar location with much of it located beyond depth of closure. **Figure 6-7** shows a representative profile for the Emerald Isle region, indicating significant losses to the upper portion of the beach, formation of the large trough, and capture of material well offshore.

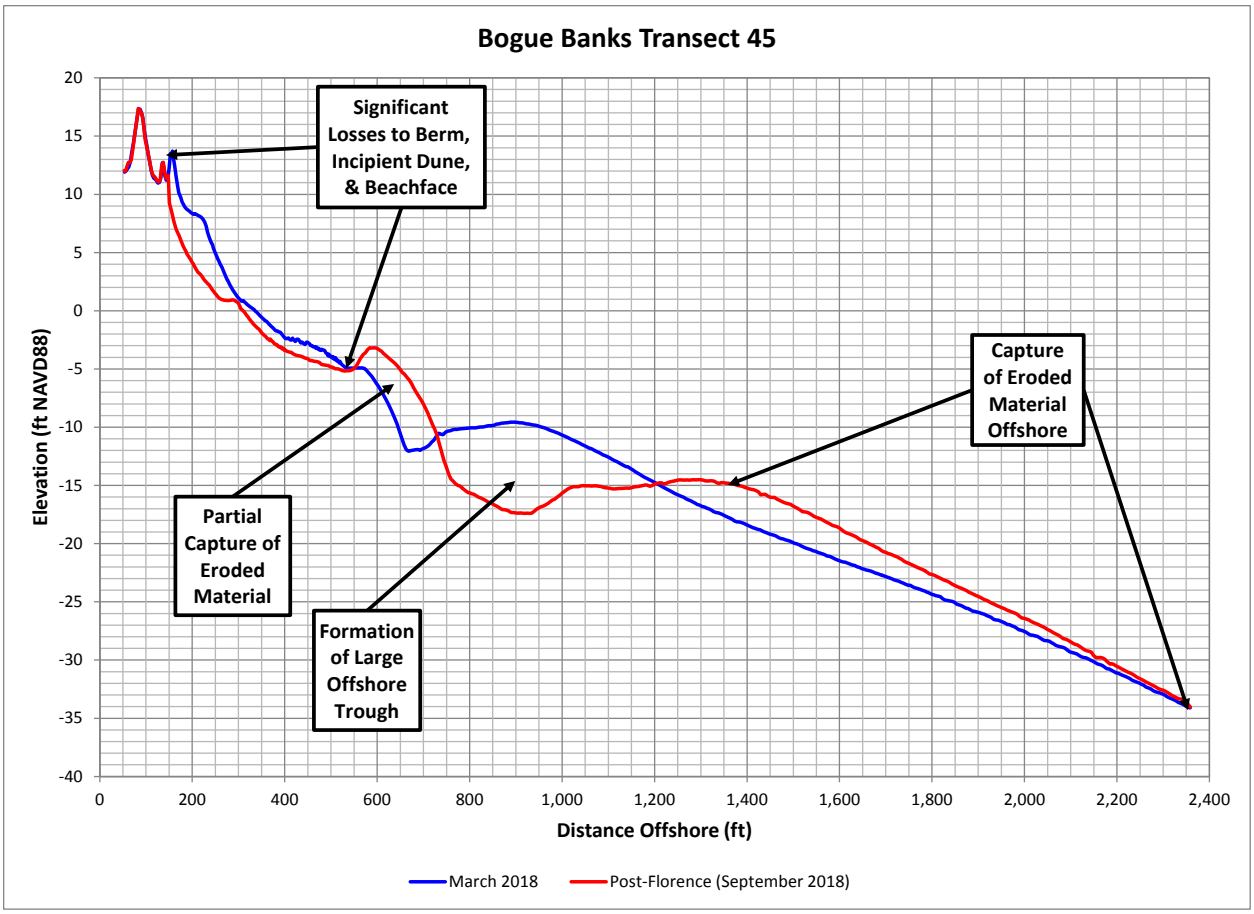


Figure 6-7. Emerald Isle Representative Profile

Figure 6-8 displays the unit volume change at each transect above the five elevations that were analyzed. As can be seen, losses above MHW, -5 ft NAVD88, -12 ft NAVD88, and -20 ft NAVD88 can be seen throughout the entire reach with the only gains being experienced well offshore above -30 ft NAVD88. Offshore gains were more prevalent in the western portion of Emerald Isle than the eastern portion.

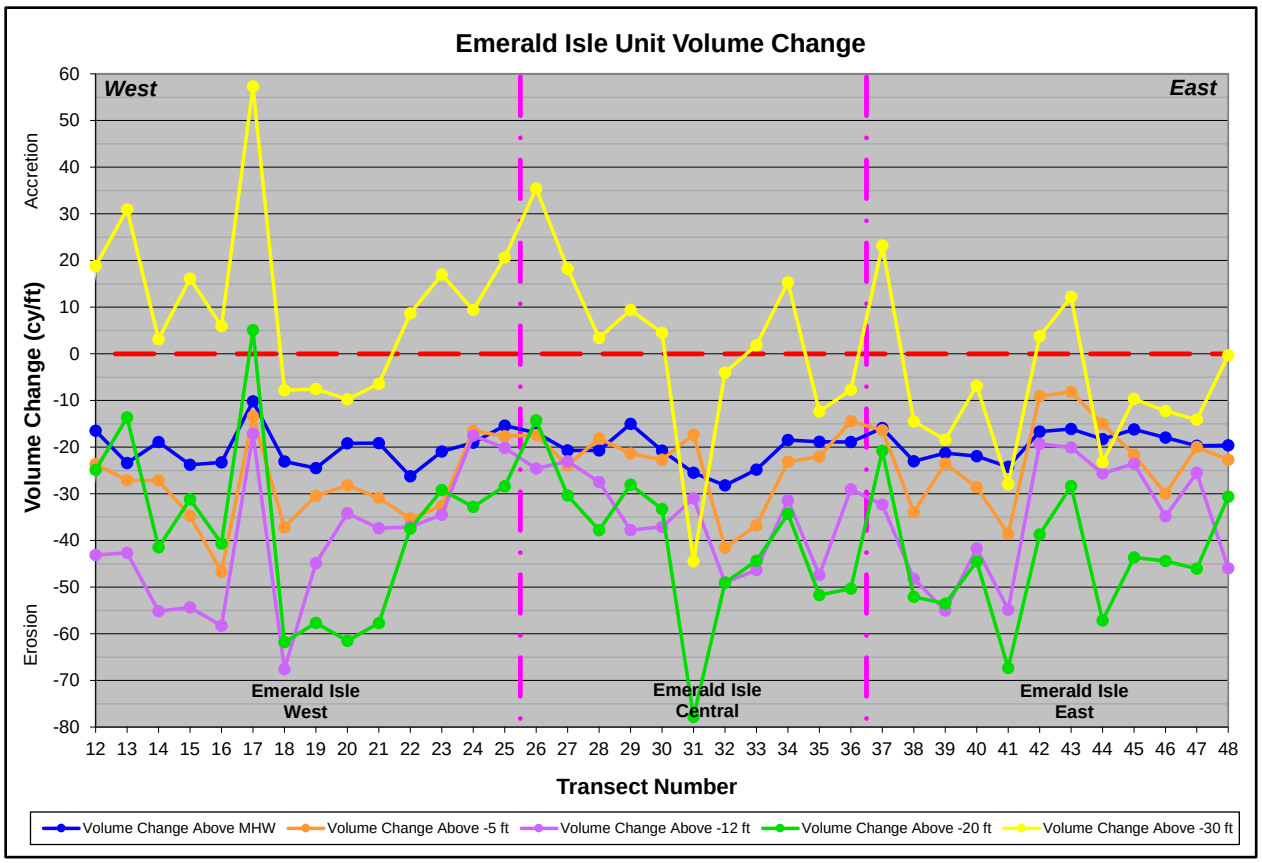


Figure 6-8. Emerald Isle Unit Volume Change (March 2018 – September 2018)

6.2.3. Indian Beach/Salter Path

The Indian Beach/Salter Path region covers Transects 49 through 58 of the Bogue Banks shoreline and is defined as a single management reach (see **Figure 3-1**). Since monitoring efforts began in 1999, this area has received 1.36 million cy of nourishment material from past local projects, USACE Section 933, and FEMA post-storm work (Ophelia). A summary of average shoreline and volume changes between March 2018 and September 2018 for the Indian Beach/Salter Path region are presented in **Table 6-3**.

Table 6-3. Average Shoreline and Volume Change for Indian Beach/Salter Path

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Indian Beach-Salter Path (Transects 49-58)	12,850	-25.4	-19.4	-249,575	-19.4	-249,199	-34.6	-444,810	-37.1	-477,032	-10.2	-130,771

The Indian Beach/Salter Path region experienced an overall average shoreline recession of -25.4 ft. While the magnitude of recession varied throughout the reach, it was evident at almost every transect (see shoreline change plot in **Appendix C**). Overall, Indian Beach/Salter Path experienced losses above MHW, -5 ft NAVD88, -12 ft NAVD88, -20 ft NAVD88, and -30 ft NAVD88. Losses above -12 ft NAVD88 totaled -444,810 cy (-34.6 cy/ft). Volume losses were slightly smaller above -30 ft NAVD88, indicating that some of the eroded material was captured offshore, however, it was well below the depth of closure. As with Bogue Inlet – Ocean and Emerald Isle,

profile plots in **Appendix D** show significant losses to the incipient dune as well as erosion of the berm and the beacface down to approximately -4 ft NAVD88. Beyond this, there is a small recovery of material down to approximately -10 ft NAVD88 followed by formation of a large trough where the offshore bar was previously located and then capture of material well offshore, seaward of the typical offshore bar location with much of it located beyond depth of closure. **Figure 6-9** shows a representative profile in the Indian Beach/Salter Path indicating significant losses to the upper portion of the beach, formation of the large trough, and capture of material offshore.

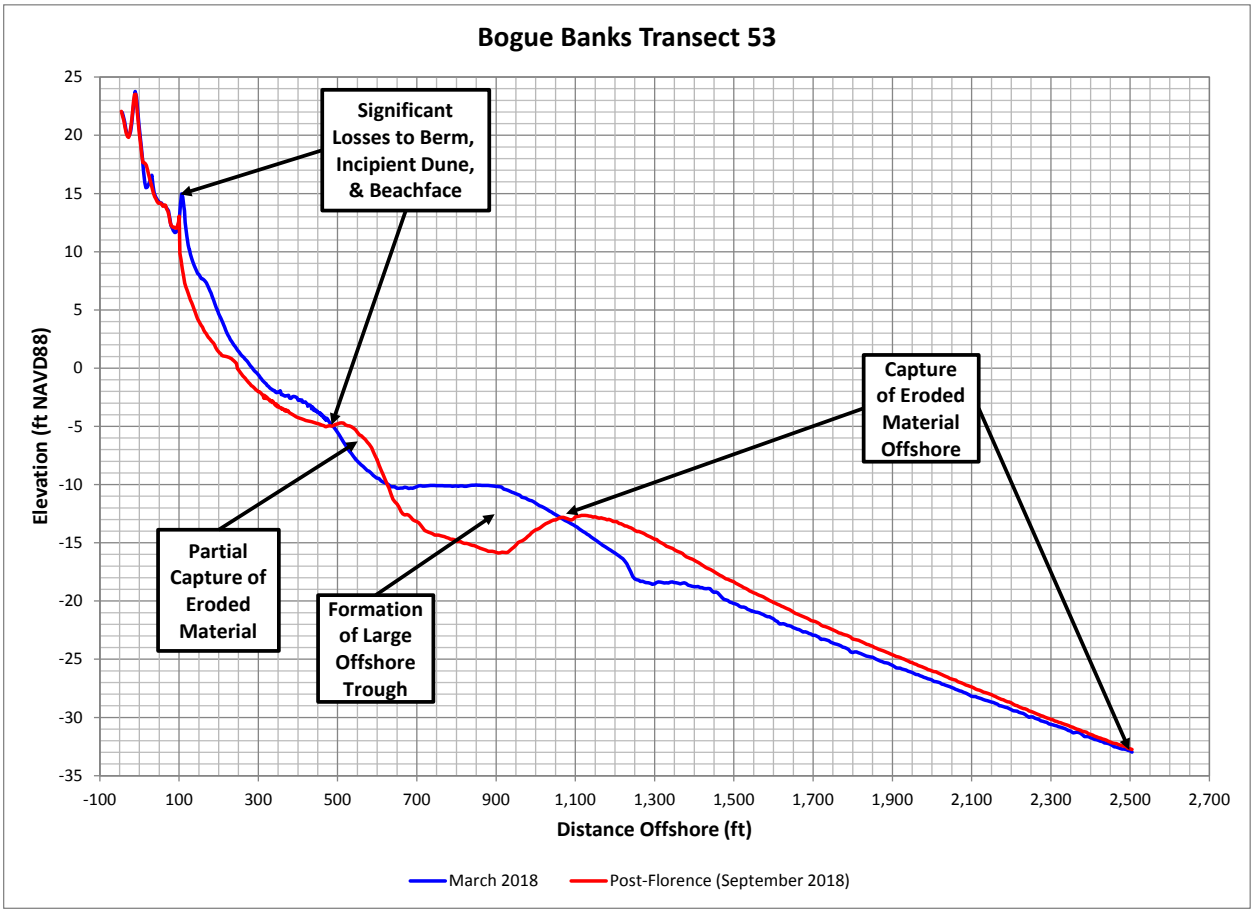


Figure 6-9. Indian Beach/Salter Path Representative Profile

Figure 6-10 displays the unit volume change at each transect for the Indian Beach/Salter Path region. As can be seen, losses above MHW, -5 ft NAVD88, -12 ft NAVD88, and -20 ft NAVD88 are prevalent throughout the entire reach with the only gains being experienced at a couple of transects well offshore above -30 ft NAVD88.

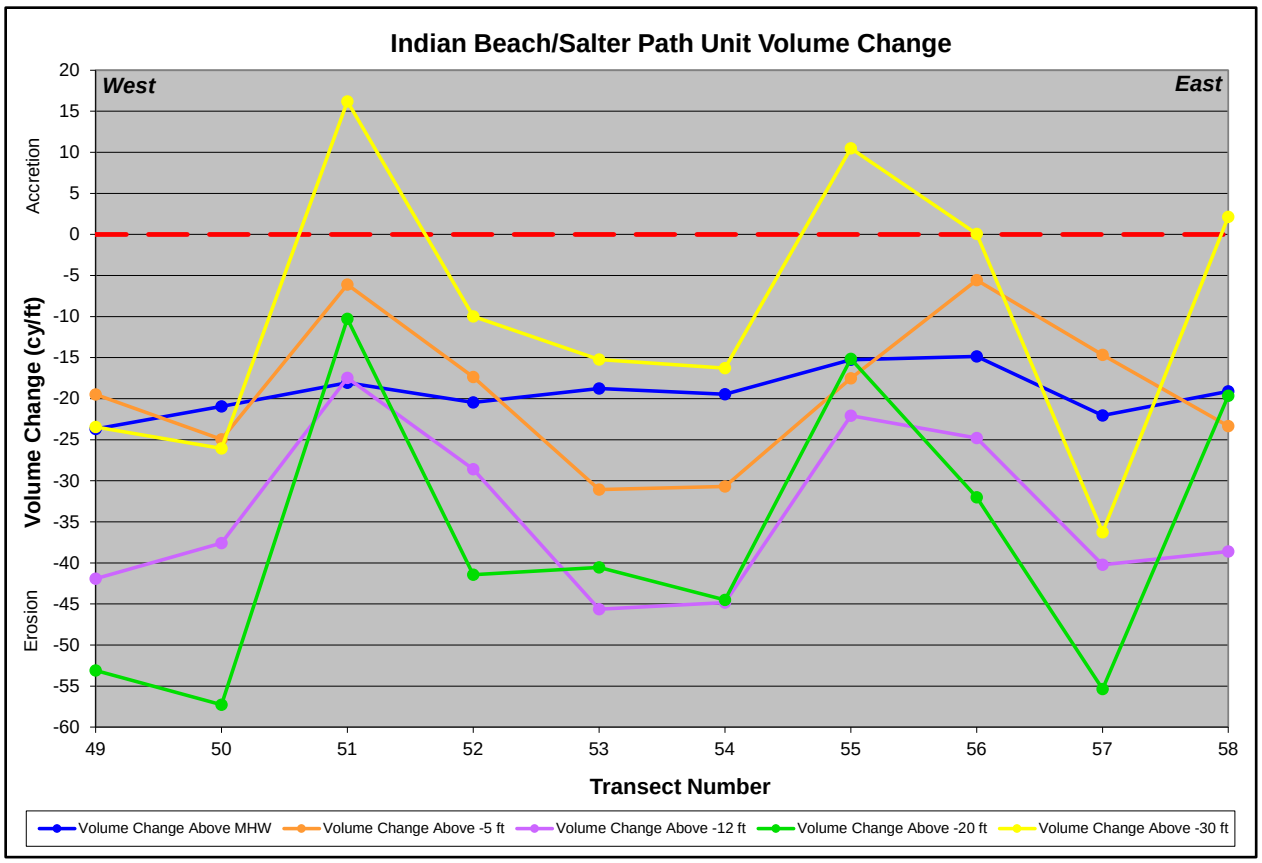


Figure 6-10. Indian Beach/Salter Path Unit Volume Change (March 2018 – September 2018)

6.2.4. Pine Knoll Shores

The Pine Knoll Shores region covers Transects 59 through 76 of the Bogue Banks shoreline and is defined as a single management reach (see **Figure 3-1**). Since monitoring efforts began in 1999, the Pine Knoll Shores area has received 2.63 million cy of nourishment material as a result of past local projects, USACE Section 933, and FEMA post-storm work (Ophelia and Irene). A summary of average shoreline and volume changes between March 2018 and September 2018 for the Pine Knoll Shores region are presented in **Table 6-4**.

Table 6-4. Average Shoreline and Volume Change for Pine Knoll Shores

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Pine Knoll Shores (Transects 59-76)	23,878	5.5	-14.6	-348,827	-13.4	-319,234	-24.1	-575,901	-20.4	-487,867	-3.4	-80,610

The Pine Knoll Shores region experienced an overall average shoreline advancement of +5.0 ft. The shoreline change plot in **Appendix C** indicates that the shoreline change alternated between landward recession and seaward advancement throughout the reach. Profile plots in **Appendix D** show a small deposition of sand right at MHW that was eroded from the dune and berm at transects experiencing seaward advancement of the shoreline. However, while there was a small amount of accretion right at MHW, volume losses were still experienced above MHW as well as above -5 ft NAVD88, -12 ft NAVD88, -20 ft NAVD88, and -30 ft NAVD88. Losses above -12 ft NAVD88

totaled -575,901 cy (-24.1 cy/ft). Volume losses were slightly smaller above -30 ft NAVD88, indicating that some of the eroded material was captured offshore, however, it was well below the depth of closure. As with Bogue Inlet – Ocean, Emerald Isle, and Indian Beach/Salter Path, profile plots in **Appendix D** show significant losses to the incipient dune as well as erosion of the berm and the beacface down to approximately -4 ft NAVD88. Beyond this, there is a small recovery of material down to approximately -10 ft NAVD88 followed by formation of a large trough where the offshore bar was previously located and then capture of material well offshore, seaward of the typical offshore bar location with much of it located beyond depth of closure. **Figure 6-11** shows a representative profile in the Pine Knoll Shores reach indicating significant losses to the upper portion of the beach, formation of the large trough, and capture of material offshore.

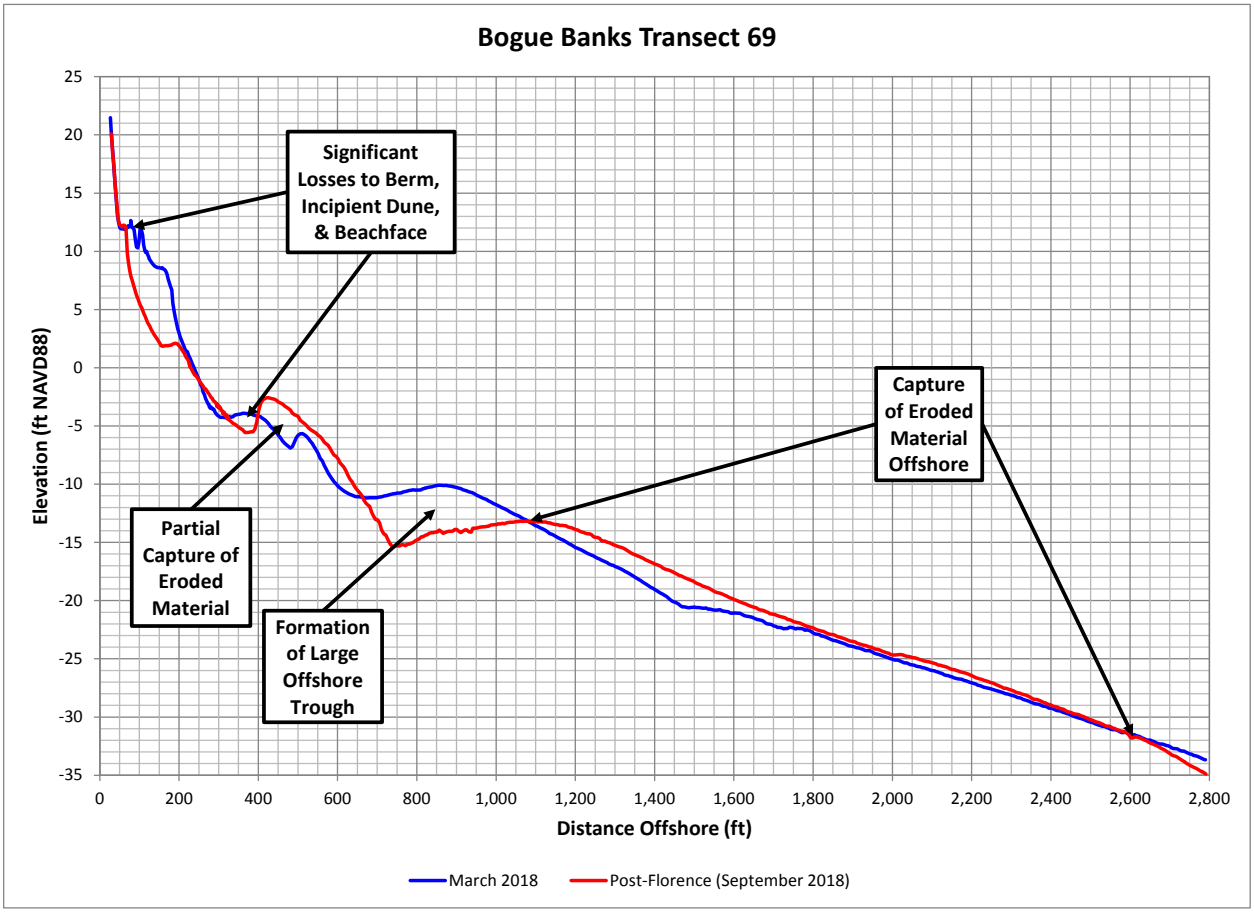


Figure 6-11. Pine Knoll Shores Representative Profile

Figure 6-12 displays the unit volume change at each transect for the Pine Knoll Shores region. As can be seen, losses above MHW, -5 ft NAVD88, -12 ft NAVD88, and -20 ft NAVD88 are prevalent throughout the entire reach with the only gains being experienced at a couple of transects well offshore above -30 ft NAVD88.

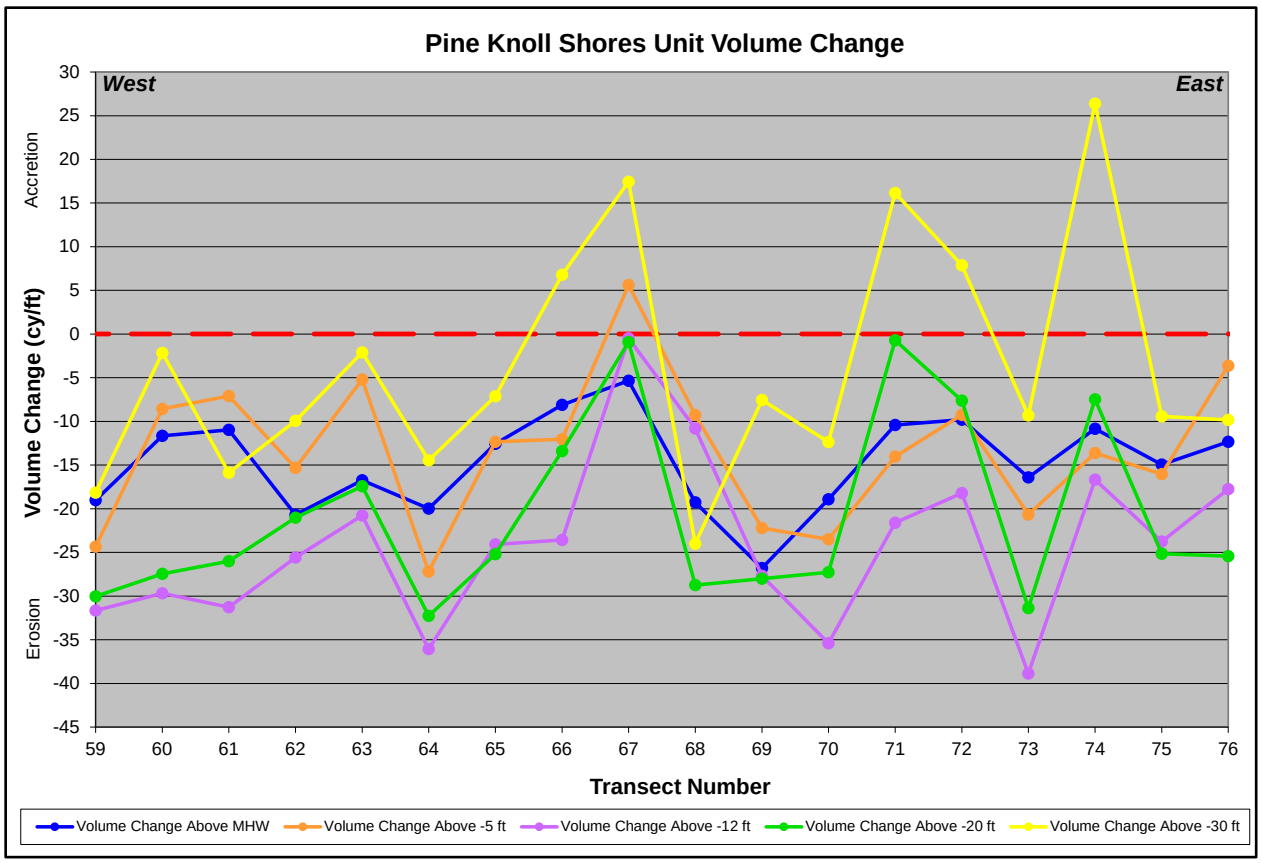


Figure 6-12. Pine Knoll Shores Unit Volume Change (March 2018 – September 2018)

6.2.5. Atlantic Beach

The Atlantic Beach region covers Transects 77 through 102 of the Bogue Banks shoreline and is defined as a single management reach (see **Figure 3-1)**. This reach is not within the current engineered beach, but is instead the recipient of material dredged from the USACE's Morehead City Harbor navigation project. Since monitoring began in 1999, the area has received 4.33 million cy of nourishment material from the Brandt Island Pump Out and USACE dredge disposal. It is important to note that Atlantic Beach is not included within the current engineered beach and is therefore not eligible for FEMA reimbursement even if storm damage occurs. However, the reach is still monitored post-storm to capture a complete picture of oceanfront impacts along Bogue Banks. A summary of average shoreline and volume changes between March 2018 and September 2018 for the Atlantic Beach region are presented in **Table 6-5**.

Table 6-5. Average Shoreline and Volume Change for Atlantic Beach

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Atlantic Beach (Transects 77-102)	26,176	-20.9	-13.2	-346,529	-12.0	-312,956	-16.8	-439,261	-4.0	-103,931	21.5	563,222

The Atlantic Beach region experienced an overall average shoreline recession of -20.9 ft. The shoreline change plot in **Appendix C** indicates that the shoreline change alternated between

landward recession and seaward advancement throughout the reach. Profile plots in **Appendix D** show a small deposition of sand right at MHW that was eroded from the dune and berm at transects experiencing seaward advancement of the shoreline. Consistent with the engineered beach portion of Bogue Banks, Atlantic Beach experienced similar trends of volume losses above MHW, -5 ft NAVD88, -12 ft NAVD88, and -20 ft NAVD88 with volume gains above -30 ft NAVD88. Volume losses above -12 ft NAVD88 totaled -439,261 cy (-16.8 cy/ft). The erosion experienced in Atlantic Beach was much less than the erosion experienced along the remainder of Bogue Banks. It is likely that the USACE project, which most recently nourished the eastern portion of Atlantic Beach (Transects 91 – 100) in 2017, was a contributing factor to this. Profile plots in **Appendix D** indicate that in the areas that were nourished in 2017, significant erosion of the constructed berm occurred but erosion of the dune was not experienced. **Figure 6-13** shows a representative profile for Atlantic Beach within the USACE project area. As can be seen, while there was significant erosion of the berm, the dune remained intact. Changes in the remainder of the profile were also less extreme than seen along the remainder of the beach.

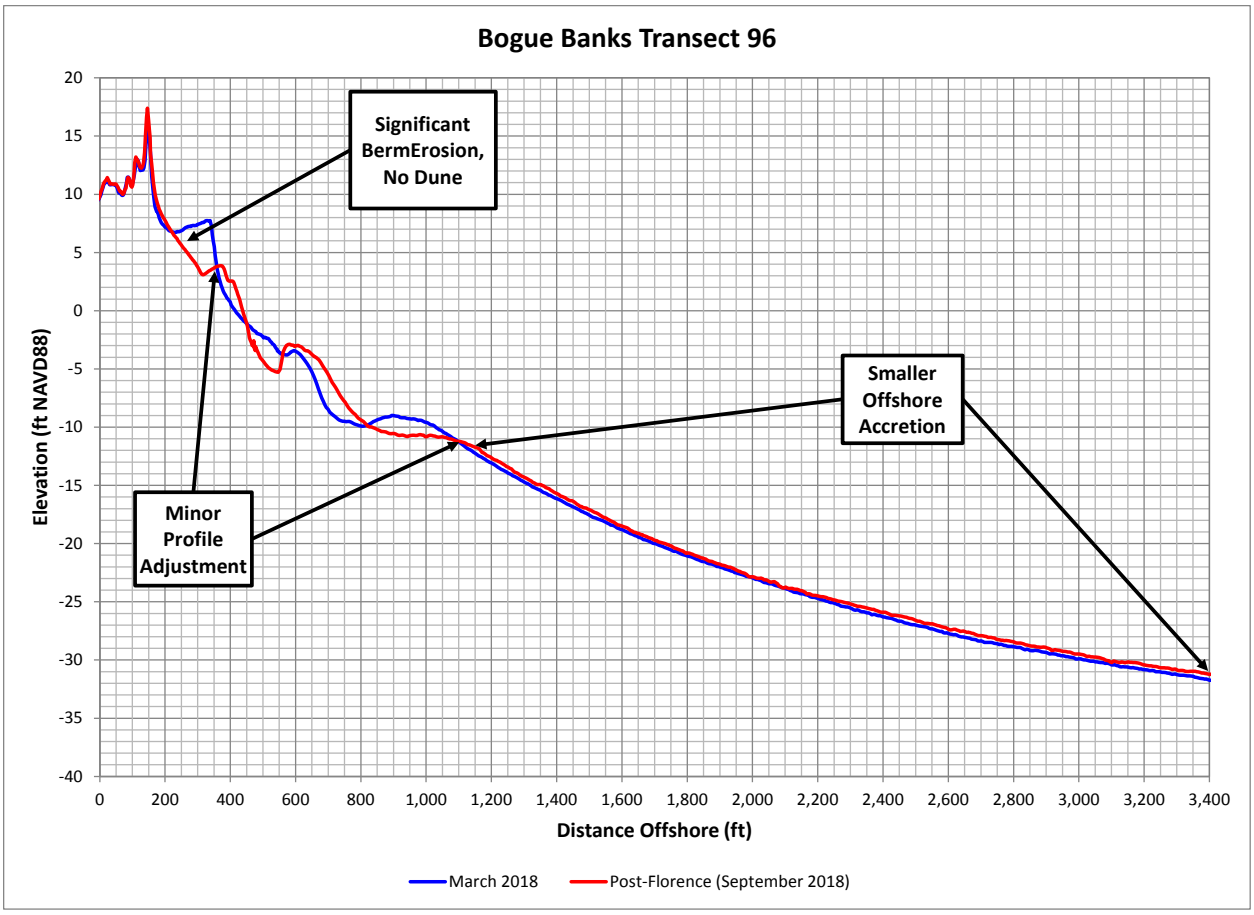


Figure 6-13. Atlantic Beach Representative Profile

Figure 6-14 displays the unit volume change at each transect for the Atlantic Beach region. As can be seen, losses above MHW, -5 ft NAVD88, -12 ft NAVD88, and -20 ft NAVD88 are prevalent throughout the reach with the only gains being experienced well offshore above -30 ft NAVD88.

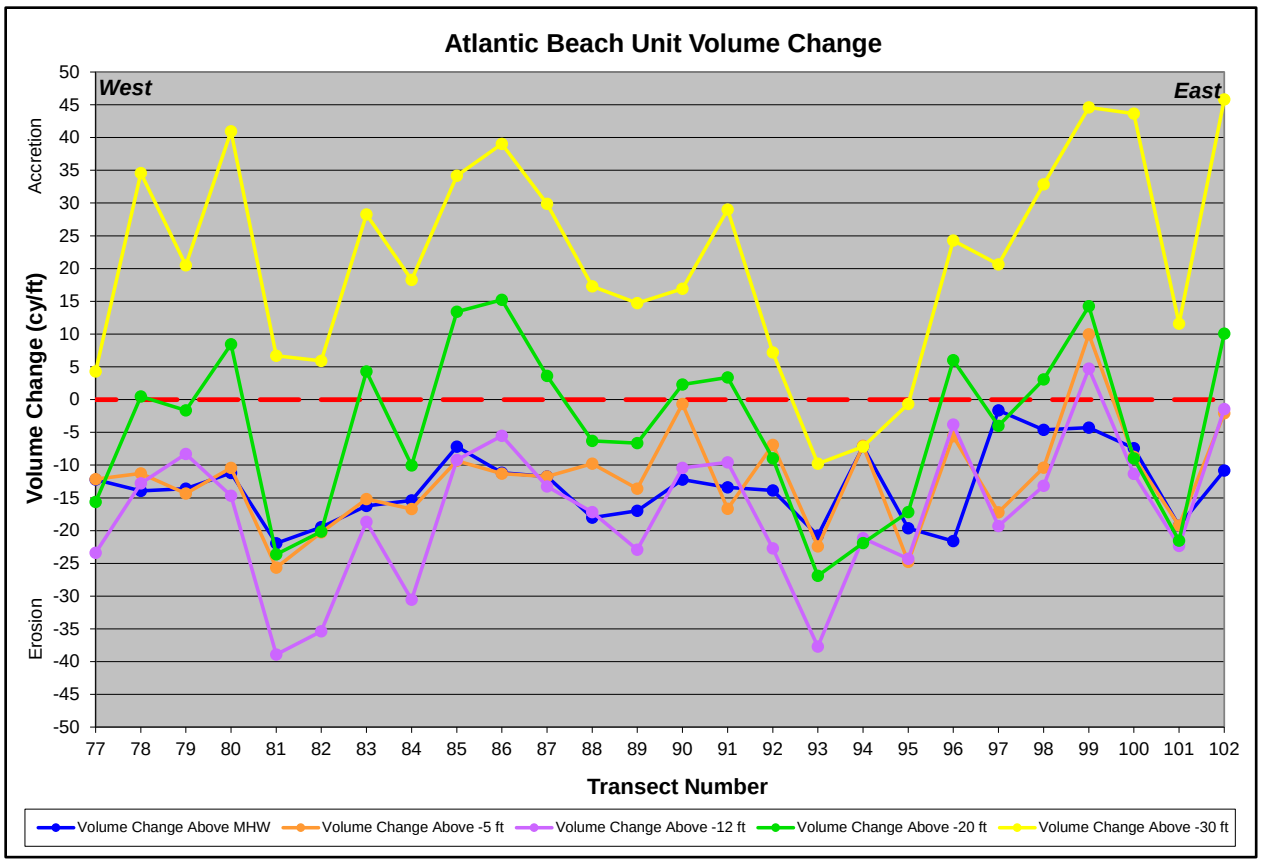


Figure 6-14. Atlantic Beach Unit Volume Change (March 2018 – September 2018)

6.2.6. Fort Macon State Park

The Fort Macon State Park region covers Transects 103 through 112 of the Bogue Banks shoreline and is defined as a single management reach (see **Figure 3-1**). This reach is not within the current engineered beach (owned by the State), but is instead the recipient of material dredged from the USACE's Morehead City Harbor navigation project. Since monitoring began in 1999, this region has received 2.21 million cy of nourishment material from USACE Inner Harbor Dredging Disposal. It is important to note that Fort Macon is not included within the current engineered beach and is therefore not eligible for FEMA reimbursement even if storm damage occurs. However, the reach is still monitored post-storm to capture a complete picture of oceanfront impacts along Bogue Banks. A summary of average shoreline and volume changes between March 2018 and September 2018 for the Fort Macon State Park region are presented in **Table 6-6**.

Table 6-6. Average Shoreline and Volume Change for Fort Macon State Park

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Fort Macon State Park (Transects 103-112)	6,691	-10.7	-9.4	-62,734	-4.9	-32,506	14.1	94,297	51.3	343,207	64.8	433,471

The Fort Macon region experienced an overall average shoreline recession of -10.7 ft. The shoreline change plot in **Appendix C** indicates that the shoreline change alternated between

landward recession and seaward advancement throughout the reach. Profile plots in **Appendix D** show erosion of the berm and deposition along the beachface down to wading depth at those transects that experienced seaward advancement of the shoreline. Fort Macon displayed different behavior than the remainder of the beach in that volume losses were contained to above MHW and -5 ft NAVD88 while volume gains were experienced above -12 ft NAVD88, -20 ft NAVD88, and -30 ft NAVD88. Volume gains above -12 ft NAVD88 totaled +94,297 cy (+14.1 cy/ft). Given its proximity to the inlet, this portion of the beach generally receives a large amount of longshore transport from Atlantic Beach which it is usually able to maintain a portion of due to the terminal groin. **Figure 6-15** shows a representative profile in the Fort Macon reach indicating some erosion to the upper portion of the beach, inflation of the offshore bar, and offshore volume gains.

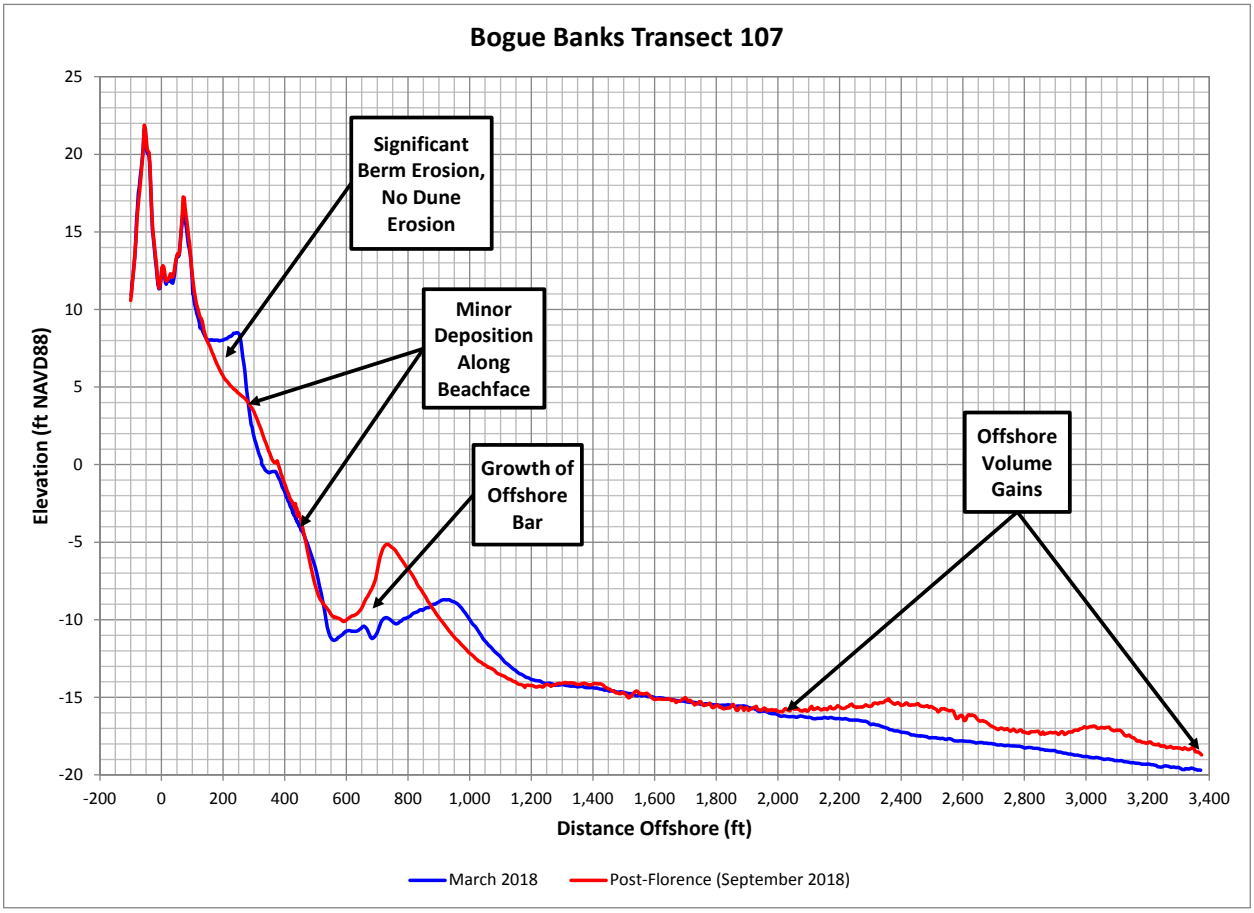


Figure 6-15. Fort Macon Representative Profile

Figure 6-16 displays the unit volume change at each transect in the Fort Macon State Park region. As can be seen losses above MHW and -5 ft NAVD88 are consistent throughout the reach while gains above the remaining elevations are also prevalent with the exception of the easternmost transect adjacent to Beaufort Inlet.

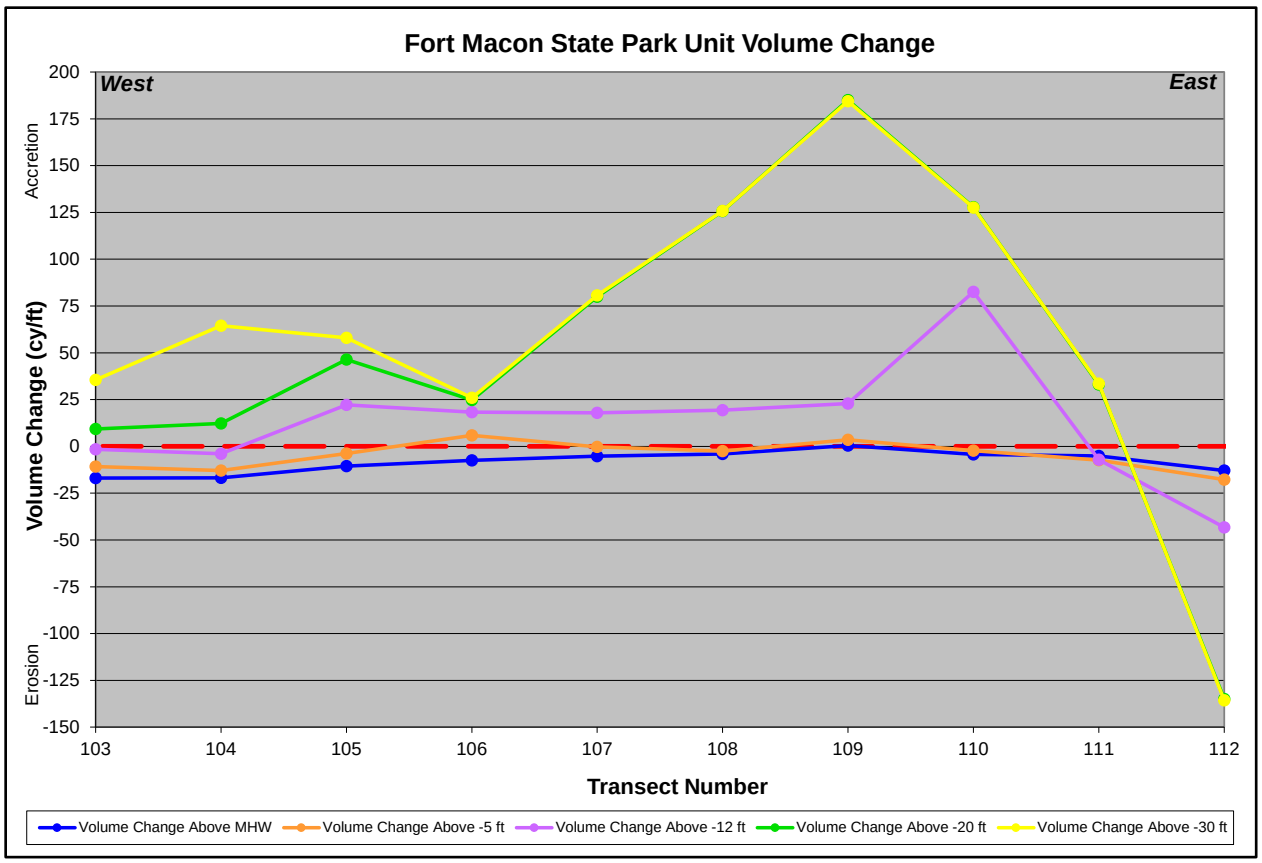


Figure 6-16. Fort Macon State Park Unit Volume Change (March 2018 – September 2018)

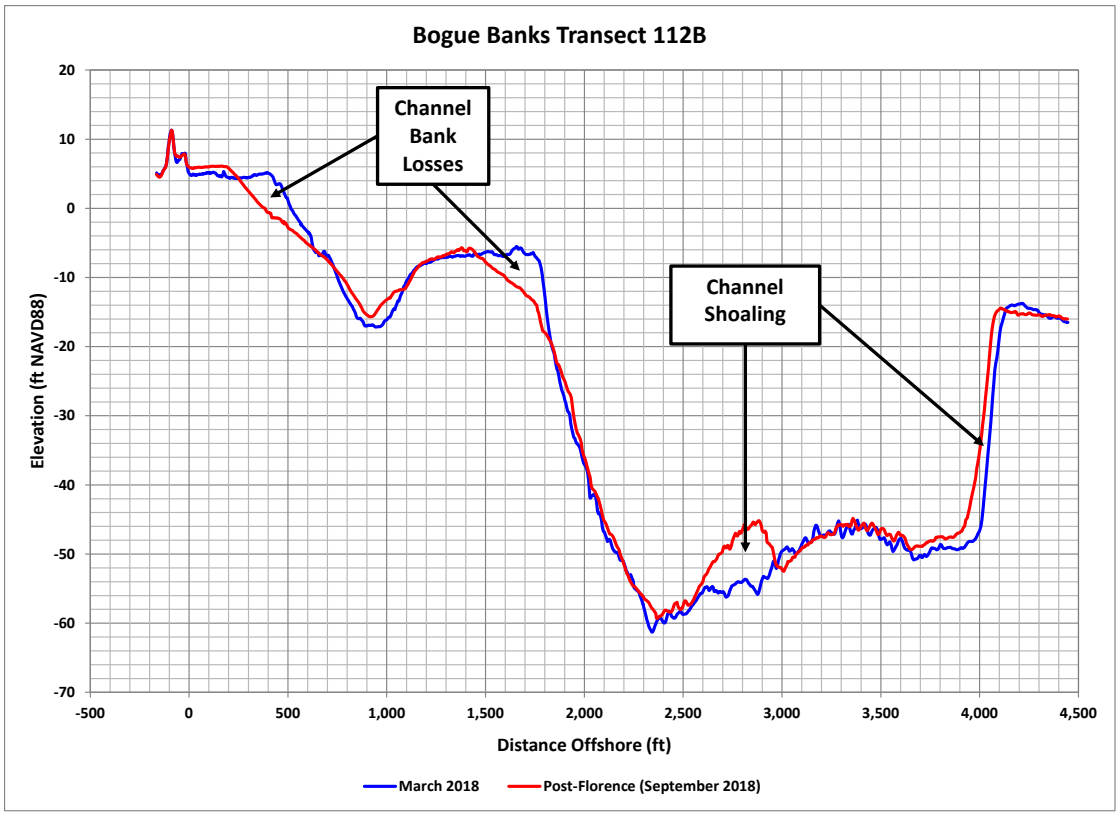
6.2.7. Beaufort Inlet

The Beaufort Inlet region is comprised of an area along the western side of Beaufort Inlet which covers Transects 112B through 116. It is important to note that Beaufort is not included within the current engineered beach and is therefore not eligible for FEMA reimbursement even if storm damage occurs. However, the reach is still monitored post-storm to capture a complete picture of impacts along Bogue Banks. A summary of average shoreline and volume changes between March 2018 and September 2018 for the Beaufort Inlet region are presented in **Table 6-7**.

Table 6-7. Average Shoreline and Volume Change for Beaufort Inlet

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Beaufort Inlet (Transects 112B-116)	2,000	-91.1	-9.2	-18,447	-15.5	-30,999	-15.6	-31,213	-8.6	-17,151	0.2	365

The Beaufort Inlet region experienced an overall average shoreline recession of -91.1 ft. Profile plots in **Appendix D** show considerable erosion of the dunes, berm, and upper portion of the channel bank. Beaufort Inlet experienced volume losses above MHW, -5 ft NAVD88, -12 ft NAVD88, and -20 ft NAVD88 with very minor gains above -30 ft NAVD88. **Figure 6-17** shows representative profiles at the throat (Transect 112B) and interior (Transect 114) of Beaufort Inlet, indicating some erosion of the channel bank. Some shoaling of the channel occurred in typical locations but the channel location remained fairly stable.



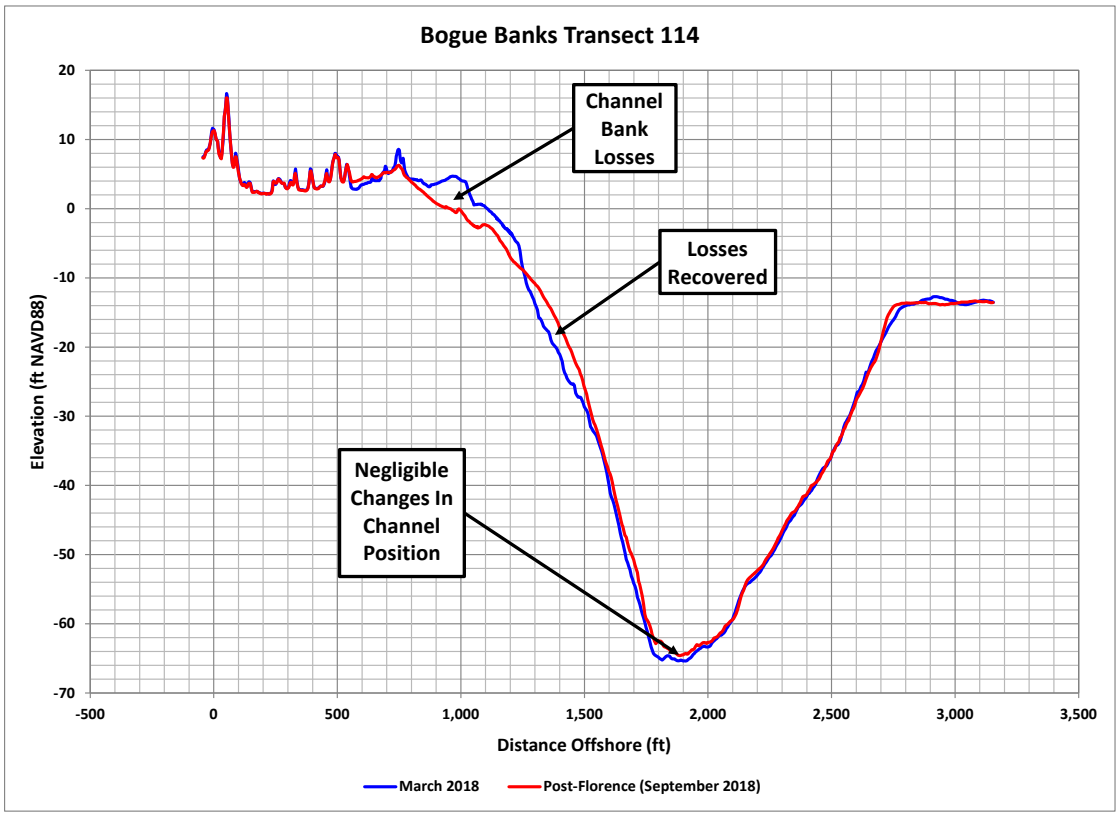


Figure 6-17. Beaufort Inlet representative Profiles

Figure 6-18 displays the unit volume change at each transect in the Beaufort Inlet region. As can be seen, volume erosion and accretion varied throughout the reach.

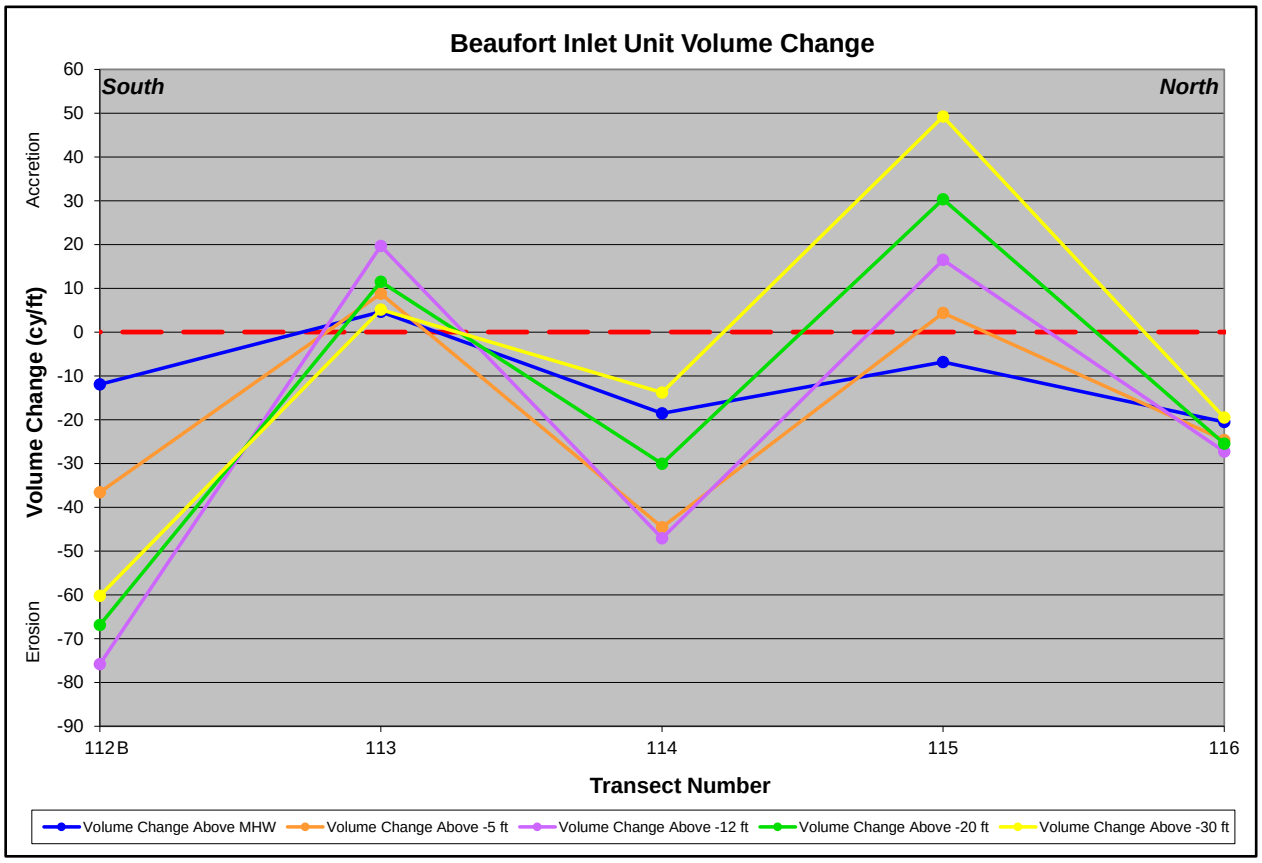


Figure 6-18. Beaufort Inlet Unit Volume Change (March 2018 – September 2018)

6.2.8. Overall Oceanfront Storm Impacts

The following sections present an overall summary of storm impacts as they relate to the entire study area along Bogue Banks including an island wide view of the previously discussed shoreline and volume changes, mobile laser scanner data analysis, base of dune position analysis, and analysis of the current condition of the beach as it compares to the nourishment triggers developed for the Bogue Banks Master Beach Nourishment Plan.

Shoreline and Volume Changes

Figure 6-19 and **Figure 6-20** present the shoreline and volume changes at each transect along the entire Bogue Banks oceanfront. While the magnitude of changes varies from transect to transect, the overall patterns described in the previous sections can be seen. A majority of transects showed landward recession of the shoreline at MHW. The western portion of Bogue Banks (Bogue Inlet, Emerald Isle, and Indian Beach/Salter Path) experienced landward recession at almost every transect while the eastern portion of Bogue Banks (Pine Knoll Shore, Atlantic Beach, and Fort Macon) experienced alternating patterns of landward recession and seaward advancement. Volume losses above MHW, -5 ft NAVD88, -12 ft NAVD88, and -20 ft NAVD88 are apparent across the oceanfront with the exception of Fort Macon which only experienced losses above

MHW and -5 ft NAVD88. Volume gains above -30 ft NAVD88 are evident, especially at either end of Bogue Banks while the middle portion of the island still experienced overall volume losses above -30 ft NAVD, albeit smaller than the losses above the other elevations.

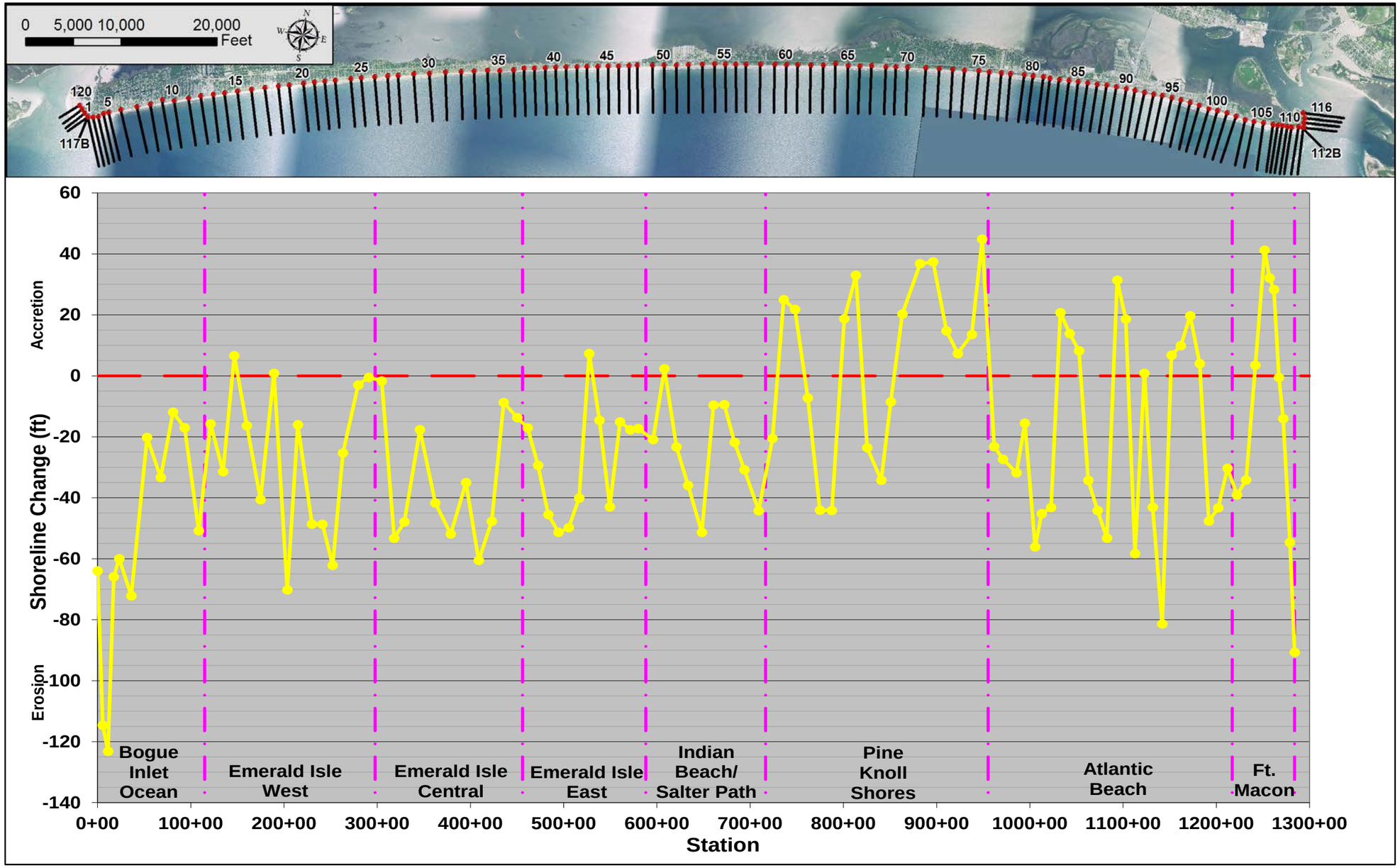


Figure 6-19. Shoreline Change At MHW Along The Bogue Banks Oceanfront

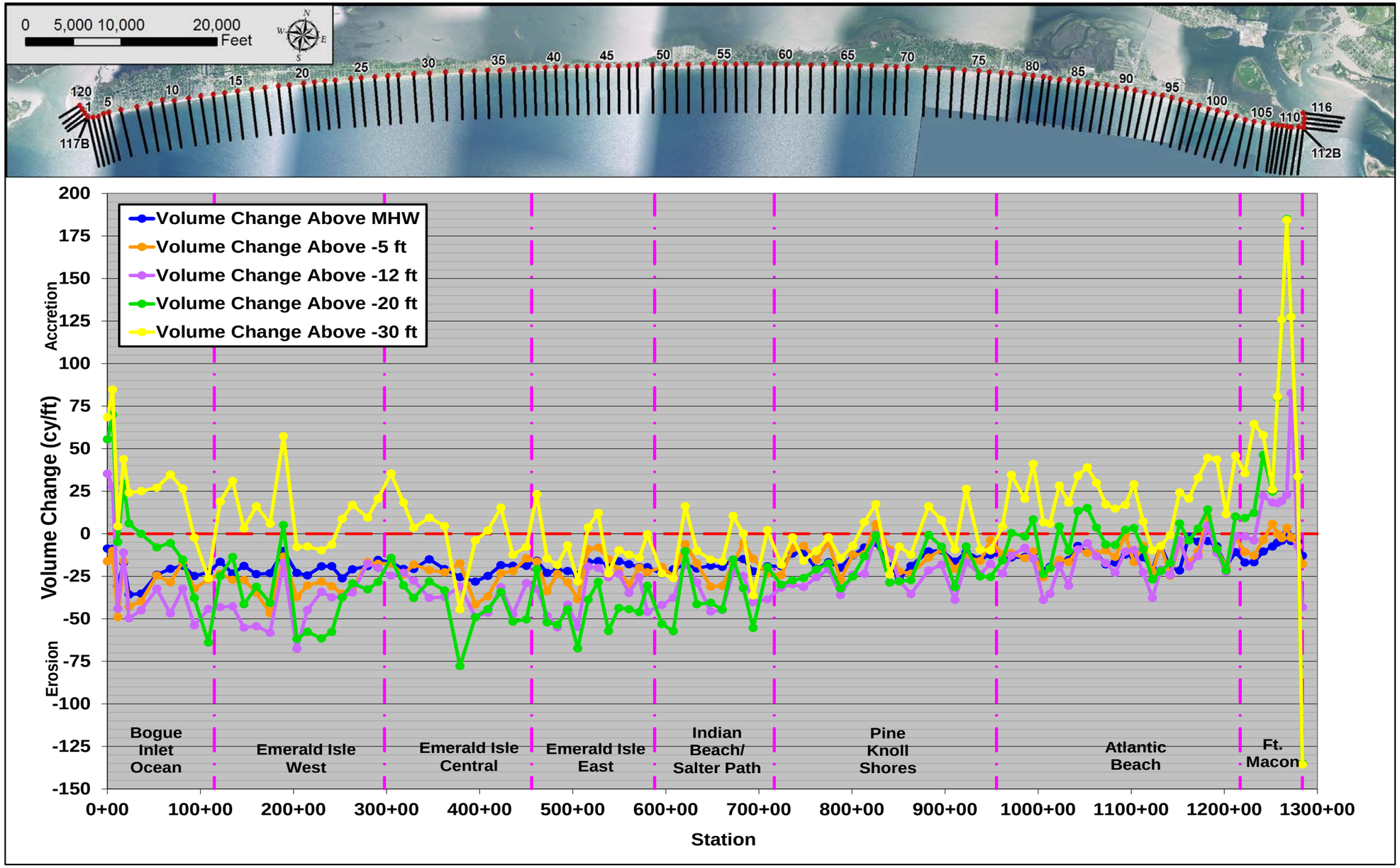


Figure 6-20. Volume Change Above Various Elevations Along The Bogue Banks Oceanfront

A summary of the shoreline and volume changes for each management reach along Bogue Banks is presented along with average and total oceanfront and engineered beach values in **Table 6-8**. For Bogue Banks, since each reach consists of a different length of shoreline, the calculations provide a weighted average for unit shoreline change (ft) and unit volume change (cy/ft) along the Bogue Banks oceanfront. The weighted average also accounts for differences in the shoreline length between each transect. Portions of the engineered beach eligible for FEMA reimbursement are highlighted in yellow.

Table 6-8. Bogue Banks Shoreline and Volume Change Statistics (March 2018 – September 2018)

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Inlet-Ocean (Transects 1-11)	11,488	-47.6	-24.3	-278,605	-28.7	-330,138	-36.1	-414,817	-9.2	-105,694	21.0	241,260
Emerald Isle-West (Transects 12-25)	18,288	-25.7	-20.2	-368,746	-28.6	-523,728	-40.3	-736,750	-36.1	-660,896	11.7	213,575
Emerald Isle-Central (Transects 26-36)	15,802	-34.6	-20.8	-329,442	-23.6	-372,360	-35.2	-556,272	-41.4	-654,711	1.0	15,325
Emerald Isle-East (Transects 37-48)	13,220	-27.8	-19.2	-254,290	-22.3	-295,149	-35.8	-472,897	-43.8	-579,021	-7.2	-95,539
Indian Beach-Salter Path (Transects 49-58)	12,850	-25.4	-19.4	-249,575	-19.4	-249,199	-34.6	-444,810	-37.1	-477,032	-10.2	-130,771
Pine Knoll Shores (Transects 59-76)	23,878	5.5	-14.6	-348,827	-13.4	-319,234	-24.1	-575,901	-20.4	-487,867	-3.4	-80,610
Atlantic Beach (Transects 77-102)	26,176	-20.9	-13.2	-346,529	-12.0	-312,956	-16.8	-439,261	-4.0	-103,931	21.5	563,222
Fort Macon State Park (Transects 103-112)	6,691	-10.7	-9.4	-62,734	-4.9	-32,506	14.1	94,297	51.3	343,207	64.8	433,471
Beaufort Inlet (Transects 112B-116)	2,000	-91.1	-9.2	-18,447	-15.5	-30,999	-15.6	-31,213	-8.6	-17,151	0.2	365
Bogue Inlet-Channel (Transects 117-120)*	2,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Reach Length	Weighted Avg	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total
FEMA Engineered Beach (Transects 1-76)	**95,527**	**-22.2**	**-19.2**	**-1,829,485**	**-21.9**	**-2,089,808**	**-33.5**	**-3,201,448**	**-31.0**	**-2,965,222**	**1.7**	**163,240**
Oceanfront (Transects 1-112)	**128,393**	**-21.4**	**-17.4**	**-2,238,748**	**-19.0**	**-2,435,271**	**-27.6**	**-3,546,411**	**-21.2**	**-2,725,946**	**9.0**	**1,159,933**

*Note: Due to the dynamic nature of Bogue Inlet, shoreline and volume calculations were not performed

According to **Table 6-8**, Bogue Banks experienced an overall landward recession of the shoreline at MHW of -21.4 ft with volume losses above MHW (-2,238,748 cy), above -5 ft NAVD88 (-2,435,271 cy), above -12 ft NAVD88 (-3,546,411 cy), and above -20 ft NAVD88 (-2,725,946 cy). At a majority of transects along the beach, there was significant erosion of the incipient dune, berm, and beachface down to approximately -4 ft NAVD88. Beyond this, there was a small recovery of material down to approximately -10 ft NAVD88 followed by formation of a large trough where the offshore bar was previously located and then capture of material well offshore, seaward of the typical offshore bar location with much of it located beyond depth of closure. The areas that would be eligible for FEMA reimbursement (Bogue Inlet-Ocean, Emerald Isle, Indian Beach/Salter Path, and Pine Knoll Shores) experienced a similar trend to the entire oceanfront with an overall landward recession of the shoreline at MHW of -22.2 ft and volume losses above MHW (-1,829,485 cy), above -5 ft NAVD88 (-2,089,808 cy), above -12 ft NAVD88 (-3,201,448 cy), and above -20 ft NAVD88 (-2,965,222 cy).

Figure 6-21 and **Figure 6-22** display the trends in **Table 6-8** with bar plots of the average and cumulative volume changes at each reach. As can be seen, volume losses are evident throughout the entire study area, with the exception of volume gains above -30 ft NAVD88 in some reaches and volume gains above -12 ft NAVD88 and -20 ft NAVD88 in Fort Macon.

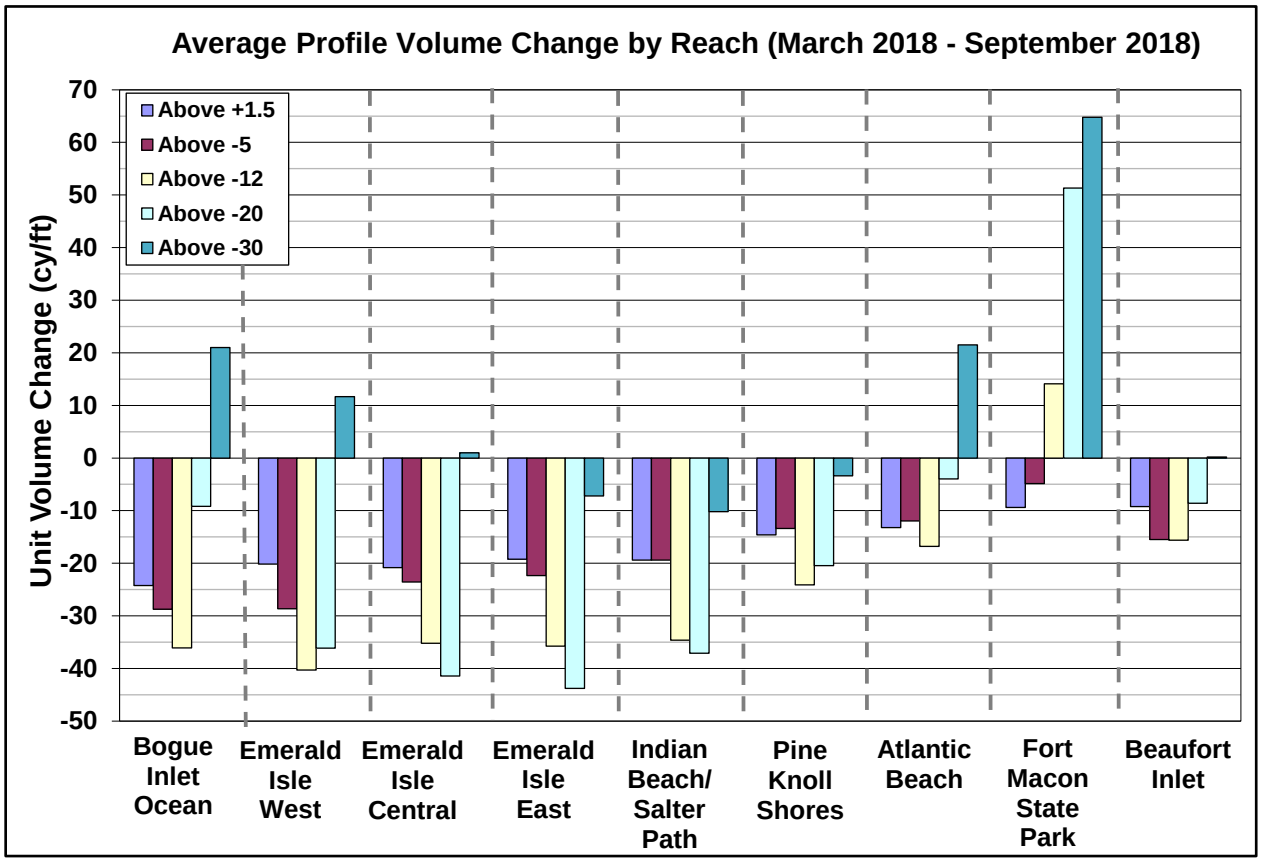


Figure 6-21. Average Unit Volume Change by Reach (March 2018 – September 2018)

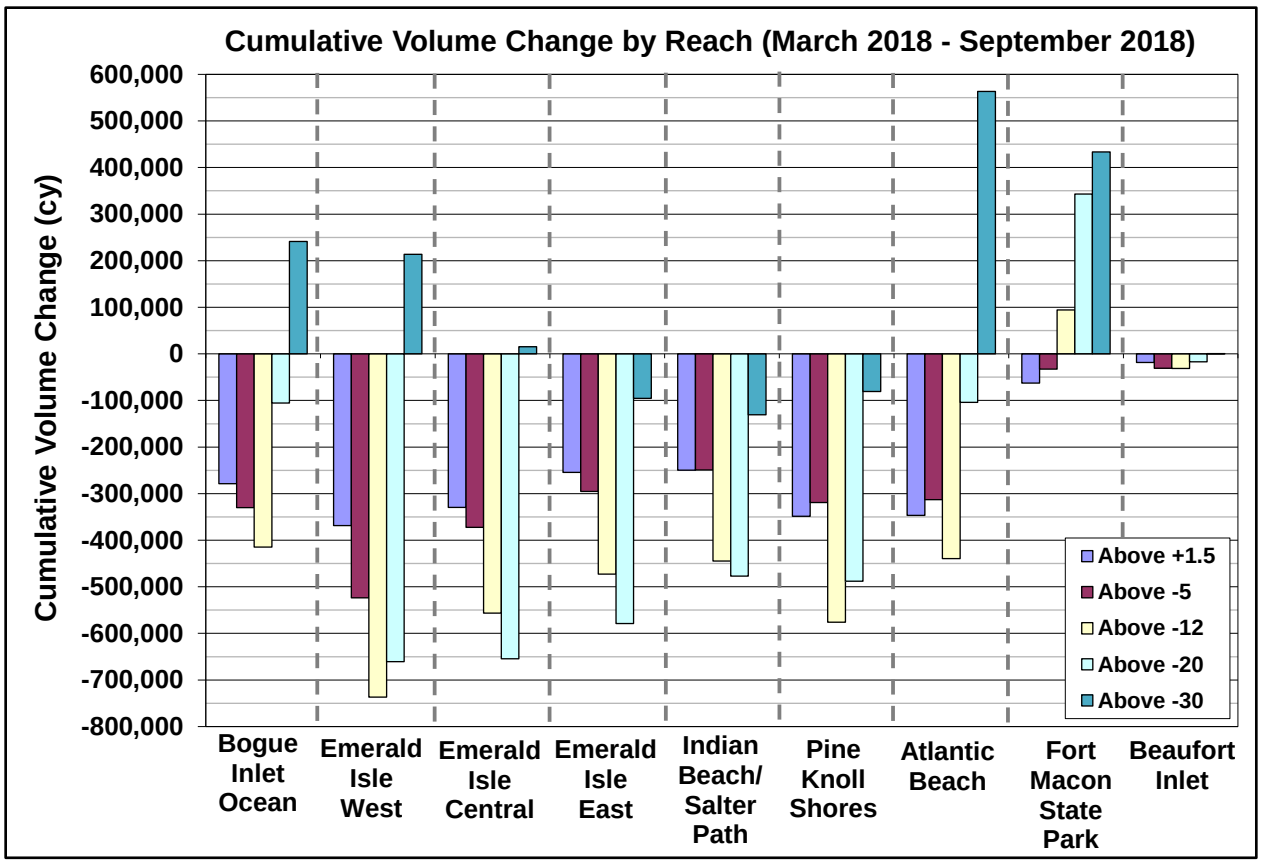


Figure 6-22. Cumulative Volume Change by Reach (March 2018 – September 2018)

Given the overall loss in material above -20 ft NAVD88 (depth of closure) of -3,040,389 cy along the portions of the shoreline currently eligible for FEMA reimbursement (Transects 7 – 76), the County will be seeking aid to replace sand on the beach. Additionally, the post-storm monitoring efforts put forth as part of the Master Beach Nourishment Plan, which totaled $119,800, are reimbursable under FEMA disaster declarations for Carteret County.

Mobile Laser Scanner Analysis

As mentioned previously, in addition to beach profiles Geodynamics used a mobile laser scanner to collect additional topographic data in hotspot areas ranging from Transect 27 in Emerald Isle Central to Transect 82 in Atlantic Beach. It is hoped that this will increase knowledge of the dynamics present in the hotspot areas in Emerald Isle and Pine Knoll Shores. **Figure 6-23** presents the extents of the mobile laser scanner data collection.

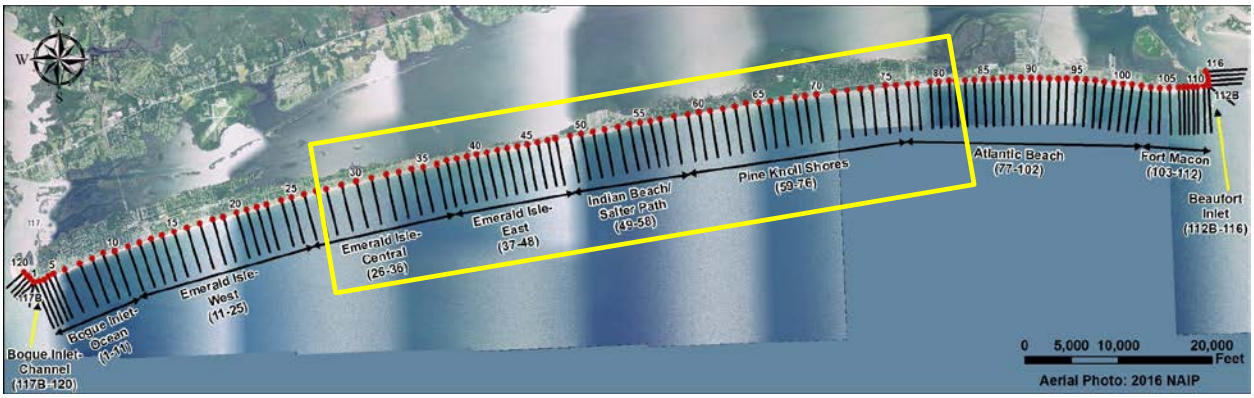


Figure 6-23. Mobile Laser Scanner Extents

The mobile laser scanner delivers high density elevation data from the seaward face of the dune (approximately +14 ft NAVD88) to the waterline (approximately 0 ft NAVD88), providing insight as to the morphology of the dry beach in between transects. From this data, extremely accurate DEM surfaces were created for each survey, seamlessly covering the laser scanning extents. The surfaces were then subtracted to show the elevation changes on the dry beach associated with Hurricane Florence. **Figure 6-24** shows an example of the March 2018 surface, Post-Florence surface, and a surface depicting the difference between the two surveys.

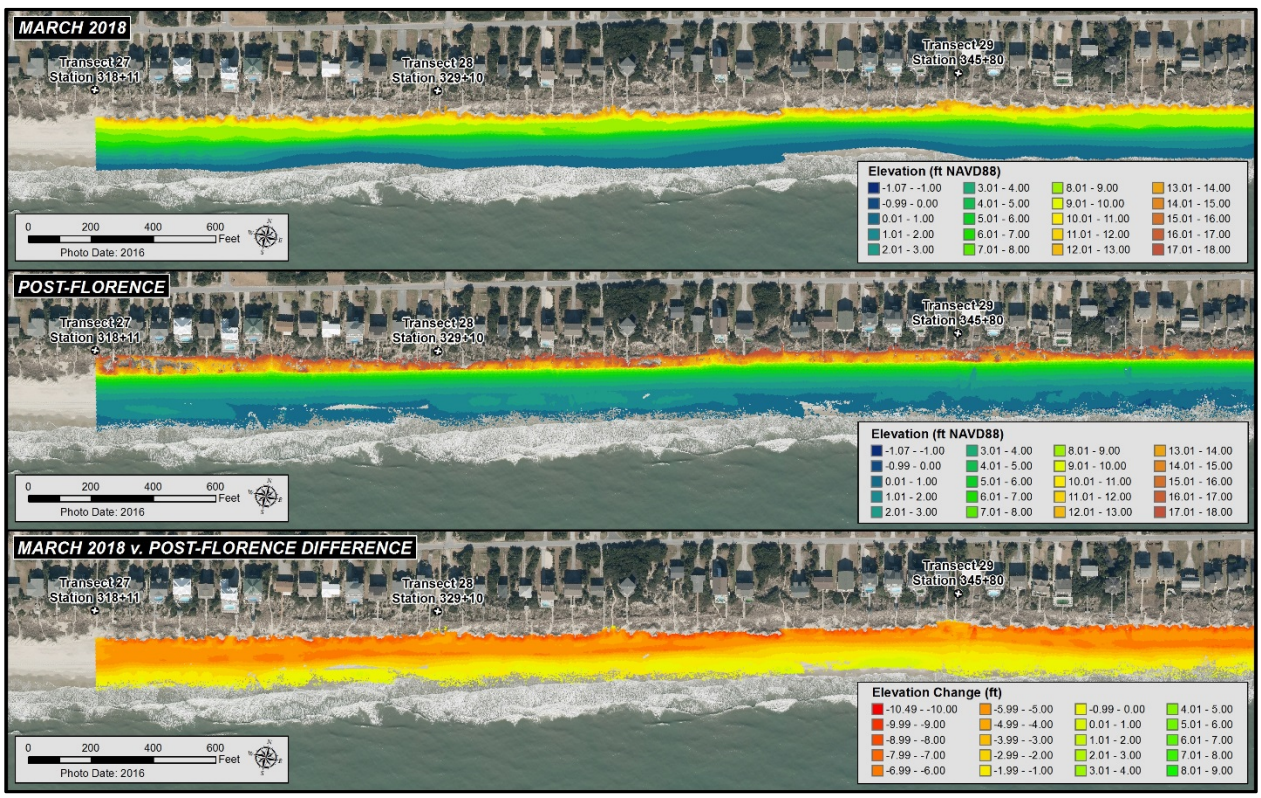


Figure 6-24. Example Mobile Laser Scanning Surfaces

As can be seen, elevation change on the dry beach is almost all negative, indicating significant erosion. Elevation change is largest near along the landward edge of the survey where significant erosion of the incipient dune and escarpment of the primary dune occurred. Changes are slightly

smaller around the water line where some of the material eroded from the dunes and berm was deposited. Figures showing the March 2018 surface, post-Florence surface, and the difference surface for the entire laser scanner extents can be found in **Appendix B**.

Base Of Dune Analysis

In recent years, it has been noted that sand fencing and vegetation have managed to capture wind blown sand and cause some growth at the base of the dune, pushing it seaward in many locations. In order to track the position of the base of the dune, the surfaces created from the mobile laser scanning data were used to extract the position of the base of the dune where the break in slope from the dune to the berm is visible. The difference in position of the base of the dune at each transect from March 2018 to September 2018 was calculated and plotted to determine any trends in movement along the oceanfront shoreline. **Figure 6-25** presents the results of this analysis, indicating overall erosion at the base of the dune. Erosion of the base of the dune was largest west of Transect 90. The portion of the shoreline east of Transect 90 had recently been nourished in 2017 and the wide construction berm protected the dunes in this part of the beach. This behavior was verified in the field and on the survey profiles.

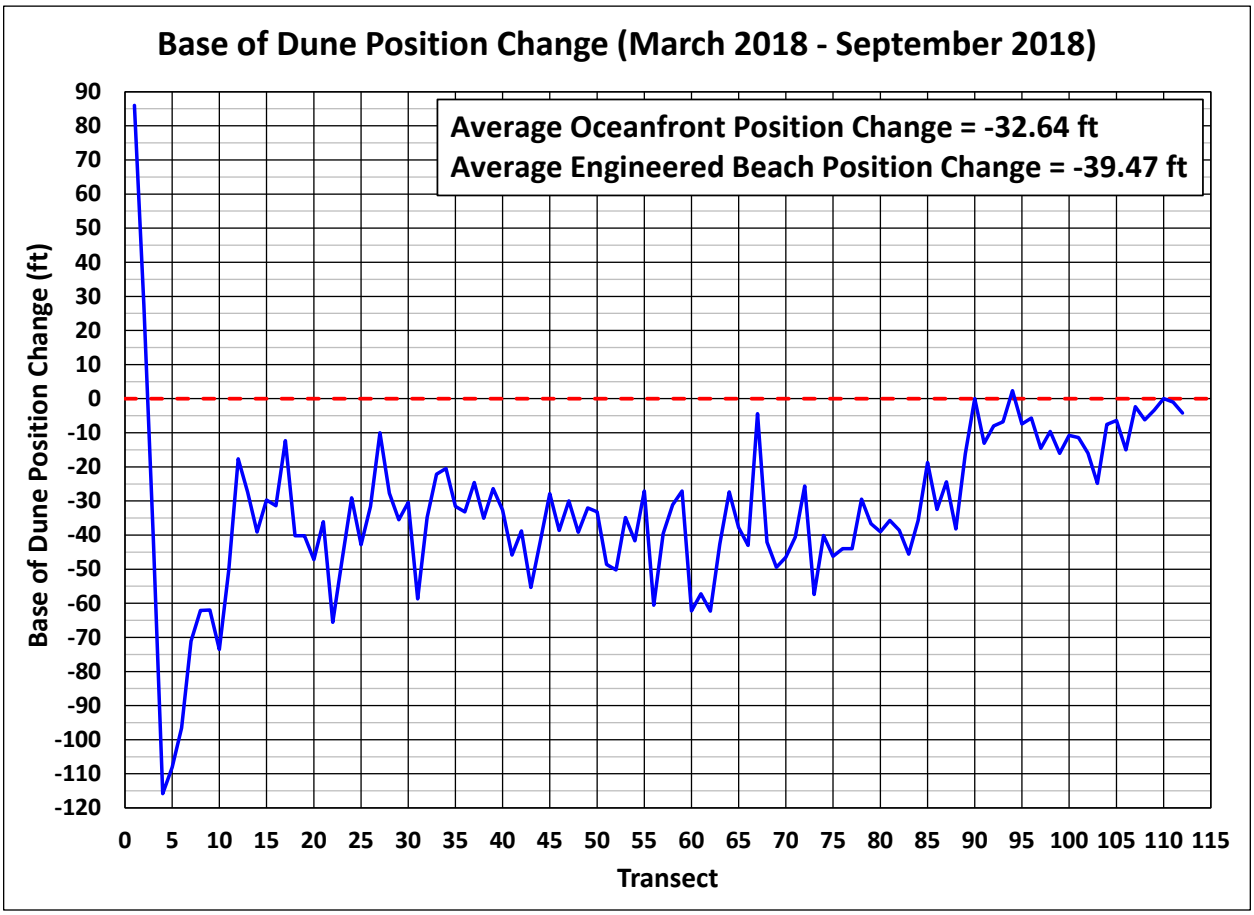


Figure 6-25. Base of Dune Position Change (March 2018 – September 2018)

Master Beach Nourishment Plan Triggers

As mentioned previously, Carteret County has recently completed permitting of a 50 year Master Beach Nourishment Plan including a programmatic Environmental Impact Statement (EIS) and engineering report which outlines the nourishment needs (quantity, location, and timeframe), sediment resources (offshore, inlet, and upland), and funding strategies for Bogue Banks for the next 50 years. As part of the Bogue Banks Master Beach Nourishment Plan, volumetric triggers for each management reach, based on the profile volume from the foredune (landward most crest of primary dune) to the outer bar (above -12 ft NAVD88), were established to provide equal protection along the Bogue Banks oceanfront from a 25-yr storm event (see **Table 2-3**). **Figure 6-26** presents the historical and current profile volumes above -12 ft NAVD88 as compared to the nourishment triggers established for the Bogue Banks Master Beach Nourishment Plan. As can be seen, all reaches contain profile volumes greater than the nourishment triggers, although the Fall 2018 post-Florence survey indicates that Emerald Isle – West, Emerald Isle – East, and Pine Knoll Shores are approaching the minimum volume requirements. Currently, a project is being planned for winter 2018/2019 to nourish Emerald Isle – East and Indian Beach/Salter Path. A plan to nourish the remainder of Emerald Isle and Pine Knoll Shores is currently being formulated for winter 2019/2020.

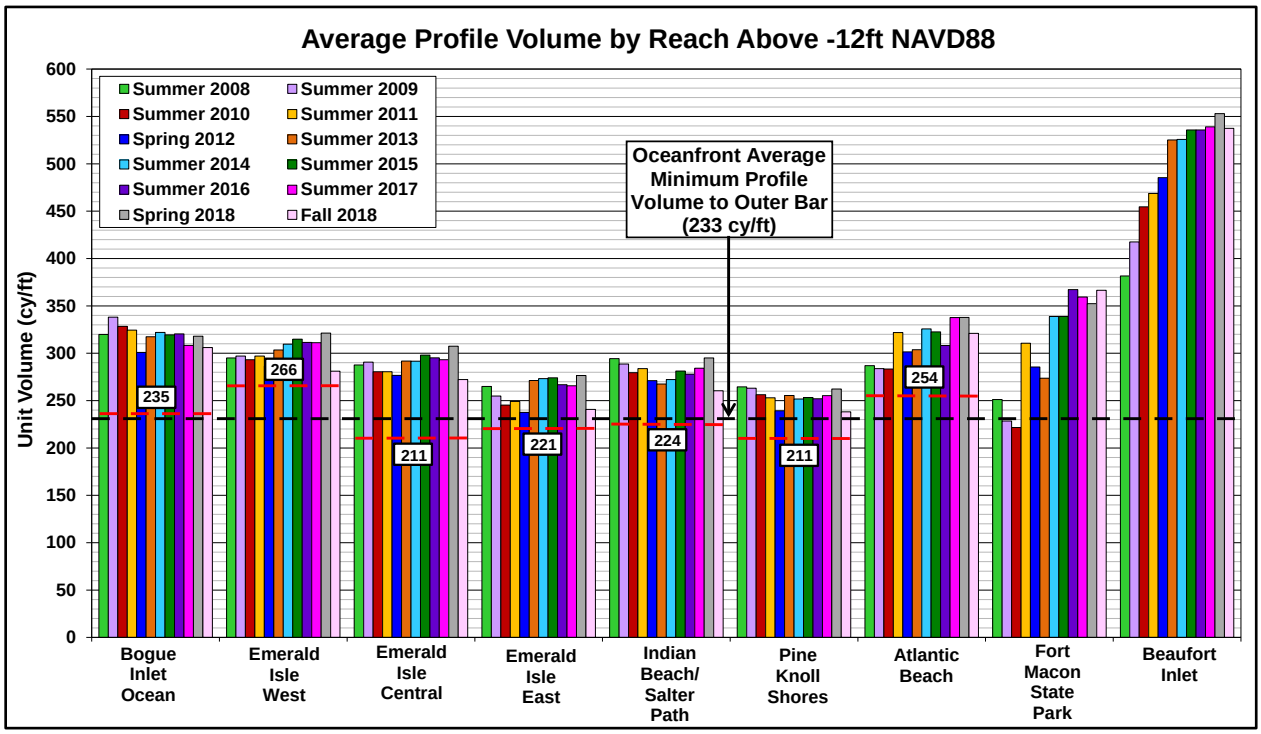


Figure 6-26. Average Profile Volume From The Foredune To The Outer Bar

7.0 Summary

Comprehensive surveying of the Bogue Banks shoreline began in 1999 as a way to formulate the Bogue Banks Beach Restoration Project (the "improved beach," or County Project). In spring 2004, the Bogue Banks Beach and Nearshore Mapping Program was initiated to assess beach conditions and form strategies for future beach nourishment projects. Bear Island and Shackleford Banks were added to the monitoring project in October 2004 and May 2005, respectively. Surveys

have been performed annually during the spring/summer timeframe along all three stretches of shoreline. In addition, after large storm events, surveying has been performed along Bogue Banks to assess and address impacts. The most recent regular (pre-storm) monitoring survey was completed during March 2018 by Geodynamics. Geodynamics conducted a post-storm survey on September 19 - 26, 2018, immediately following the passage of Hurricane Florence. For this storm impact evaluation, the March 2018 survey was compared with the September 2018 survey. The profile data have been used to compute shoreline change at MHW (+1.5 ft NAVD88) and volume change above MHW, -5 ft NAVD88 (wading depth), -12 ft NAVD88 (outer bar), -20 ft NAVD88 (approximate closure), and -30 ft NAVD88. Key statistics were computed for defined regions along the Bogue Banks shoreline between the pre- and post-storm survey profiles as summarized in **Table 7-1**. Portions of the engineered beach eligible for FEMA reimbursement are highlighted in yellow.

Table 7-1. Average Shoreline and Volume Change Attributable to Hurricane Florence

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Inlet-Ocean (Transects 1-11)	11,488	-47.6	-24.3	-278,605	-28.7	-330,138	-36.1	-414,817	-9.2	-105,694	21.0	241,260
Emerald Isle-West (Transects 12-25)	18,288	-25.7	-20.2	-368,746	-28.6	-523,728	-40.3	-736,750	-36.1	-660,896	11.7	213,575
Emerald Isle-Central (Transects 26-36)	15,802	-34.6	-20.8	-329,442	-23.6	-372,360	-35.2	-556,272	-41.4	-654,711	1.0	15,325
Emerald Isle-East (Transects 37-48)	13,220	-27.8	-19.2	-254,290	-22.3	-295,149	-35.8	-472,897	-43.8	-579,021	-7.2	-95,539
Indian Beach-Salter Path (Transects 49-58)	12,850	-25.4	-19.4	-249,575	-19.4	-249,199	-34.6	-444,810	-37.1	-477,032	-10.2	-130,771
Pine Knoll Shores (Transects 59-76)	23,878	5.5	-14.6	-348,827	-13.4	-319,234	-24.1	-575,901	-20.4	-487,867	-3.4	-80,610
Atlantic Beach (Transects 77-102)	26,176	-20.9	-13.2	-346,529	-12.0	-312,956	-16.8	-439,261	-4.0	-103,931	21.5	563,222
Fort Macon State Park (Transects 103-112)	6,691	-10.7	-9.4	-62,734	-4.9	-32,506	14.1	94,297	51.3	343,207	64.8	433,471
Beaufort Inlet (Transects 112B-116)	2,000	-91.1	-9.2	-18,447	-15.5	-30,999	-15.6	-31,213	-8.6	-17,151	0.2	365
Bogue Inlet-Channel (Transects 117-120)*	2,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Reach Length	Weighted Avg	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total
FEMA Engineered Beach (Transects 1-76)	**95,527**	**-22.2**	**-19.2**	**-1,829,485**	**-21.9**	**-2,089,808**	**-33.5**	**-3,201,448**	**-31.0**	**-2,965,222**	**1.7**	**163,240**
Oceanfront (Transects 1-112)	**128,393**	**-21.4**	**-17.4**	**-2,238,748**	**-19.0**	**-2,435,271**	**-27.6**	**-3,546,411**	**-21.2**	**-2,725,946**	**9.0**	**1,159,933**

*Note: Due to the dynamic nature of Bogue Inlet, shoreline and volume calculations were not performed

Trends to be noted along a majority of the shoreline were volume losses above MHW, -5 ft NAVD88, -12 ft NAVD88, and -20 ft NAVD88. Profile plots showed there was significant erosion of the incipient dune, berm, and beachface down to approximately -4 ft NAVD88. Beyond this, there was a small recovery of material down to approximately -10 ft NAVD88 followed by formation of a large trough where the offshore bar was previously located and then capture of eroded material well offshore, seaward of the typical offshore bar location with much of it located beyond depth of closure. **Given the overall loss in material above -20 ft NAVD88 (depth of closure) of -3,040,389 cy along the portions of the shoreline currently eligible for FEMA reimbursement (Transects 7 – 76), the County will be seeking financial aid to replace sand on the beach. Additionally, the post-storm monitoring efforts put forth as part of the Master Beach Nourishment Plan, which totaled $119,800, are reimbursable under FEMA disaster declarations for Carteret County.**

Table 7-2 presents a summary of losses incurred by town. It is expected that Emerald Isle (Bogue Inlet – Ocean, Emerald Isle – West, Emerald Isle – Central, and Emerald Isle – East) will seek reimbursement for 2,075,490 cy. Indian Beach and Salter Path are grouped as one management reach during monitoring and will seek reimbursement for 477,032 cy total (416,536 cy in Indian Beach and 60,496 cy in Salter Path). Pine Knoll Shores will seek reimbursement for 487,867 cy of material.

Table 7-2. Summary of Losses Incurred by Town

Reach (Transects)	Volume Lost Above -20 ft NAVD88 (cy)
Emerald Isle (Transetcs 7-48)	-2,075,490
Indian Beach-Salter Path (Transects 49-58)	-477,032
Pine Knoll Shores (Transects 59-76)	-487,867
Engineered Beach (Transects 7-76)	**-3,040,389**

There is a small portion of oceanfront State owned land in Indian Beach/Salter Path, totaling approximately 2,750 feet of shoreline. If sand lost on this portion of the beach is removed from the total losses, the Indian Beach/Salter Path reimbursement claim will be reduced to 374,947 cy (314,451 cy in Indian Beach and 60,496 cy in Salter Path).

It should be noted that the background erosion rates in the FEMA engineered beach portion of Bogue Banks are relatively small and currently range from +1.10 cy/ft/yr of accretion to -2.42 cy/ft/yr of erosion. Therefore, given the small timeframe between the pre-storm surveys in March 2018 and post-storm surveys in September 2018, it is unlikely that there was significant measurable background erosion.

As noted, there are inevitable margins of uncertainty associated with hydrographic survey data that may reduce the accuracy of volumetric change analyses. Therefore, it is essential to thoroughly review the beach and bathymetric profiles using various analytical techniques and general engineering judgment to assure that results are not falsely interpreted. The findings presented in this report have undergone quality control by two senior coastal engineers.

8.0 References

Moffatt & Nichol, 2014. *Bogue Banks Master Beach Nourishment Plan*. Raleigh, NC. February 2014.

Moffatt & Nichol, 2015a. *Town of Emerald Isle Beach Monitoring and Maintenance Plan*. Raleigh, NC. July 2015.

Moffatt & Nichol, 2015b. *Town of Indian Beach and Salter Path Beach Monitoring and Maintenance Plan*. Raleigh, NC. July 2015.

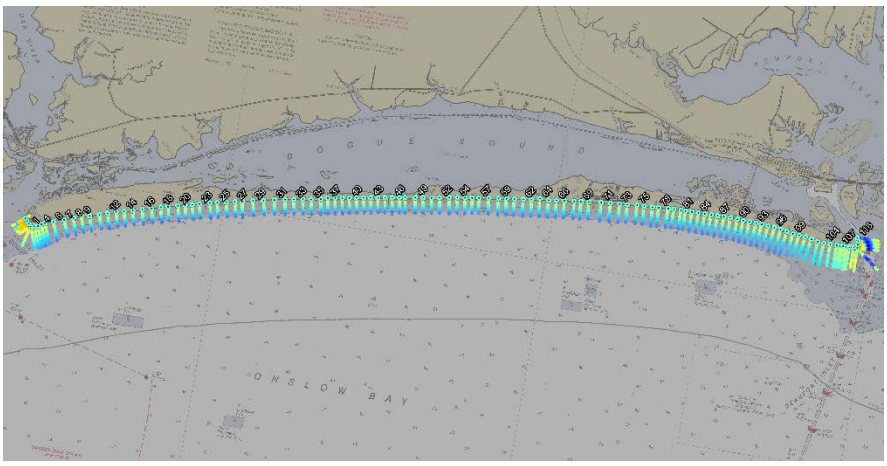
Moffatt & Nichol, 2015c. *Town of Pine Knoll Shores Beach Monitoring and Maintenance Plan*. Raleigh, NC. July 2015.

APPENDIX A

Geodynamics Field Report

Bogue Banks Beach & Nearshore Mapping Program
Carteret County, North Carolina

Post Florence
September 2018



DESCRIPTIVE REPORT

Contract / Project No.: #6668

Submitted by:

geodynamics
COMPLEX COASTAL CHANGE MADE CLEAR

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1.0 Introduction

1.1 Background

Geodynamics was contracted by the Carteret County Shore Protection Office (CCSPO) to map designated cross-section profiles, onshore and offshore of Carteret County beaches, specifically Bogue Banks, as part of the Bogue Banks Beach and Nearshore Mapping Program (BBBNMP) post storm survey following Hurricane Florence. These efforts are divided into two separate products; seamless topographic – bathymetric elevations collected along predefined monitoring profiles and a continuous Digital Elevation Model (DEM) of hotspot areas along Bogue Banks. This work utilizes hydrographic surveying techniques that meet or exceed the criteria outlined in the U.S. Army Corps of Engineers Hydrographic Surveying Manual, EM 1110-2-1003.

1.2 Survey Area

The survey covered approximately 34 NM of shoreline, including Bogue and Beaufort Inlets (Figure 1). Bounding coordinates of the planned survey lines are as follows; northwestern corner, 34°41’19.6” N, 077°06’49.4” W, and 34°38’08.1” N, 076°39’24.2” W for the southeast corner. The topo-bathy profile survey was conducted on and offshore Bogue Banks (122 profiles) exclusively for post storm assessments. Profile length varied from ~2000ft – 5000ft, with variations in the inlet areas. The DEM was generated using data from a fully calibrated Mobile Laser Scanner (MLS) system, used to collect millions of XYZ points, gridded into a 3 ft DEM for designated hotspot areas on Bogue Banks.

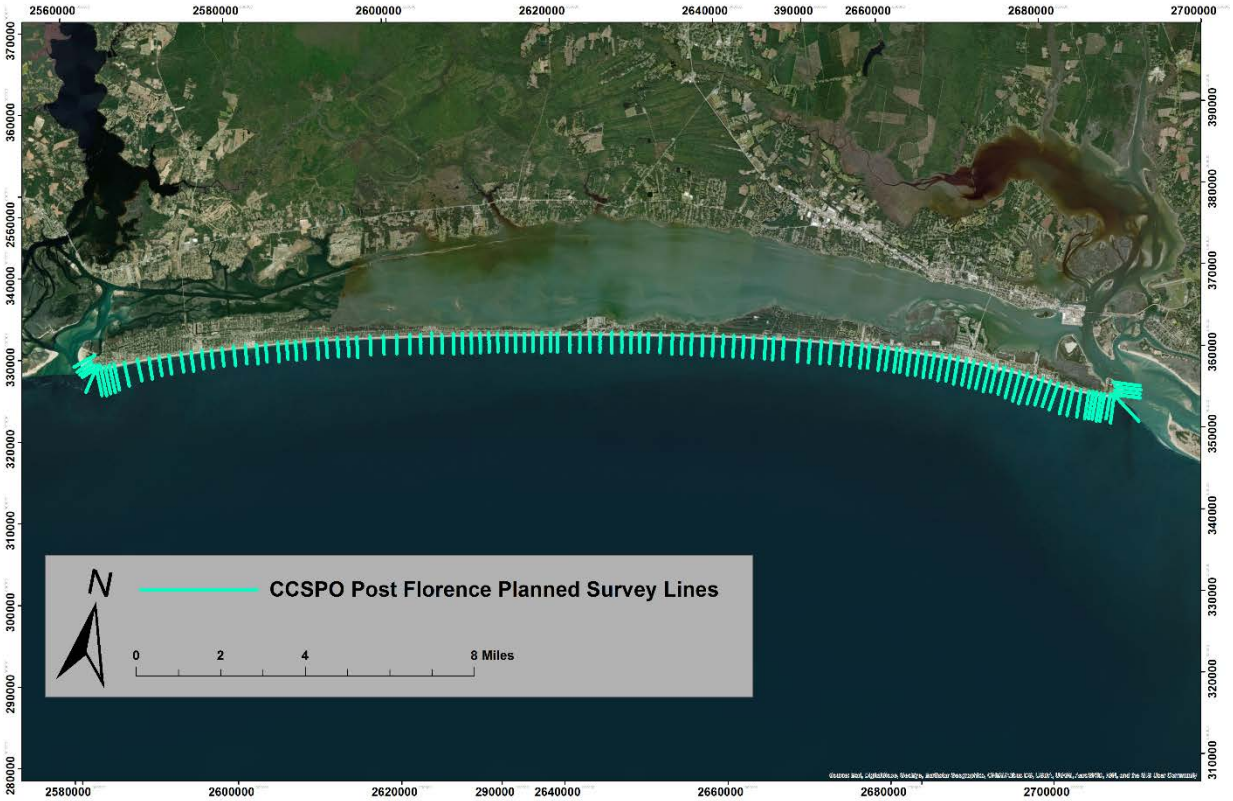


Figure 1. Planning map overview of survey lines for the BBBNMP.

1.3 Survey Objectives

As outlined in the official Scope of Work (SOW) (Appendix D), the specific goals of the surveys were to provide the following data products:

- Topo-Bathy Profiles
  - ASCII/Excel Data Files
    - Profile Location
    - Profile Number
    - Record Number
    - Method
    - Date (YYYYMMDD)
    - Time (UTC HH:MM:SS)
    - Easting (X SPF)
    - Northing (Y SPF)
    - Elevation (Z_NAVD88)
  - Point Shapefiles with attached FGDC compliant metadata
- Arc-Grid DEM of Hotspots on Bogue Banks

    - DEM generated from Mobile Laser Scanning of the shoreface
- Contours and MHW Contour
    - ArcGIS compatible line shapefiles of contours and MHW contour for survey Bogue Banks Hotspot areas, and MHW for all of Bogue Banks
    - FGDC compliant metadata
- Project Deliverables
    - Survey Report
        - Written description of workflow to complete task order (start to finish) including flow chart diagram and detailed description of QA/QC process
        - Dates and times of each data collection activity
        - Atmospheric Conditions for each day of data collection activity
        - All Horizontal and Vertical Control used, including monument name, establishing agency, date established, description, and published horizontal and vertical values
        - TBM descriptions with vertical values
        - Copy of all field notes
        - Complete and detailed list of all survey equipment used, including copy of last factory calibration report
        - Metadata Records
        - Photographs of the site and any significant features or data collection techniques used

1.4 Report Purpose

The purpose of this document is to summarize the survey activities and report on the acquisition and processing methodology performed the project. This report also serves to provide illustrations and descriptions of deliverable items. For any additional information regarding survey activities, contact Geodynamics in Newport, North Carolina.

1.5 Survey Logistics

Survey activity was conducted between September 19, 2018 and September 26, 2018. Listed below is a generalized timeline of data acquisition (Table 1). A detailed field summary of daily activities related to the survey is presented in Appendix A. See daily notes for more details (Appendix A).

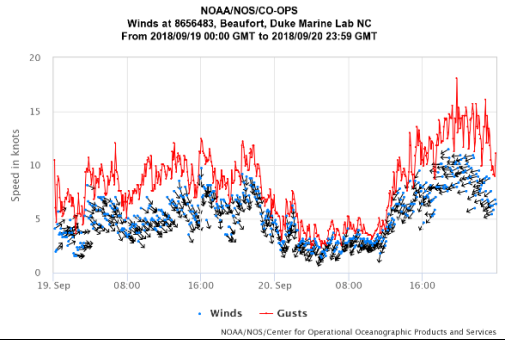
Table 1. Summary of Survey Activities

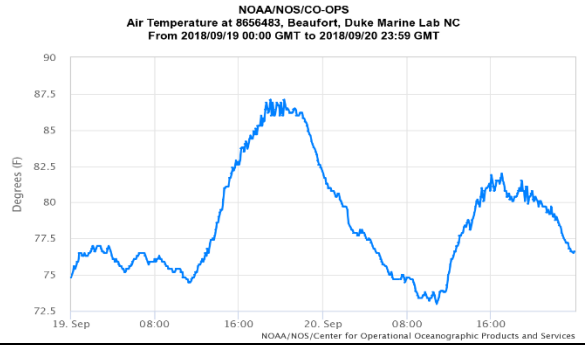
Date	Julian Day	Activity
9/19/18	262	The topo collected lines 68-104. Laser data was collected from Fort Macon to the Iron Steamer region. Hydro crew collected offshore and surfzone lines 116-67. RTK-Base station was set up on TRIPLE at the start of the day then moved to ERBA later on.
9/20/18	263	Topo crew collected surf zone lines 26-116, dune lines 55-67, and laser data from the Iron Steamer region to just west of the Emerald Island Pier. Hydro crew completed offshore lines 67-1 and 117-120. Hydro surf zones were then collected from line 35-66. RTK-base station on ERBA was used.
9/21/18	264	Topo crew collected laser data from Emerald Isle Pier west to Emerald Isle Point. Topo surfzone lines 25-1 and 117-120 were collected as well as dune lines 120-117 and 1-8. Hydro crew collected surf zone lines 1-34, 72-106, 117-120. RTK-base station on base ERBA was used as well as a repeater.
9/24/18	267	Topo crew collected dune lines 105-118 east of Fort Macon. RTK-base station was set up at base TRIPLE.
9/25/18	268	Topo crew collected dunes from line 25 west to line 9. Dunes that were previously inaccessible due to debris, including lines 60, 42, 39, 36, and 35 were collected. Recoveries were completed for lines 75, 58, 57, 52, 48, and 40. The final recoveries were collected by the team on lines 1 and 2 along the beach, and lines 117, 117B, and 118 around Emerald Island Point. All data were collected using base ERBA and the repeater in the western portion of the survey area.
9/26/18	269	Topo crew recovered line 104 using RTK-base station on base TRIPLE thus completing the survey

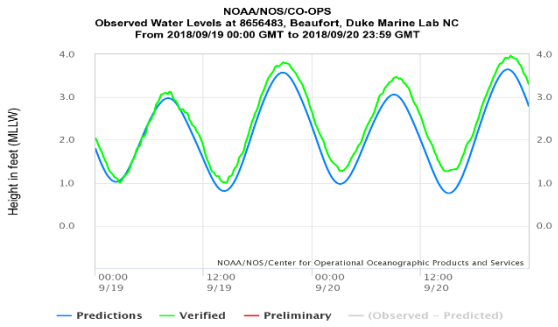
1.6 Survey Conditions

Survey activities were conducted whenever atmospheric and environmental conditions warranted. Listed below (Figure 2) are graphs of NOAA predicted and verified tide for Beaufort, NC (Station ID: 8656483) as well as surface wind and air temperature.

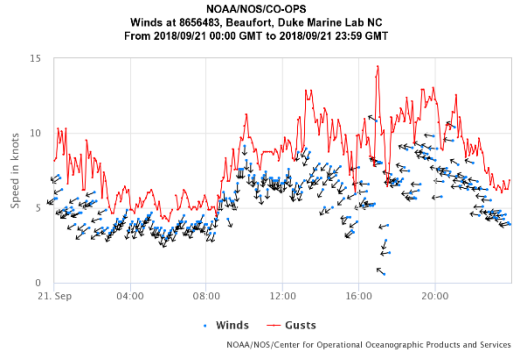
09/19/18- 09/20/18 Bogue Banks Survey

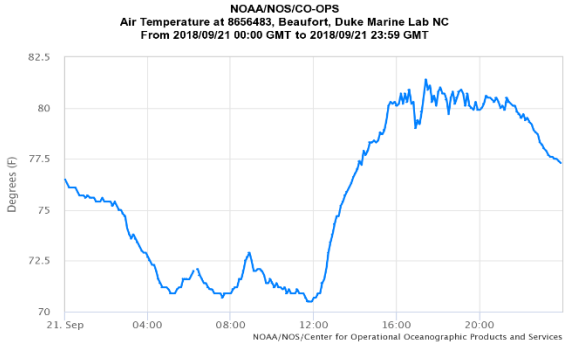


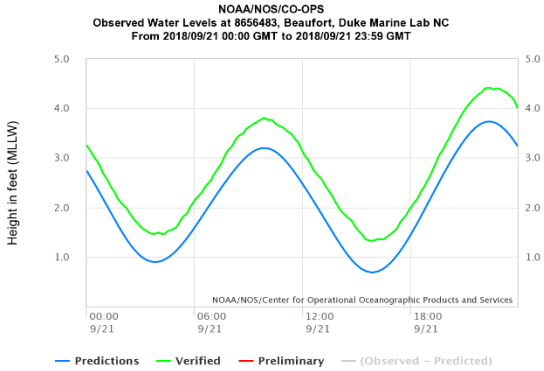




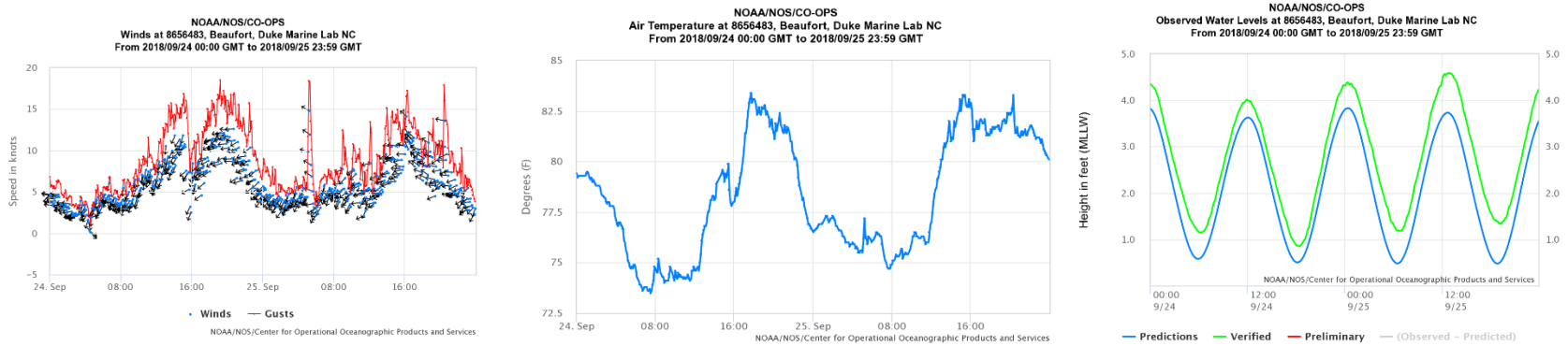
09/21/18 Bogue Banks Survey







09/24/18-09/25/18 Bogue Banks Survey



09/26/18 Bogue Banks Survey

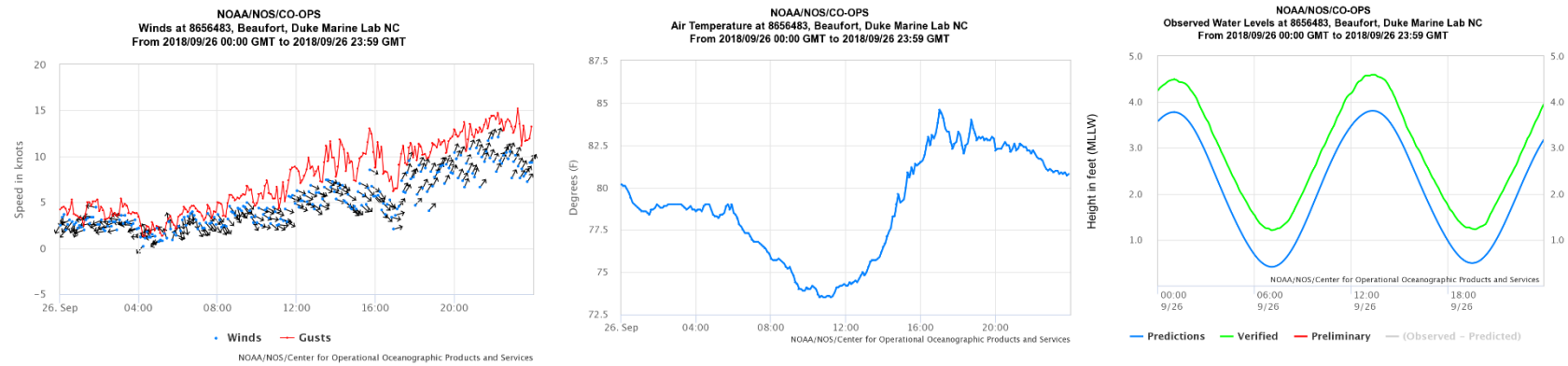


Figure 2. Atmospheric and tidal records for survey days.

1.7 Survey Personnel

All survey crew throughout the surveys were provided by Geodynamics. These personnel contributed to the vessel mobilization, data collection, vessel demobilization efforts, processing, and reporting (Table 2).

Table 2. List of Survey Personnel and Responsibilities

Survey Participant	Title	Affiliation
Ben Sumners	Lead Hydrographic Surveyor	Geodynamics
Aron Lembke	Captain, Survey & Logistics Manager	Geodynamics
Dave Bernstein	Project Manager	Geodynamics
Rohan Rao	Field Surveyor	Geodynamics
Dan Ott	Captain, Hydrographic Surveyor	Geodynamics
James Willey	Field Surveyor	Geodynamics
Nick Damm	Field Surveyor	Geodynamics
Brian Johnson	Captain, Hydrographic Surveyor	Geodynamics
Zach Gray	Field Surveyor	Geodynamics

1.8 Navigation and Positioning

Each data point obtained during the hydrographic and topographic survey activities have a geographic location associated with it to facilitate database entry and display of these data within a GIS frame work. To more accurately position elevations, all elevations/soundings were collected with Real Time Kinematic (RTK) GPS corrections to provide < +/-0.20 ft vertical and < +/-1.0 ft horizontal accuracy, as requested per SOW. RTK-GPS corrections were generated from a Global Navigation Satellite System (GNSS) enabled, R7 Trimble receiver and broadcasted via 5 dB gain UHF antenna from the base station installed by Geodynamics at one of two locations, based on area to be surveyed and extents of UHF transmission (Table 3, Figure 3). HYPACK Max utilized an X/Y grid system based on the North American Datum of 1983 (NAD83), North Carolina State Plane Feet Zone 3200 (NC SPF83) and reduced from the ellipsoid using Geoid 2012A.

Table 3. RTK-GPS base station coordinates.

Base station Name	Latitude	Longitude	Ellipsoid Height (NAD83)	Orthometric Height
ERBA BASE	34 40 32.92648 N	076 57 24.30785 W	-28.436 m	8.873 m
TRIPLE BASE	34 41 58.99941 N	076 42 39.47771 W	-35.725 m	1.752 m

TRIPLE Base

ERBA Base

Figure 3. Photos showing the "ERBA Base" and "TRIPLE" base stations.

A. TOPO-BATHY PROFILES

2.0 Singlebeam Sonar Survey Methodology

2.1 Equipment and Control

2.1.1 Vessels

2.1.1.1 R/V Echo

The R/V Echo served as the primary survey platform for nearshore singlebeam data acquisition (Figure 4, Table 4). The R/V Echo is specifically designed to be a vessel of opportunity for shallow water inshore and coastal ocean mapping. The R/V Echo is equipped with a thru-hull transducer that is tightly coupled with inertial navigation system (INS) for positioning and elevation. On-the-fly sound speed sensors and customized computer systems allow seamless logging of bathymetric data.

Figure 4: R/V Echo

Table 4: R/V Echo Vessel Specifications

Dimensions:	21' x 9' x 1.2'
USCG:	Designated Research Vessel
Flag:	U.S.
Registry:	North Carolina
Official Number:	NC 7341 DT
Tonnage:	1
Lab space:	1 open console operator station
Max Speed:	30 knots
Min. survey speed:	2.5 knots
Propulsion:	1 x 140 HP Suzuki 4-Stroke Outboard Motor -2011
Auxiliary Power:	24v DC battery bank and 12v DC parallel battery banks
Fuel capacity:	60 gallons
GPS:	Simrad
Sounder:	Lowrance StructureScan
Compass:	n/a
Radar:	n/a
Autopilot:	n/a
VHF:	Icom 25 watt
Internet:	Verizon 4G Jetpack

2.1.1.2 Software Systems Inventory

Software utilized throughout the project can be seen in Table 5.

Table 5: Software Systems Inventory

	Software	**Version**
Data Acquisition	HYPACK	2018
	Odom E-Chart	1.4.0
	POSView	8.21
	SeaCast	4.3.1
	NTRIP Client	2013.11.24
Data Processing	HYPACK	2018
	POSPac	7.1 SP3
	ArcGIS	10.5
	MS Office	2016
	Surfer	9

2.1.1.3 Hardware Systems Inventory

Hardware utilized throughout the hydrographic survey can be seen in Table 6.

Table 6: R/V Echo Hardware Systems Inventory

	Hardware Equipment	Manufacturer	Model
Horizontal & Vertical Control	RTK Radio Modem	Trimble	TDL 450H
	RTK Radio Antenna	Pacific Crest	n/a
	GPS Antenna	Trimble	Zephyr
	Cellular Internet Card	Verizon	4G LTE JetPack
	POS MV	Applanix	WaveMaster
Echo Sounding	StructureScan	Simrad	1.7.0
	ODOM CV100	ODOM	CV100
	Operator Station	CCS-inc	FPC-04649
Attitude Positioning	Inertial Motion Unit (IMU)	Applanix	WaveMaster
	Position Compute System (PCS)	Applanix	WaveMaster
	Primary GPS Antenna (port)	Trimble	Zephyr
	Secondary GPS Antenna	Trimble	Zephyr
Sound Speed	Sound Profile Velocimeter	AML Oceanographic	Minos X SVP

2.1.1.4 Sonar Equipment

An Odom CV100 singlebeam sonar system was used to acquire singlebeam bathymetry data during the topo-bathy profile survey (Figure 5). The CV100 system operates at frequencies in the 200 kHz band; ideal for shallow depths. The transducer forms a 4 degree conical beam. With an operational depth range from <30 cm to 600 m and a ping rate up to 20 Hz, the CV100 is ideal for shallow water surveys (Table 7).

Table 7: CV100 specification

Frequencies.	200 kHz / 33 kHz
Maximum ping rate.	up to 20 Hz
Heave compensation	Yes
Depth resolution	1 cm
Transducer	Airmar SMSW200-4a

Figure 5: Odom CV100 digital echosounder mounted on the R/V Echo.

2.1.2 Vertical Control

The vertical datum for the final survey data is the North American Vertical Datum of 1988 (NAVD88). The ellipsoid-based real-time vertical water level corrections were reduced to the NAVD88 by integrating a local Geoid 2012A model in the singlebeam data processing stage.

2.1.3 Horizontal Control

Horizontal positioning and vessel attitude for singlebeam data was provided by the POS MV system and was corrected using Inertial-Aided Real-Time Kinematic (IARTK) technology. This system provides roll and pitch accuracy to 0.01°, heading to 0.02° (with a 2 m antenna baseline), heave accuracy to 5 cm or 5% (whichever is greater).

2.2 Singlebeam Data Acquisition

2.2.1 Data Acquisition Software

The HYPACK software suite was used during survey preparation to create survey line plans and evaluate the overall survey scheme. The initial line plan was created in HYPACK using a line spacing such to acquire survey data over pre-existing profiles developed by USACE. HYPACK was also used during the survey in order to record sounding and position data. HYPACK was also used to log targets of importance and provide the captain with line tracking.

The ODOM eChart software was used as a start-up interface to establish communications with the echosounder, check/verify essential echosounder settings and provide transmit and receive gain controls of the singlebeam echosounder.

The POSView software by Applanix was used with the POS MV system. The software provides the interface to view, monitor, and record tightly-coupled integration of the attitude measurements from the IMU and position and heading measurements recorded by the GPS. The recorded POSPac file which contained all of the attitude, positioning, heading, and error estimates of attitude and positioning provides a method to post-process attitude and navigation data in the event of RTK-GPS cycle slips.

2.3 Singlebeam Data Processing

2.3.1 Processing Workflow

Figure 6 illustrates the workflow in singlebeam sonar data processing.

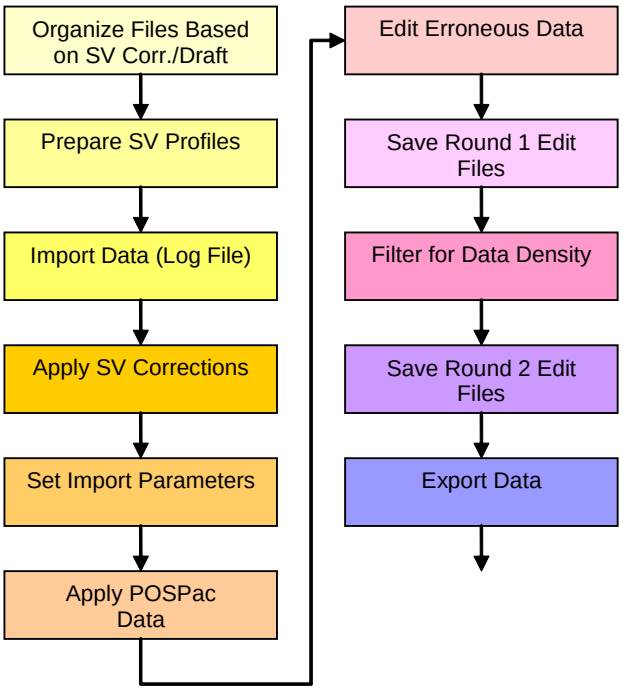


Figure 6: HYPACK singlebeam data processing workflow.

2.3.1.1 Corrections to Echo Soundings

2.3.1.2 POS MV WM Correctors

The Applanix POS MV unit was setup to receive phase-differential RTK position offsets from the RTK-GPS base station. This configuration allowed the POS MV to integrate decimeter positional solutions with highly-accurate vessel attitude positions obtained from the IMU. When the GAMS is online, positional solutions were being received from 5 or more satellite fixes with a Positional Dilution of Precision (PDOP) equal to or less than 3. When these conditions were not satisfied, the GAMS solution becomes dormant. The GAMS program continues to track satellites while in this state, but does not process the phase-differential corrections real-time.

A verification of the GAMS system was conducted prior to the start of the project. The values in use for this survey were obtained from a GAMS calibration that followed the auto-start procedure laid out in the POS MV V5 Installation and Operation Guide. The GAMS parameters in the setup menu were initially set to zero, with the exception of the heading calibration threshold which was set to 0.500°. The vessel then made aggressive figure-8 maneuvers until the GAMS solution came online and the values in the parameter setup menu were automatically updated. This calibration remains valid until vessel offsets are changed.

Due to inherent and common problems associated with RTK-GPS, such as cycle slips, high DOP periods, and data gaps, the POSPac data is routinely post-processed in the Applanix POSPac software suite. For this survey, however, RTK-GPS quality was excellent during hydrographic data collection and adding the processed POSPac data to the final data was deemed unnecessary. The POSPac data were processed only to verify and provide quality assurance for the RTK-GPS data.

2.3.1.3 Dynamic Draft Correctors

Dynamic draft is the summation of the static draft and settlement and squat corrections, and is a required corrector for the echo soundings. Dynamic draft was accounted for in the echo soundings by using RTK-GPS ellipsoid-based vertical corrections. The combined correctors work to continuously factor out the static draft, settlement, and squat of the survey vessel.

2.3.1.4 Sound Speed Correctors

The AML Oceanographic Minos X SVP (Figure 7) sound velocimeter was used during the survey in order to obtain accurate sound speed profiles throughout the survey area.

The Minos X system onboard R/V Echo is used to log sound velocity casts throughout the day and is later connected to a computer where the survey technician downloads the sound speed profile data.

Figure 7: AML Oceanographic Minos X Velocimeter.

Sound speed profiles were taken at the start of each survey day, and again throughout the day as warranted by the survey area and water properties. Sound speed profiles were also acquired when the survey vessel moved to a different location in the survey area (Figure 8). Each sound speed cast was assessed in processing to determine the need to isolate casts for specific regions within the surveyed areas.

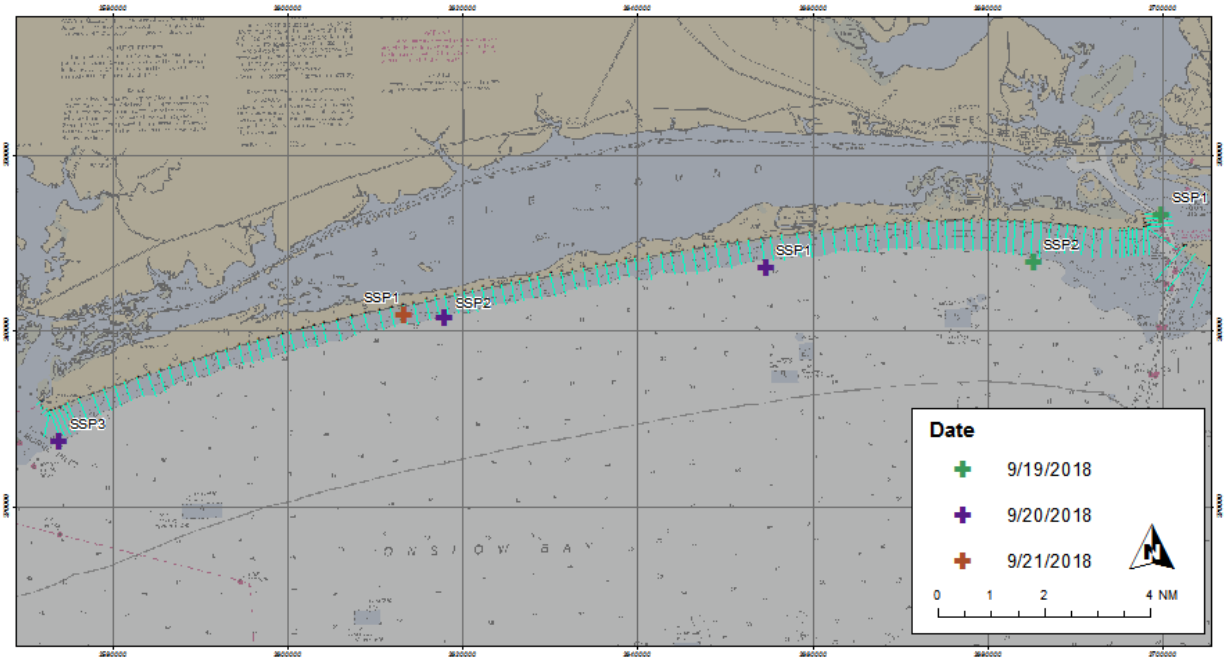


Figure 8: Sound speed profile locations for singlebeam survey operations.

2.3.1.5 Water Level Correctors

RTK-GPS based tidal measurements were continuously recorded throughout the survey by HYPACK Survey. The GPS height determined by the POS MV was integrated into the raw singlebeam sonar data during data acquisition in real time. After importing the raw singlebeam data in HYPACK, the GPS tide was merged with the heave such to provide accurate tidal corrections and subtract vessel heave from the final elevations.

2.4 Quality Control

2.4.1 Singlebeam Data Acquisition and Monitoring

At the start of each survey day, a series of pre-survey protocols were run to aid in quality control and to determine any possible errors/issues prior to surveying. For hydro, the GAMS parameters and POS MV installation parameters located under the installation settings of the POS MV were all checked each day prior to enabling Ethernet logging of POSPac data.

Data was collected at vessel speeds of approximately 3 - 10 kt. The HYPACK data acquisition software provides data waterfalls and coverage indicators, which allowed for real-time monitoring of the data quality and coverage. Data displays in HYPACK Survey were used to monitor all survey parameters and the quality of data being recorded.

Sound speed profiles were acquired routinely and when the survey vessel moved to a different location within the survey area. Each successive sound speed cast was compared and assessed to determine the optimal casts per reach of profiles.

2.4.2 Singlebeam Calibration Checks

The R/V Echo has a built-in transducer in the rear of the starboard hull. Geodetic and mechanical bar index checks have been performed to calibrate for a constant, electronic offset, inherent in all singlebeam systems (Figure 9). Please refer to Appendix C: Singlebeam Echosounder Calibration Report, for more details.

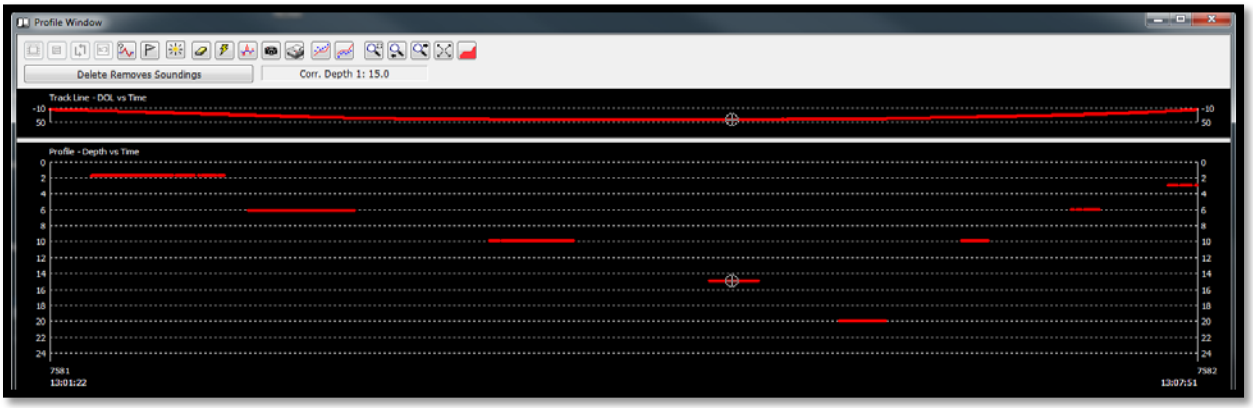


Figure 9: Image illustrating the mechanical bar check of sonar index.

A more recent technique to calibrate sonars for sound velocity is a digital bar check, or sound speed cast (Figure 8). Similar to performing a bar check, in theory, digital bar checks are a safer and more efficient alternative to traditional bar checks, and are critical to sonar data acquisition in shallow, inter-tidal, coastal zones. Therefore, in order to maintain the best data quality across vast areas in this dynamic coastal environment, the traditional mechanical bar check (Figure 9) is only used to verify the sonar system index since corrections are made to the transducer (not the waterline) and sound speed profiles correct the sounder for speed of sound in the water column.

3.0 Topographic Elevation Data Methodology

3.1 Equipment and Control

3.1.1 Survey Equipment

A Trimble R7 RTK-GNSS rover backpack system was used to acquire topographic data in the dunes and surfzones. The Trimble R7 RTK-GNSS receiver integrates GNSS observables with real-time RTK network corrections to provide centimeter-level position and elevation. The RTK-GNSS data is output from the R7 receiver at 10 Hz to the Panasonic Tough book FZ-M1 data acquisition tablet PC (Table 8). An ATV is used to transport personnel between profiles, as well as a platform to collect MLS data (Figure 10).

Figure 10: ATV used for transportation.

3.1.2 Hardware Systems Inventory

Hardware utilized throughout the backpack-topographic survey can be seen in Table 8.

Table 8: Hardware Systems Inventory

Hardware Equipment	Manufacturer	Model
Acquisition PC	Panasonic	Toughbook FZ-M1
GPS Receiver	Trimble	R7
GPS Antenna	Trimble	Zephyr 2

3.1.3 Vertical and Horizontal Control Equipment

Horizontal and vertical positioning for topographic data was acquired by a Trimble R7 RTK-GNSS system. The topographic rover received and integrated the differential corrections from the RTK-GNSS base station for centimeter-level positioning.

3.1.4 Software Systems Inventory

Software utilized throughout the backpack-topographic survey can be seen in Table 9.

Table 9: Software Systems Inventory

	Software	Version
Data Acquisition	HYPACK	2018
	NTRIP Client	2013.11.24
Data Processing	HYPACK	2018
	ArcGIS	10.5
	MS Office	2016
	Surfer	9

3.1.5 Data Acquisition Software

The HYPACK software suite was used during survey preparation in order to create profile line plans. The initial line plan was supplied by USACE Wilmington District. HYPACK was also used during the survey to collect topographic data, as well as for in-field quality control and real-time quality assessment.

3.1.6 Data Processing Software

HYPACK was used to manage and process the topographic data. The Singlebeam Editor in HYPACK was used to import, clean, and thin the data.

ArcGIS is a complete Geographic Information Systems (GIS) software package. All survey area maps, coverage extents, and final chart products were created using ArcGIS.

3.2 Quality Control

3.2.1.1 Procedures

3.2.1.2 Survey Planning

All survey line planning was completed in HYPACK. The landward extent of topographic data collection was set to provide coverage to the extents of prior USACE topographic data. All profiles were generated from predefined start point, distances, and azimuths per USACE.

3.2.1.3 Topographic Data Acquisition and Monitoring

At the start of each survey day, a series of pre-survey protocols were run to aid in quality control and to determine any possible errors/issues prior to surveying. Each surveyor's backpack antenna draft was checked and input in the HYPACK survey software. Data acquisition was performed by experienced surveyors, walking as upright and consistent as possible while following the planned survey line, as to mimic the topography. The surveyor constantly monitored GPS status, off-line value, distance from baseline (DBL), previous data coverage, and overall morphology along the profile. To ensure ample topographic data overlap with the hydrographic data, the

surveyor would plot the targets acquired during the surfzone hydrographic survey. These targets indicated how far the surveyor needed to go down the profile and into the surfzone. Upon completion of a survey day and throughout the day, data was thoroughly reviewed and various profiles overlaid on previous profile data for an in-field quality assurance check.

3.3 Topographic Data Processing

Topographic data processing occurred in HYPACK Singlebeam Editor software and follows the general procedure illustrated in Figure 11.

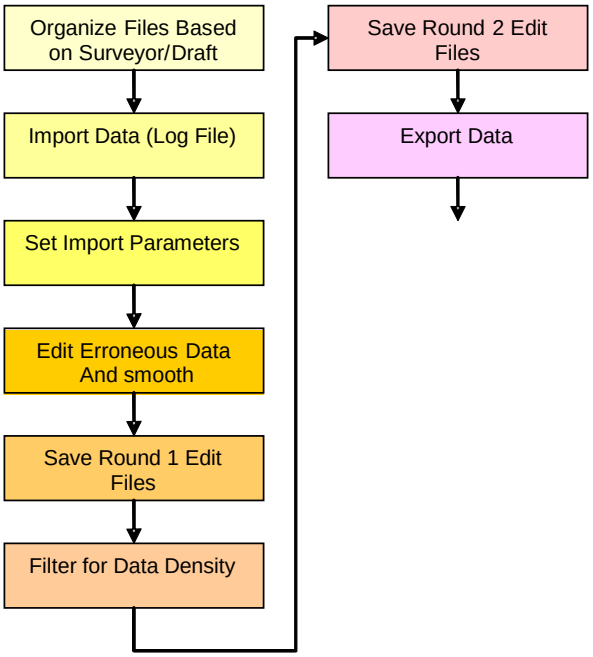


Figure 11: HYPACK topographic data processing workflow

4.0 Mobile Laser Scanning Data Acquisition and Processing

4.1 Equipment

4.2 Mobile Laser Scanning Equipment

MLS topographic data were collected using a RIEGL VZ-400i 3D laser scanning system. The MLS was mounted on a Polaris ATV approximately eight feet above the terrain (Figure 12). This system was coupled with its own internal navigation and attitude system, the POS MV OceanMaster (OM), whose IMU is placed directly below the laser scanner to minimize lever arms and potential sources of alignment errors. The MLS and POS MV were integrated into QINSy, a comprehensive software suite utilized for survey planning, survey acquisition and alignment verification. POSView was utilized to monitor real-time GNSS health as well as log all navigation / attitude data for post-processing. The MLS was setup to scan the human eye field of view (from 70-130 degrees) at a scanning resolution of 0.180° at 80 kHz measurement rate and a high speed scan rate. Additionally, the MLS was setup in radar mode, therefore, the laser rotates a full 360° during data collection.

Figure 12: The Polaris ATV with the custom mount for mobile laser scanning (MLS) acquisition.

4.3 Hardware

4.3.1.1 Hardware Systems Inventory

Hardware used throughout the MLS survey can be found in Table 10.

Table 10: Laser Scanning Hardware Systems Inventory

Hardware Equipment	Manufacturer	Model
Laser Scanner	RIEGL	VZ-400i 3D
Acquisition Laptop	Dell	Rugged Laptop
Cellular Internet	Verizon	JetPack 4G
Inertial Motion Unit (IMU)	Applanix	65
Position Compute System (PCS)	Applanix	OceanMaster
Primary GNSS Antenna (port)	Trimble	AT1675-540TS
Secondary GNSS Antenna	Trimble	AT1675-540TS

4.3.2 Software

4.3.2.1 Software Systems Inventory

Software used throughout the MLS survey can be found in Table 11.

Table 11: Software Systems Inventory

	Software	Version
Data Acquisition	QINSy	8.16.0
	POSView	8.21
Data Processing	Qimera	1.6.1, 64 Bit
	ArcGIS	10.5
	POSPac MMS	8.3
	Hypack	2018

4.3.2.2 Data Acquisition Software

QINSy software suite was used to collect MLS data and provide real-time QC and QA of the MLS data.

The POSView software by Applanix was used with the POSMV OM system. The software provides a tightly-coupled integration of the attitude measurements recorded by the Inertial Motion Unit (IMU) and the position measurements recorded by the GNSS. POSView allowed the survey technician to monitor the attitude and positioning accuracy throughout the survey. POSView logged a POSPac file which contained all of the error estimates for attitude and positioning.

4.3.2.3 Data Processing Software

The POSPac MMS software by Applanix was used to post-process attitude and navigation data collected in POSView. By post-processing the attitude and navigation data stored in the POSPac data file with a logged GNSS observable file from the base station, common artifacts of RTK-GNSS can most often be eliminated and the overall accuracy of the attitude and navigation can be increased. Therefore, POSPac data is routinely post-processed in the Applanix POSPac software suite. For this survey, POSPac data was post-processed to correct MLS data where quality of GNSS collection was slightly degraded.

Qimera was used to integrate the post-processed GPS solution and manipulate and process the laser scanner data in both 2D and 3D. In Qimera, a 3 ft surface of the beach face was created using the MLS data. Upon cleaning the data for errors and noise, the Export Dynamic Surface tool was used to export the surface as an ASCII file. This ASCII was then extracted to the mid-beach portion of the profiles in HYPACK and was also used in DEM generation. The Singlebeam Editor in HYPACK was then used to clean and merge the XYZ points on the line with the profile data.

4.4 Quality Control

4.4.1 Procedures

4.4.1.1 Survey Planning

Pre-survey checks were done to ensure the laser was mounted properly. Integrated systems were tested at the Morehead City office facility prior to on-site mobilization.

4.4.1.2 Laser Scanning Data Acquisition

At the start of the survey day, a series of pre-survey protocols were run to aid in QC and to determine any possible errors/issues prior to surveying. The POS MV OM installation parameters located under the installation settings of the POS MV OM were all checked each day prior to enabling Ethernet Logging of POSPac data.

All laser data acquisition was completed using QINSy software. Data acquisition was performed at speeds of approximately 5 knots along the main beach face, between the bottom of the first dune and the waterline. The QINSy data acquisition software produced a constantly-updated OTF gridding, which allowed for real-time monitoring of the data coverage. Data displays in QINSy software and POS MV OM were used to monitor all survey parameters and the quality of data being recorded.

4.5 Corrections to Laser Data

4.5.1 Sensor Offsets

The vessel offsets are measured with respect to the vessel's reference point, located at the top center of the IMU. The vessel offsets are entered into POSView to ensure an accurate merging of the IMU data with the MLS data. The remaining correctors for roll, pitch, and yaw were analyzed in a patch test of the system, and integrated into Qinsy.

4.5.2 POS/WM Correctors

The Applanix POSMV OM unit was setup to receive phase-differential RTK position offsets from the base station. This configuration allowed the POS MV OM to integrate decimeter positional solutions with highly-accurate vessel attitude positions obtained from the IMU. When the GAMS is online, positional solutions were being received from 5 or more satellite fixes with a PDOP equal to or less than 3. When these conditions were not satisfied, the GAMS solution becomes dormant and survey operations halted. The GAMS program continues to track satellites while in this state, but does not process the phase-differential corrections real-time.

Verification of the calibration of the GAMS system was conducted at the start of survey on 09/19/18 on site, following the auto-start procedure laid out in the POS MV V5 Installation and Operation Guide. To calibrate the GAMS system, GAMS parameters in the setup menu are initially set to zero, with the exception of the heading calibration threshold which was set to 0.500°. The platform then makes aggressive figure-8 maneuvers until the GAMS solution came online and the values in the parameter setup menu were automatically updated.

4.5.3 Dynamic Draft Correctors

Dynamic draft is the summation of the static draft and settlement and squat corrections, and is a required corrector for the MLS data. Dynamic draft was accounted for in the MLS data by using RTK-GNSS. The ellipsoid-based vertical corrections received from the RTK-GNSS base station

provided the survey vehicle with an accurate real-time elevation based on the vehicle's position. The combined correctors work to factor out the static draft, settlement, and squat of the survey vehicle.

4.6 Data Processing

4.6.1 Laser Scanning Data Processing

MLS data was processed using Qimera. The data was filtered by height to remove unwanted data landward of the first dune and seaward of 0' NAVD88. In addition, to reduce the millions of points to a manageable dataset and remove fliers, a medium spline filter was run on all the data. Once the data was filtered it was hand cleaned to remove any errant data points the filters missed.

4.6.1.1 Processing Workflow

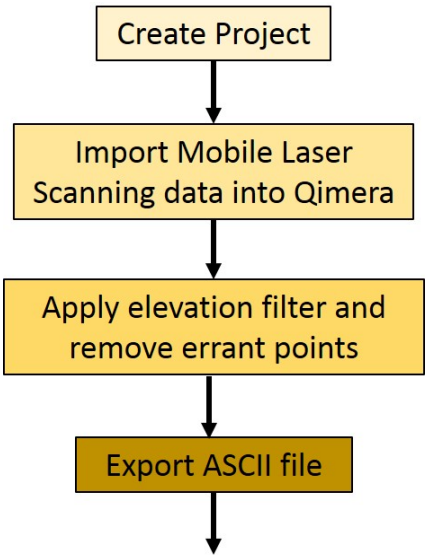


Figure 13: Qimera data processing workflow

4.6.1.2 Correctors Applied in Post-Processing

Due to inherent and common problems associated with RTK-GNSS, such as cycle slips, high DOP periods, and data gaps, the POSPac data is routinely post-processed in the Applanix POSPac software suite. For this survey, POSPac data was post-processed and utilized for MLS data to fix areas of slight degraded GNSS quality.

5.0 Topo-Bathy Profile Merging

The production of seamless topo-bathy profiles follows the general procedure illustrated in Figure 14. XYZ data from a 3 ft MLS grid was trimmed to the mid-beach extents, and Topographic and bathymetric portions of the profiles are merged in HYPACK following independent processing procedures. Overlap was assessed and cleaned for consistency where necessary. Profile elevation data was generated in formats required by the SOW. Completed profiles for all Bogue Banks are shown in Figure 15.

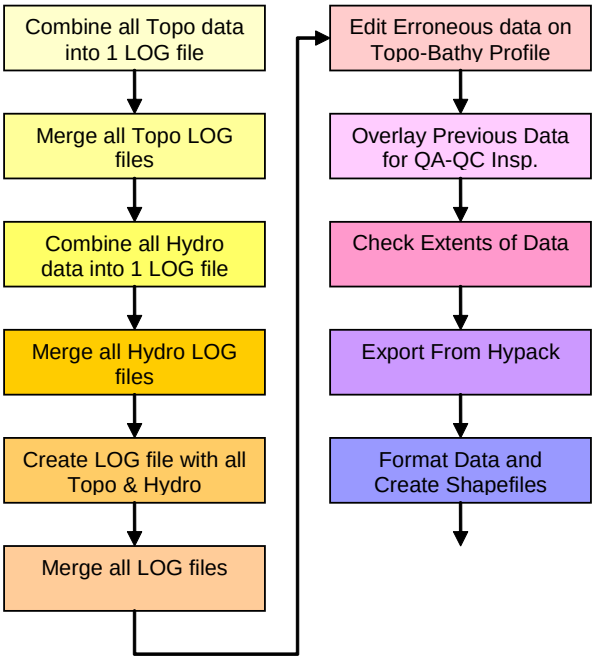


Figure 14: HYPACK topo-bathy profile data processing workflow

Rigorous QA-QC assessments are performed on the final topo-bathy profiles to ensure the accurate data products. For topographic data, in the less variable dune areas, current data is overlaid with previous data and the horizontal and vertical alignment is evaluated. For hydrographic data, in the furthest offshore sections, elevations are compared where they are expected not to significantly change. The following maps (Figure 15) illustrate depths and extents of the topo-bathy profiles. The merged topo-bathy profiles are examined one-by-one to review the overlap of topographic and hydrographic data to guarantee reliable surfzone data and overlap (Figure 16).

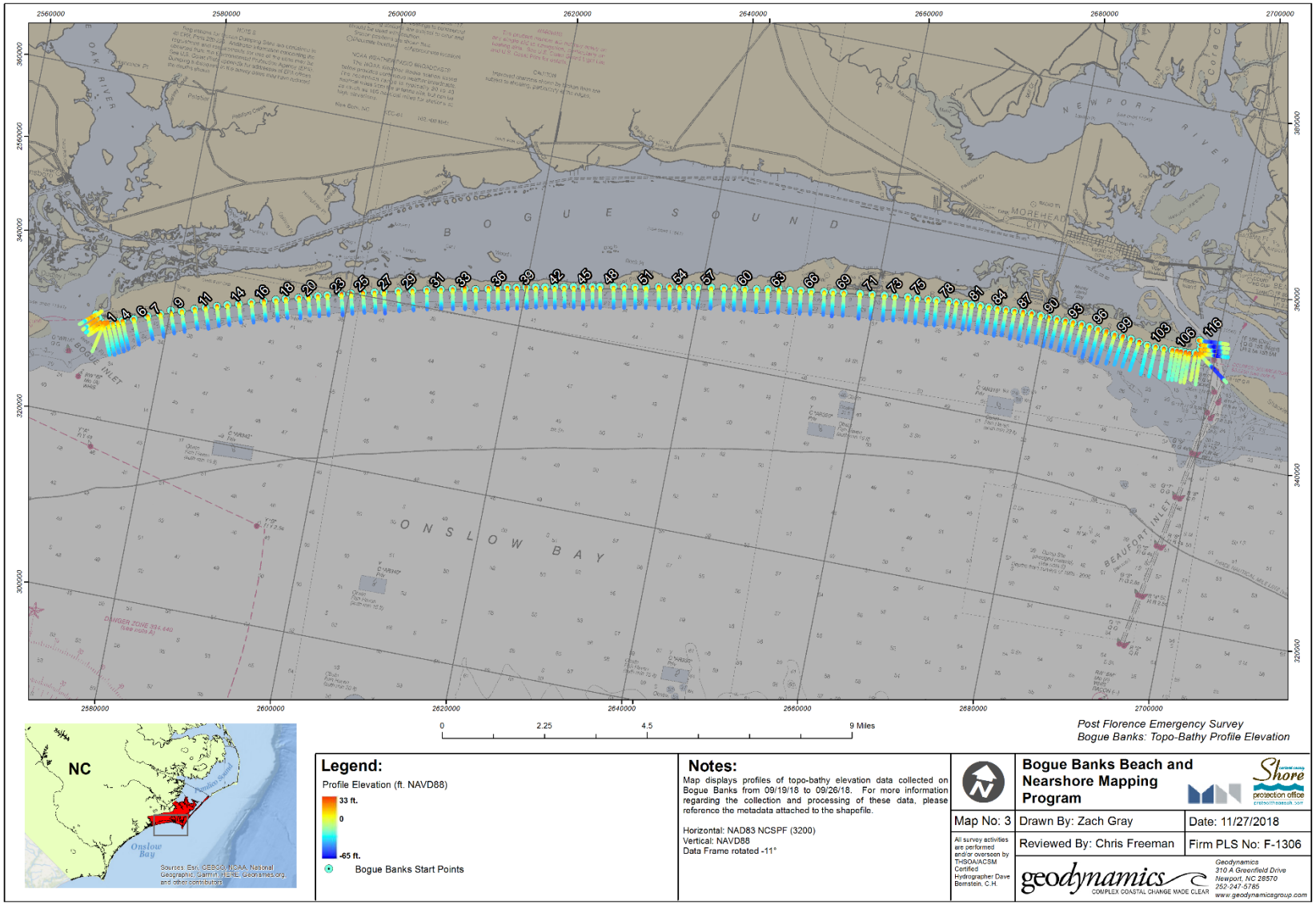


Figure 15. Topo-bathy profiles for Bogue Banks.

Figure 16. Typical topo-bathy overlap for BBNMP.

B. HOTSPOT DIGITAL ELEVATION MODELLING

A 3 ft cell sized DEM was developed using the mobile laser scanner data for three areas defined as Hotspots, labelled West, Central, and East (Figure 17). The DEM was cleaned and developed in Qimera and exported for ArcGIS analysis. These DEMs are annual products, and following the first year, can be differenced to analyze change within these areas. As mentioned in the last report, landward and seaward extents will vary between years, depending on the overall shape of the beach, dune base, width of beach, and tidal level during the time of the survey, but will capture dune base to MLLW contour each year. This is particularly noticeable when comparing the Post Florence DEM to the previous, 2018 annual survey DEM, as much of the dune fronts were eroded. Figure 18 displays a detailed 3D example of the shoreface captured by the MLS for a portion of the Central Hotspot DEM. The dune base was digitized through a coordinated elevation, slope, aerial, and statistical analysis.

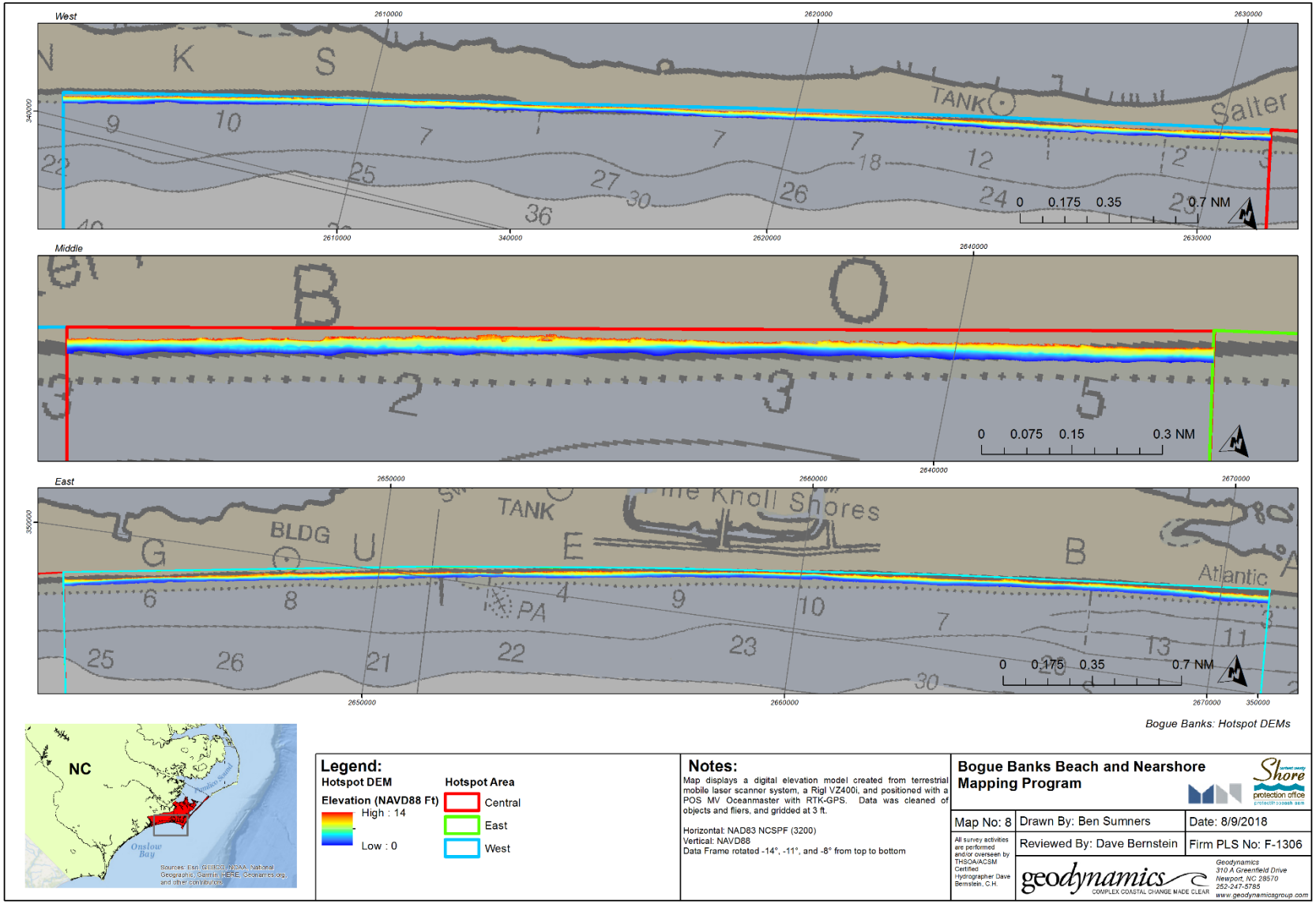


Figure 17. DEM generated for defined hotspot areas along Bogue Banks.

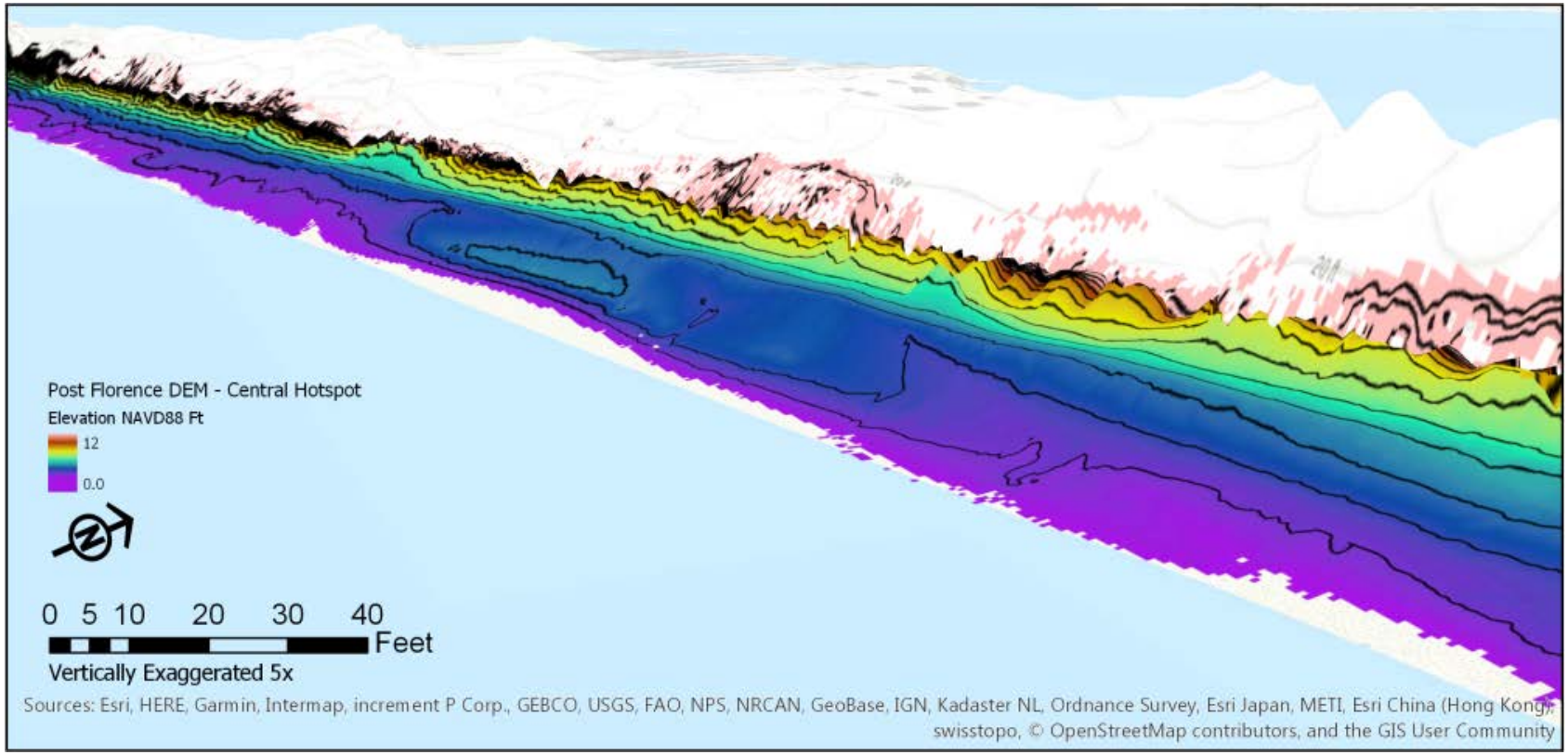


Figure 18. A zoomed-in view of the Bogue Banks Central Hotspot DEM with 1 ft contours.

C. QUALITY ASSURANCE

5.1 Digital Elevation Model: Chart Comparison

DEMs have been developed in the past using a combination of topo-bathy profiles and ATV tie-lines, developed with a range of kriging variogram parameters among multiple grids, and stitched together to create one complete DEM for each island. For the 2018 – 2022 surveys, MLS data is now used for DEM generation, targeted at three main hotspots across Bogue Banks. As the accuracy and parameters are drastically different than previous methods. This post-storm survey is the first to provide a high-resolution dataset comparison. It should be noted that the MLS methods employed are not targeted at obtaining data beyond the first dune front. As a result, the difference between the post-storm and annual survey datasets do not capture the total volume lost, as the 2018 annual survey DEM does not capture dune elevations to where the current top of dune exists. Figure 19 illustrates the extents of both DEMs and the change between the two 2018 surveys.

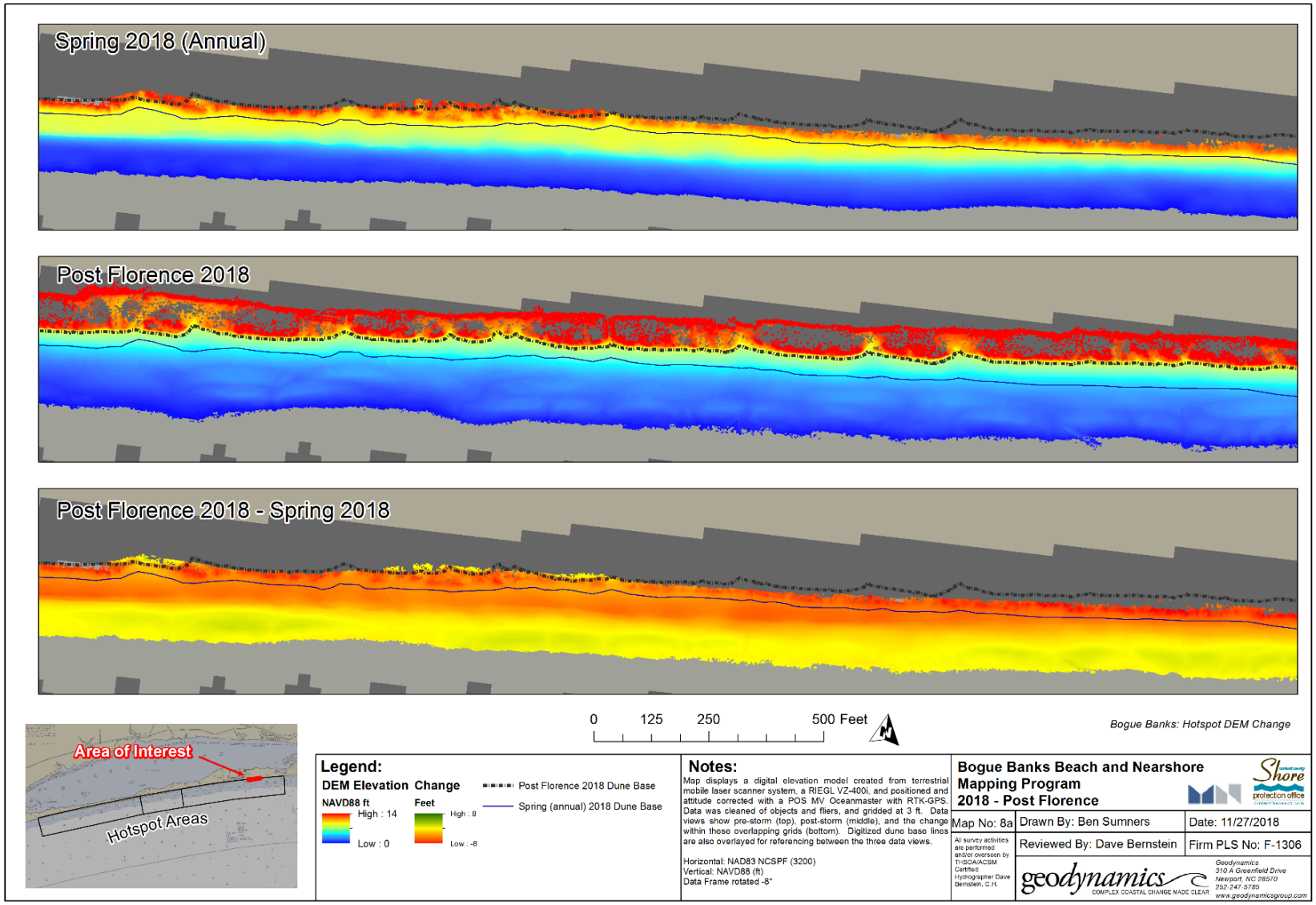


Figure 19. A comparison of DEMs from the annual, Spring 2018 survey and the Post Florence survey, showing change in morphology and the location of the dune base between the surveys.

5.2 Topo-bathy Profile and Tie-line Overlap Comparison

A statistical comparison was made between the XYZ dataset extracted from a 3 ft MLS grid, along with the topographic data acquired with the traditional RTK-GPS Backpack method for dunes and surf zones (Figure 20). A search radius of 0.5 ft was used to look for MLS points and compare their elevations with the backpack acquired elevations. The statistics show the data are within 0.05 ft on average, and report a standard deviation of 0.5 ft, indicating good agreement considering the variability of beach slopes surveyed with this detail and the variable elevations of shoreface features that may be up to 1 ft apart horizontally.

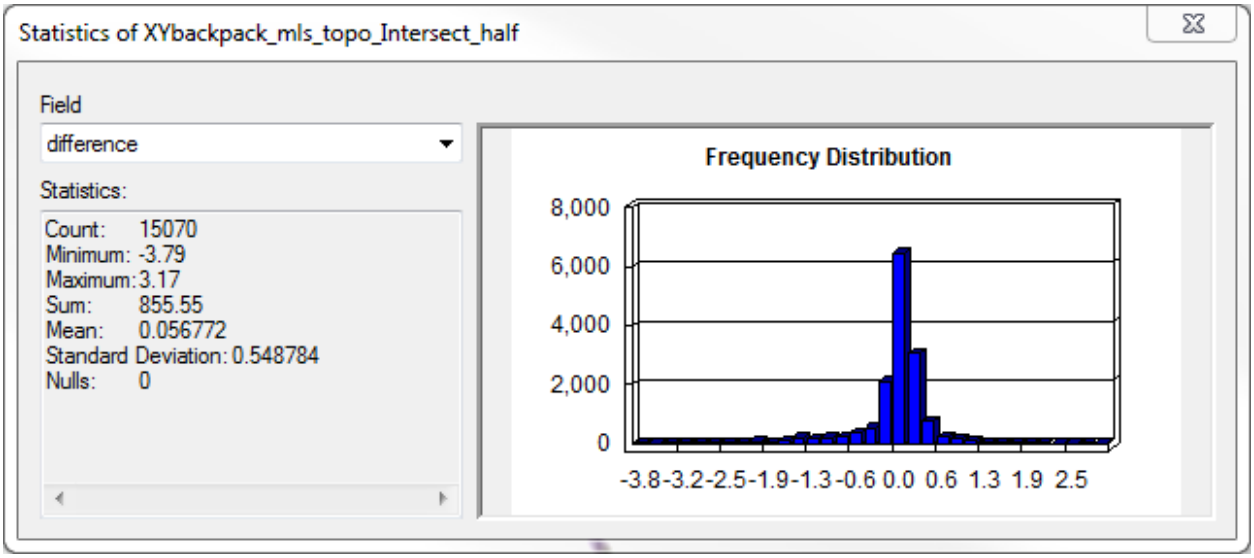


Figure 20. MLS topo from DEM-XYZ to backpack topo comparison.

D. CONCLUDING REMARKS

Survey data collected for the Bogue Banks Beach and Nearshore Mapping Program project meets and exceeds the requirements set forth in the USACE provided SOW, including the criteria for Class 1 Hydrographic Surveys as outlined in the U.S. Army Corps of Engineers Hydrographic Surveying Manual, EM 1110-2-1003 and Hydrographic Surveying and Engineering Circular, EC 1130-2-210.

The topographic-bathymetric profiles along Bogue Banks showed excellent agreement to prior surveys. All attempts were made so that topographic and hydrographic prior extents met the 2017 survey. Any notable obstructions on profiles causing offline distances greater than previous surveys are supplied as a KML file with georeferenced photos. This survey only had one obstruction on profile 75. It should be noted that some sections of topo had to be navigated on alternate routes from previous years to avoid collecting data over large piles of debris.

The application of using MLS data to collect mid-beach portions of data, generate the MHW contour, and extract the dune base was successful while improving the overall product accuracy. This dataset will provide a thorough means to assess shoreface erosion in the following years and in the event of a major storm.

APPENDIX A: SURVEY ACTIVITY LOGS

Daily Survey Field Notes

Date:	9/19/2018	**Day of Year:**	262
Time SOS (local):	7:30	**Time EOS(local):**	18:00
Project:	CCSPO Post Florence 2018		
Survey Location:	Bogue Banks, NC		
Hydro Crew:	Aron Lembke	James Willey	
Topo Crew:	Dan Ott	Brian Johnson	Rohan Rao

Atmospheric Conditions		**Water Conditions**	
Sky:	Partly Cloudy	**Swell:**	0.5 - 1.0 ft
Wind Speed:	5-10 KT	**Chop:**	0.5 - 1.0 ft
Wind Direction:	SW	**Temp:**	70-80 F
Temp:	80-90 F		

Survey Activities

Control

Aron and James set base station TRIPLE. They then checked benchmark station Anchorage. Two points were collected and checked successfully.

Topo

Dan and Rohan unloaded ATVs at the Atlantic Beach Circle and collected from the Iron Steamer region east to Fort Macon, covering lines 68 to 104. Brian collected laser from the Fort Macon to the Iron Steamer region. All data were acquired while operating off of base station TRIPLE. Brian and Dan concluded the day by setting up base station ERBA.

Hydro

Aron and James launched the Echo from Anchorage Marina, and transited to the survey area. Offshore lines were collected from line 116 to line 67. Later in the day, the boat transitioned to surf zones in the same area in accordance with the high tide. Two sound velocity casts were collected, one inshore near Fort Macon and one offshore of the Atlantic Beach Pier.

Daily Survey Field Notes

Date:	9/20/2018	**Day of Year:**	263
Time SOS (local):	7:30	**Time EOS (local):**	18:00
Project:	CCSPO Post Florence 2018		
Survey Location:	Bogue Banks, NC		
Hydro Crew:	Aron Lembke	James Willey	
Topo Crew:	Dan Ott	Ben Sumners	Brian Johnson

Atmospheric Conditions		**Water Conditions**	
Sky:	Partly Cloudy	**Swell:**	1-2 ft
Wind Speed:	5-10 KT	**Chop:**	1-2 ft
Wind Direction:	SW	**Temp:**	70-80 F
Temp:	80-90 F		

Survey Activities

Control

Aron and James set up base station TRIPLE, and collected two points at benchmark station Anchorage. Both checked successfully. Brian started base station ERBA, and Dan collected two points at benchmark station Chapel. Both checked successfully.

Topo

Ben and Dan unloaded ATVs at the Atlantic Beach Circle and started surf zones. Dan worked towards east towards Fort Macon. Ben worked to the west towards the Emeral Island pier. When Dan finished Fort Macon, he went to the East Regional beach access and worked east towards Ben. Surf zones 26 to 116 were completed. Ben returened to office and Dan transitioned to dunes, collecting lines 55 to 67. Brian collected laser data from the Iron Steamer region to just west of the Emeral Island Pier, using base ERBA.

Hydro

Aron and James launched the Echo from Anchorage. All remaining offshore hydro lines were completed from line 67 to line 1, and then offshores for 117 through 120 around Emerald Island Point. Surf zones were collected from line 35 to line 66. Further collection was postponed due to worsening surf conditions. Two sound velocity casts were collected throughout the day.

Daily Survey Field Notes

Date:	9/21/2018	Day of Year:	264
Time SOS (local):	7:00	Time EOS(local):	18:00
Project:	CCSPO Post Florence 2018		
Survey Location:	Bogue Banks, NC		
Hydro Crew:	Aron Lembke	James Willey	
Topo Crew:	Dan Ott	Ben Sumners	Aron Lembke	James Willey

Atmospheric Conditions		Water Conditions	
Sky:	Clear	Swell:	0.5 - 1.0 ft
Wind Speed:	0-5 KT	Chop:	1-2 ft
Wind Direction:	ENE	Temp:	70-80 F
Temp:	80-90 F		

Survey Activities

Control

Base station ERBA was used, and checked successully in the morning at benchmark station Chapel. Aron set up a repeater at base LOON in the afternoon to improve radio signal on Emerald Island Point.

Topo

Dan completed collection of laser data from the Emerald Island Pier west to Emerald Island Point. Ben completed surfzones from line 25 down to line 1, and then from line 117 to 120 around Emerald Island Point. James transitioned to dunes, and collected from line 120 to 117 on the Point, and then from line 1 to line 8. All data were collected using base ERBA and a repeater.

Hydro

Aron and James launched the Echo from the public ramp located at Cedar Island. Surf zones were collected for lines 120 through 117 in Bogue Inlet, and then from line 1 to line 34 along Emerald Island Beach. The crew then transited to lines 72 and 106 to collect recoveries. A sound velocity cast was collected in both the primary work area in the west and the recovery area in the east.

Daily Survey Field Notes

Date:	9/24/2018	Day of Year:	267
Time SOS (local):	8:00	Time EOS(local):	18:00
Project:	CCSPO Post Florence 2018		
Survey Location:	Bogue Banks, NC		
Hydro Crew:			
Topo Crew:	Zach Gray	James Willey	

Atmospheric Conditions		Water Conditions	
Sky:	Light Rain	Swell:	
Wind Speed:	5-10 KT	Chop:	
Wind Direction:	NE	Temp:	
Temp:	80-90 F		

Survey Activities

Control

Zach and James set up base station TRIPLE. They then checked benchmark station Anchorage. Two points were collected and checked successfully.

Topo

The ATVs were unloaded at the Atlantic Beach Circle. They then transited east to Fort Macon and began collecting dunes from line 105 to 118 using base TRIPLE. During a weather delay, the truck was moved to the Fort Macon beach access, and the ATVs were loaded there.

Hydro

N/A

Daily Survey Field Notes

Date:	9/25/2018	Day of Year:	268
Time SOS (local):	8:00	Time EOS(local):	19:00
Project:	CCSPO Post Florence 2018		
Survey Location:	Bogue Banks, NC		
Hydro Crew:			
Topo Crew:	Dan Ott	Zach Gray	James Willey

Atmospheric Conditions		Water Conditions	
Sky:	Light Rain	Swell:	
Wind Speed:	5-10 KT	Chop:	
Wind Direction:	ENE	Temp:	
Temp:	80-90 F		

Survey Activities

Control

Zach and James turned on base ERBA, and Dan set up a repeater on the Black Skimmer Rd beach access.

Topo

Zach and Dan collected dunes from line 25 west to line 9. James collected dunes that were previously inaccessible due to debris, including lines 60, 42, 39, 36, and 35. Recoveries were completed for lines 75, 58, 57, 52, 48, and 40. The final recoveries were collected by the team on lines 1 and 2 along the beach, and lines 117, 117B, and 118 around Emerald Island Point. All data were collected using base ERBA and the repeater in the western portion of the survey area.

Hydro

N\A

Daily Survey Field Notes

Date:	9/26/2018	Day of Year:	269
Time SOS (local):	9:00	Time EOS(local):	10:30
Project:	CCSPO Post Florence 2018		
Survey Location:	Bogue Banks, NC		
Hydro Crew:			
Topo Crew:	Zach Gray	James Willey	

Atmospheric Conditions		Water Conditions	
Sky:	Cloudy	Swell:	
Wind Speed:	5-10 KT	Chop:	
Wind Direction:	WNW	Temp:	
Temp:	80-90 F		

Survey Activities

Control

Zach and James set up base station TRIPLE. They then checked benchmark station Anchorage. Two points were collected and checked out successfully.

Topo

The ATVs were unloaded at the Fort Macon beach access. Zach and James recovered line 104.

Hydro

N\A

APPENDIX B: HYDROGRAPHIC SURVEY CONRTOL CALIBRATION

Survey Control

Project Timeframe:	9/19/2018-9/26/2018			
Project:	Bogue Banks Beach & Nearshore Mapping Program- Post Florence Survey			
Survey Location:	Bogue Banks, Carteret County, North Carolina			
Survey Crew:	Ben Sumners	Aron Lembke	Dan Ott	Rohan Rao
	James Willey	Zach Gray	Brian Johnson	
Coordinate System/Units:	NAD83 NC State Plane		***Units*** Meters	***Repeater Use:*** TDL 450
Vertical:	NAVD88	**Geoid:** 2012a		
	Receiver	GPS Antenna	Radio	Radio Broadcasting
Base Station Equipment:	Trimble R7	Zephyr II Geodetic (55971)	TDL 450	5 dB UHF Antenna

Notes: This project was conducted over a period of 1 week. Due to the extent of the survey area, multiple Base Stations and a repeater were used. Base Station "TRIPLE_BASE" was used for eastern section of Bogue Banks. For the central an d western portion of Bogue Banks, Base Station "ERBA_BASE" was utilized. The western most portion of Bogue Banks required the use of a repeater on the Black Skimmer Road beach access. This was consistent for hydro, topo, and laser scanning surveys.

Base Station Information

Designation: ERBA BASE
PID: N/A
H Order: N/A
V order: N/A
Geoid: 2012a

State Plane Coordinates
Easting (X): 796830.552
Northing (Y): 104628.609
Z: 8.873

WGS-84 Coordinates
Longitude: 76 57 24.30785
Latitude: 34 40 32.92648
Elevation (m): -28.436

Notes: Semi-permanent fully GNSS enabled Base Station installed and monitored by Geodynamics. Used for the middle and western portions of Bogue Banks.

Base Station Information

Designation: TRIPLE BASE
PID: N/A
H Order: N/A
V order: N/A
Geoid: 2012a

State Plane Coordinates
Easting (X): 819287.796
Northing (Y): 107771.496
Z: 1.752

WGS-84 Coordinates
Longitude: 076 42 39.47771
Latitude: 34 41 58.99941
Elevation (m): -35.729

Notes: Fully GNSS enabled Base Station installed and monitored by Geodynamics. Used for the eastern extents of Bogue Banks.

The following tables display coordinate and site information on any benchmarks checked for this project

Benchmark Station Reference

Designation: Chapel
PID: AC7471
H Order: N/A
V order: N/A
Geoid: 2012a

State Plane Coordinates
Easting (X): 792391.696
Northing (Y): 103908.703
Z: 6.967

N/A N/A

Notes: NGS Benchmark located in Emerald Isle along Emerald Dr, at the Emeral Isle Chapel by the Sea. Mark was used for checking ERBA BASE

Benchmark Station Reference

Designation: Anchorage
PID: AC7457
H Order: 0
V order: 2nd
Geoid: 2012a

State Plane Coordinates

Easting (X): 817528.658
Northing (Y): 107716.660
Z: 2.574

Notes: NGS Benchmark located in Atlantic Beaach along HWY 58 across from Anchorage Marina. Benchmark was used for checking in on TRIPLE BASE.

Benchmark Report

Date	Time	Weather	Benchmark	N	E	Z	ΔN	ΔE	ΔZ
9/19/2018	09:26:58	Partly Cloudy	Anchorage	107716.662	817528.651	2.584	-0.002	0.007	-0.010
Base Station Used: TRIPLE									
9/19/2018	09:27:07	Partly Cloudy	Anchorage	107716.663	817528.651	2.578	-0.003	0.007	-0.004
Base Station Used: TRIPLE									
9/20/2019	08:27:14	Overcast	Anchorage	107716.664	817528.655	2.590	-0.004	0.003	-0.016
Base Station Used: TRIPLE									
9/20/2018	08:27:25	Overcast	Anchorage	107716.665	817528.656	2.589	-0.005	0.002	-0.015
Base Station Used: TRIPLE									
9/20/2018	09:00:32	Overcast	Chapel	103908.683	792391.666	6.964	0.020	0.030	0.003
Base Station Used: ERBA									
9/20/2018	09:00:51	Overcast	Chapel	103908.683	792391.667	6.965	0.020	0.029	0.002
Base Station Used:ERBA									
9/21/2018	07:30:36	Overcast	Chapel	103908.682	792391.673	6.973	0.021	0.023	-0.006
Base Station Used:ERBA									
9/21/2018	07:30:53	Overcast	Chapel	103908.679	792391.669	6.971	0.024	0.027	-0.004
Base Station Used: ERBA									
9/21/2018	13:16:12	Overcast	Chapel	103908.683	792391.668	6.977	0.020	0.028	-0.010
Base Station Used: ERBA									
9/21/2018	13:16:20	Overcast	Chapel	103908.682	792391.667	6.973	0.021	0.029	-0.006
Base Station Used: ERBA									
9/24/2018	10:39:03	Clear	Anchorage	107716.666	817528.656	2.563	-0.006	0.002	0.011
Base Station Used: TRIPLE									
9/24/2018	10:39:15	Clear	Anchorage	107716.67	817528.657	2.565	-0.010	0.001	0.009
Base Station Used: TRIPLE									
9/26/2018	09:12:34	Overcast	Anchorage	107716.659	817528.655	2.556	0.001	0.003	0.018
Base Station Used: TRIPLE									
9/26/2018	09:12:46	Overcast	Anchorage	107716.658	817528.655	2.560	0.002	0.003	0.014
Base Station Used: TRIPLE									

GPS consistency (measured in meters)

Average Easting (X) error	0.014	STD Easting (X)	0.013
Average Northing (Y) error	0.007	STD Northing (Y)	0.013
Average Elevation (Z) error	-0.001	STD Elevation (Z)	0.011

APPENDIX C: SINGLEBEAM ECHOSOUNDER CALIBRATION REPORT

No changes were applied from the Post Florence survey settings to the time of calibration. This calibration document verifies the real-time settings and configurations.

R/V ECHO OCTOBER 2018

ODOM CV100 CALIBRATION

Contact: Geodynamics
310 A Greenfield Drive
Newport, NC 28570
252-247-5785
www.GeoDynamicsGroup.com

SYSTEM INFORMATION

Vessel:	R/V Echo	Sonar Type:	ODOM CV100
Date:	10/2/2018	Sonar Head Serial #(s):	n/a
Personnel:	Bernstein, D., Willey, J.,	PU Serial #:	26068
	Gray, Z.	Sonar Software:	eChart
Positioning System	POSMV WM V5	Sonar Frequency:	200 kHz
POSMV Serial #	6577	Swath Width:	4°
GPS Antennas	AT1675-540TS (2 antennas)	Sound Speed Sensor at Sonar:	n/a
IMU Type	37	Sound Speed Profiler:	AML Minos -SV sensor 200936
			Pressure sensor 304496

CALIBRATION DETAILS

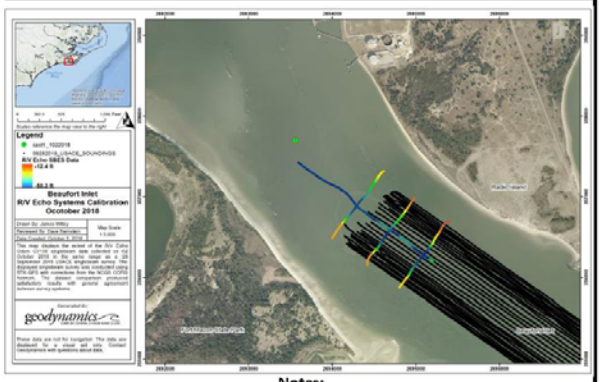
Location:	Morehead City Harbor / Beaufort Inlet
Weather	Clear skies, 70 - 80°
Wind	0-5 kts NNE
Seas	0' swell, 0-0.25' chop
Sound Speed (avg)	1527 m/s

Approximate Position:	Deg	Min	Sec
Lat:	34°	42'	23"
Long:	76°	41'	24"

GPS Corrections

GPS Correction:	RTK-GPS		
Correction Type:	CMR+		
Station Name	BEAUFORT CORS ARP		
Coordinates:	Deg	Min	Sec
Lat:	34°	43'	08.50895" N
Long:	76°	40'	18.99140" W
Ellips. Height (m):	-27.858		

Systems Calibration Area Basemap



Sonar Offsets / Biases

	X (m)	Y (m)	Z (m)
Position	0.000	0.000	0.000
Draft	0.000	0.000	0.000
Index	0.000	0.000	0.090

POSMV Configuration

Lever Arms	X (m)	Y (m)	Z (m)
Ref. to IMU Lever Arm	0.000	0.000	0.070
Ref. to Primary GPS	0.016	-0.01	-2.063
Ref. to Vessel Lever Arm	-0.292	0.745	0.648
Ref. to Sensor 1	-0.292	0.745	0.648
Ref. to COG	0.000	0.000	0.290
	X (deg)	Y (deg)	Z (deg)
IMU w.r.t. Ref. Frame	1.000	-0.200	0.000

Note: The Sensor 1 offset is referenced to the sonar head.

GAMS Parameters

Two Antenna Sep (m)	1.997	Baseline Vector		
Heading Cal.Threshold	0.500	X (m)	Y (m)	Z (m)
Heading Correction (deg)	0.000	1.997	0.015	0.003

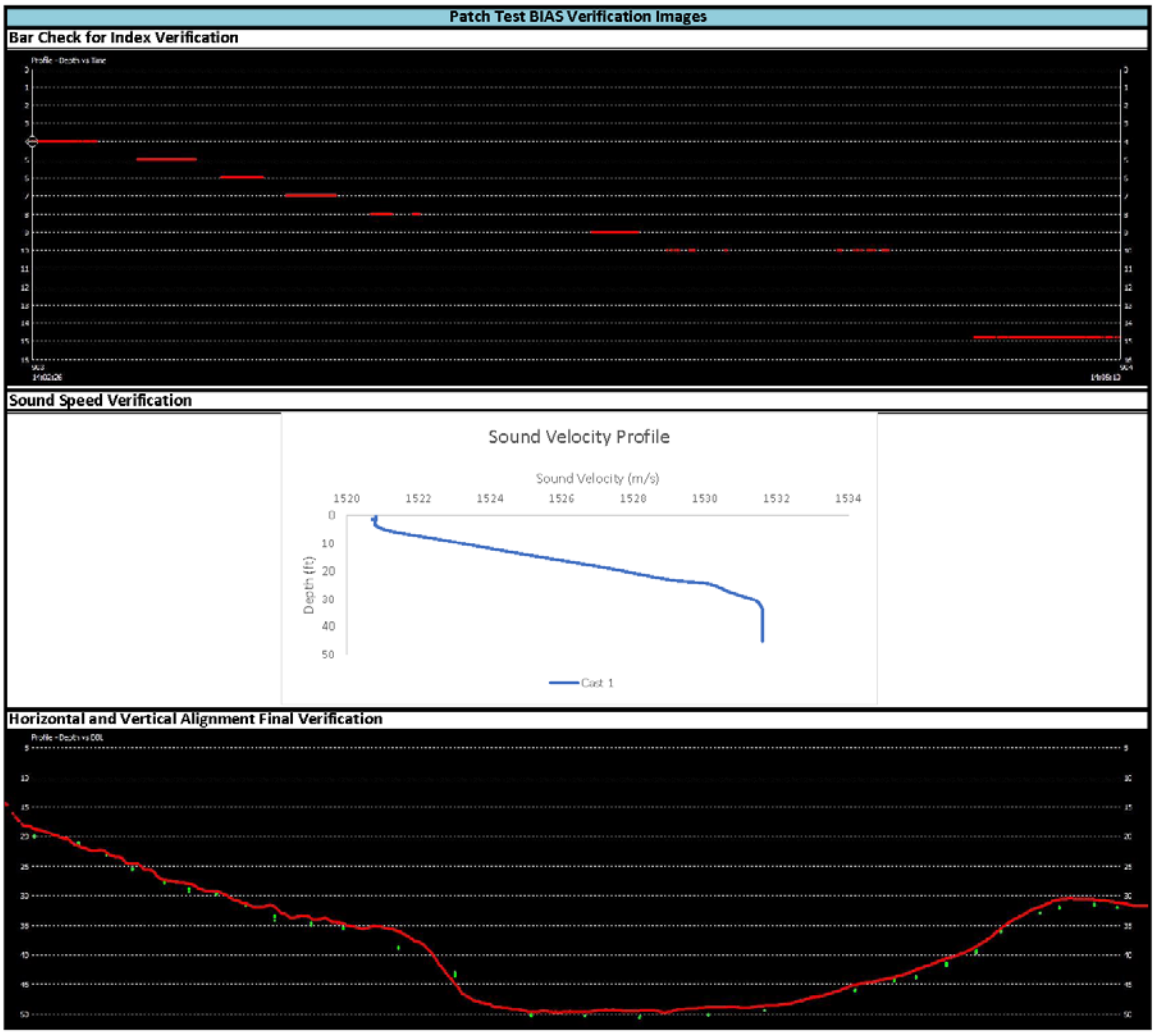
Index Check

Bar Value (ft)	Sonar Value (ft)
4.000	4.000
5.000	5.000
6.000	6.000
7.000	7.000
8.000	8.000
9.000	9.000
10.000	10.000
15.000	14.800

Notes:

Calibration test performed in a USACE surveyed area of Morehead City Harbor. The R/V Echo singlebeam data was collected with an Odom CV100 on 02 October 2018. The singlebeam survey was conducted using RTK-GPS with corrections from NC CORS Network station "BEAUFORT CORS ARP". When compared with the 28 September 2018 USACE data, the dataset produced satisfactory results with general agreement between surveys. Additionally, the bar check performed in October 2018 on the Odom CV100 system in Morehead City Harbor, Morehead City, NC confirmed the index value in use and provided further confidence in the system.

Sound Velocity X-change Sensor Calibration Report



AML OCEANOGRAPHIC
Xchange your old ideas

Certificate of Calibration

Asset Serial Number:	204291
Calibration Type:	Sound Velocity
Certification Date:	August 28, 2018
Calibration Range:	1414.3 to 1509 m/s
Sensor Range:	1375 to 1625 m/s
Residual (RMSE):	0.008 m/s
Standards:	Hart 1560/4067

Coefficients

Coefficient A:	0.000000E+0	Coefficient H:	1.947544E-7
Coefficient B:	0.000000E+0	Coefficient I:	0.000000E+0
Coefficient C:	5.095144E-7	Coefficient J:	0.000000E+0
Coefficient D:	1.947885E-7	Coefficient K:	0.000000E+0
Coefficient E:	-1.816949E-5	Coefficient L:	0.000000E+0
Coefficient F:	1.954494E-7	Coefficient M:	0.000000E+0
Coefficient G:	6.743102E-7	Coefficient N:	0.000000E+0

AML Oceanographic

Robert Haydock
President, AML Oceanographic

AML Oceanographic certifies that the asset described above has been calibrated or recalibrated with equipment referenced to traceable standards. If this instrument or sensor has been re-calibrated, please be sure to update your records. Please also ensure that you update the instrument's coefficient values in any post-processing software that you use, if necessary.

AML Oceanographic Ltd. 2071 Malaview Avenue Sidney, B.C. V8L 5X6 CANADA Tel: +1 250-656-0771 Fax: +1 250-655-3655

Pressure X-change Sensor Calibration Report

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Certificate of Calibration

Asset Serial Number:	146220
Calibration Type:	Pressure
Certification Date:	June 14, 2018
Calibration Range:	0 to 1001 dBar
Sensor Range:	0 to 1000 dBar
Residual (RMSE):	0.129 dBar
Standards:	Paro 785

Coefficients

Coefficient A:	-1.256182E+2	Coefficient H:	0.000000E+0
Coefficient B:	0.000000E+0	Coefficient I:	-8.147839E-9
Coefficient C:	0.000000E+0	Coefficient J:	0.000000E+0
Coefficient D:	0.000000E+0	Coefficient K:	0.000000E+0
Coefficient E:	1.934372E-2	Coefficient L:	0.000000E+0
Coefficient F:	0.000000E+0	Coefficient M:	5.230032E-14
Coefficient G:	0.000000E+0	Coefficient N:	0.000000E+0

AML Oceanographic

Robert Haydock
President, AML Oceanographic

AML Oceanographic certifies that the asset described above has been calibrated or recalibrated with equipment referenced to traceable standards. If this instrument or sensor has been re-calibrated, please be sure to update your records. Please also ensure that you update the instrument's coefficient values in any post-processing software that you use, if necessary.

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APPENDIX D: SCOPE OF WORK

Description of Work for Annual & Post-Storm Beach Profile Monitoring Surveys: Bogue Banks Beach & Nearshore Mapping Program Years 2018 - 2022

1. General & Location of Work. Geodynamics, under contract for Moffatt & Nichol (M&N), will perform seamless topographic and bathymetric beach profile surveys of beaches within Carteret and Onslow County. The work shall primarily consist of surveying and mapping of designated onshore and offshore profiles established on Shackleford Banks, Bogue Banks, and Bear Island, North Carolina, also referred to as the Bogue Banks Beach & Nearshore Mapping Program (BBBNMP). The work includes elevation and positioning data collected along specified azimuths at specified intervals primarily along the existing profiles stations (CCSPO 2010+), with additional inlet and QA/QC profiles developed by Geodynamics / Moffat & Nichol. The final profile stationing and the horizontal limits of the areas to be surveyed annually and post-storm are shown in Figures 1-3. Additionally, topographic laser lidar scanning surveys will be conducted to provide more detailed survey information within a designation "hot spot" area (Figure 4). All survey designs have been approved by the Carteret County Shore Protection Manager.

2. Survey Control. For the contract period, all work shall be relative to the current North American Datum (NAD) of 1983 (2011) North Carolina State Plane Survey Feet in the horizontal plane and the North American Vertical Datum (NAVD) of 1988 Survey Feet in the vertical plane and will use the local geoid model (Geoid 12b) to transform Global Position System (GPS) based ellipsoidal heights to orthometric elevations. A detailed geodetic control survey will be performed prior to all shoreline mapping activities to document Real-Time Kinematic Global Navigation Satellite System (RTK-GNSS) and the North Carolina GNSS Real-Time Network (NCRTN) accuracy, to determine basestation location, assess accuracy at range and to establish daily benchmark "check-in" points (Figure 5). The series of RTK-GNSS basestations will be established as the primary control network to provide elevation and positioning corrections to the survey crews; however, the NCRTN may also be used in areas with poor RTK-GNSS communication. Geodynamics shall furnish M&N with information on all horizontal and vertical control and daily control checks used to complete the surveys for each survey report.

3. Topographic Data Collection (Profiles). The topographic data collection for this project will consist of elevation and positioning data collected along specified azimuths at specified intervals on the approved profile stationing design (Figures 1-3). The landward extent of topographic data collection in areas with coastal infrastructure will be to the farthest extent inland that can be achieved with GNSS data collection techniques. In areas with no infrastructure breaks, the landward extent will be over the primary dune at a minimum such that dune and over-wash related storm impacts can be assessed (in general to the extents of existing data). Elevations shall be continuously collected using GNSS platforms (backpack, rod, atv) and processed elevations shall be at a spacing not to exceed 10 feet and all data will be collected within +/- 25 feet of the profile line. All topographic data collected from the berm to a depth sufficient to meet overlap requirements shall be collected no greater than 4 hours bounding the low tide. Geodynamics will perform the topographic surveys in a manner to limit acts that may cause erosion or damage to existing dunes or vegetation. Geodynamics shall utilize RTK / RTN-GNSS surveying techniques that meet or exceed the USACE *Recommended Survey Elevation Accuracies Common to Various Shore Protection Projects (Table 11-1* EM 1110-2-1003 Nov 2013). Geodynamics shall provide a record of quality control and assurance performed prior to, during and after each survey to be included in the final survey report.

   3.1. MHW / Dune Base Location (Mobile Laser Scanning). Over previous contract years, the acquisition of the MHW contour and Dune Base was acquired through direct measurement techniques using a roving GNSS-based survey system collected from a calibrated all-terrain vehicle. Over the 2018-2022 contract, Geodynamics will acquire these data using mobile laser

scanning techniques which will allow for better long-term analysis of these data but also provide high-resolution 3D topographic data available for use in assessing post-storm morphology change if needed. A similar acquisition strategy will be employed by making use of a calibrated laser-based all-terrain vehicle.

4. Hydrographic Data Collection. The hydrographic data collection for this project will consist of bathymetric data collected along specified azimuths at specified intervals along the established profile stationing. The offshore extent of hydrographic data collection on the established profile will be a minimum of 5000' from the baseline or -30' NAVD 88 whichever is furthest. This includes shore-normal profiles with adjacent nearshore shoal features but generally excludes profiles in the vicinity of tidal inlets. Soundings shall be continuously collected using a survey-grade 200 kHz digital echosounding device compensated for motion, sound speed and positioned with RTK or RTN-GPS corrections. All processed soundings shall be at a spacing not to exceed 10 feet and all data will be collected within +/- 25 feet of the profile. All hydrographic data collected in the surfzone shall be sufficient to meet overlap requirements shall be collected no greater than 4 hours bounding the high tide. Geodynamics shall utilize hydrographic surveying techniques that meet or exceed the USACE *Recommended Survey Elevation Accuracies Common to Various Shore Protection Projects (Table 11-1* EM 1110-2-1003 Nov 2013). Post-processing of attitude and navigation data collected from the survey vessel is acceptable and encouraged, especially when the accuracy and repeatability of the final bathymetry is improved. Geodynamics shall provide a record of quality control and assurance performed prior to, during and after each survey to be included in the final survey report.

5. Yearly "Hotspot" Survey (Topo / Bogue Banks Only). To better define and understand the long-term processes observed within the erosional "Hotspot" areas along Bogue Banks, Geodynamics will acquire two 3D laser-based topographic surveys a year along the stretch of shoreline illustrated in Figure 4. The first survey of each year will be acquired simultaneously with the yearly profiles and the second survey will be collected sometime in the late fall / early winter upon completion of the Atlantic Hurricane Season and / or as directed by M&N. High-resolution surfaces will be generated for each dataset and Quality Controlled by Geodynamics. The general workflow is as follows:

   5.1. Grid Data & Extents. Geodynamics will work with M&N to select the data extents that will be used for each survey to ensure continuity. Grids will be generated at the highest allowable resolution to balance file size while maintaining detail. Once the final resolution is set, Geodynamics will use the same resolution for each of the datasets.

   5.2. In-House QA-QC. Geodynamics will perform and report on, a basic set of QA-QC procedures to ensure accuracy prior to delivery. Currently, Geodynamics is not tasked to perform any analysis or volume calculations on these data.

6. Post-Storm Survey (As Directed by M&N / CCSPO). M&N and the CCSPO, in the event of a Federally Declared Disaster or any storm of significance, may choose to acquire a Post-Storm Survey. In this situation, all Pre-Storm profiles will be acquired along Bogue Banks only; unless specified otherwise. In addition, 3D laser-based topographic surveys, per section 5, will also be acquired in the "hotspot" area. Geodynamics is required to maintain close communications with M&N and the CCSPO up to and following a storm event in order to efficiently collect these data in the timeliest manner.

7. General QA/QC & Survey Requirements

   7.1. RTK / RTN-GPS & GNSS Requirements. Geodynamics will primarily utilize Real-Time GPS / GNSS corrections from the established basestation network. However, in areas with poor base communications or repeated Ultra-High Frequency (UHF) traffic the NC Geodetic Survey RTN will be utilized to obtain Geodetic-GNSS corrections. For the contract period, Geoid12b shall be used to reduce GNSS-based ellipsoidal heights to orthometric elevations. Update rates from the GPS / GNSS receiver to the data collection processor shall operate at a minimum of 5 Hz to a

maximum of 20 Hz and masking angles are not to exceed 15 degrees. Geodynamics is required to augment the Hydrographic RTK / RTN-GPS & GNSS data with appropriate heave, pitch, and roll corrections from an inertial navigation system. Static GPS / GNSS observables will be acquired at the GPS basestations during each hydrographic survey to allow for hydrographic position and attitude post-processing. Geodynamics shall provide a record of vertical and horizontal control utilized during surveys and the daily RTK / RTN-GPS "check-in" calculations to be included in the final survey report.

7.2. Sound Speed. Sound speed profiles will be collected within the USACE standard requirement of a minimum 2 casts per day. However, it is also Geodynamics standard practice to acquire additional sound speed profiles in and around tidal inlets, when noticeable change in surface water properties occur and when long stretches of area are covered. Sound speed profiling equipment calibrations and the corresponding documentation will be included in the final survey report.

7.3. Sonar Calibration. The echosounder shall be calibrated such to provide the most accurate and repeatable soundings possible. Echosounder index and draft calibrations should be performed at least once per year and if any system changes are made. Additionally, a conventional bar check or sounding-to-survey rod check shall be performed at least once per year and if any system changes are made. Echosounder calibrations will be documented and included in the final survey report.

7.4. Laser Calibration. The laser shall be calibrated with a full patch test prior to data collection each time it is mobilized. Static object or buildings will be scanned in multiple directions and distances in order to account for the offset values needed to ensure consistent and accurate data collection.

7.5. Line Tracking Requirements. All hydrographic and topographic data collection shall not vary more than 25 feet horizontally from the specified azimuths shown in Figures 1-3 except in areas where obstructions are present. In such instances, complete notes identifying the obstruction shall be taken and submitted in the required survey report. Alongshore laser scanning data will be acquired in a manner that best suites the data over a fixed tracking requirement.

7.6. Overlap Requirements (Profiles). Geodynamics is required to overlap topographic and hydrographic data a minimum of 10 feet over a minimum of 50% of the specified profile azimuths; however, certain scenarios such as sharp turns that may cause spikes or other erroneous data points, will be edited to achieve at least 6 feet of quality overlap data to fully assess all QA/QC parameters. Overlap will be assessed in real-time and at the end of each day. Those profiles not meeting the specification will be reacquired to meet the overlap requirement. All efforts will be made to achieve the overlap specification safely; however, it should be noted that no guarantee exist that overlap can be achieved due to site specific conditions. Regardless, all topographic data in the swash zone will be collected 4 hours bounding the low tide and all hydrographic data in the swash zone will be collected no more than 4 hours bounding the high tide. Every effort must be made to ensure that either the topographic or hydrographic survey party will have knowledge of the furthest extents such that maximum overlap can be achieved. Geodynamics will ensure that overlapping data will not exceed a maximum vertical difference of 0.5 feet over a distance of 10 feet or greater along a specified line.

7.7. Temporal Requirements. All efforts shall be made to acquire a complete set of profiles at the end of each survey day. The overlap timing of the topographic and hydrographic portion of the profile shall be scheduled so as not to exceed a maximum of 48 hours. However, the stable portion of dunes within the monitoring area can be collected well in advance of the primary survey efforts. Overlapping segments that exceed the maximum Temporal Requirement will be reacquired in their entirety. Spatially, Geodynamics is to make every effort to only survey the

stretch of shoreline, including the surfzone overlap, which can be achieved within the forecasted weather window to avoid any morphological changes that may occur during a weather delay. To maintain the temporal continuity between shoreline reaches, Geodynamics has been authorized by M&N to acquire topo/bathy data at Shackleford Banks, Bogue Banks and Bear Island independently from one another if necessary to achieve this Temporal Requirement.

7.8. Quality Control. Data for each profile line and the overall survey shall be quality-control checked for the following concerns:

- Profile coverage from landward limits to seaward limits including overlap
- Capture of all features along profile
- Required accuracies
- Required horizontal and vertical datum
- Proper motion sensor and sound speed corrections
- Data collection within required offset limits
- Cross lines over a minimum of 3 profiles within each survey compartment collected at different tide stages for quality control and assurance.
- Laser data to a base surface devoid of structures, people, etc.

7.9. Systems Calibration and Checks. Geodynamics shall calibrate and check both topographic and hydrographic systems in accordance with all appropriate USACE Standards. A digital log containing the results of all calibrations and checks shall be supplied to M&N for the final survey report.

8. Clearances & Permits. Geodynamics shall acquire all Clearances & Permits necessary to obtain the required data. Clearances / Permits for Shackleford Banks and Bear Island will go through the National Park Service and Hammocks Beach State Park respectively. Official clearances for Bogue Banks will be obtained through the various Town Managers and / or Police Departments. All parties will be advised initially on the target month and then informed once the weather window is known and mobilization begins. Geodynamics cannot guarantee that survey permission will be granted by individual homeowners; however, all attempts will be made to ensure data is collected to the furthest landward extent of the profile as possible. All discussion for access to private or public property or restricted waters and airspace must be kept on file and made available to include in the survey report if deemed necessary.

9. Required Deliverables. Geodynamics is required to deliver corrected profile data in XYZ ASCII format, profile data as an ESRI ArcGIS shape file or feature class, metadata and pertinent QA/QC sections for the Written Survey Report.

9.1. Profile Data. All profiles shall be fully edited for erroneous data (spikes), motion, tides and sound speed. Overlap on each profile will be analyzed for the specifications and that the data are in the proper vertical and horizontal datum's.

9.1.1. ASCII Data Files. An ASCII text file of the final data shall be delivered with a descriptive header containing the following eight (8) columns and generally in BMAP format:

- Profile
- Profile Number
- Survey Type using numerator tag (ex. Topo 1 or Hydro 2)
- Date
- Easting (X)
- Northing (Y)
- Elevation (Z)
- Distance from Beginning of Line (DBL)

9.2. GIS Compatible Files. Geodynamics shall deliver profile data in a format compatible with ESRI ArcGIS 10.5 or higher and in such a manner as to easily import into the Carteret County's coastal GIS database.

9.2.1. Topo/Bathy Beach Profiles. All merged topo/bathy profiles as an ESRI .shp file.

9.2.2. "Hotspot" DEM's. Alongshore laser-based topographic survey data of the "hotspot" area will be provided as a digital elevation model. Data will be delivered in ArcGrid format.

9.2.3. MHW Contour. The mean high-water contour produced from the alongshore data will be provided as an ESRI shapefile or feature class for Bogue Banks only.

9.2.4. Dune Base Line. The dune base line produced from the alongshore data will be delivered as an ESRI shapefile or feature class for Bogue Banks only.

9.3. Metadata Record. An FGDC compliant metadata record for each survey shall be created using ESRI ArcGIS ArcCatalog 10.5 or higher. Appropriate information shall be entered in all required fields. The metadata record shall be submitted with all other digital files required in the deliverable to M&N.

9.4. Written Survey Report. A general written report summarizing all pertinent data collection activities shall be submitted as an Microsoft Word file to incorporate into the overall survey / analysis report generated by M&N. The following items shall generally be included in the survey and QA/QC portion of the master report:

- Dates and times of each data collection activity
- Atmospheric conditions including temperature, wind direction, wind speed, *tide stage, and wave conditions for each day of data collection activity*
- All horizontal and vertical control used and will include monument name, establishing agency, date established, description, and published horizontal and vertical values
- Temporary Bench Marks (TBM) descriptions with vertical values (if applicable)
- Record of horizontal and vertical calibration of the survey vessel and daily topographic benchmark checks for each survey
- All field notes including descriptions of obstructions preventing data collection along specified azimuths
- General description of all equipment used

9.5. Data QA Comparison. Geodynamics performs a wide range of comprehensive QA comparisons / procedures on all datasets to ensure accuracy and continuity between each successive survey. However, Geodynamics is not required to provide this information but can be obtained upon request.

9.6. PLS Certification. All topographic and hydrographic profile work performed by Geodynamics shall be approved and sealed by a Professional Land Surveyor (PLS) licensed in the State of North Carolina. All hydrographic data shall also be reviewed and accepted by a Certified Hydrographer (CH) with the Hydrographic Society of America (THSOA) or Category A/B (CAT A/B) certification from an International Hydrographic Organization (IHO) sanctioned program. All final data, GIS data products and cartographic products shall be reviewed and accepted by a certified GIS Professional (GISP or ESRI).

10. Technical POC. All technical questions concerning survey work under this task order shall be directed to Chris Freeman and / or Dave Bernstein at (252) 247-5785.

11. Administrative POC. All non-technical questions concerning administrative or contractual matters under this task order shall be directed to Johnny Martin at (919) 781-4626.

12. Schedule of Work & Completion Date. Upon commencement of work and weather permitting, fieldwork for the BBBNMP annual surveys should begin March / April of each year and proceed such that the survey data acquisition phase shall be completed no later than 1 August of each year. Safety of the field crew is the priority, followed by data quality and timeliness of schedule respectively. Geodynamics is to use judgment on the exact days of data collection for both safety and data quality concerns and scheduling of surveys will be coordinated in advance with M&N, the Carteret County Shore Protection Manager and local authorities. Data analysis, documentation, and computer files should be delivered to M&N by 15 August of each year pending the ultimate schedule for data acquisition which is solely dictated by the weather, tide stage and surface conditions. This schedule is subject to adjustment by Geodynamics for documented conditions beyond the control of the parties hereto. Post-storm surveys will be completed at the direction of Carteret County and Moffatt & Nichol.

13. Deliver To. All survey work completed by Geodynamics shall be delivered to:

    Johnny Martin / Nicole Vanderbeke
    Coastal Engineer / Project Manager
    Moffatt & Nichol Engineers
    4700 Falls of the Neuse Rd. Suite 300
    Raleigh, NC 27609-6275
    Or via FTP / Sharefile

14. Public Interaction. Geodynamics is working on the BBBNMP as a representative of Carteret County and Moffatt & Nichol Engineers and will conduct its work in a professional manner that is respectful of the public. At no time shall Geodynamics knowingly damage private or public property, display public indecency or enter into any argumentative conversations with the public. Conversations with the public shall be cordial and limited to general information about the survey operation. Questions relating to beach renourishment, individual profile analysis, political involvement or any such question outside this Scope of Work shall be directed to:

    Greg “Rudi” Rudolph
    Shore Protection Manager
    Carteret County Shore Protection Office
    grudolph@carteretcountygov.org
    252-393-2663

There were no crosslines ran for the hydrological data therefore no crossline analysis could be completed

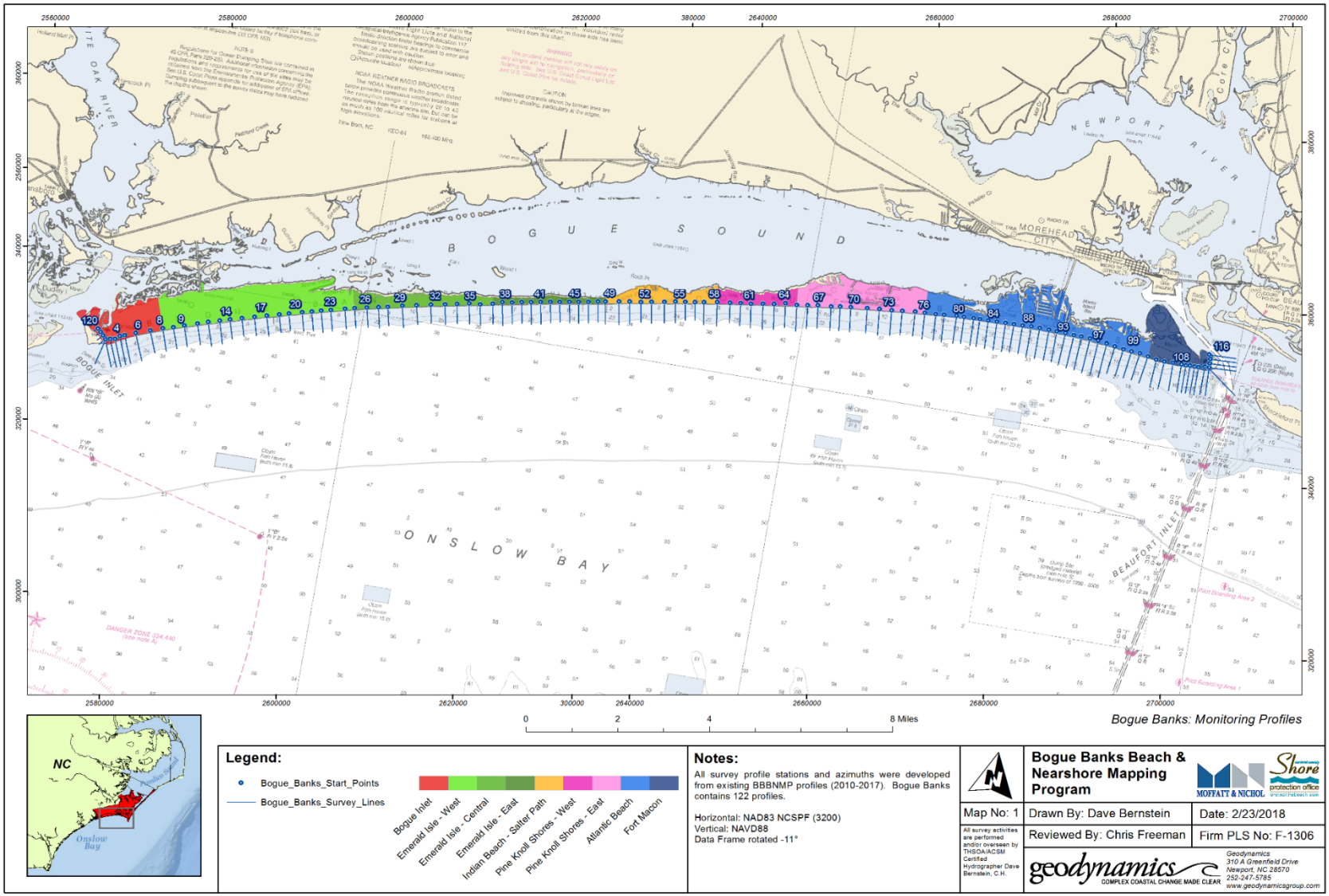


Figure 1. Survey profile map for Bogue Banks

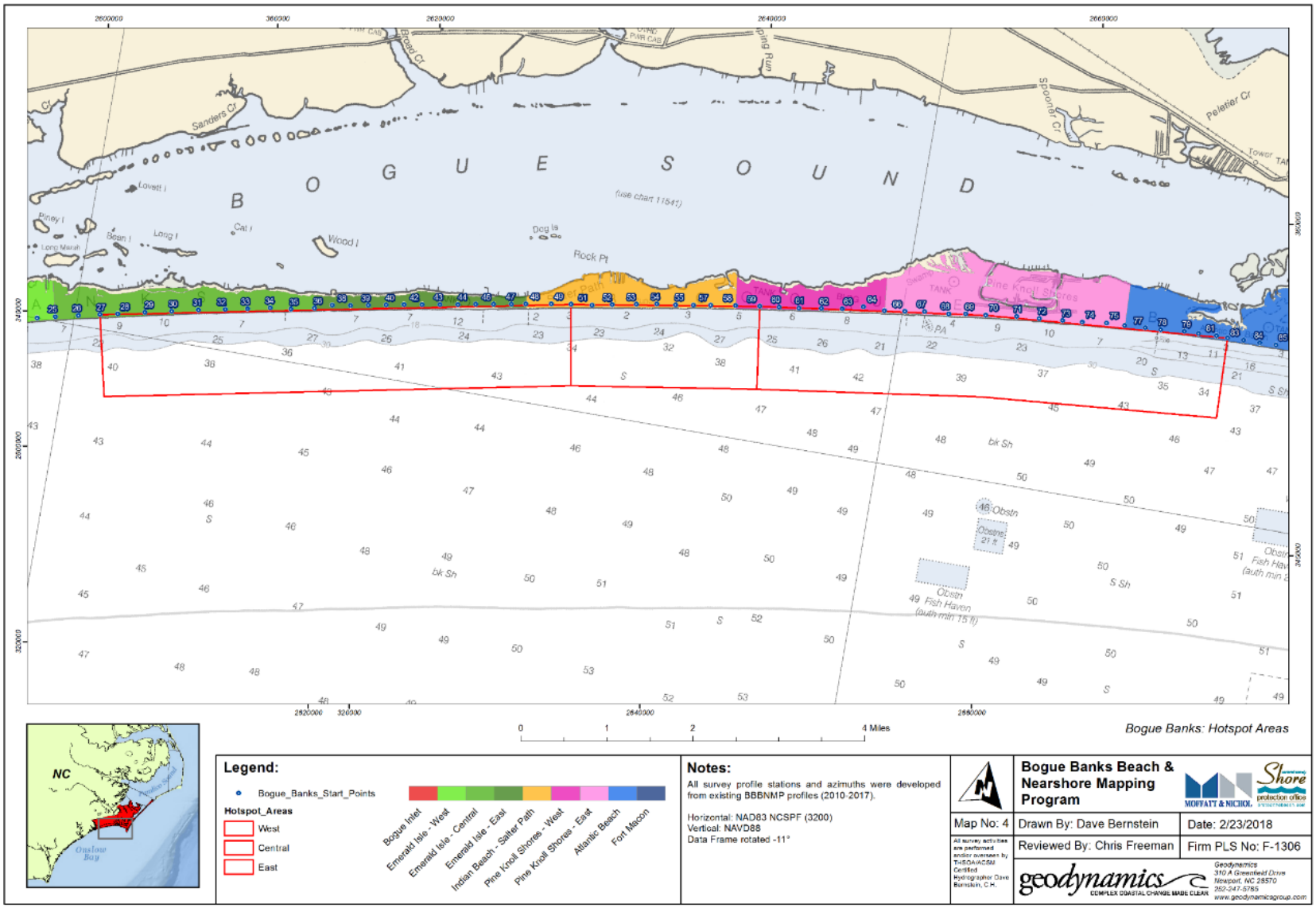
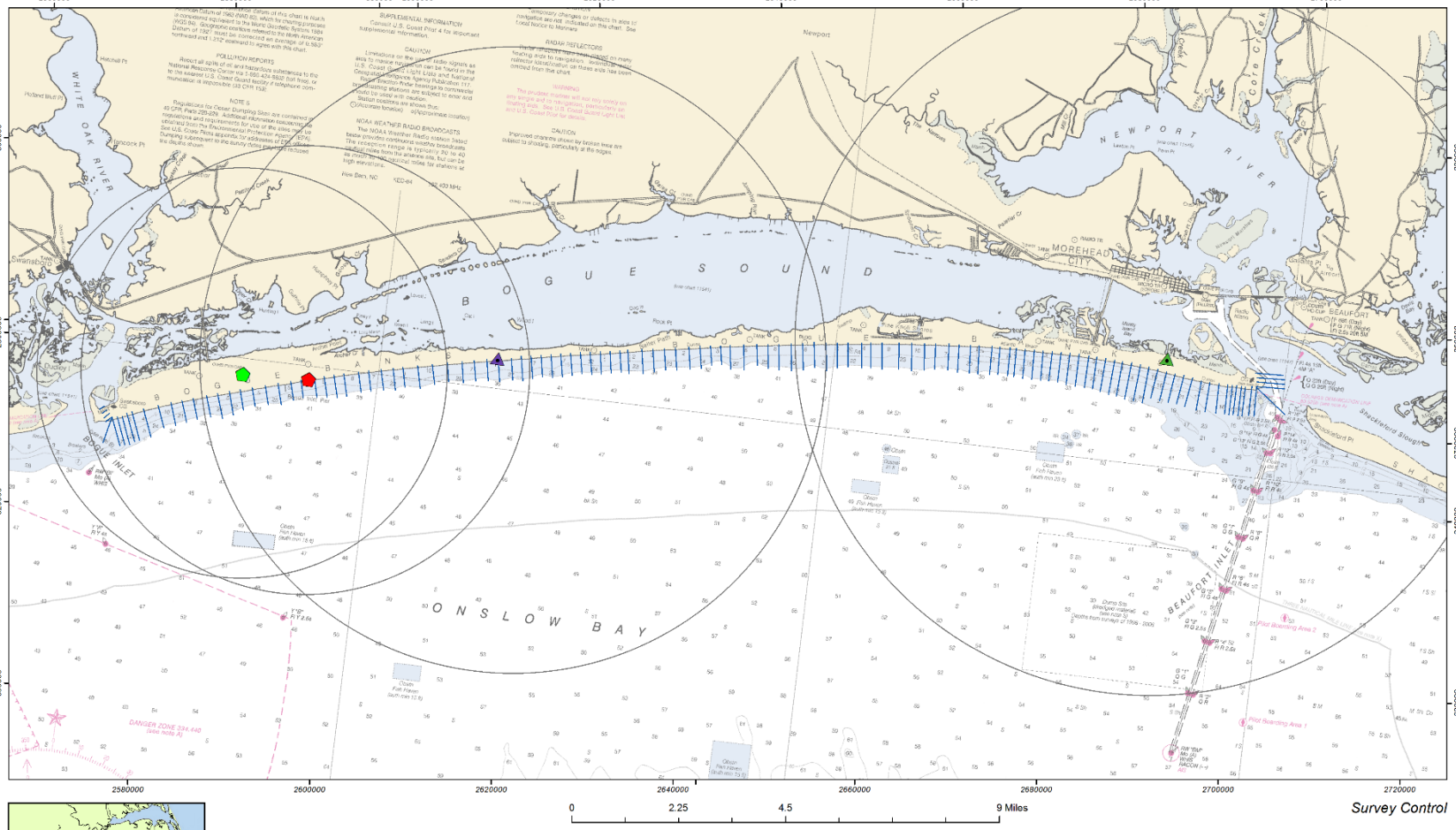


Figure 4. Bogue Banks "Hotspot" Topographic Survey Boundary.



Legend:

Control Stations

- ERBA Base
- TRIPLE Base
- Repeater 1
- Repeater 2
- Bogue_Banks_Survey_Lines

Notes:

All survey profile stations and azimuths were developed from existing BBBNMP profiles (2010-2017). Survey control covers 116 total profiles.

Horizontal: NAD83 NCSPF (3200)
Vertical: NAVD88
Data Frame rotated -11°

All survey activities are performed and/or overseen by THSOA/ACSM Certified Hydrographer Dave Bernstein, C.H.

Bogue Banks Beach & Nearshore Mapping Program

MOFFATT & NICHOL

Shore protection office

Map No: 5	Drawn By: Zach Gray
	Date: 11/14/2018
	Reviewed By: Chris Freeman
	Firm PLS No: F-1306

geodynamics
COMPLEX COASTAL CHANGE MADE CLEAR

Geodynamics
310 A Greenfield Drive
Newport, NC 28570
252-247-5785
www.geodynamicsgroup.com

APPENDIX B

Field Investigations

1) Carteret County Shore Protection Office
2) Moffatt & Nichol

1) Carteret County Shore Protection Office

Shore Protection Manager

Greg L. Rudolph
Tel: (252) 222.5835
Fax: (252) 222.5826
grudolph@carteretcountync.gov

Hurricane *Florence* - Preliminary Assessment for Bogue Banks Oceanfront (9/16/18)

Summary Points:

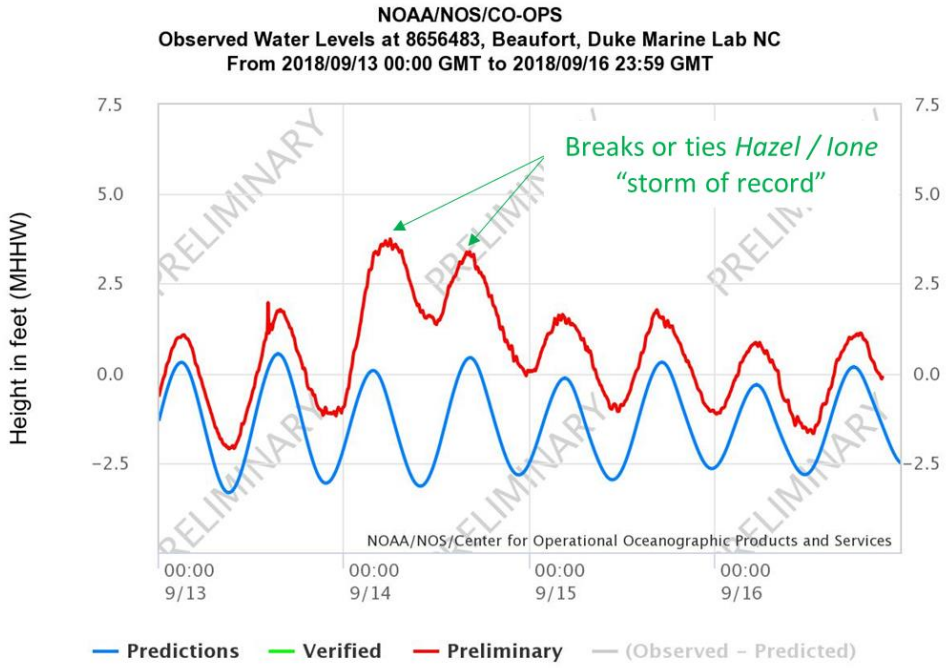
(1) Significant beach and incipient dune erosion, limited frontal dune erosion that generally starts at the Circle, Atlantic Beach and progresses westward.

Before and after photo slideshow – CLICK HERE

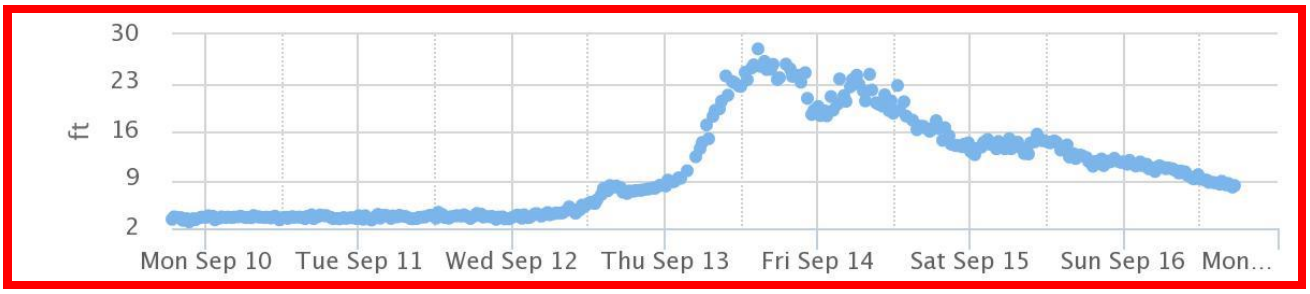
(2) *Florence* becomes the ***storm of record*** (twice) for high water level at the Beaufort tide gage.

(3) The infusion of sand via beach nourishment and subsequent development of incipient, or "baby" dunes since hurricane *Floyd* (1999) protected ~23 miles of homes, hotels, public accesses, and infrastructure for the storm of record. There was no *flood* damage to oceanfront structures, nor any breaches of the frontal dune. Structural damage was limited to walkways only.

Storm of Record (2) – NOAA's National Ocean Service top ten highest water levels at 110 of their longest-term tide gage stations is provided at https://tidesandcurrents.noaa.gov/est/Top10_form_ft.pdf. The highest water level ever recorded at the Beaufort, NC gage (8656483) was 3.39 feet relative to MHHW – achieved exactly twice during *Hazel* (1954) and *Ione* (1955). *Florence* exceeded this benchmark the first time early Friday morning (9/14/18 @ 5:54 GMT) with a 3.75 feet MHHW reading, and proceeded to tie the *Hazel/Ione* record the subsequent high tide later that afternoon (3.39 feet MHHW @ 16:12 GMT). This resulted in an unprecedented ***"one-two"*** punch to Carteret County.



Offshore Waves and Storm Surge – The nearest wave buoy is located roughly 40 miles due south of Beaufort Inlet (LEJ3) and recorded a wave height of 28 feet on Thursday afternoon (9/13/18) as *Florence* approached Bogue Banks (image below). The maximum wave height for the last hurricane significantly impacting Bogue Banks was 25 feet (*Irene* 2011).



Storm surge is the wall of water being pushed by a hurricane in the northeast quadrant, while storm tide includes the additive or subtractive impacts of the tide. The magnitude of storm surge is predicated on numerous factors such as; storm intensity, forward speed, angle of approach, and slope of the continental shelf. The storm surge plus wave action drives peak erosion during hurricanes - at the present it is unclear what the actual storm surge and/or storm tide was for Bogue Banks.

Beach Erosion – The incipient dune field is generally a result of pioneer vegetation along the beach berm initiating dune growth and/or as an offshoot of various sand fencing and dune planting activities that have been coordinated through the local municipalities, home owner groups, and individuals; and importantly acts as a line of defense to the large foredune that fronts most of Bogue Banks and often exceeds an elevation of 20 feet. The berm is the "flat part" of the beach. ***Florence* significantly impacted the berm and incipient dune field, and only in very isolated areas impacted the foredune** (see preceding page – Memorial Park, Pine Knoll Shores)

Photos

All Pre Storm Photos

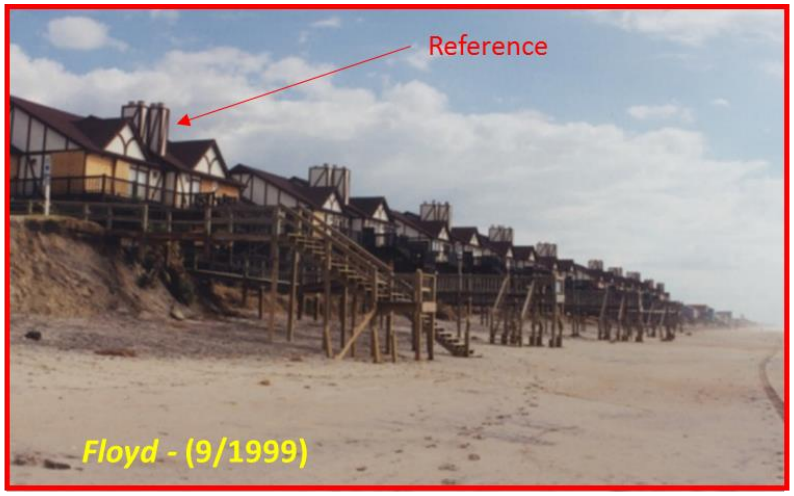
All Post Storm Photos

Select Before and After Slideshow

Surveying, Volume, and Beach Nourishment – Later this week, *Geodynamics, LLC* will mobilize and begin surveying 122 transects along Bogue Banks (spaced roughly 1,000 feet apart), which is part of one of the most comprehensive, annually surveyed beach monitoring networks in the U.S. The last survey was conducted in the Spring of 2018 prior to the hurricane season and will serve as our pre-storm survey.

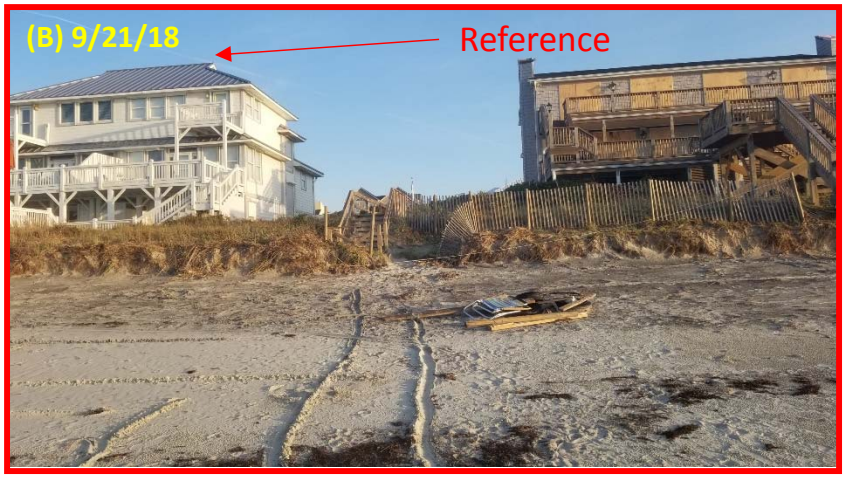
The County/Bogue Banks predominantly takes a volumetric approach to ascertain beach health. 2018 marks the nineteenth anniversary of hurricane *Floyd* and since 1999; Bogue Banks has gained roughly 9.6 million cubic yards (cy) of sand, which is mostly attributed to the many beach nourishment projects that have been constructed along the island beginning in 2001. A total of approximately 14.5 million cy of sand have been placed directly on Bogue Banks as a result of beach nourishment, meaning 4.9 million cy have since eroded off the beach (14.5 million cy placed on the beach minus 9.6 million cy remaining). If we average the volume loss (-4.9 million cy) across the entire 128,393 feet (24.3 miles) of Bogue Banks oceanfront, the island has lost sand at a rate of -2.0 cy per linear foot per year (cy/ft/yr) since 1999 (a 19-year window). In addition to gaining a better understanding of how much sand was lost/eroded during *Florence*, we will be able to place this event in a greater long term context and begin planning for future beach nourishments projects immediately.

The infusion of sand via beach nourishment and subsequent development of incipient, or "baby" unquestionably protected ~23 miles of homes, hotels, public access, and infrastructure for a storm of record. There was no flood damage to oceanfront structures, nor any breaches of the frontal dune. Any physical damage was limited to walkways only. Compared to *Floyd* (1999), which was not a storm of record nor arguably as much of a "direct hit" as *Florence*, the beaches performed very well with the added sand borne from beach nourishment (see image below).

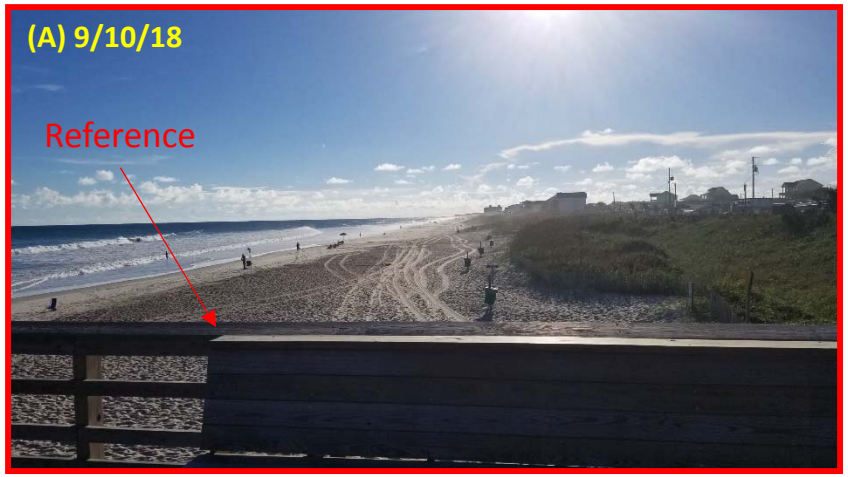

Reference
Floyd - (9/1999)

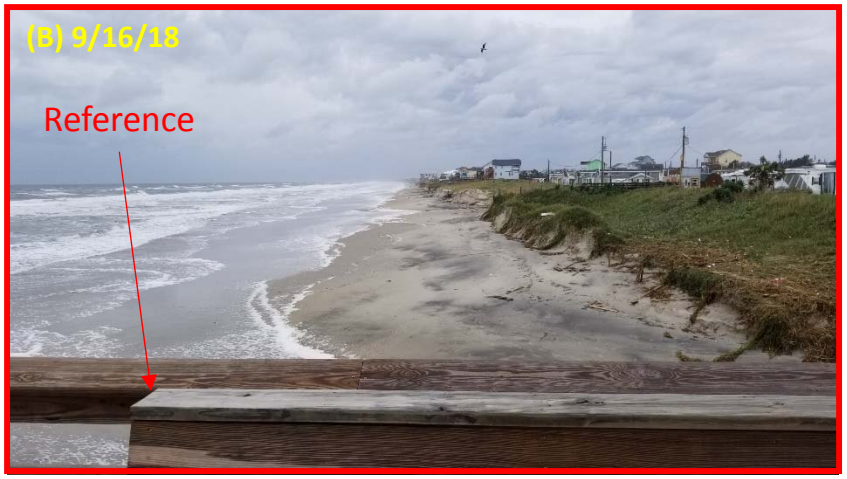
Reference
Florence - (9/2018)

OCEAN OAKS, Emerald Isle

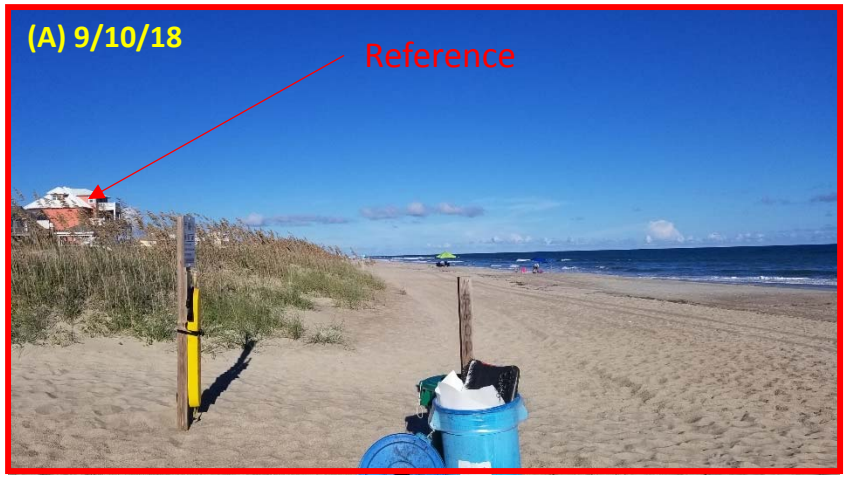


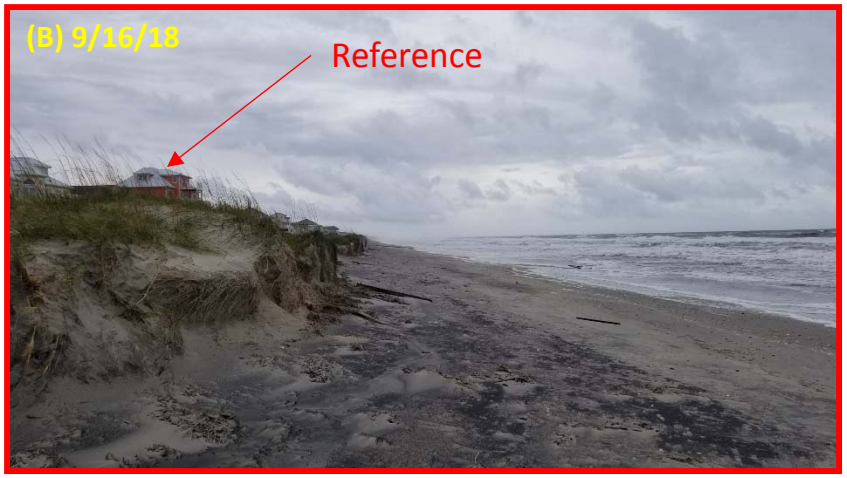
BOGUE INLET PIER, Emerald Isle





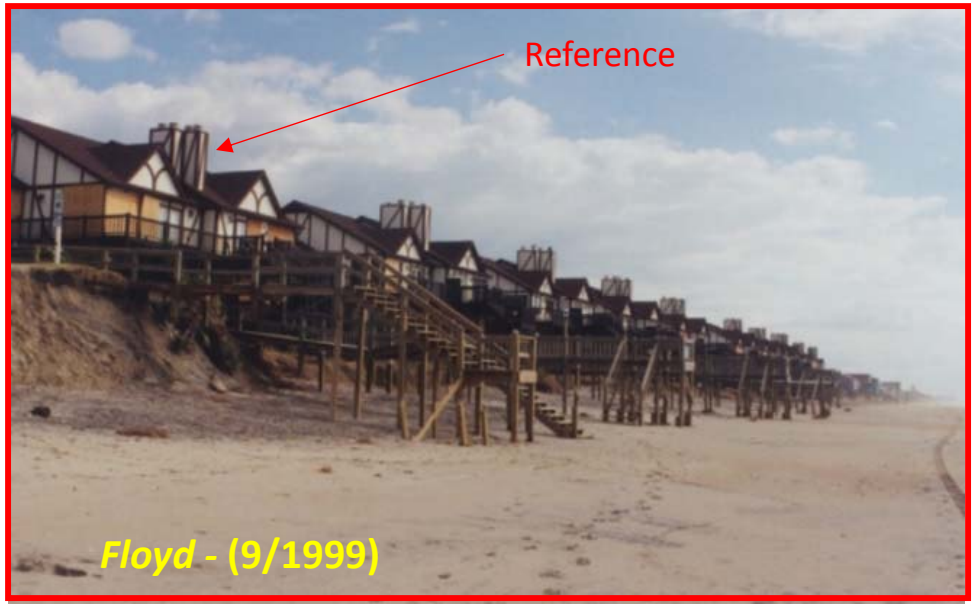
5900 OCEAN DRIVE, Emerald Isle

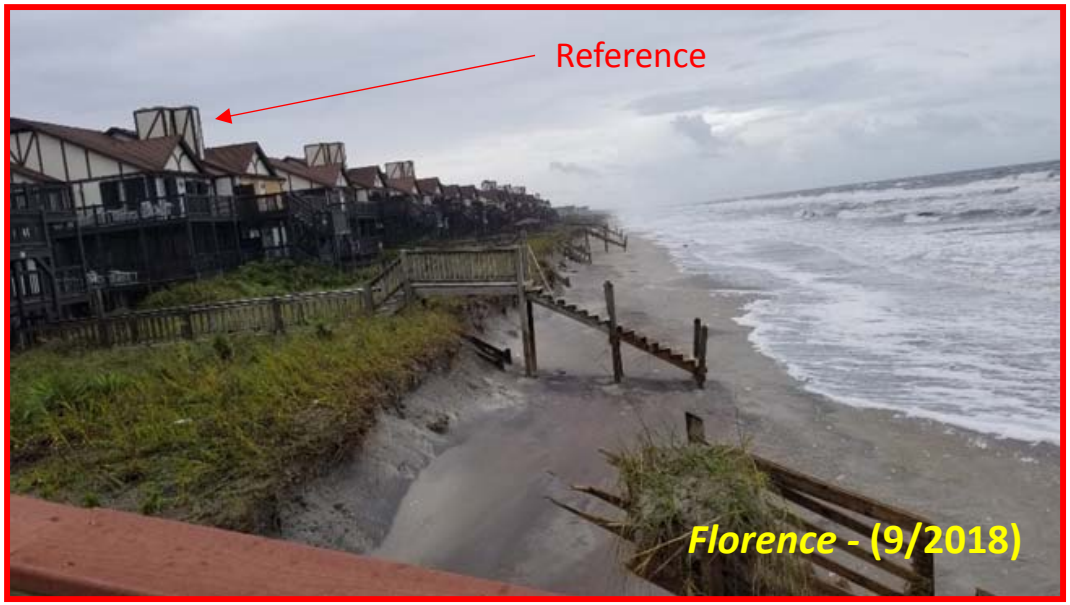




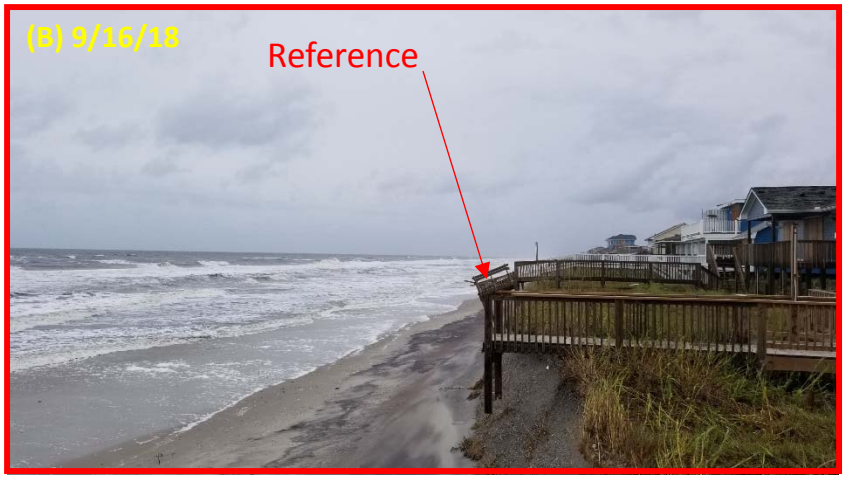
OCEAN REEF, Emerald Isle

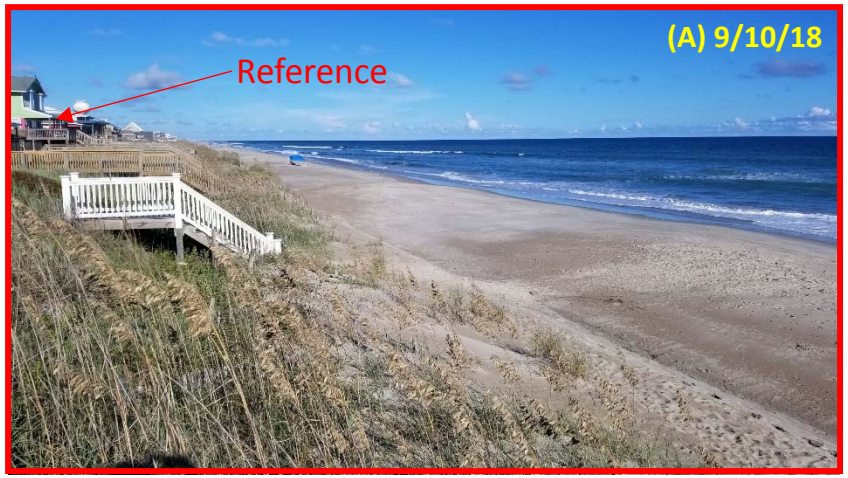
OCEAN REEF, Emerald Isle





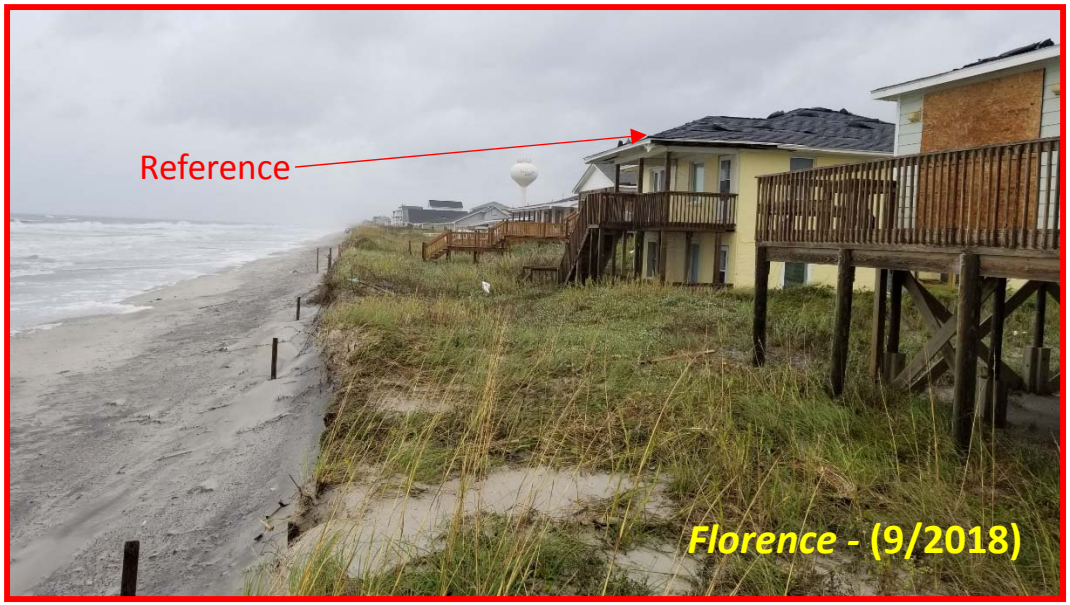
12th STREET, Emerald Isle



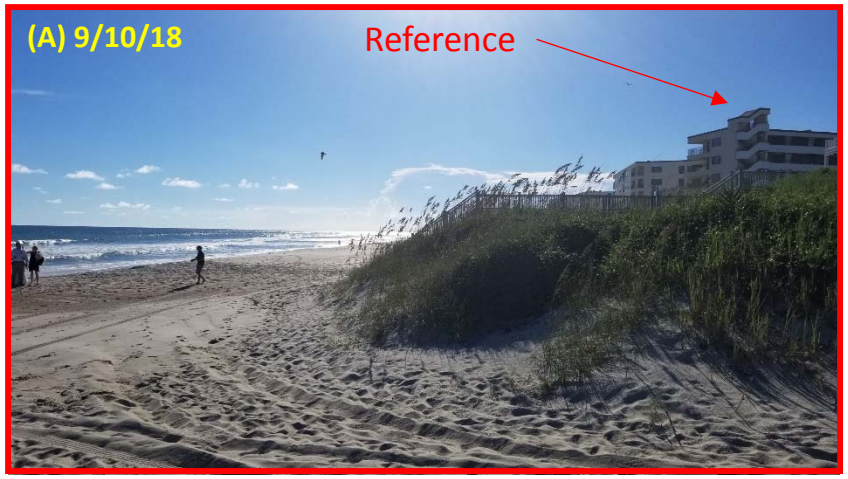


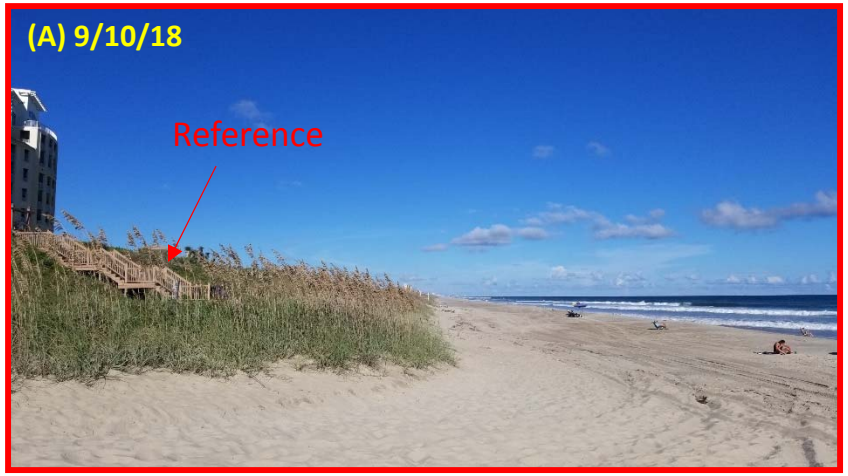
3rd STREET, Emerald Isle

“BRICK HOUSE”, Emerald Isle



4WD DRIVE RAMP, Indian Beach

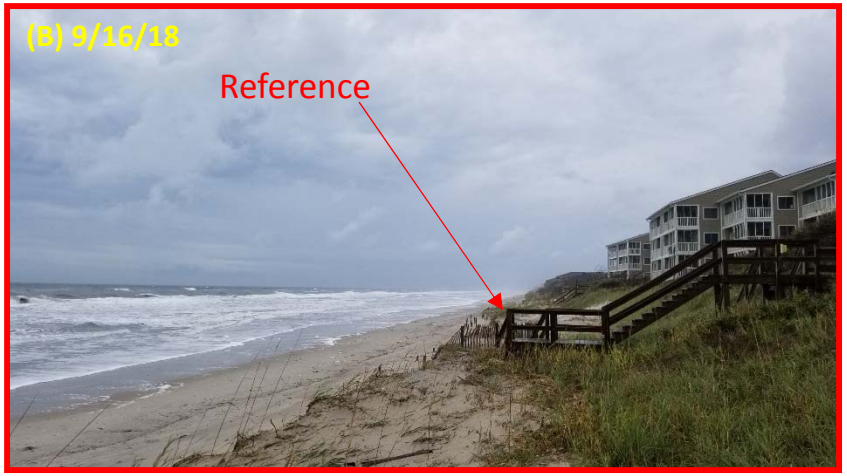




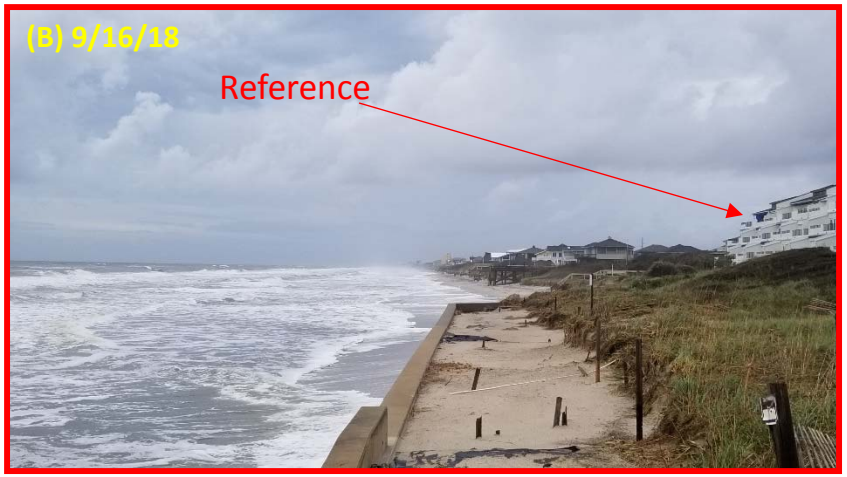
HOFFMAN BEACH, Salter Path

TRINITY CENTER ACCESS, Pine Knoll Shores

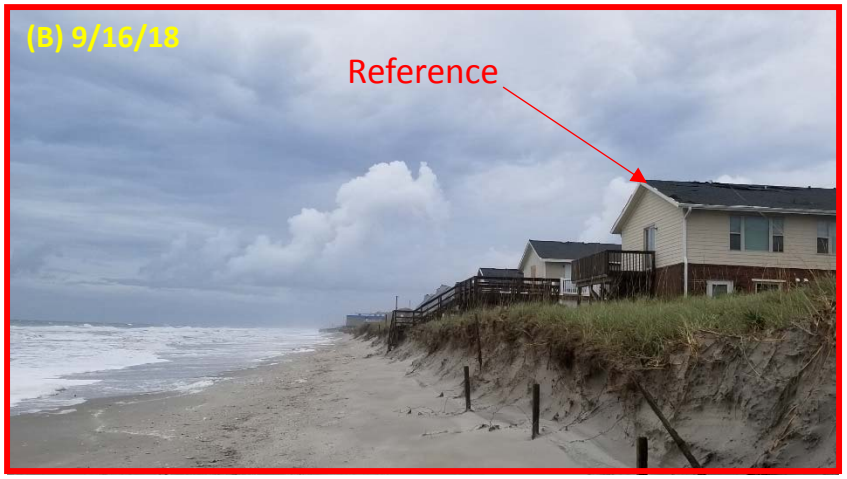
CLAMDIGGER, Pine Knoll Shores



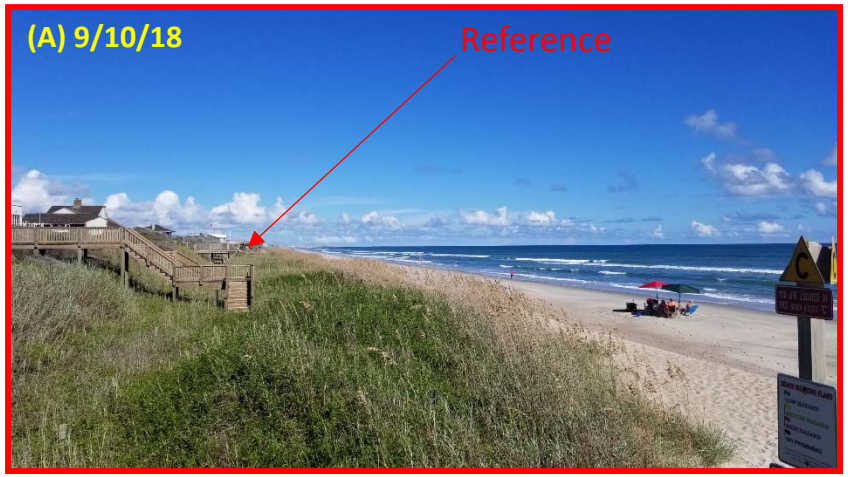
IRON STEAMER, Pine Knoll Shores



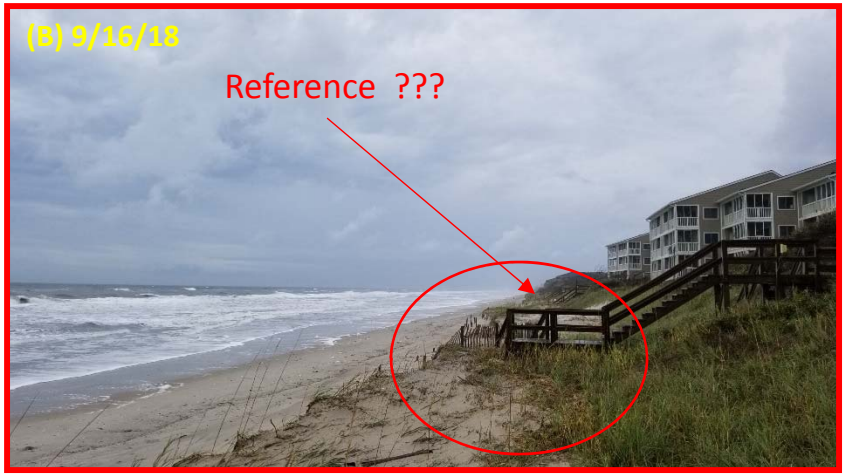
PINE KNOLL TOWNES, Pine Knoll Shores



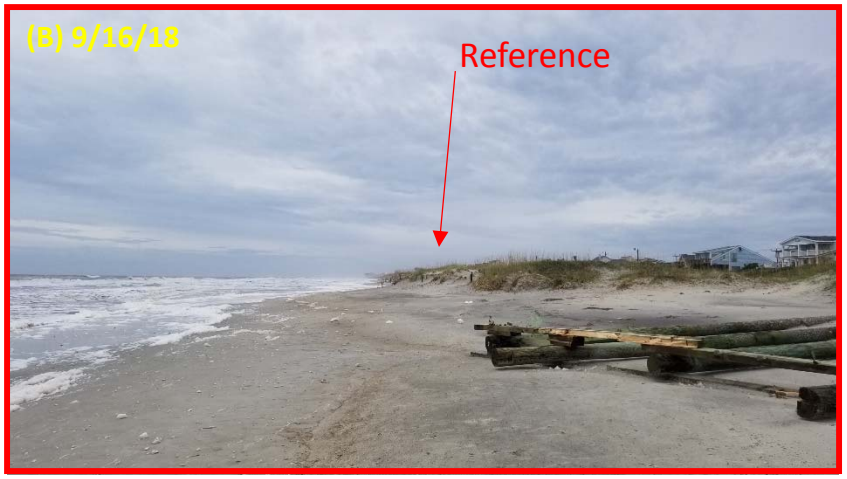
MEMORIAL PARK, Pine Knoll Shores



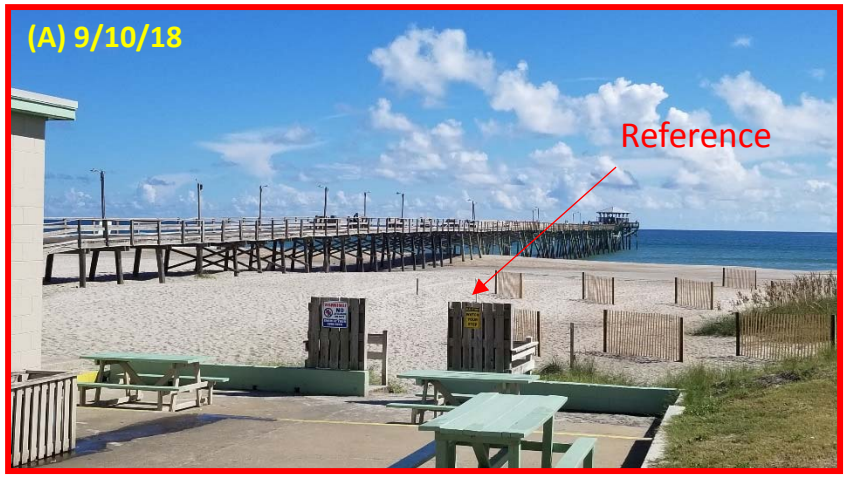
DOUBLETREE, Atlantic Beach



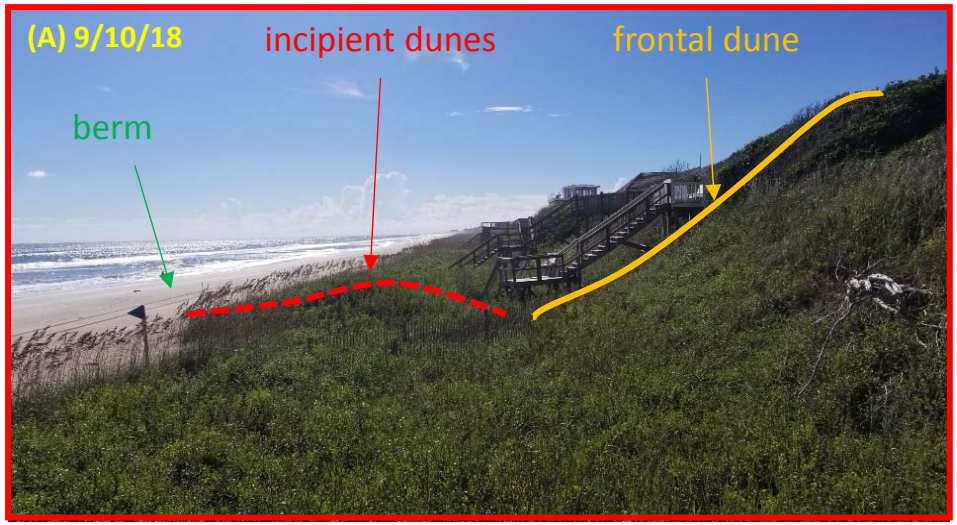
THE CIRCLE, Atlantic Beach

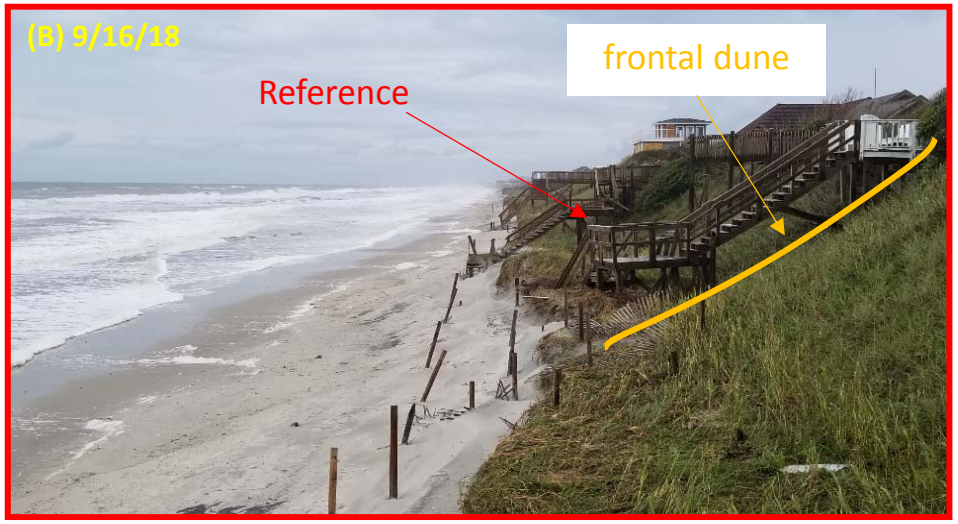


OCEANANA PIER, Atlantic Beach



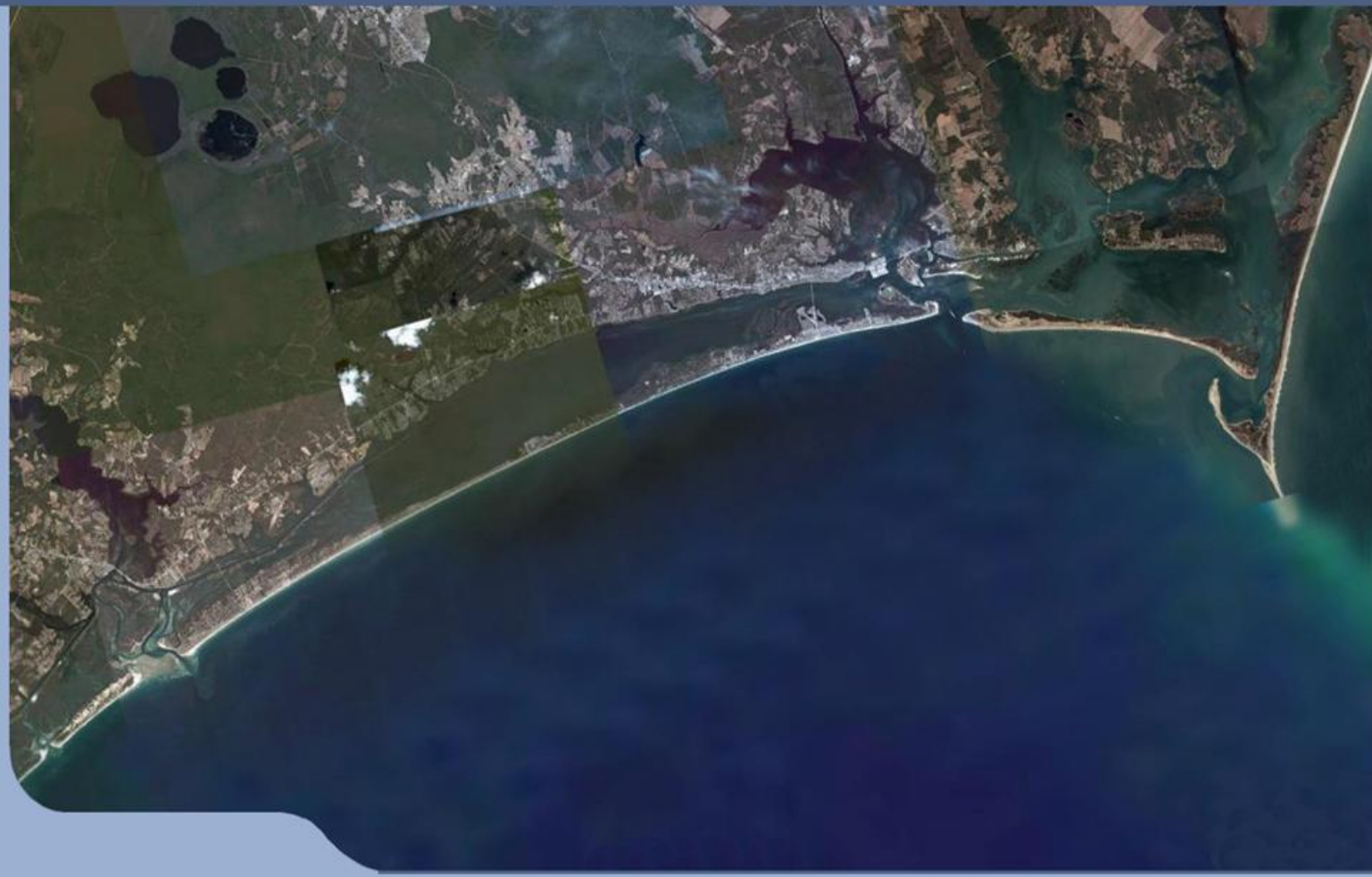
BATH HOUSE, Ft. Macon State Park


(A) 9/10/18
incipient dunes
frontal dune
berm


(B) 9/16/18
frontal dune
Reference

2) Moffatt & Nichol

Post Hurricane Florence Field Investigation



moffatt & nichol

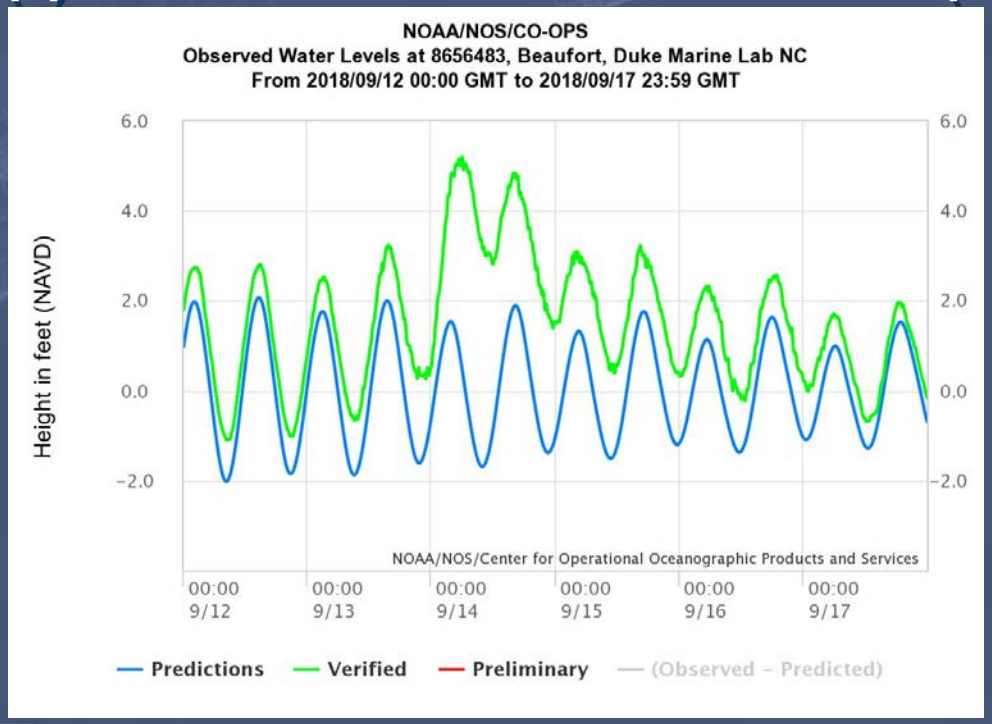
October 2018

Outline

- Data Collection Sept 19-20, 2018
  - Storm Data Summary
  - Video of Beach Impacts
  - Photos of Dune Escarpment
  - Survey of Dune Retreat

Storm Data Sumamry

- **Hurricane Florence Summary:**
  - **Water Level 9/12/2018 – 9/17/2018 GMT**
    - 9/14 (1) Peak Water Level: 5.21 ft NAVD88 (3.75 ft MHHW)
    - 9/14 (2) Peak Water Level: 4.85 ft NAVD88 (3.39 ft MHHW)



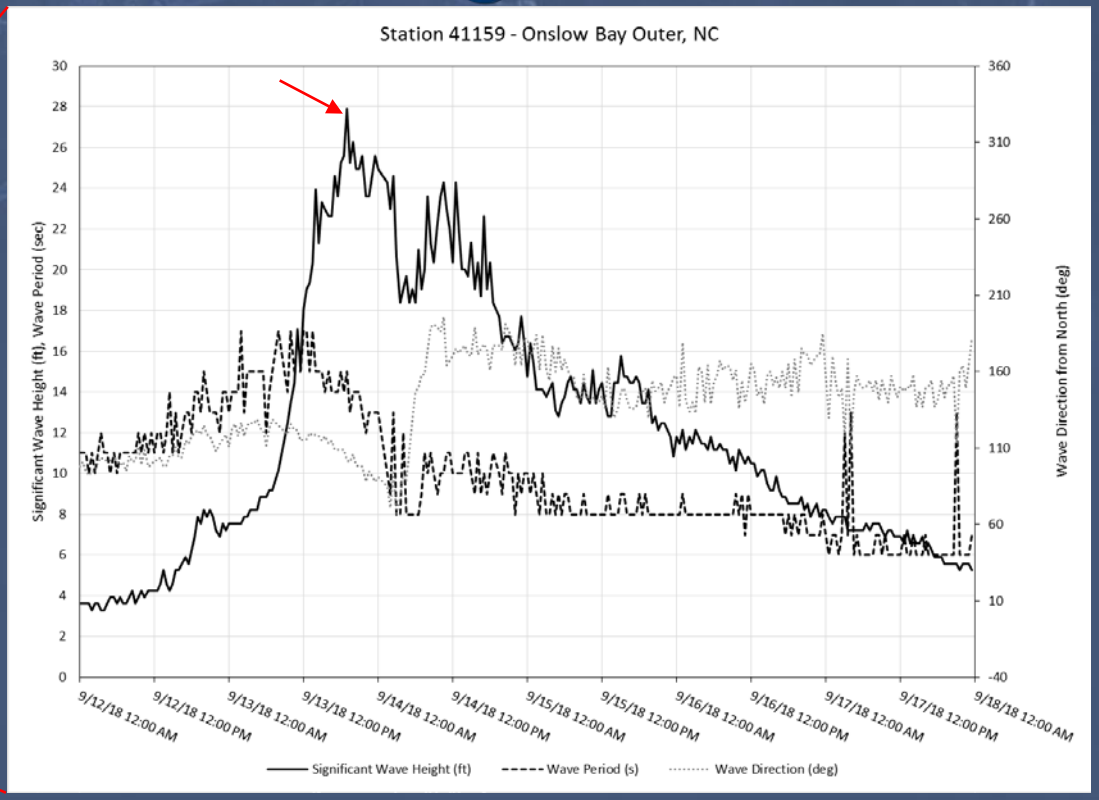
Storm Data Summary

➢ Hurricane Florence Summary:

❖ Wave Conditions 9/12/2018 – 9/17/2018 GMT

- **9/14 Peak Wave Condition: 27.89 ft @ 15 sec**

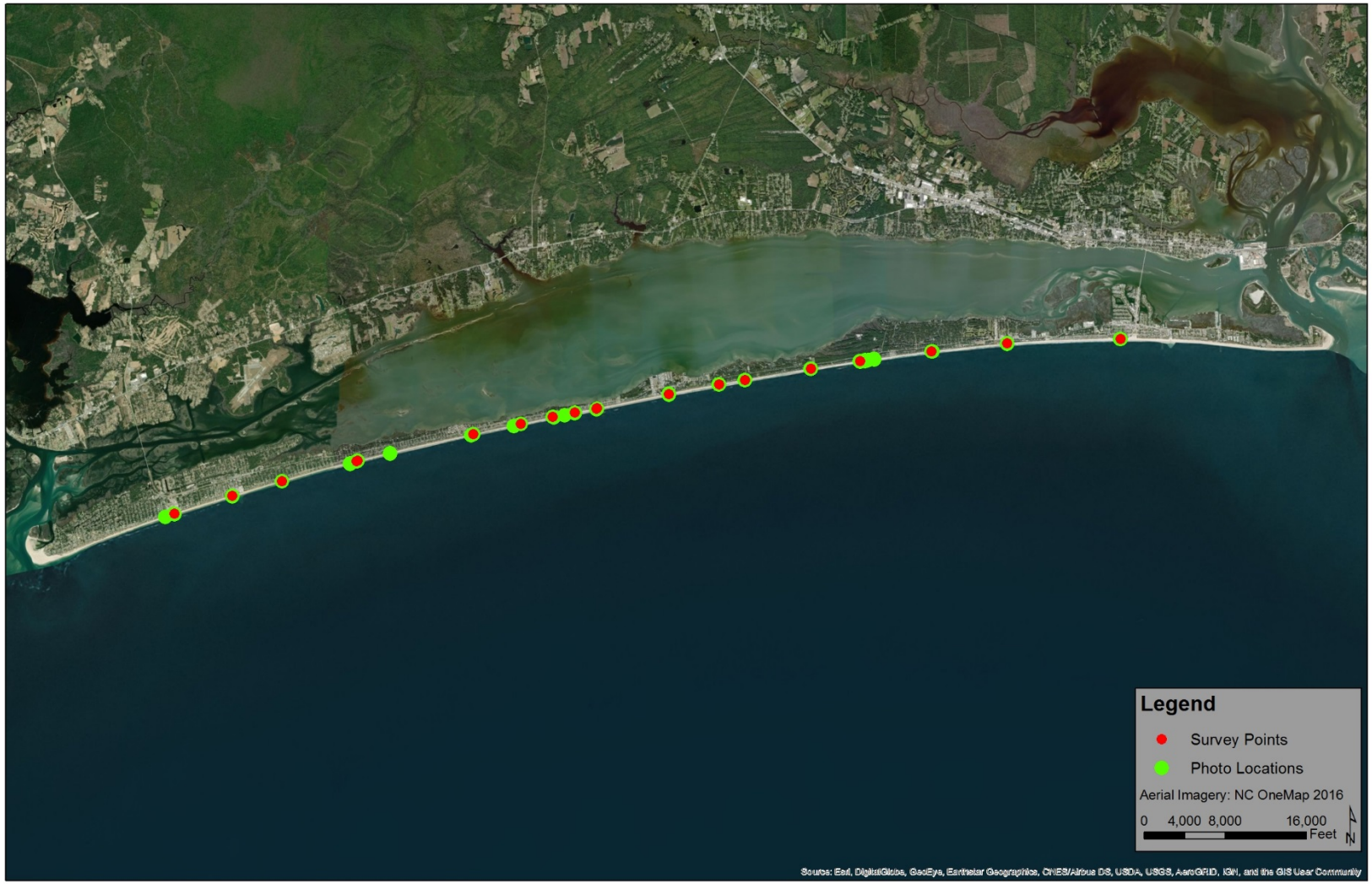
(Hurricane Irene 2011: 25 ft)



Data Collection – Video of Beach Impacts

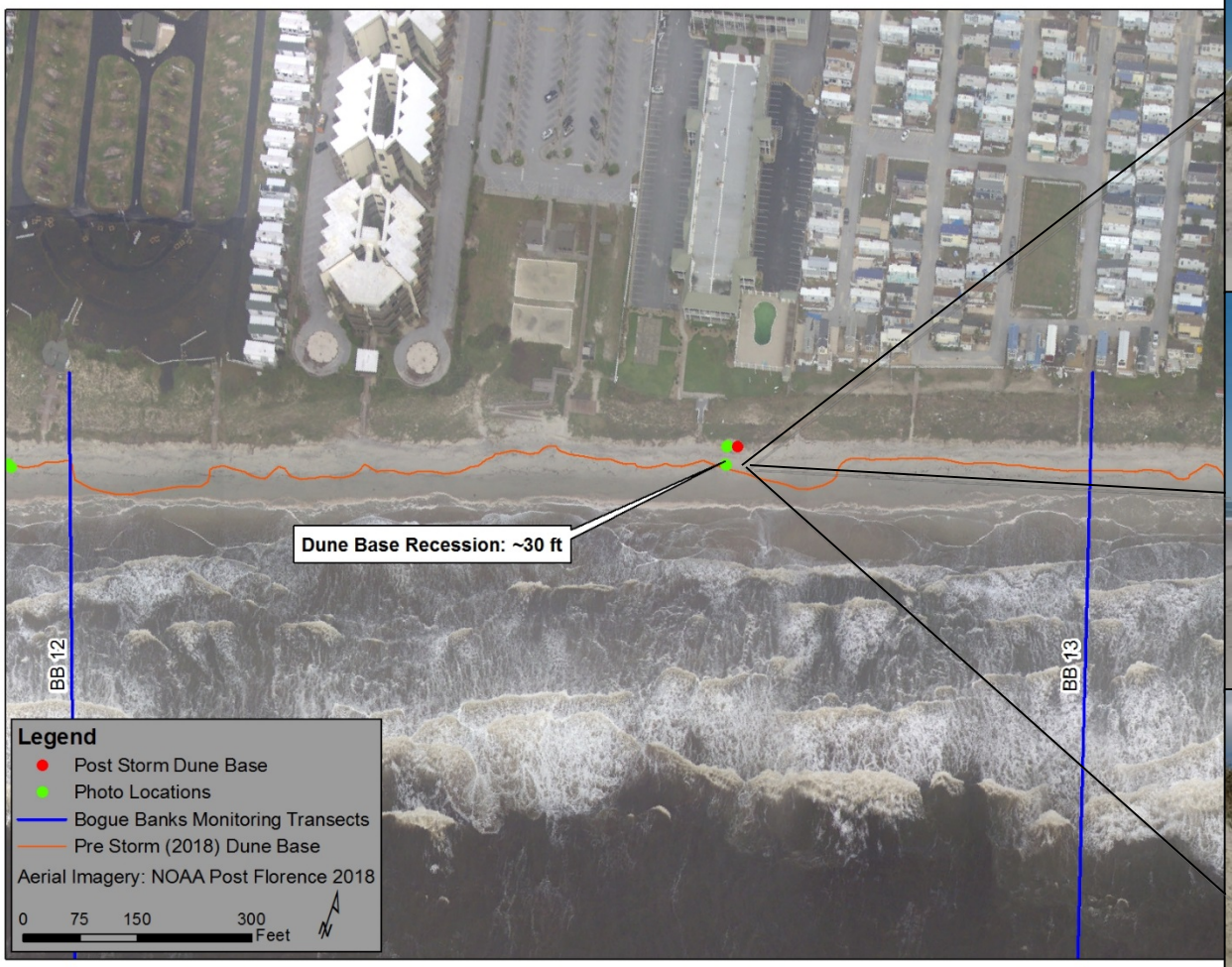
- Video's of the Entire Beach can be Found on the Shore Protection Office YouTube Channel
  - https://www.youtube.com/channel/UCsUNBJr2CbImfH4H5OctbTw/videos

Data Collection – Survey Points and Photos



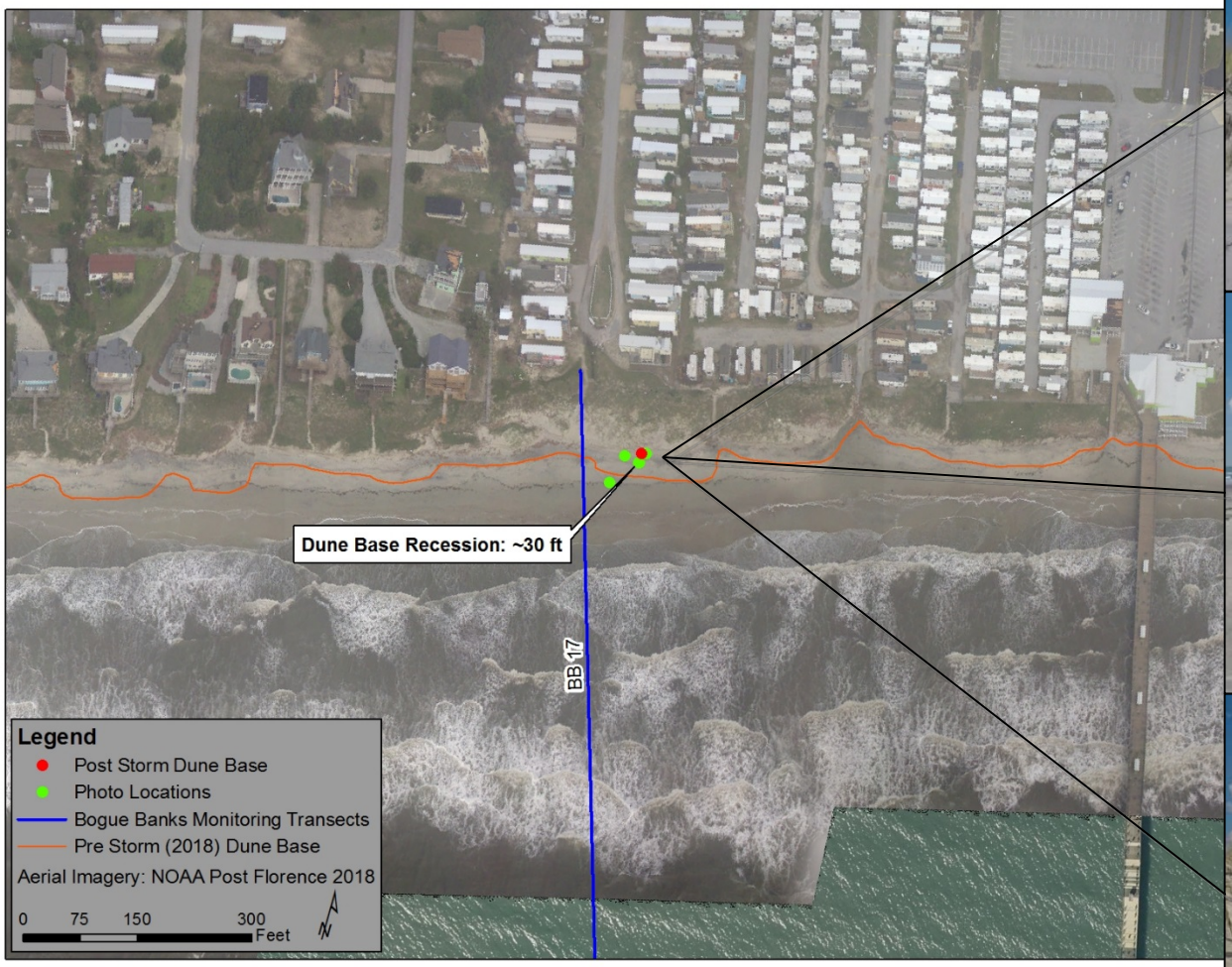
Data Collection – Survey Points and Photos

➢ BB12 – BB13 (Islander Resort)



Data Collection – Survey Points and Photos

➢ B17 (Bogue Banks Fishing Pier)



Data Collection – Survey Points and Photos

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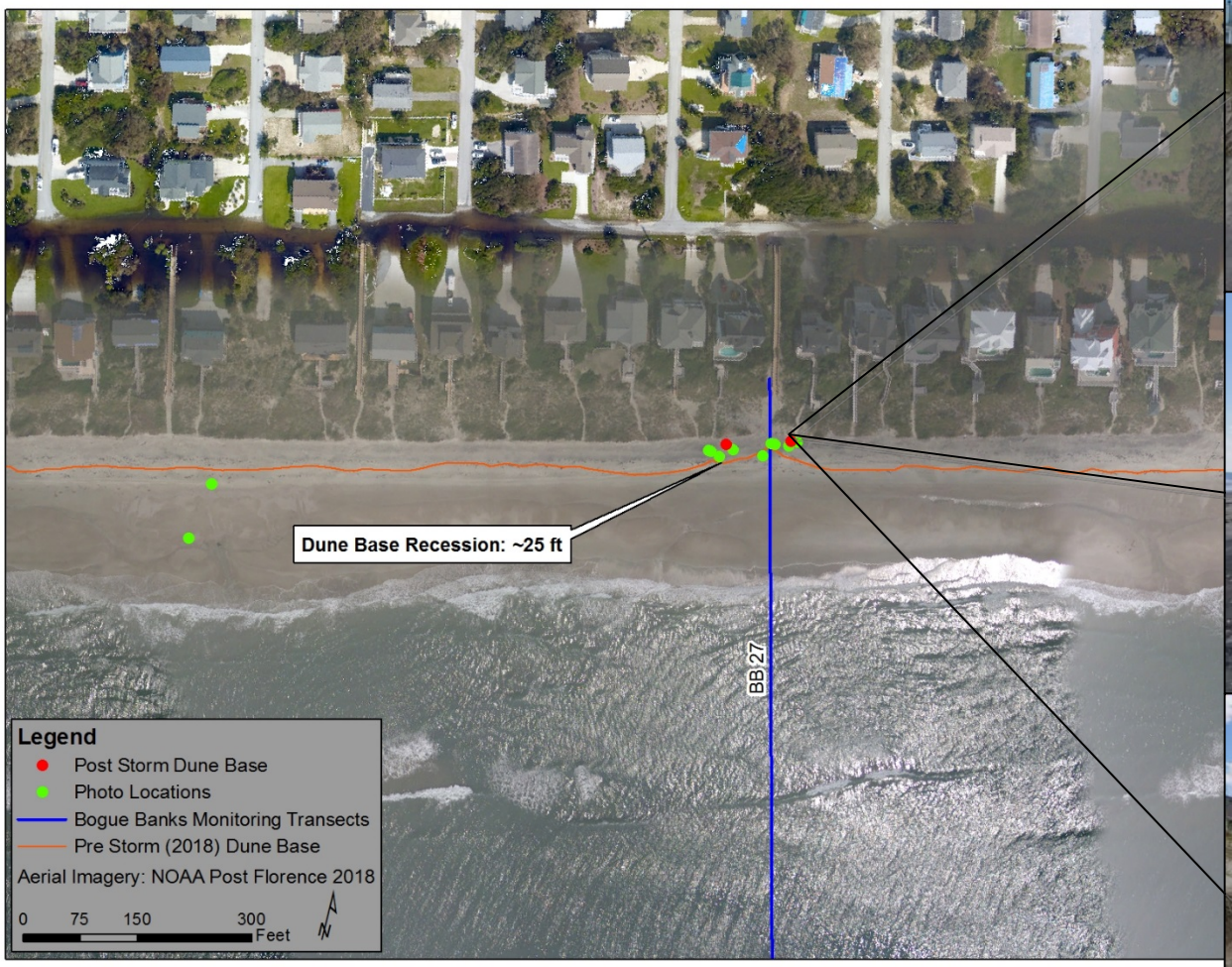
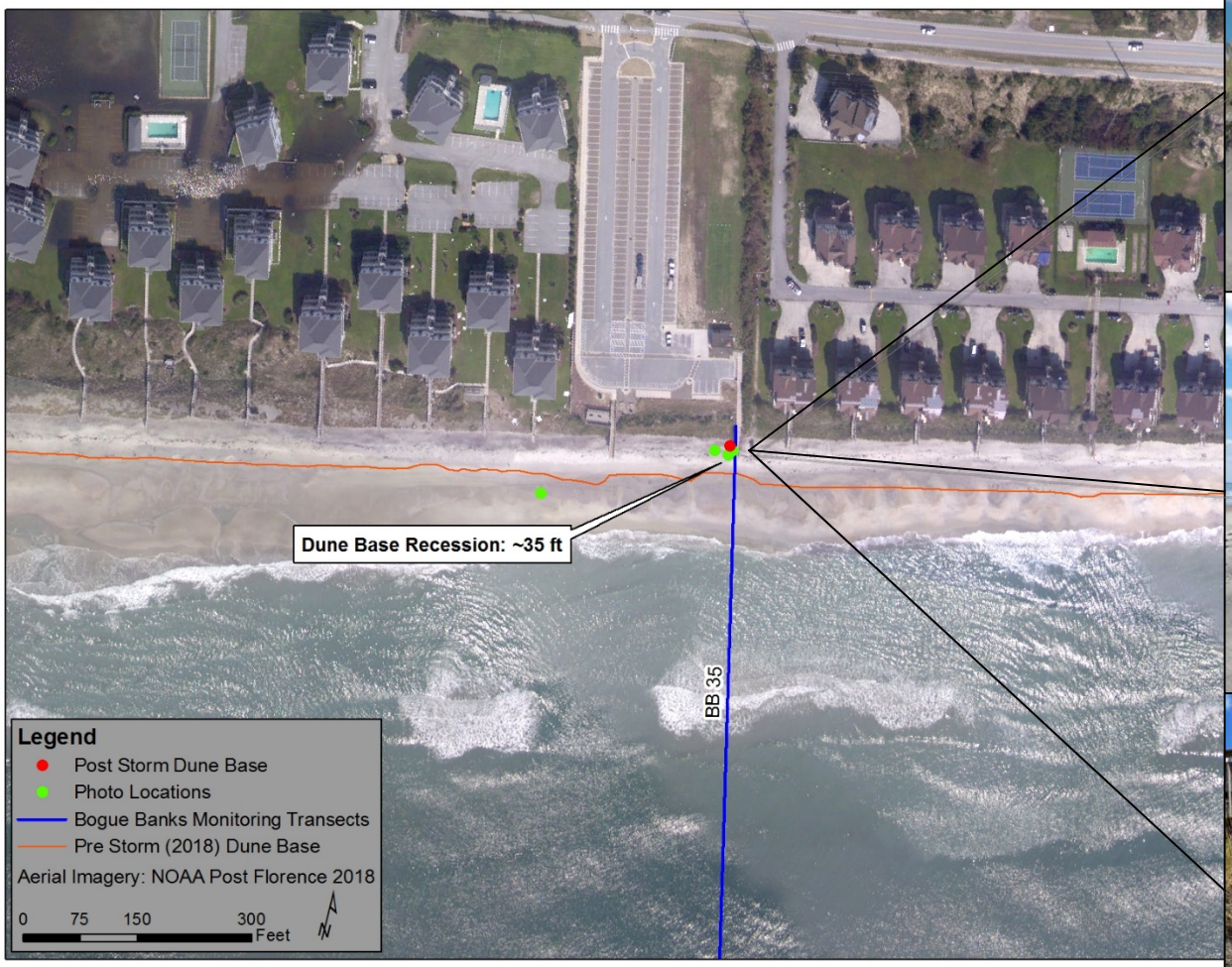


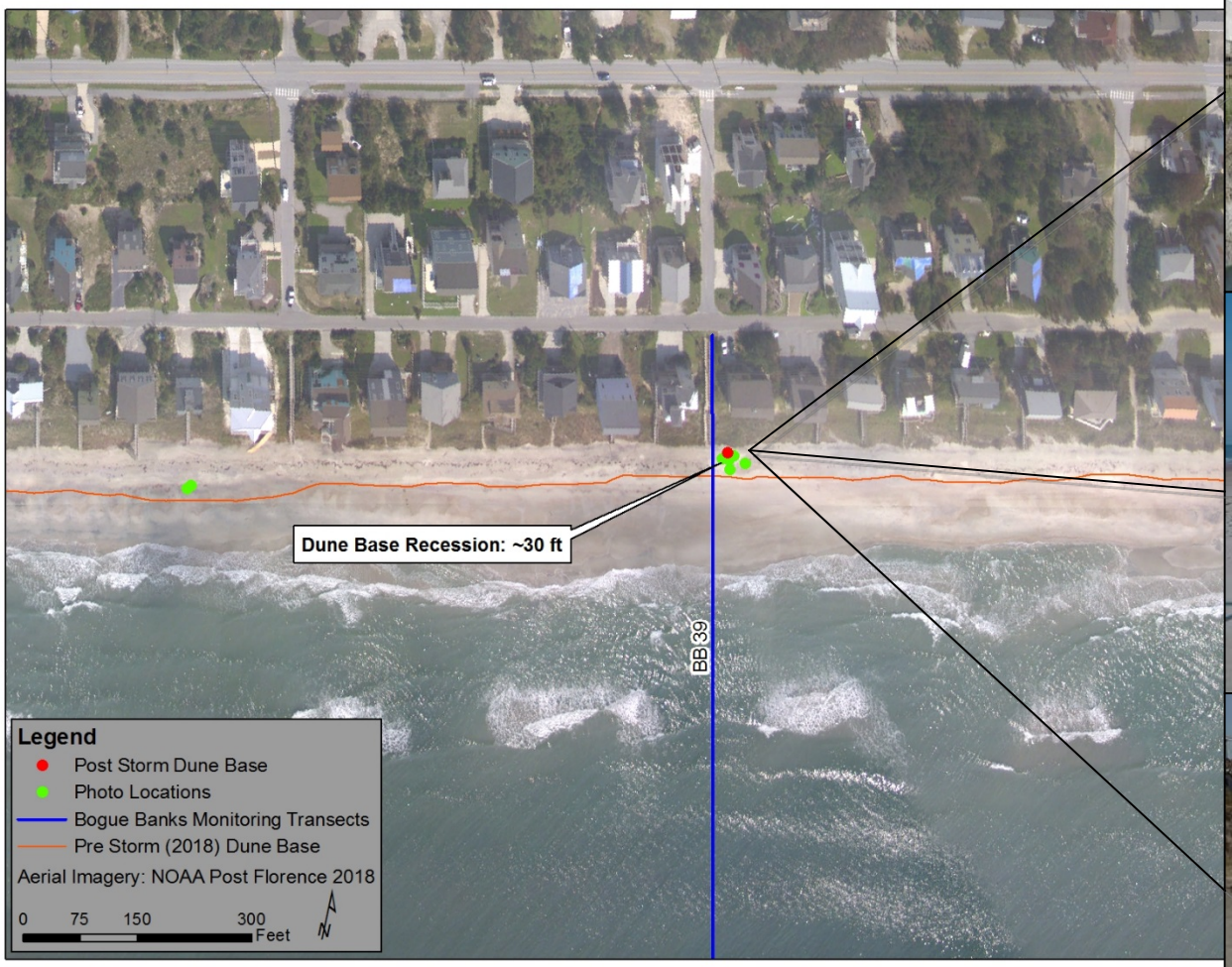
Data Collection – Survey Points and Photos

➢ BB35 (Ocean Reef)



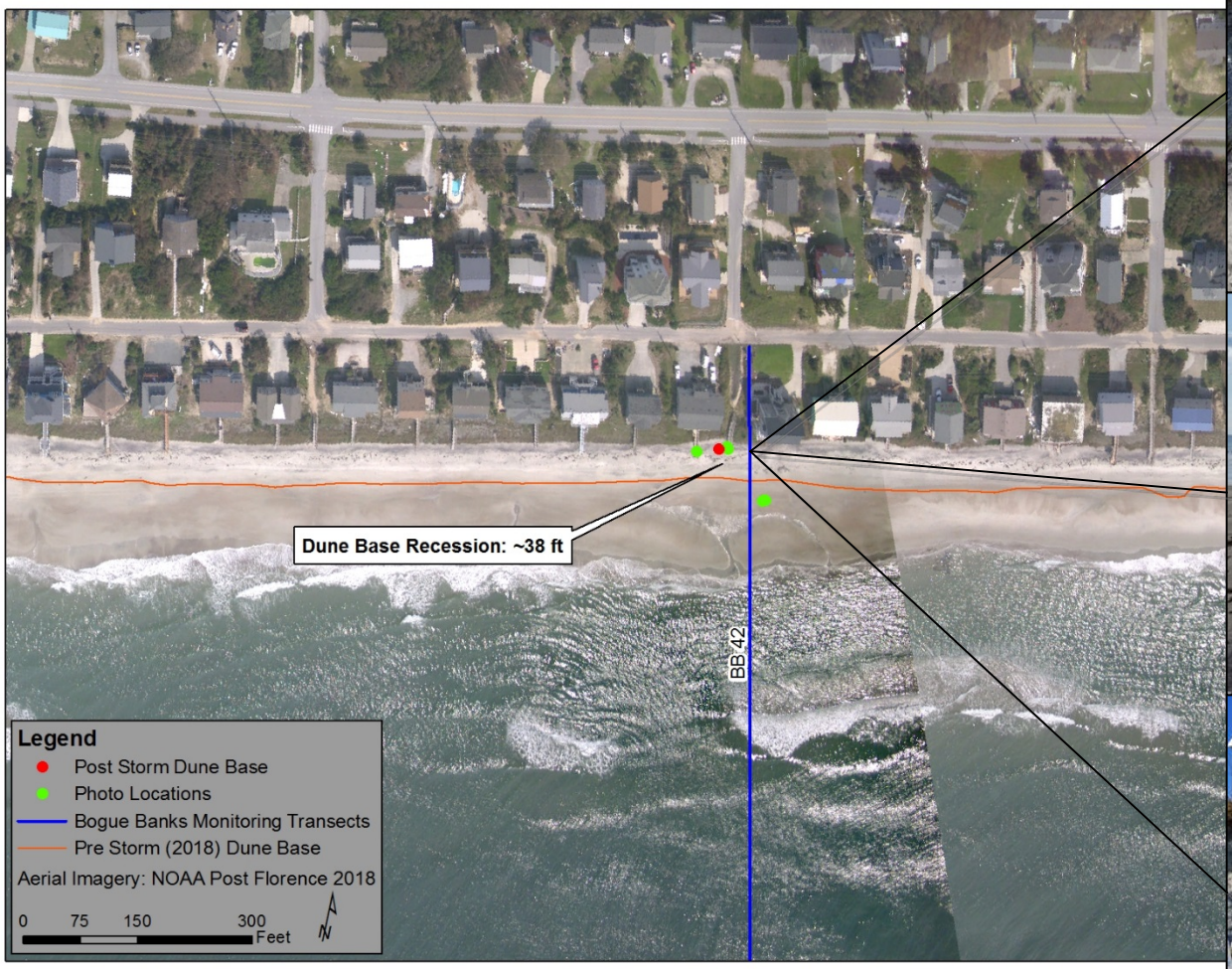
Data Collection – Survey Points and Photos

- **BB39 (18th St.)**



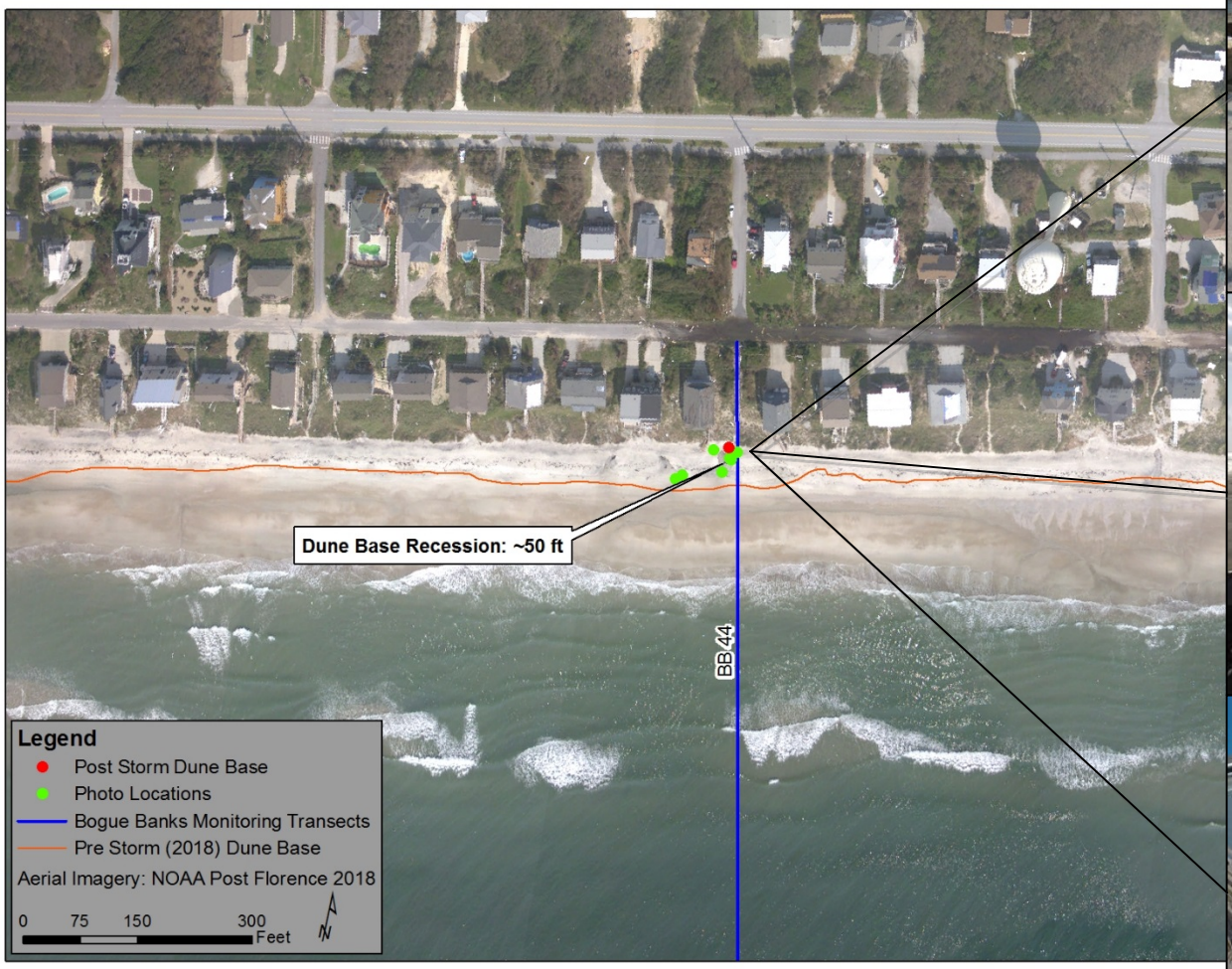
Data Collection – Survey Points and Photos

- **BB42 (12th St.)**



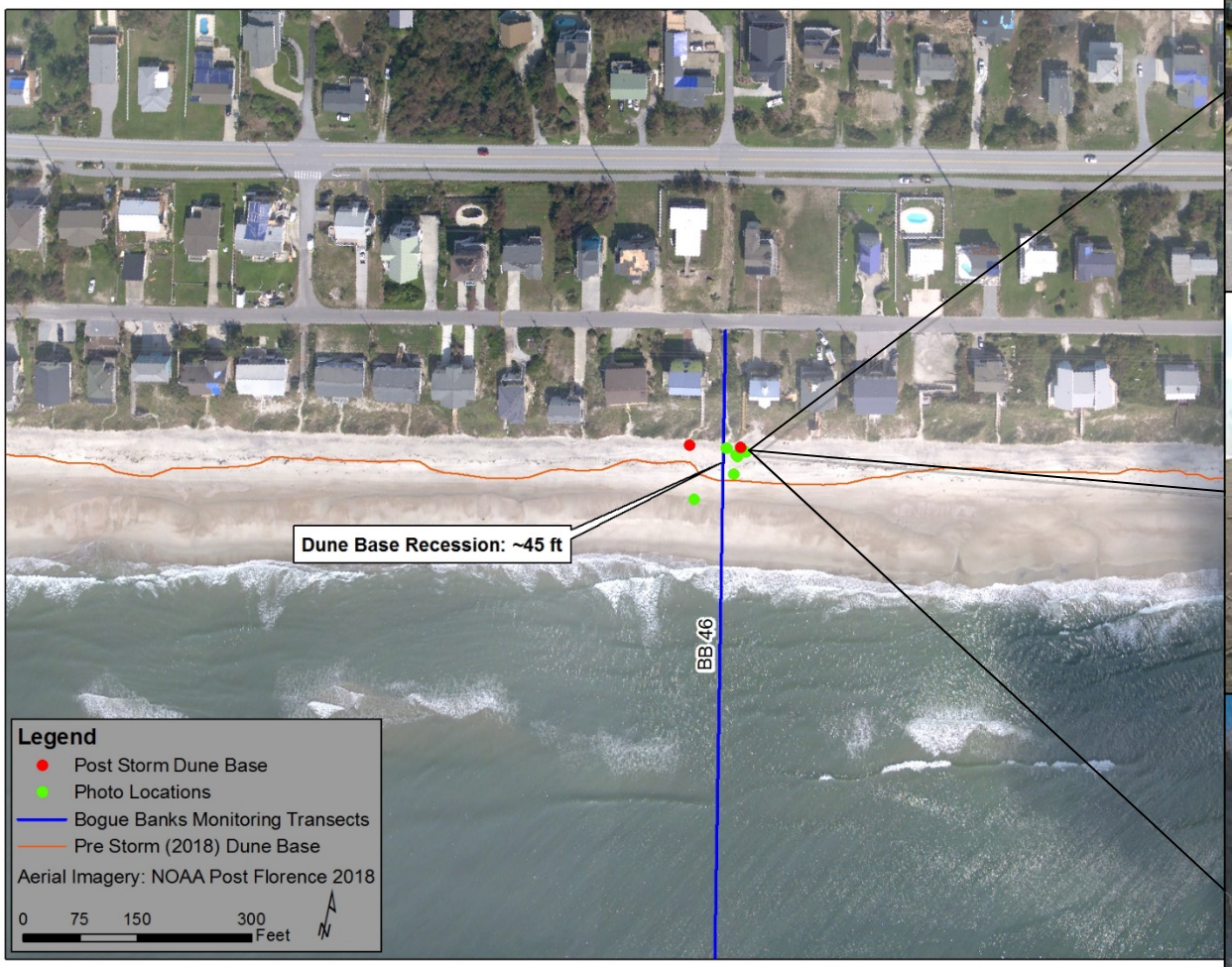
Data Collection – Survey Points and Photos

- **BB44 (8th St.)**



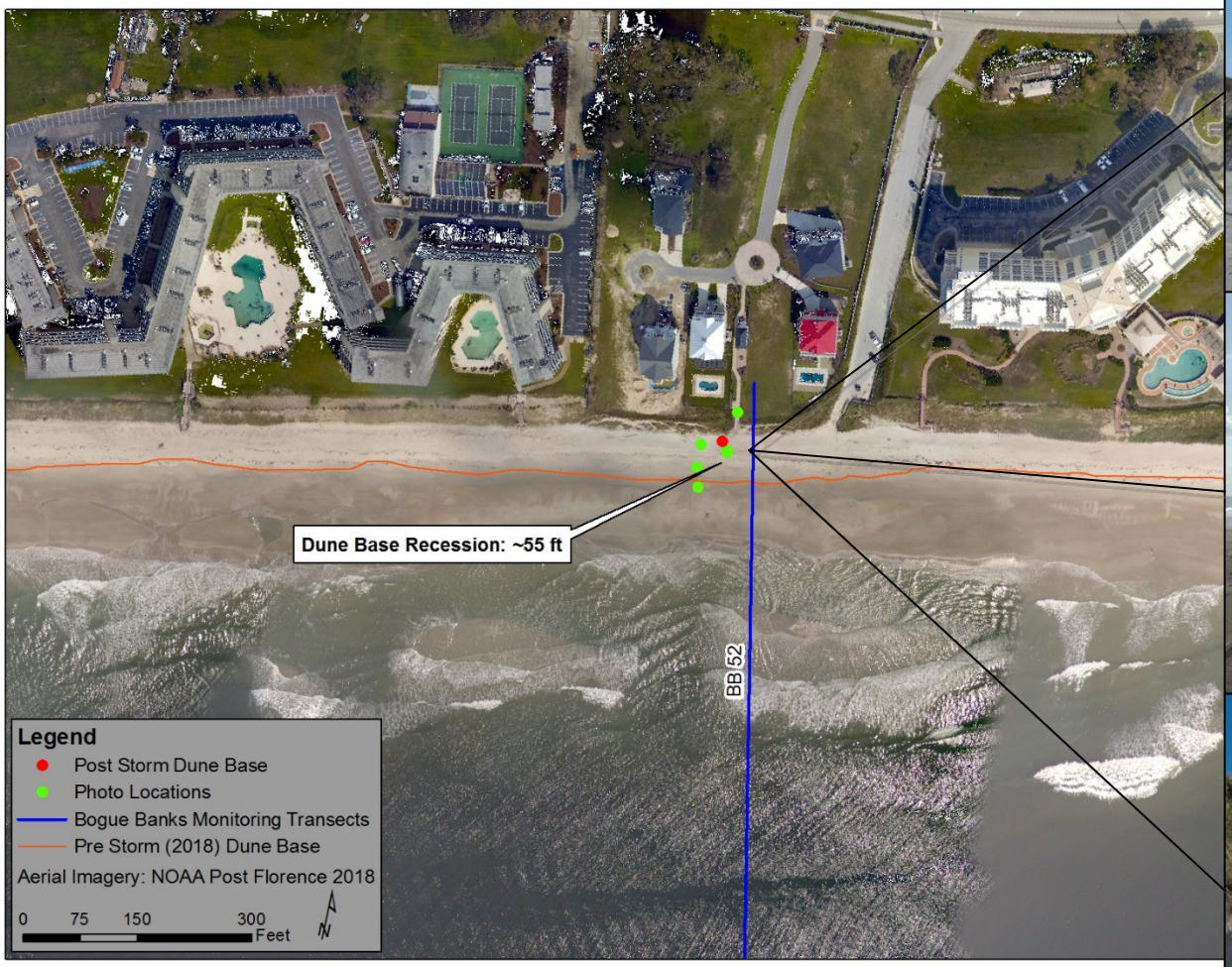
Data Collection – Survey Points and Photos

- **BB46 (3rd St.)**



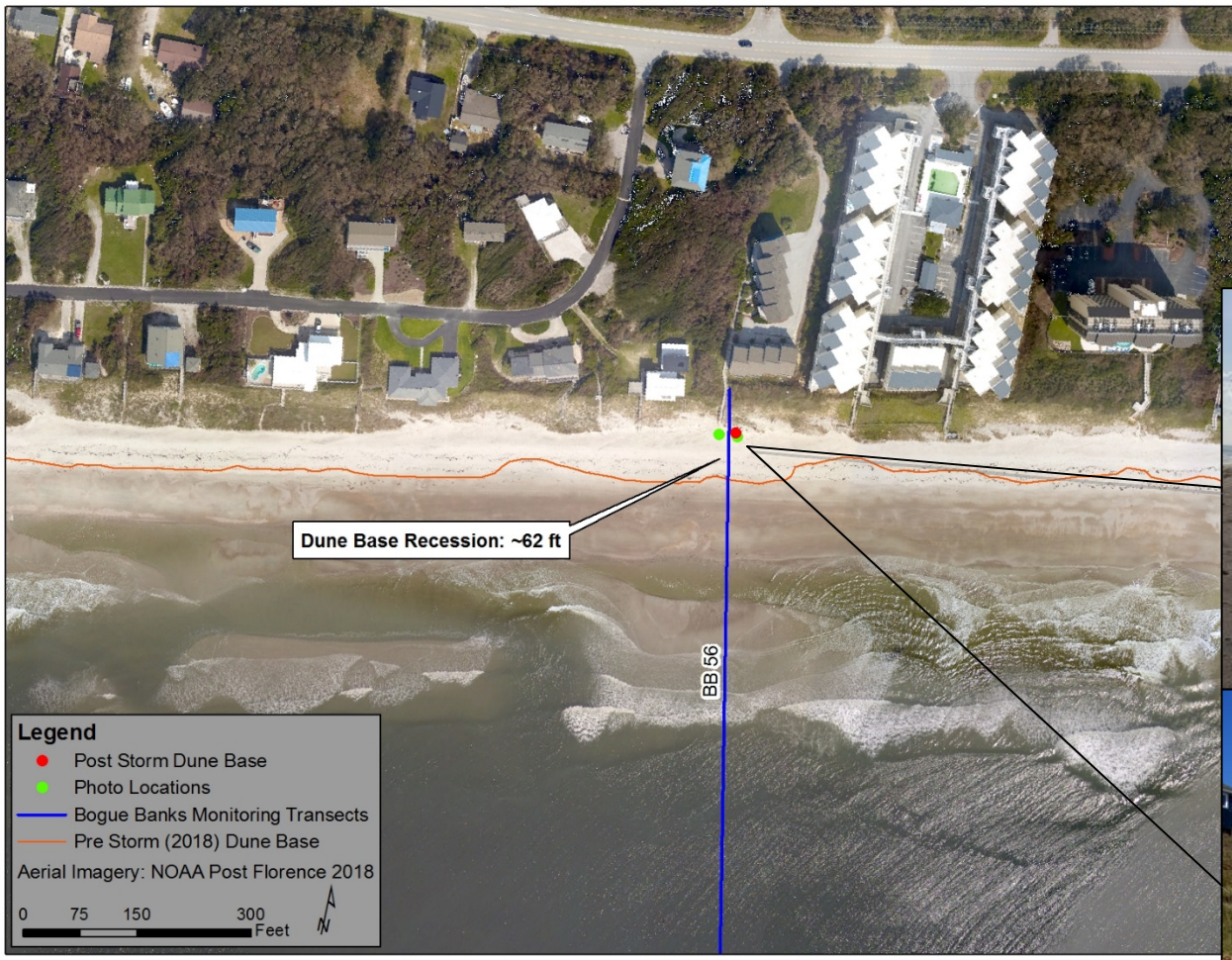
Data Collection – Survey Points and Photos

➢ BB52 (Indian Beach 4wd Ramp)



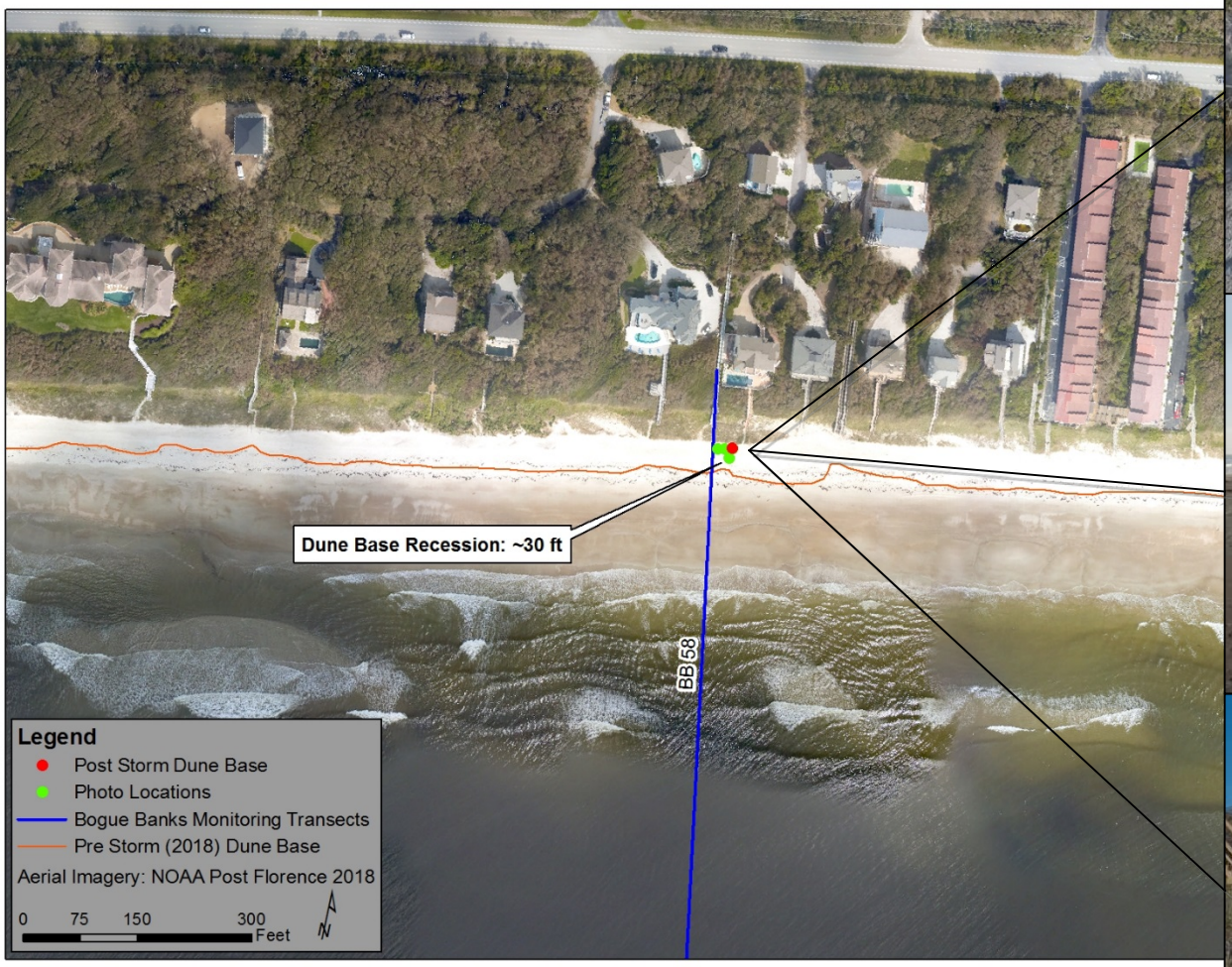
Data Collection – Survey Points and Photos

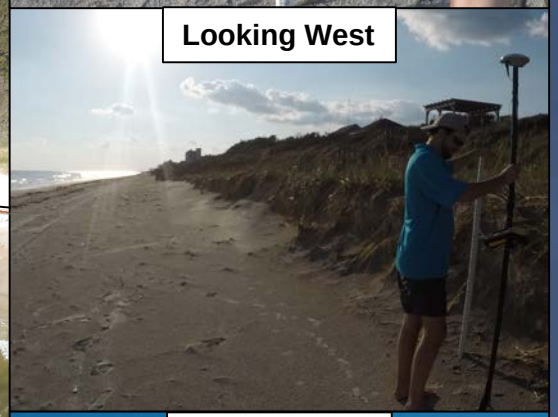
➢ BB56 (Hoffman Beach)



Data Collection – Survey Points and Photos

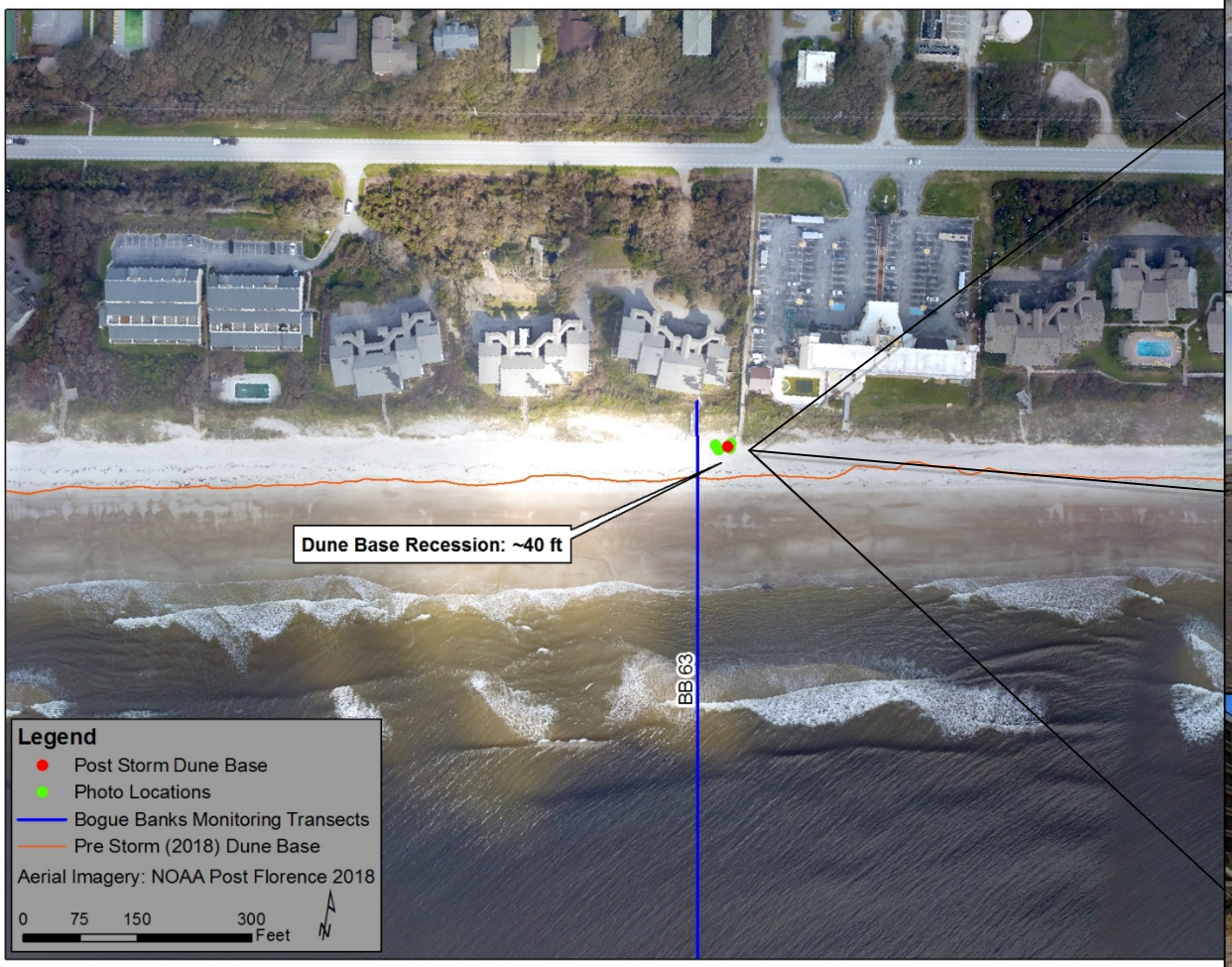
➢ BB58 (Trinity Center Access)

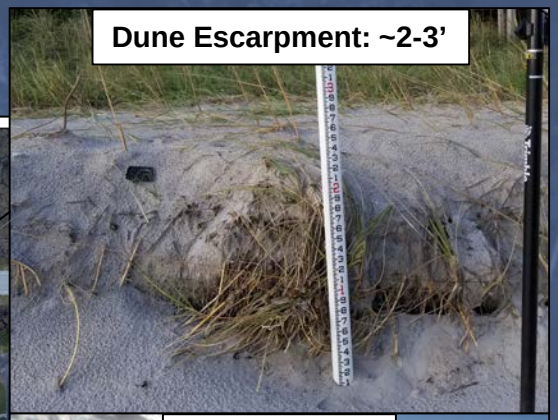


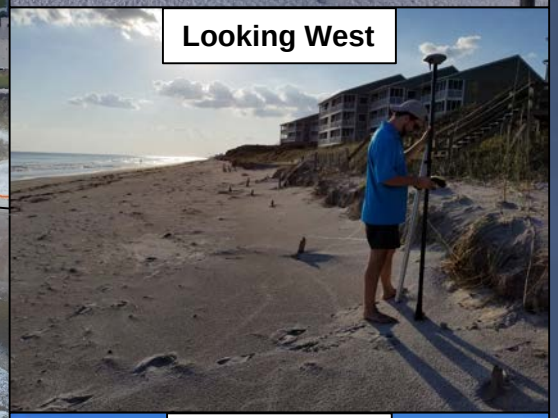


Data Collection – Survey Points and Photos

➢ BB63 (Clamdigger)

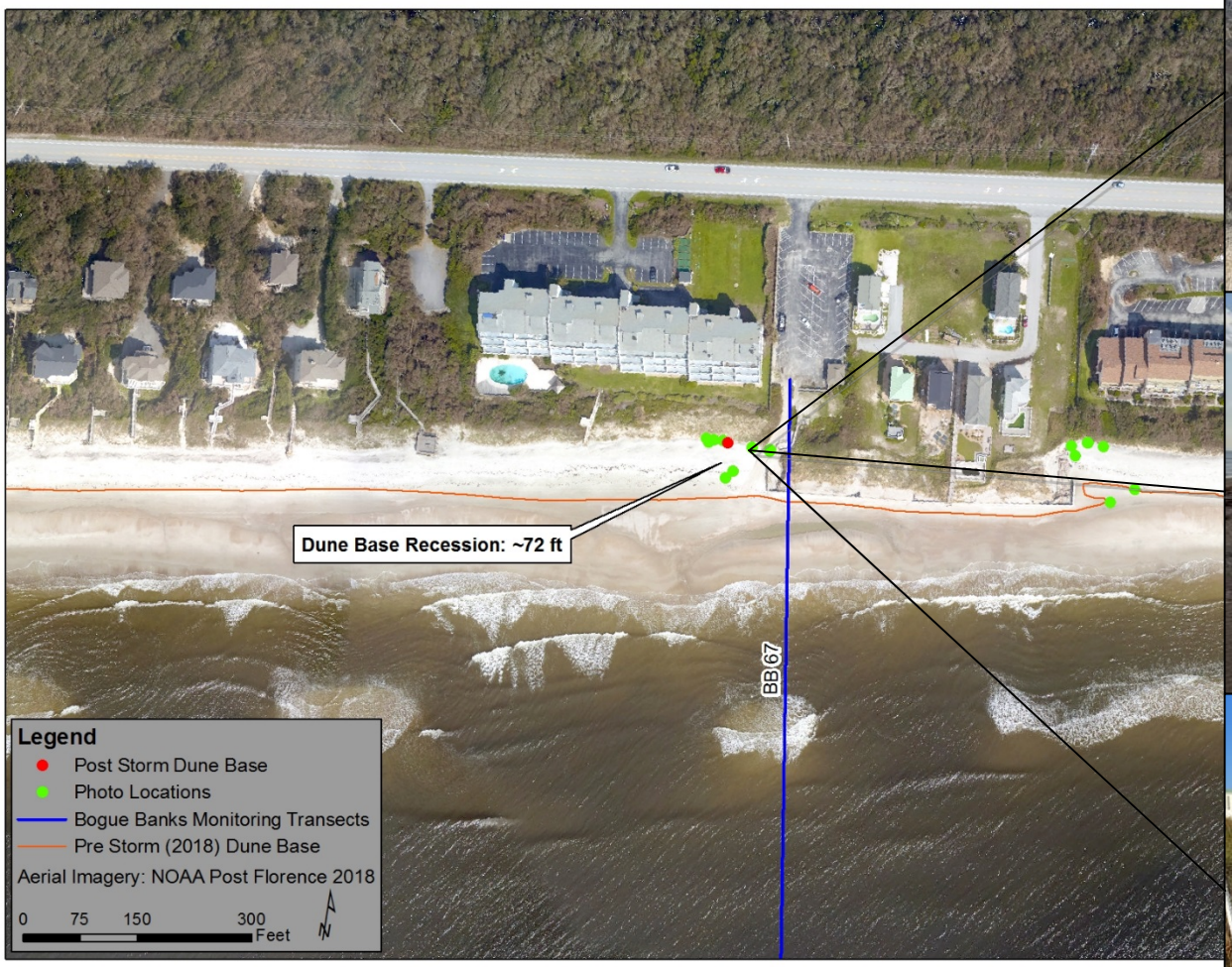


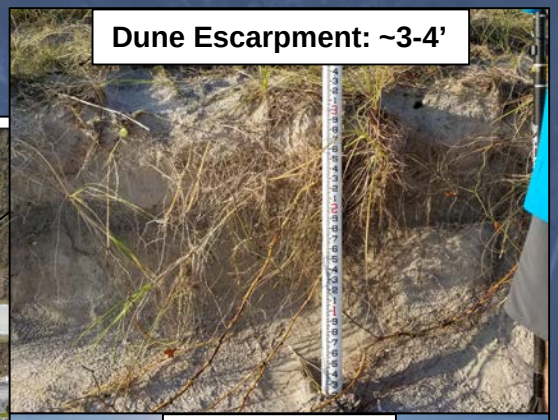


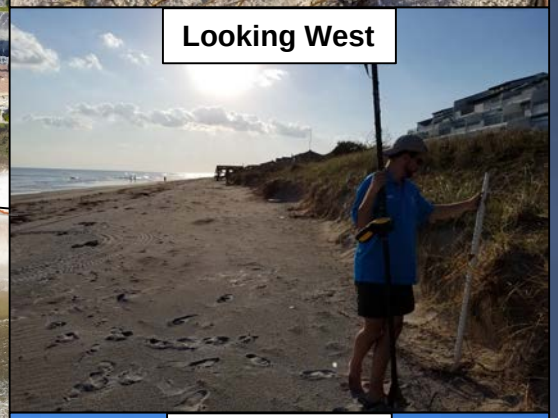


Data Collection – Survey Points and Photos

➢ BB67 (Iron Steamer)

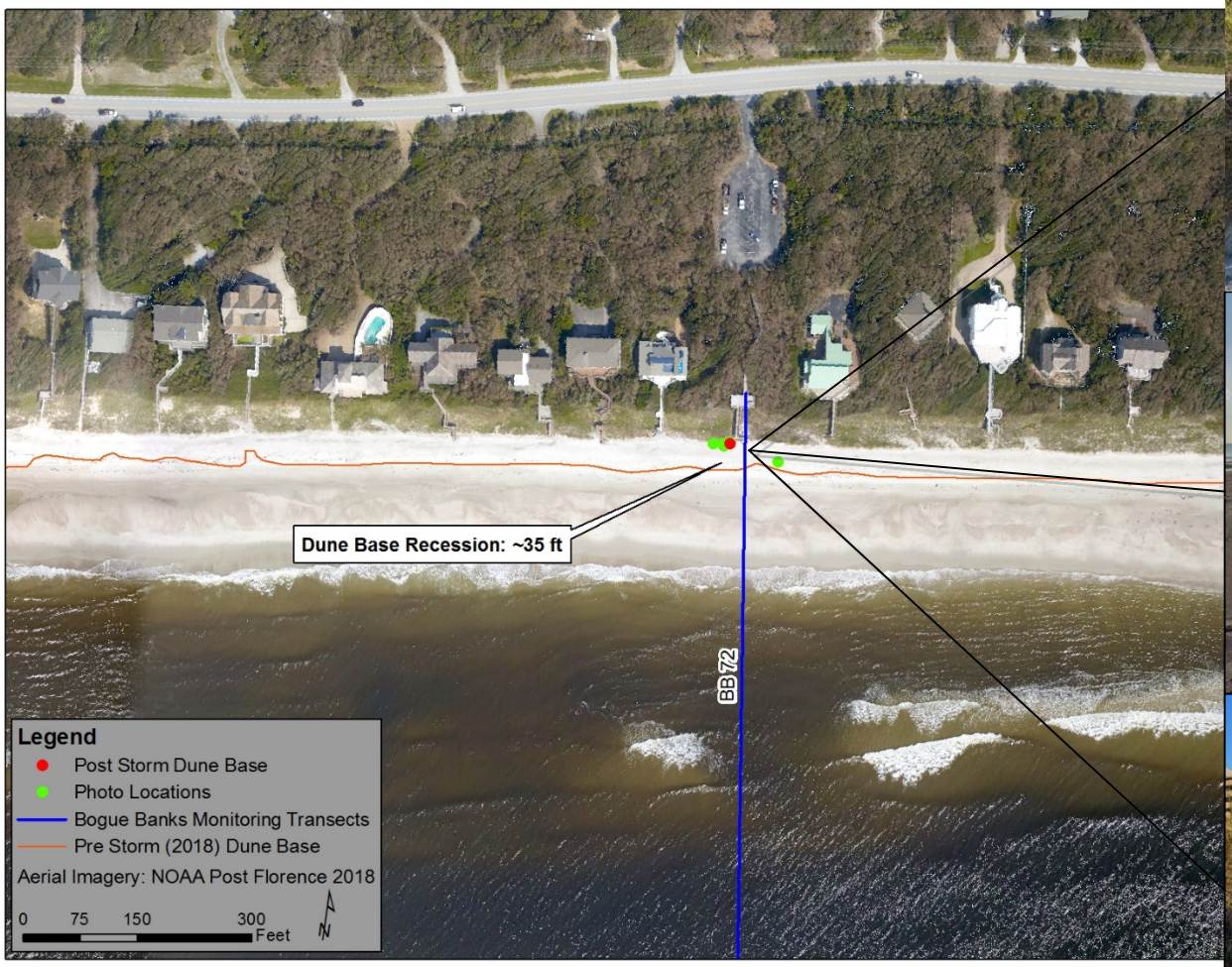


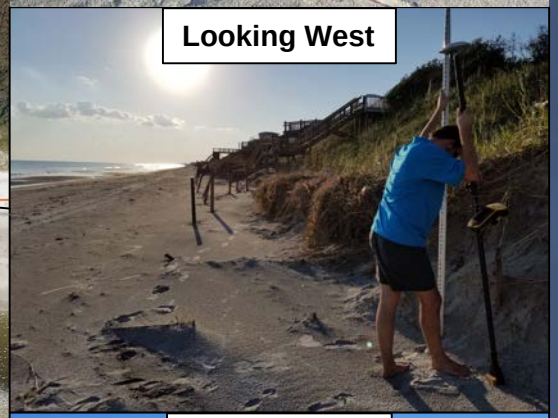




Data Collection – Survey Points and Photos

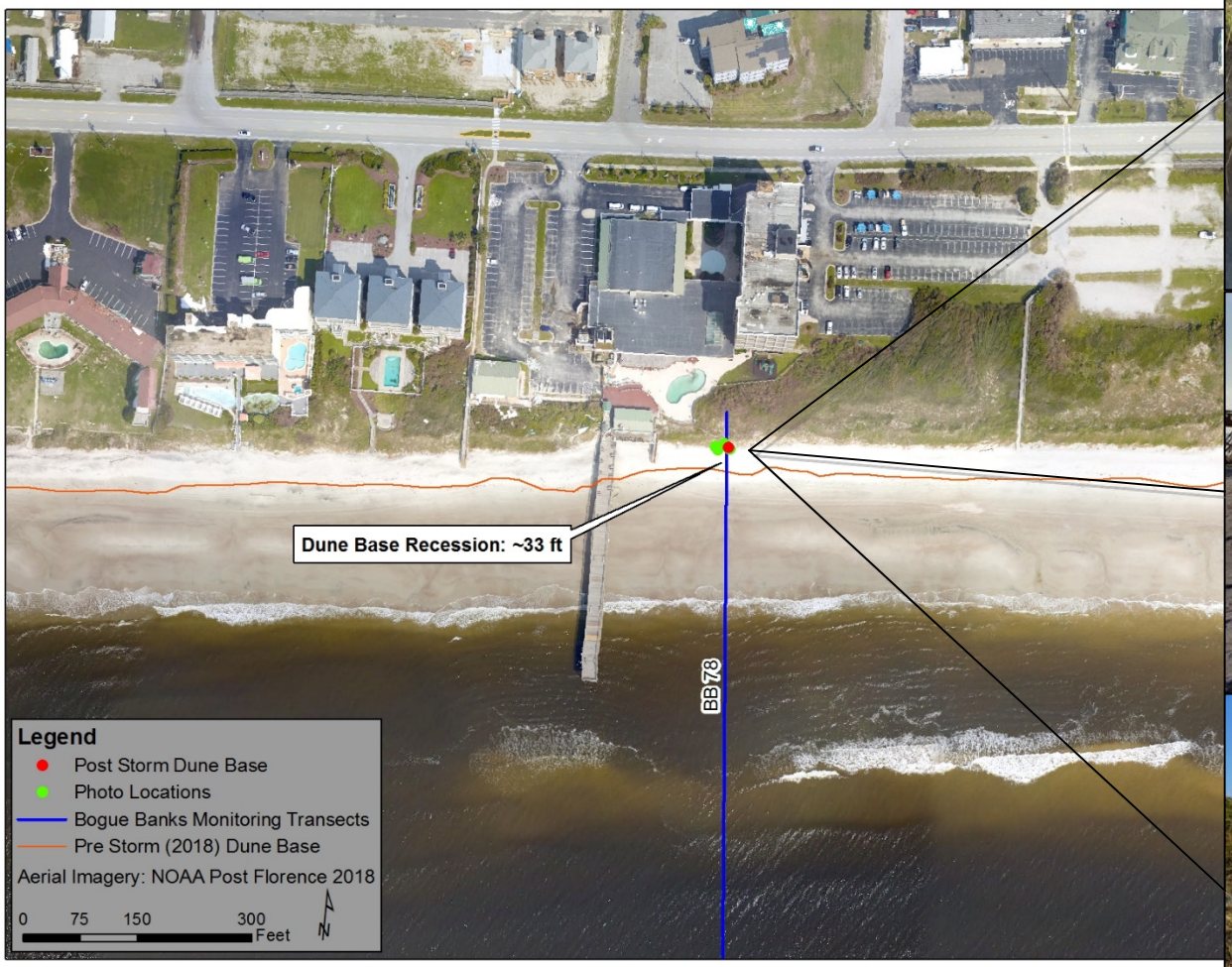
➢ BB72 (Memorial Park)

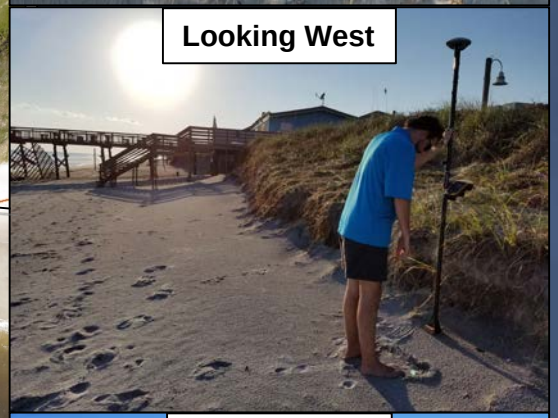




Data Collection – Survey Points and Photos

➢ BB78 (Double Tree)





Data Collection – Survey Points and Photos

➢ BB89 - 90 (The Circle)

Hurricane Florence Summary

- Significant Escarpment of Incipient Dune with areas of Incipient Dune Removal Across Oceanfront from BB1-BB90
- Primary Dune Remains with Little Damage
- Damage to Beach Walkovers Prevalent Throughout the Oceanfront
- Little to No Damage to Infrastructure with the Exception of the Iron Steamer
- Post-Storm Survey has been Completed and a Detailed Analysis of Volume Loss is Currently Being Performed

APPENDIX C

MHW Shoreline & Hotspot DEM Surface

1) MHW Shoreline Comparison
2) March 2018, Post-Florence, and Comparison Surfaces

1) MHW Shoreline Comparison

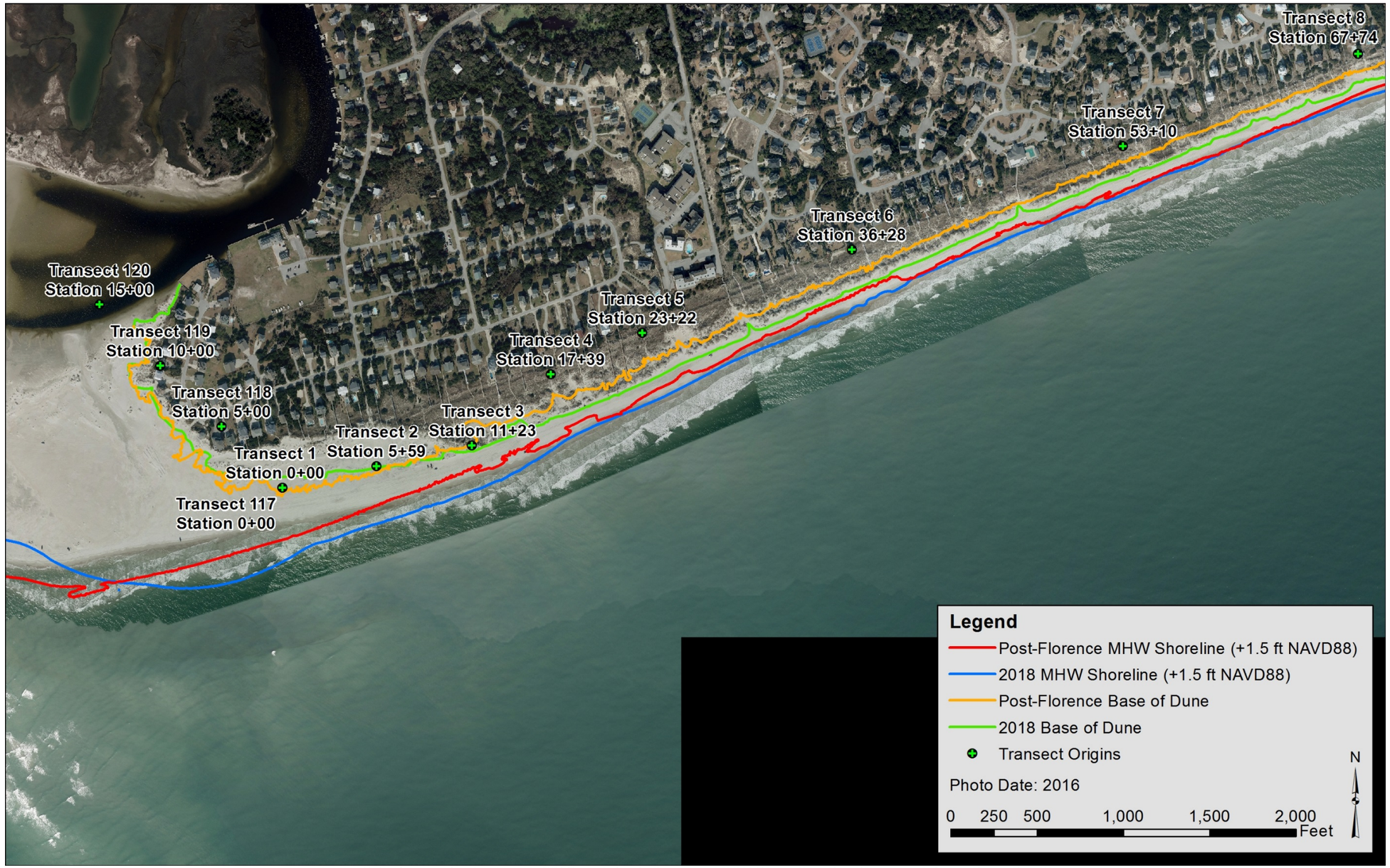


Figure C-1. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

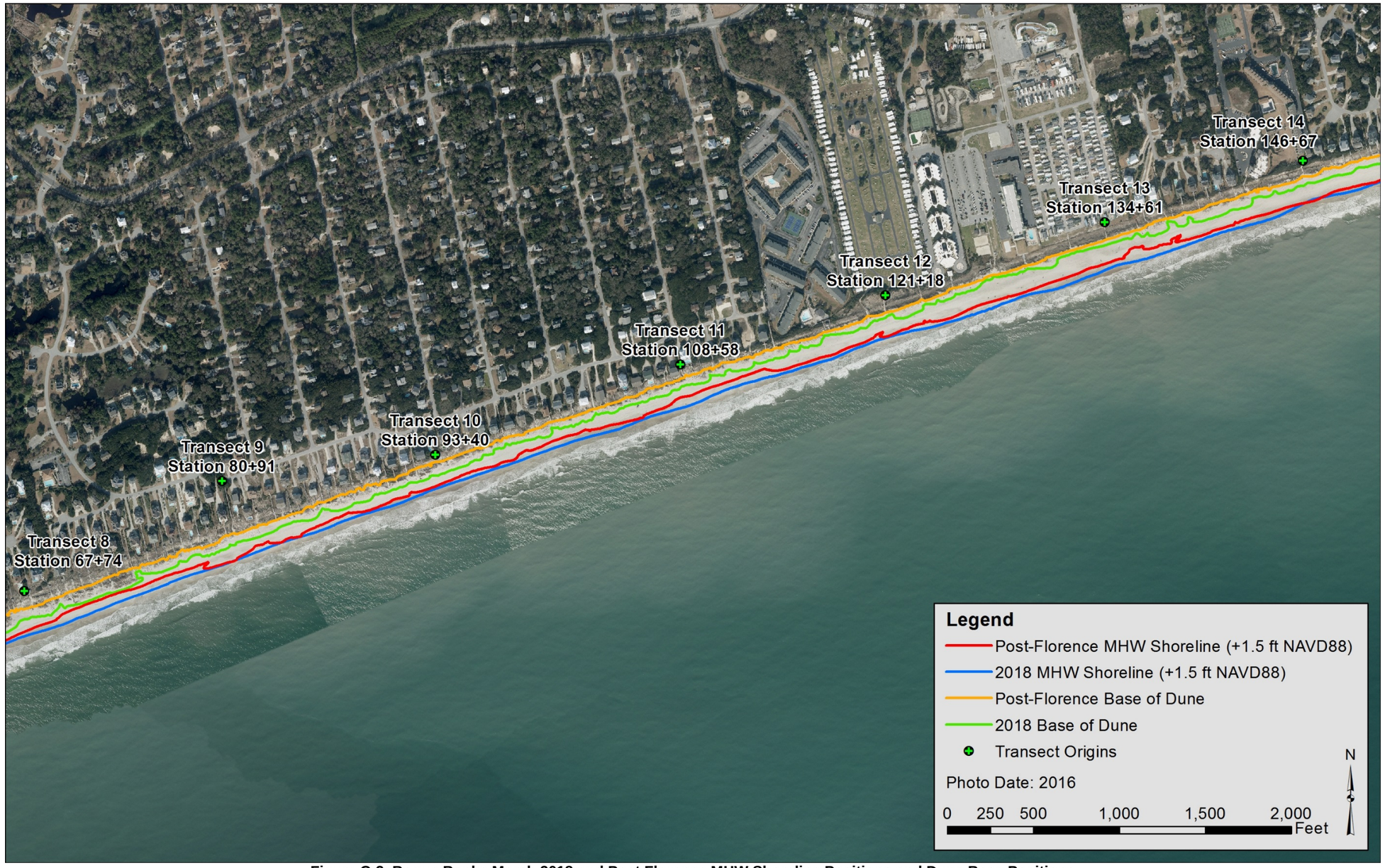


Figure C-2. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

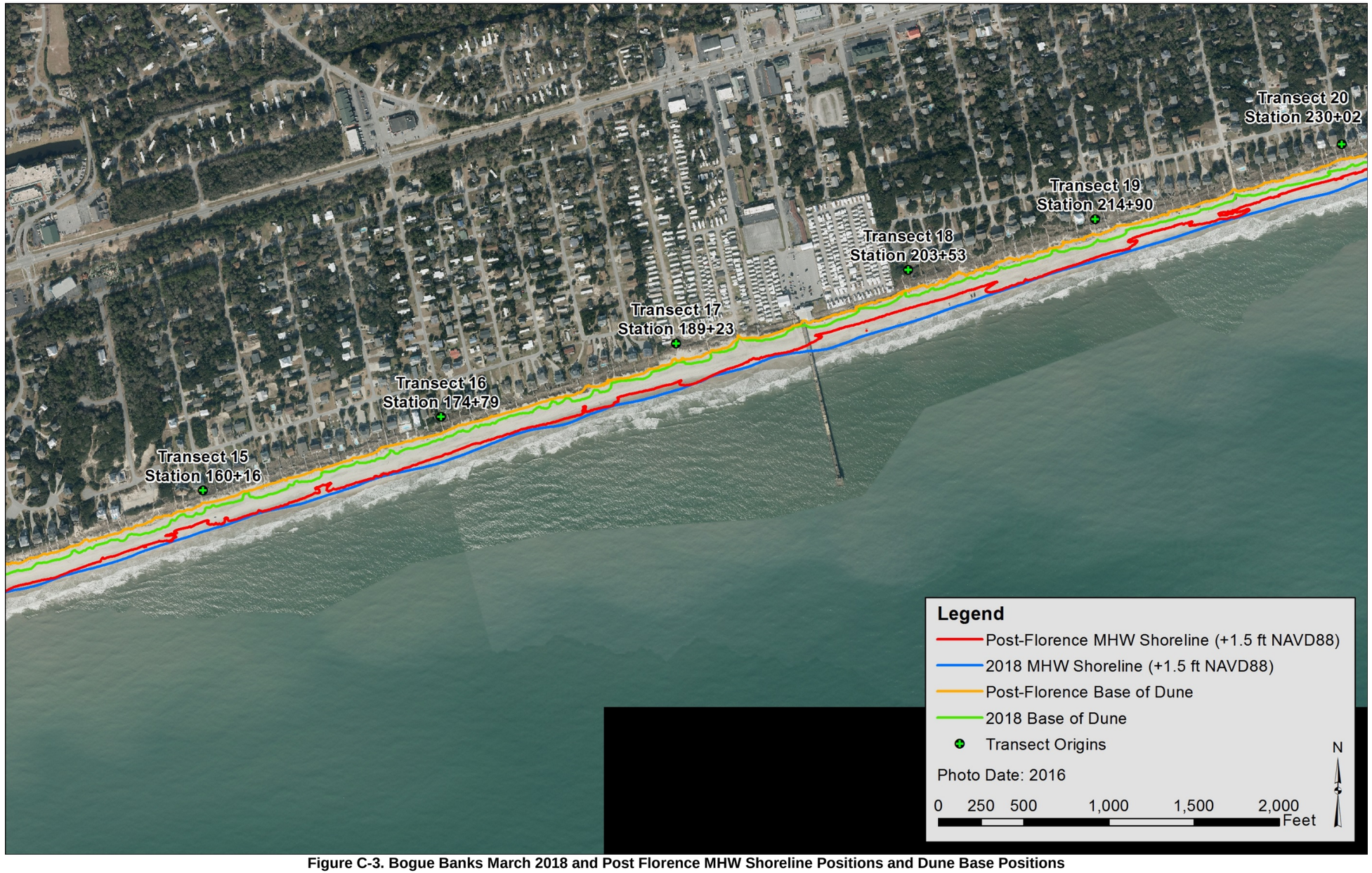


Figure C-3. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

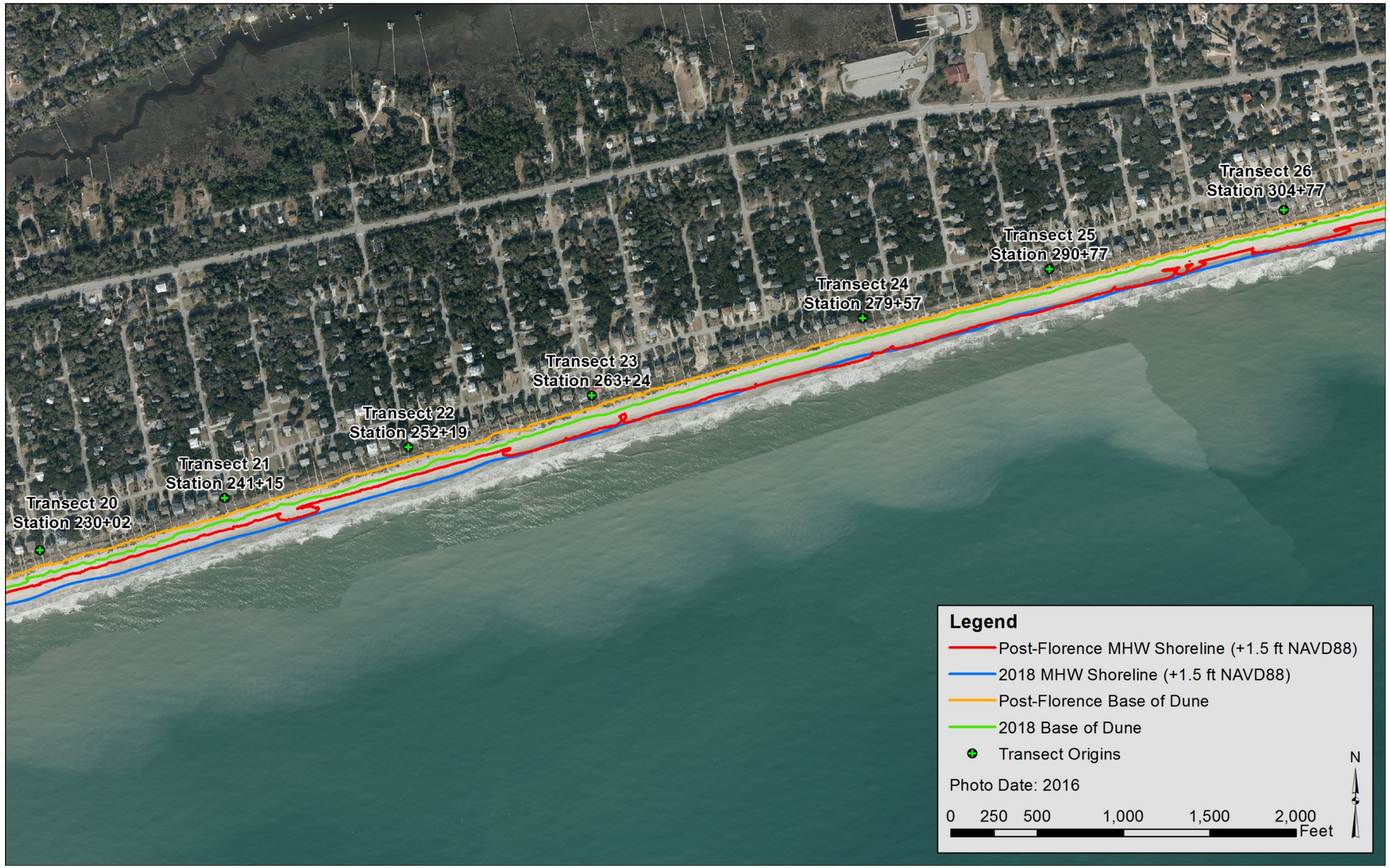


Figure C-4. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

Figure C-5. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

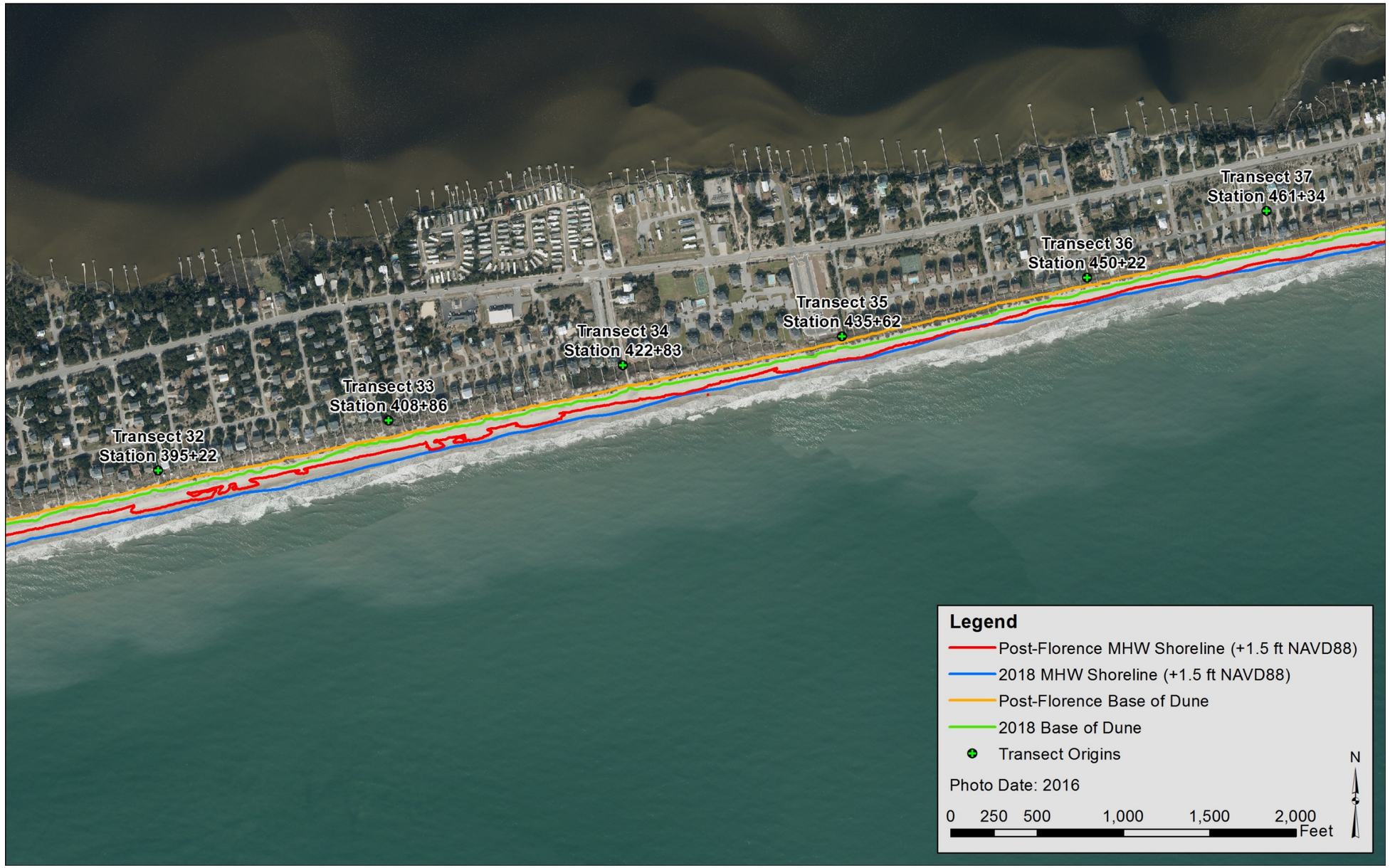


Figure C-6. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

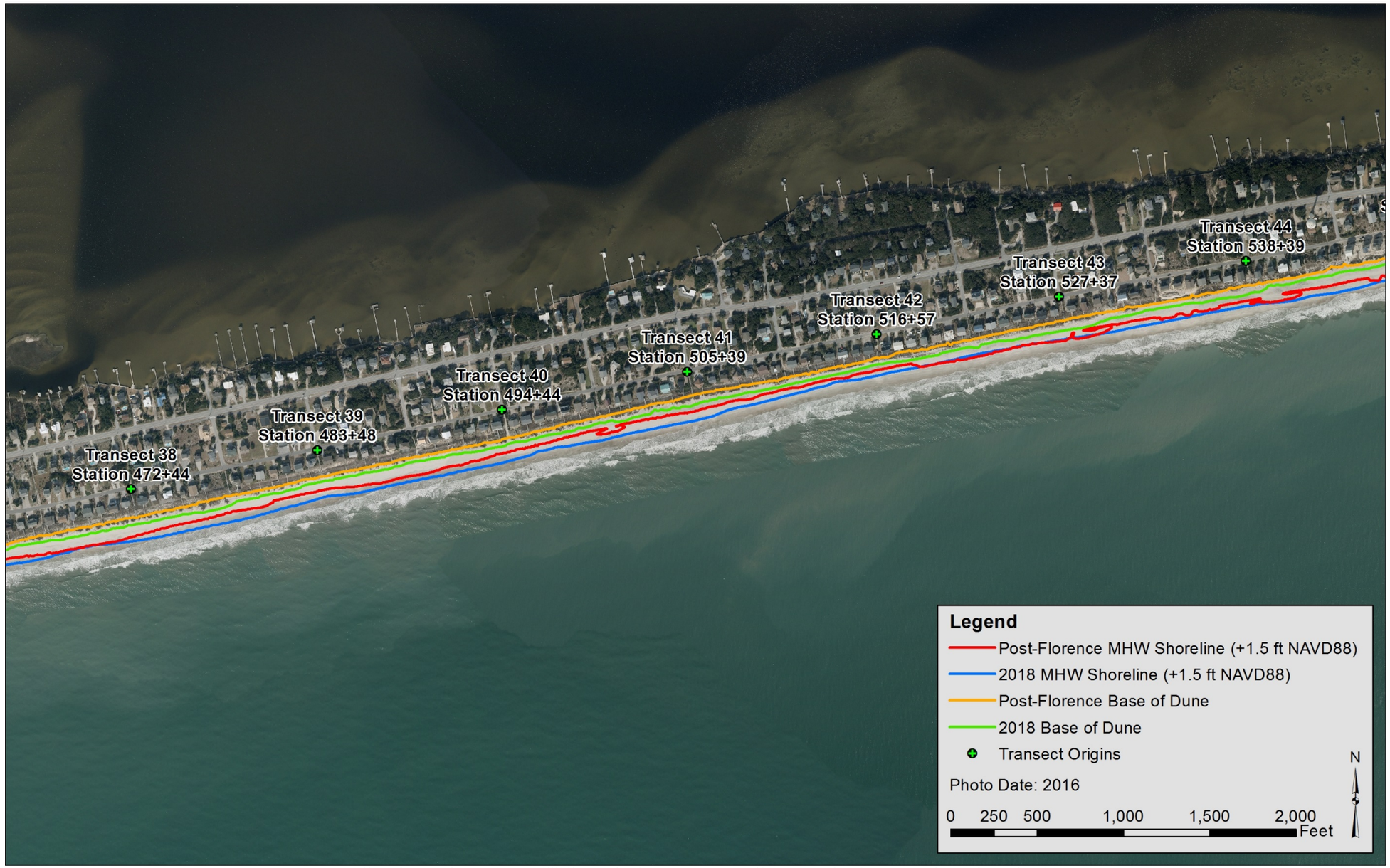


Figure C-7. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

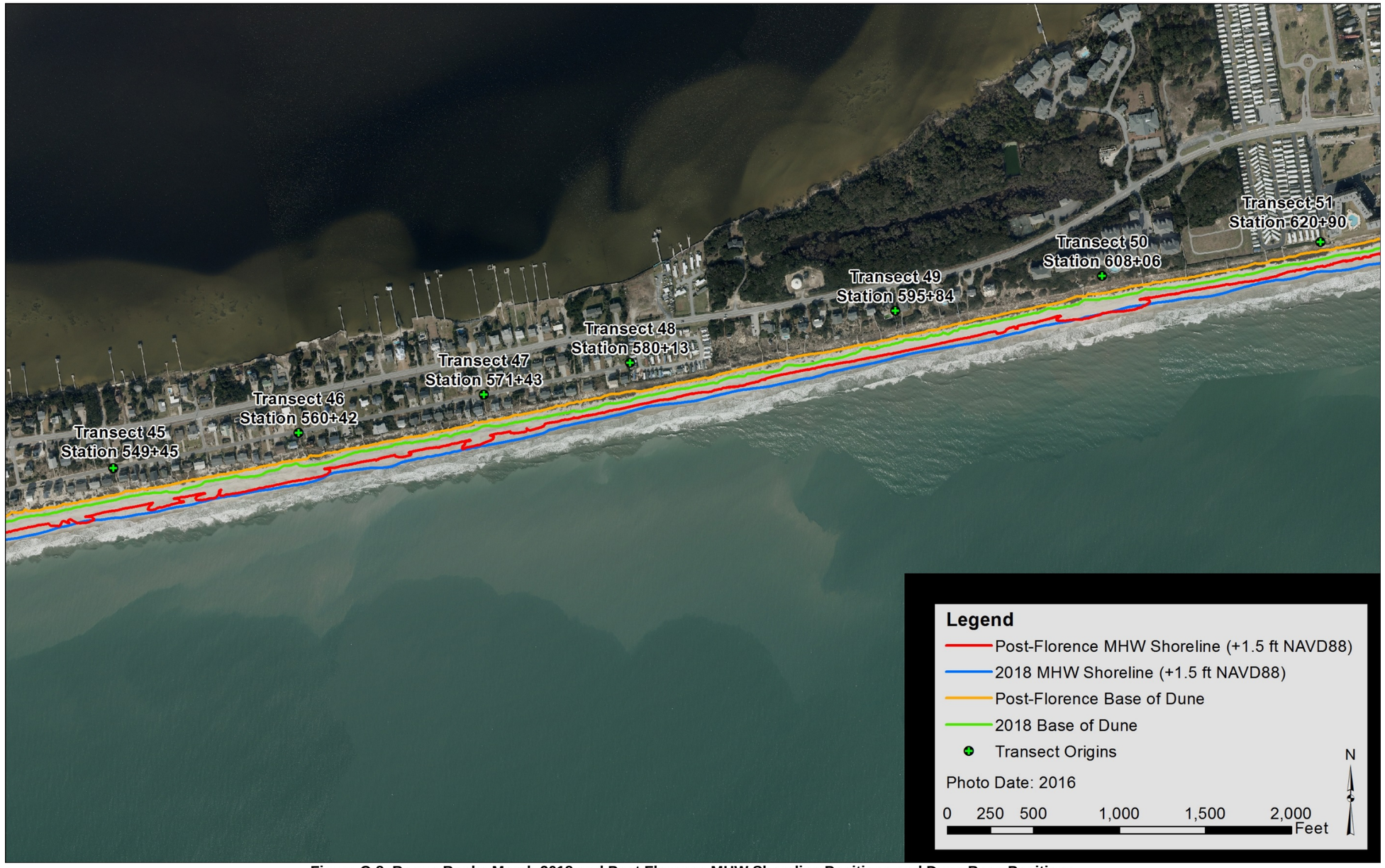


Figure C-8. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

Figure C-9. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

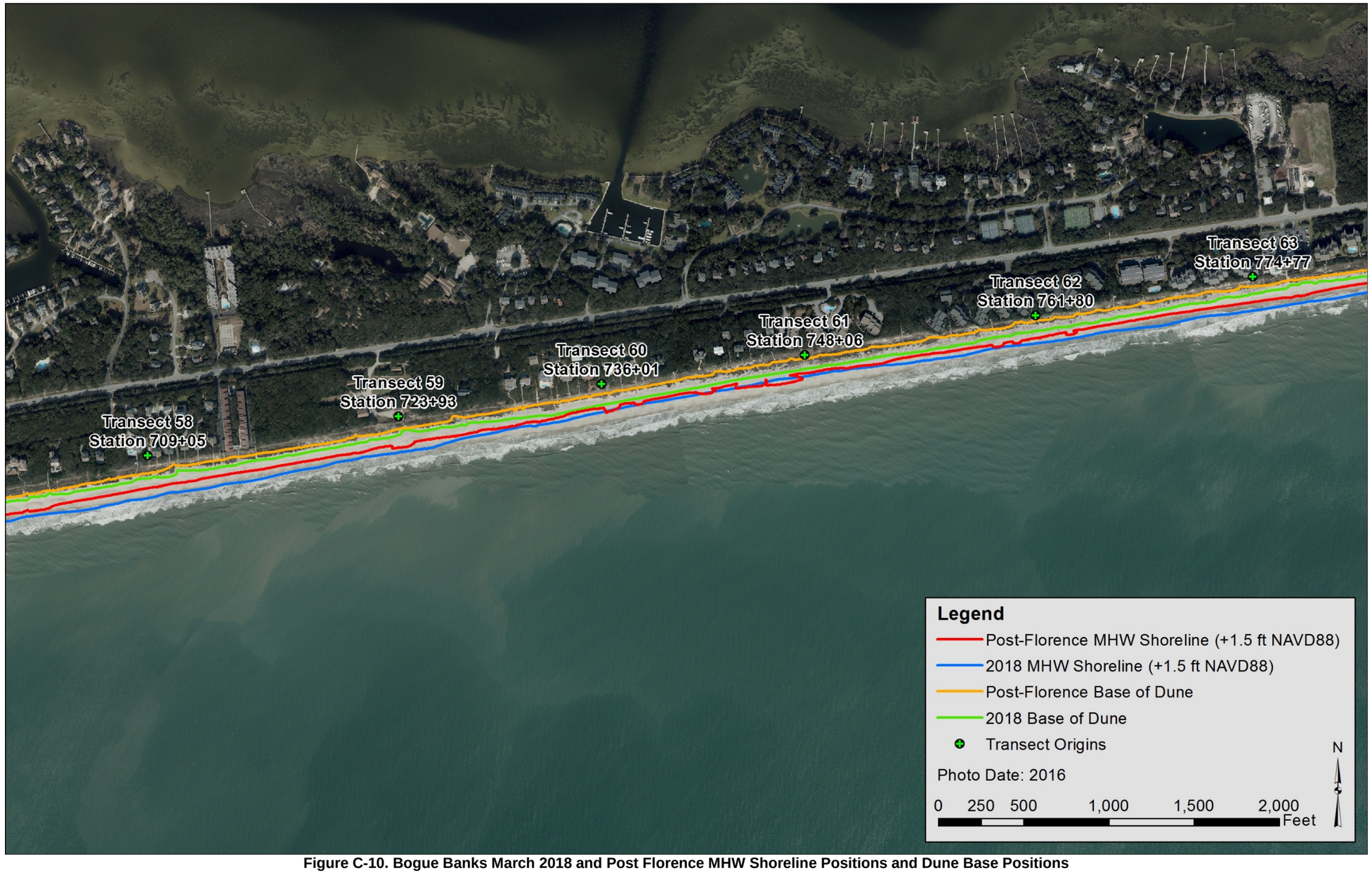


Figure C-10. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

Figure C-11. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

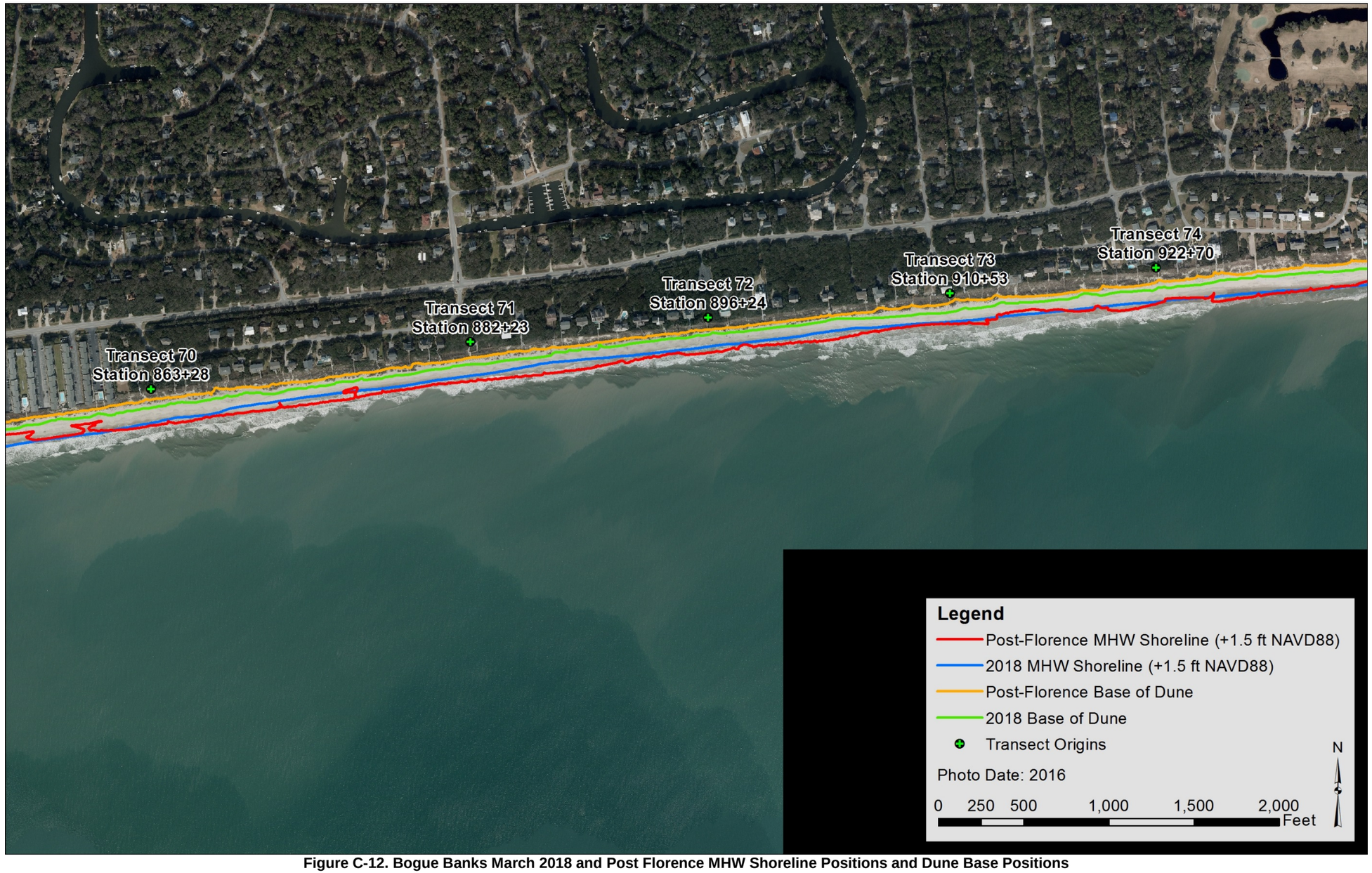


Figure C-12. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

Figure C-13. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

Figure C-14. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

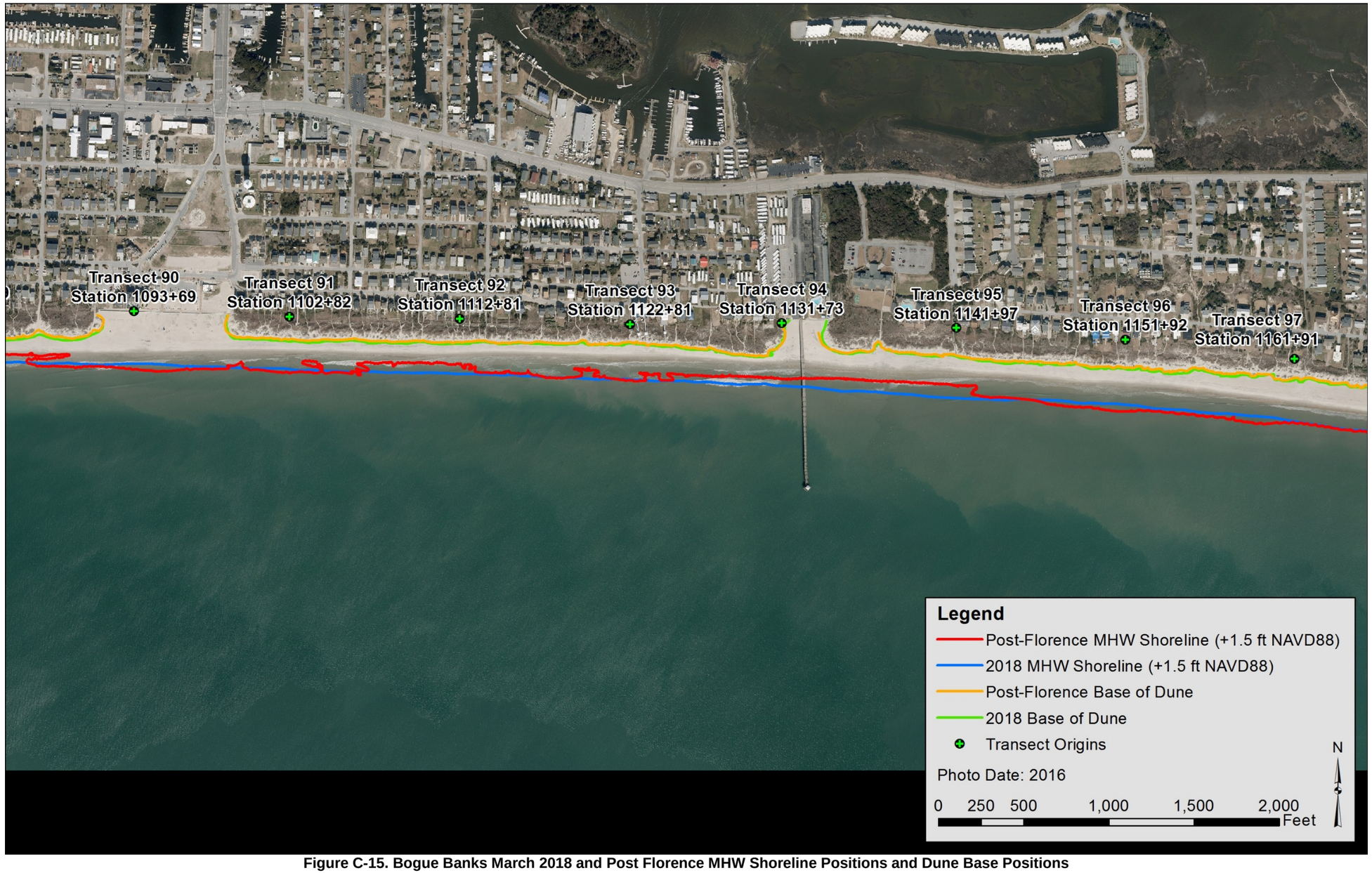


Figure C-15. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

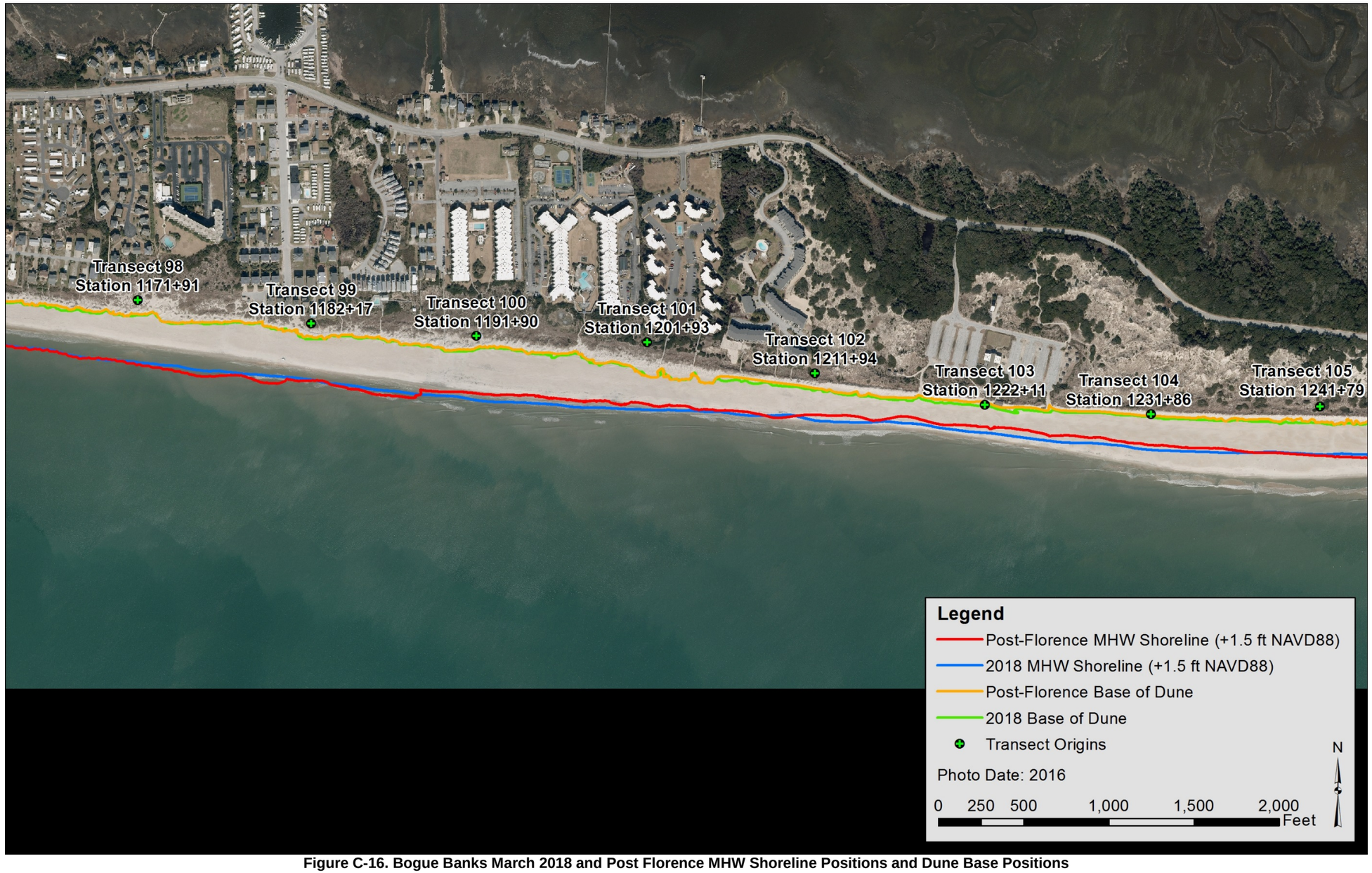


Figure C-16. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

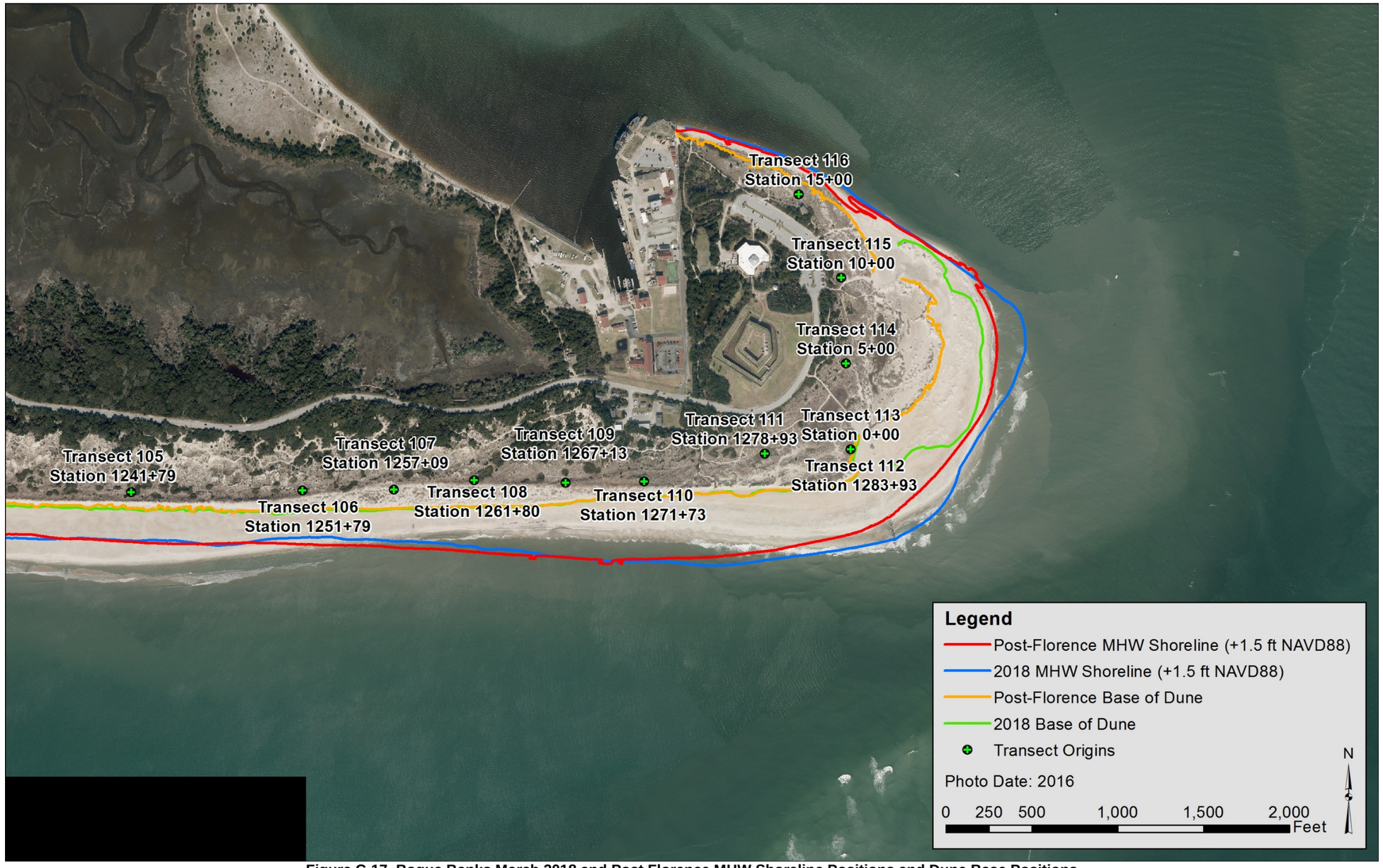


Figure C-17. Bogue Banks March 2018 and Post Florence MHW Shoreline Positions and Dune Base Positions

2) March 2018, Post-Florence, & Comparison Surfaces

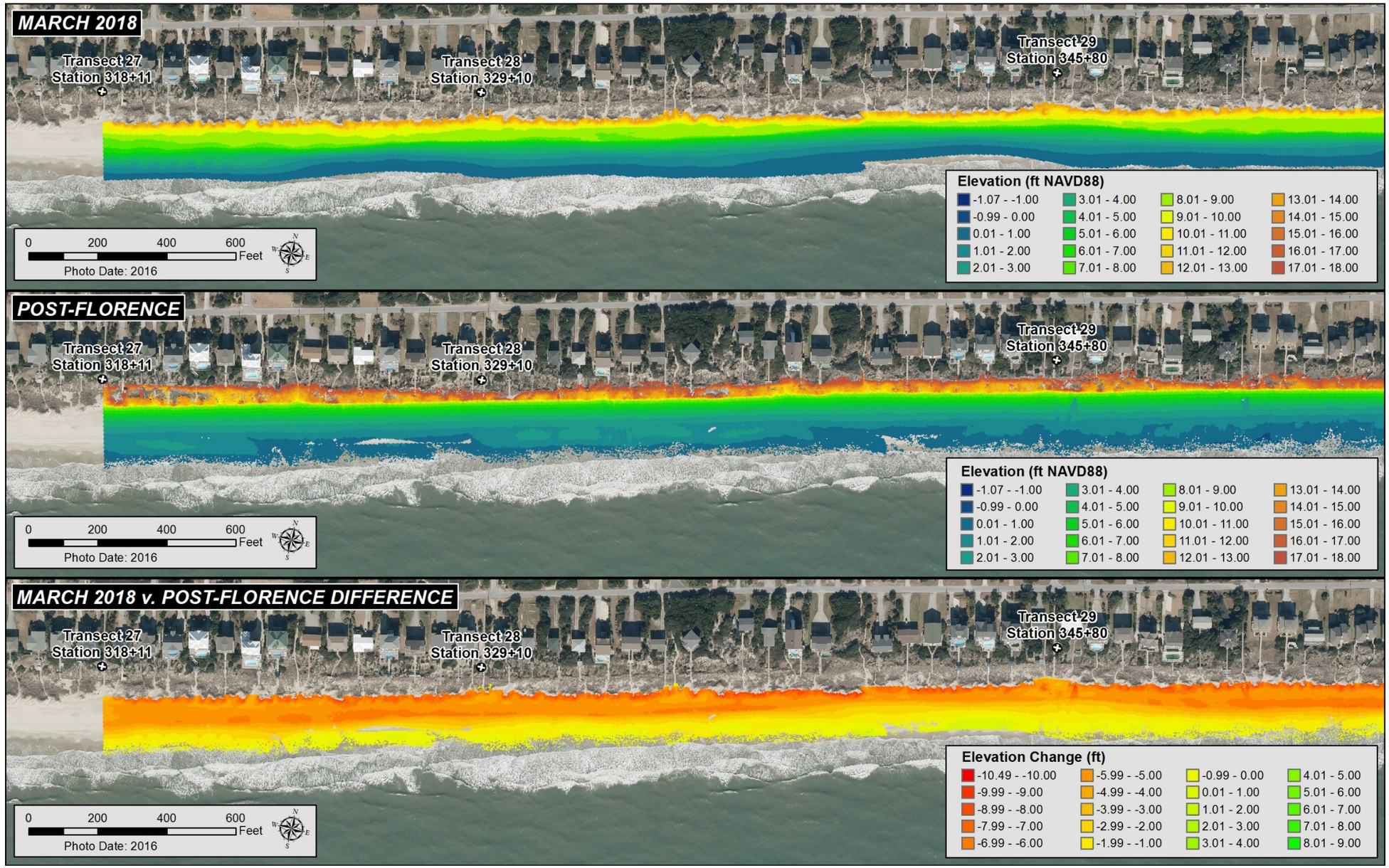


Figure C-18. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

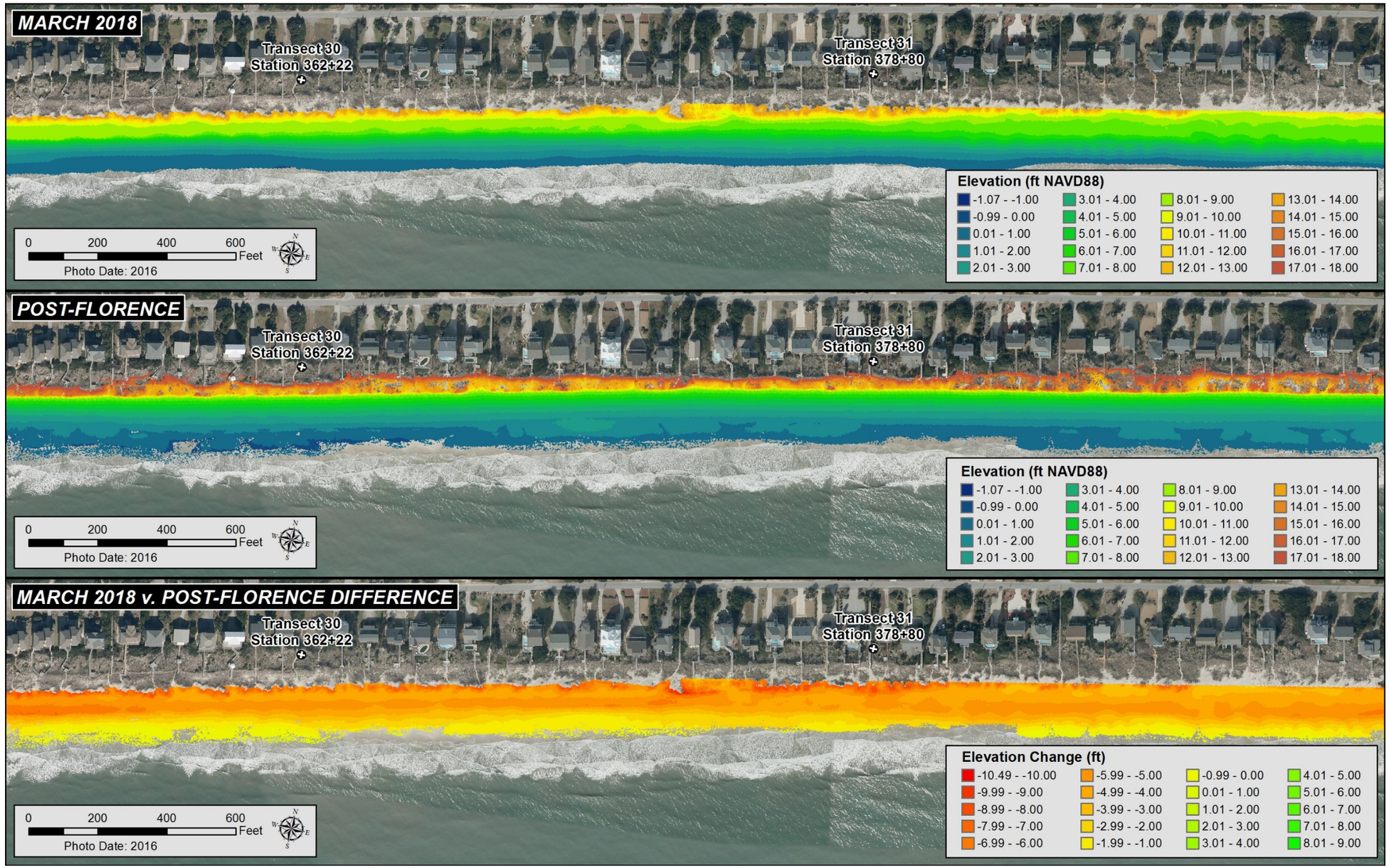


Figure C-19. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

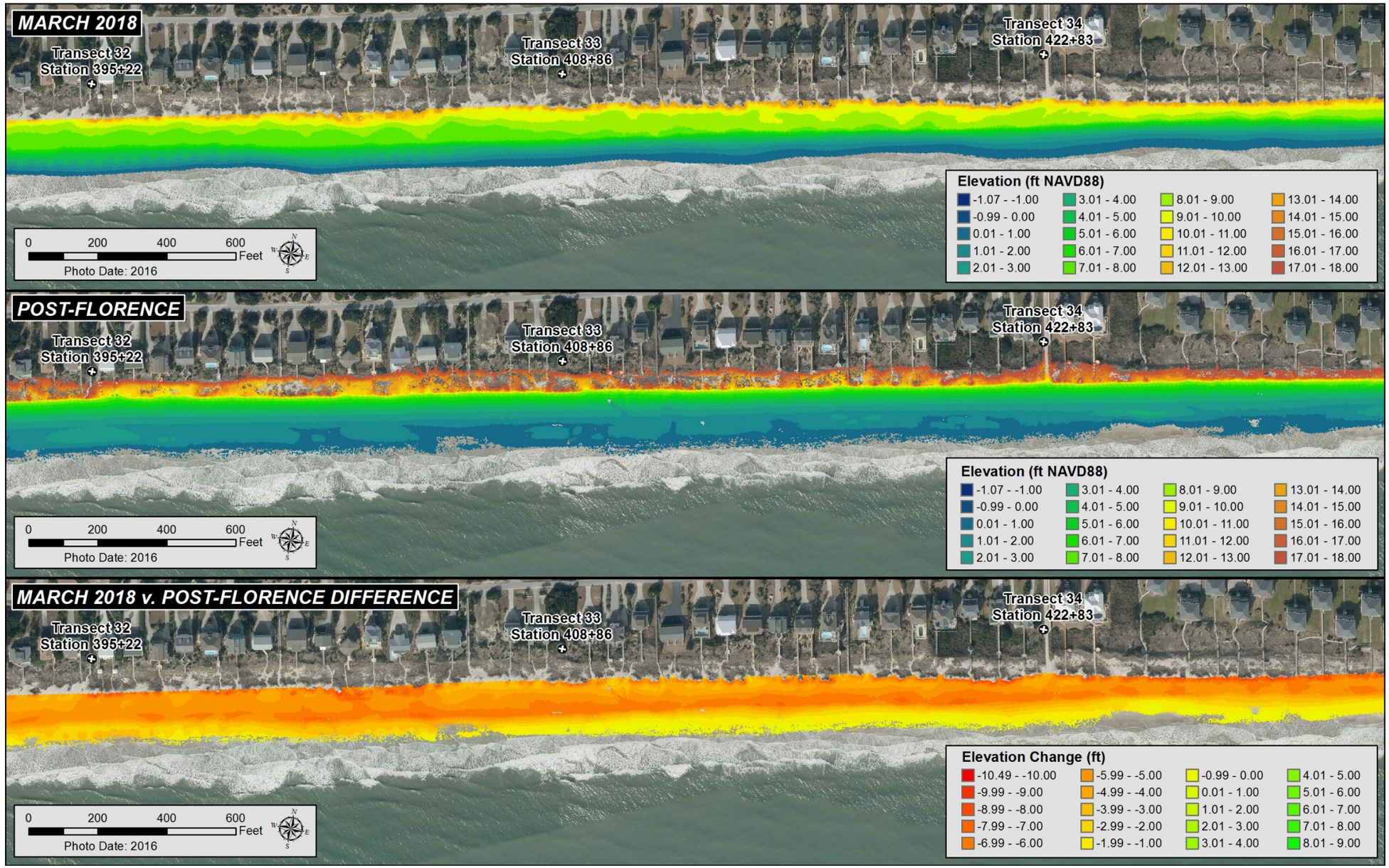


Figure C-20. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

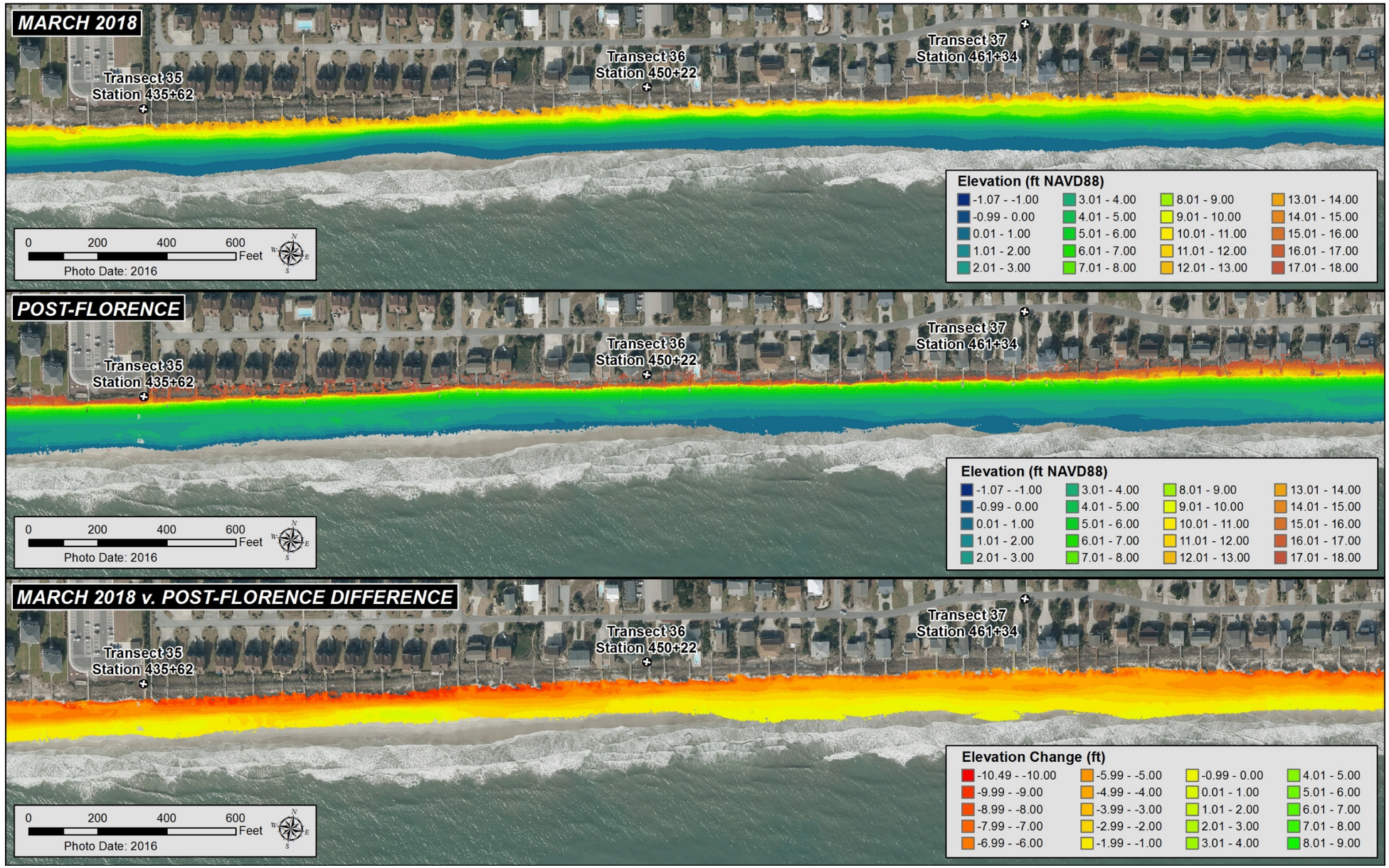


Figure C-21. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

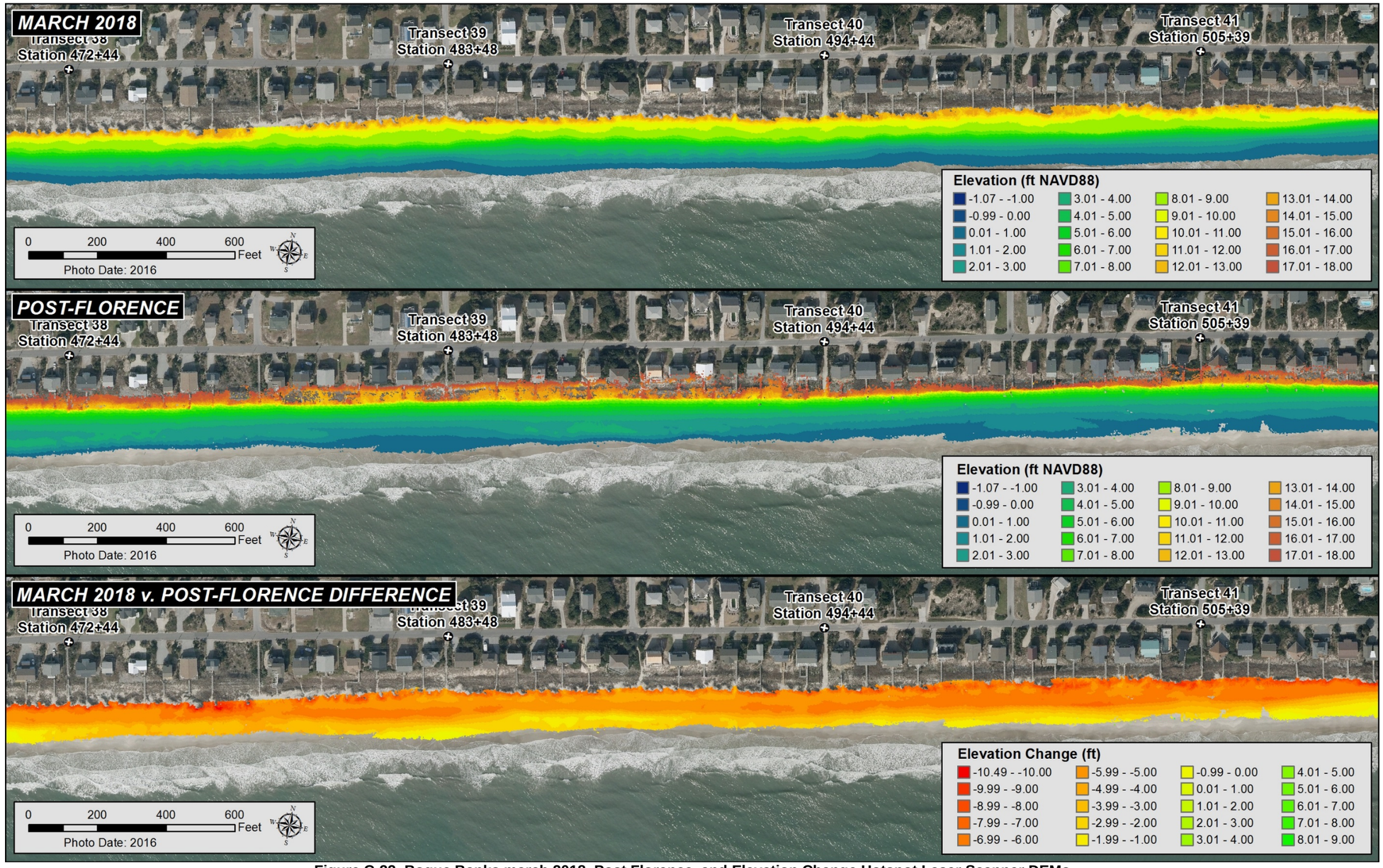


Figure C-22. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

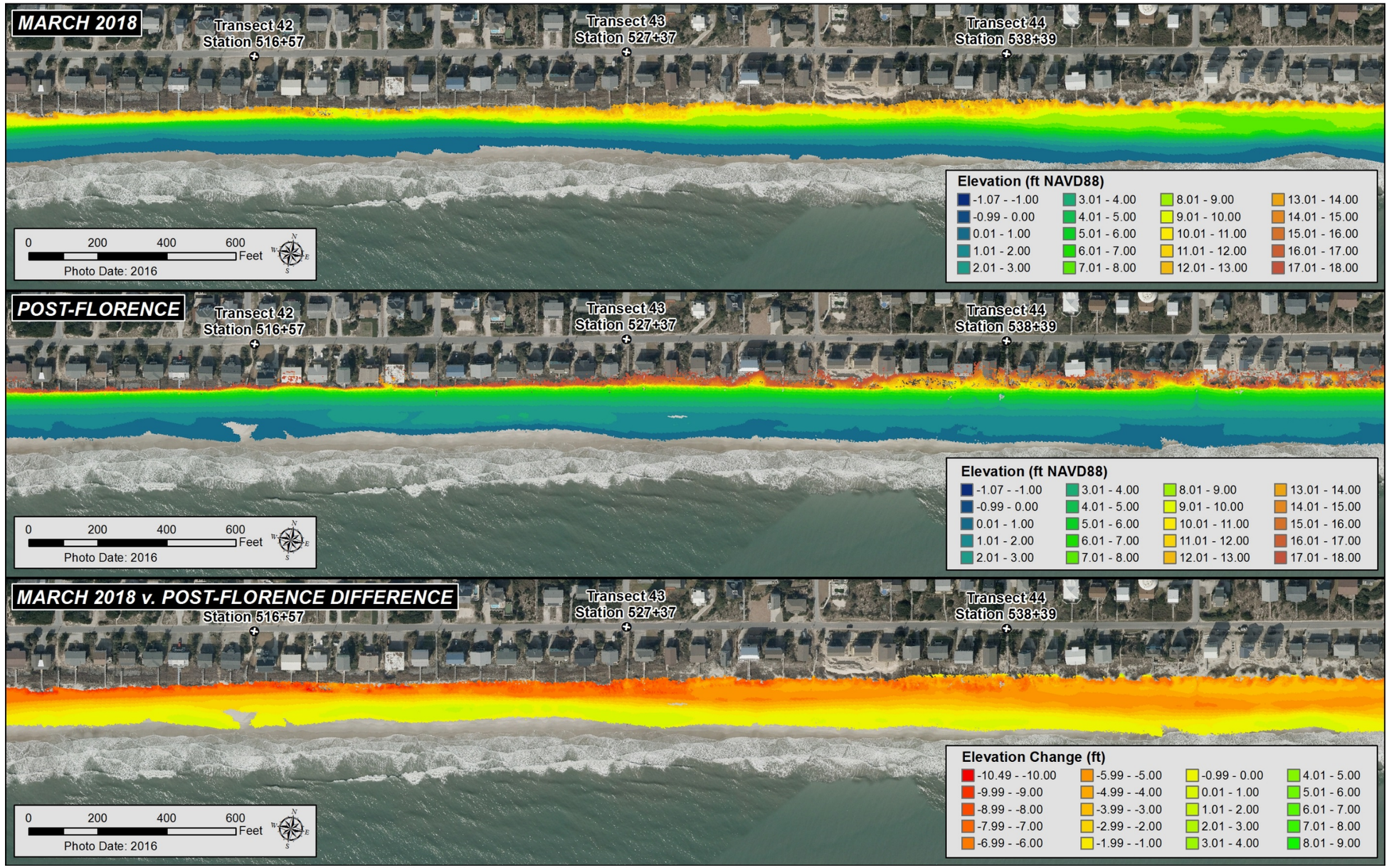


Figure C-23. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

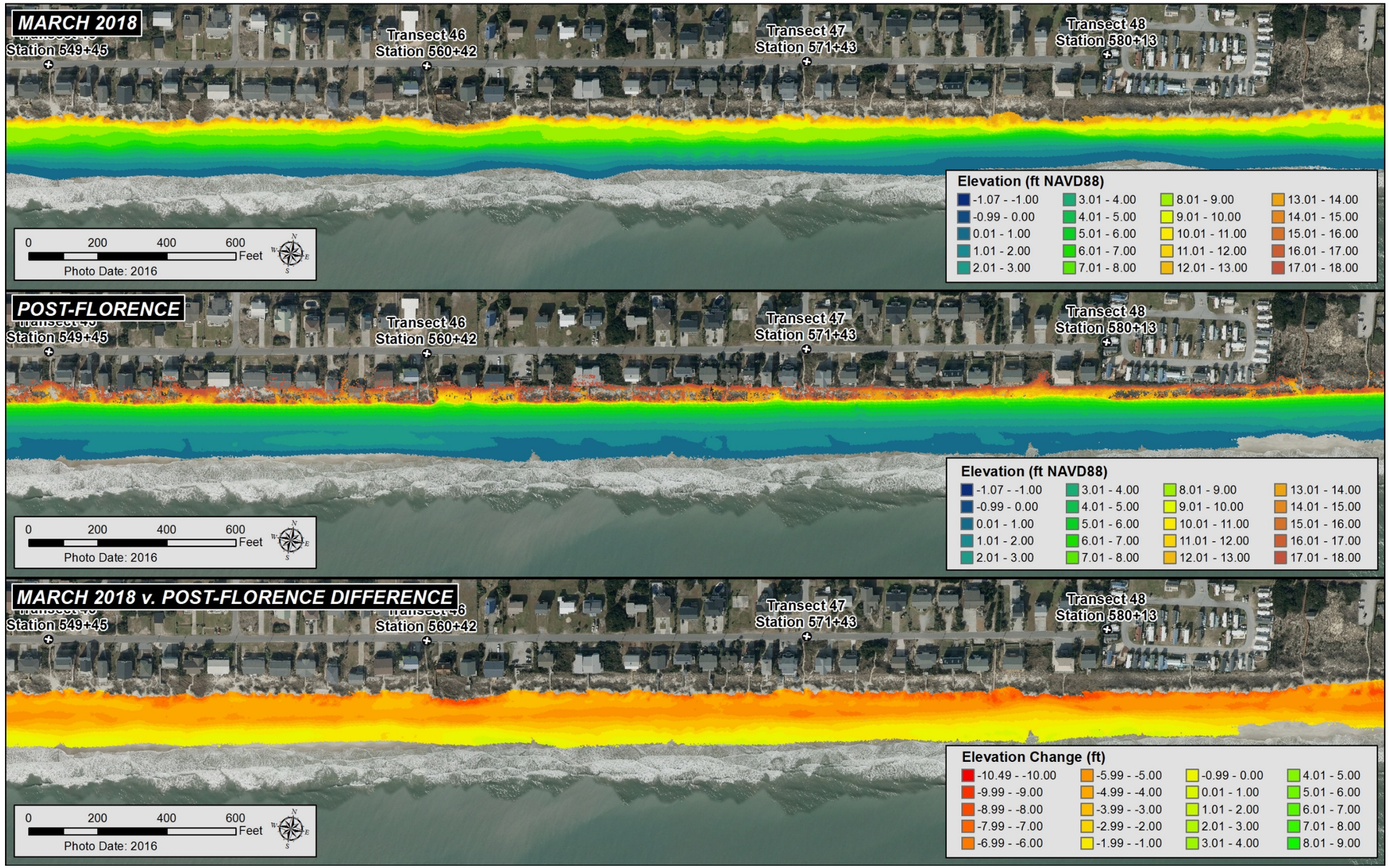


Figure C-24. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

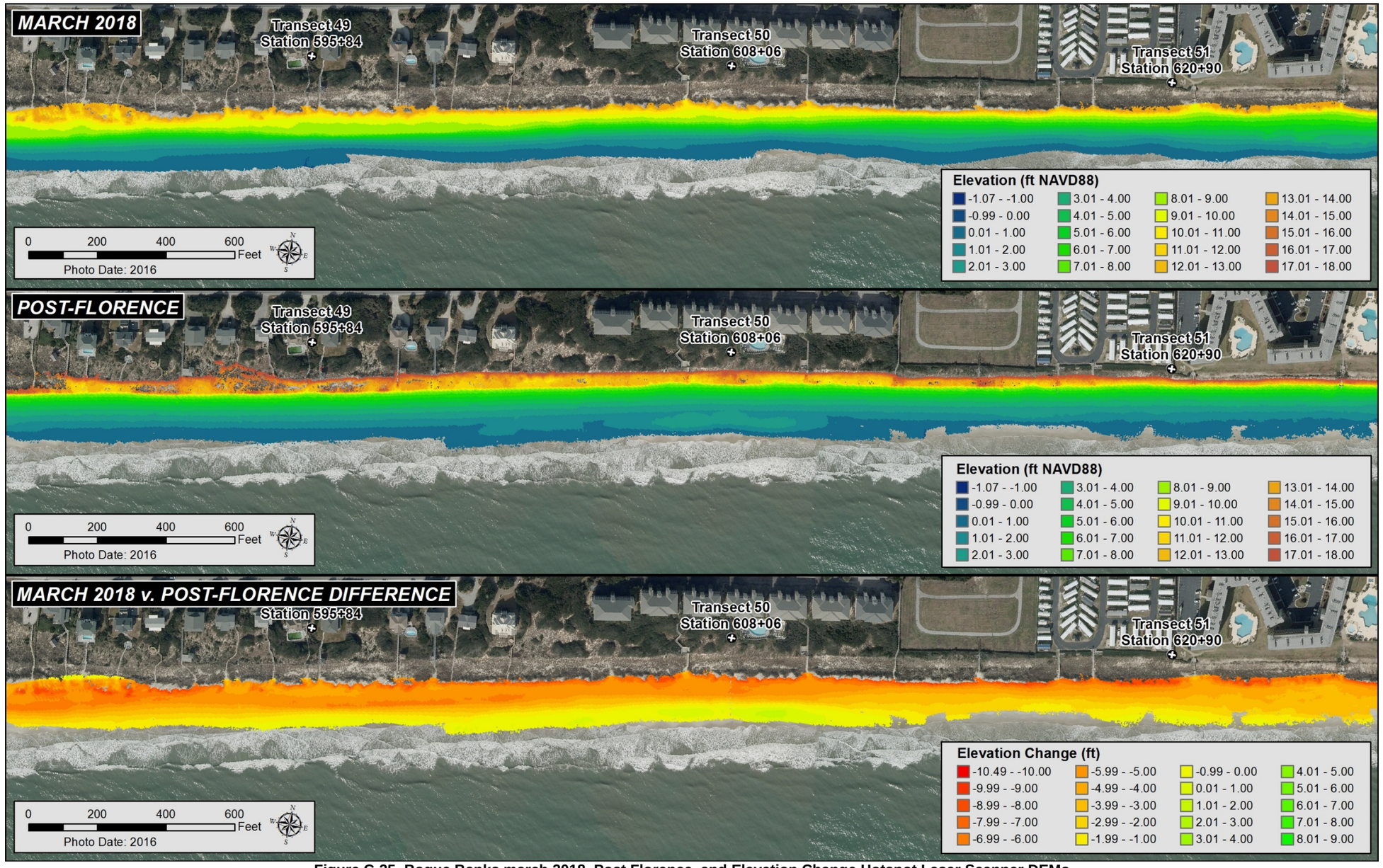


Figure C-25. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

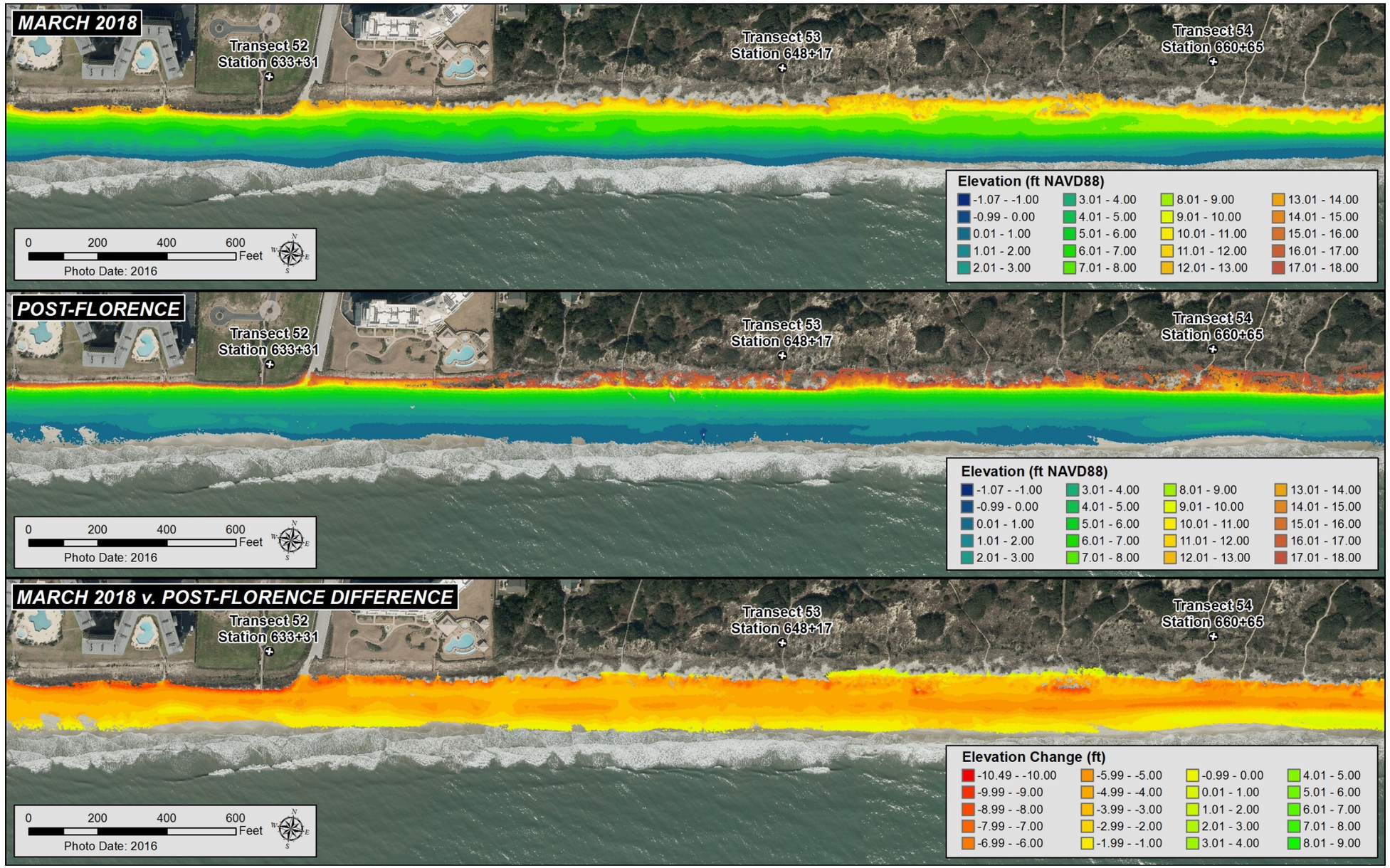


Figure C-26. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

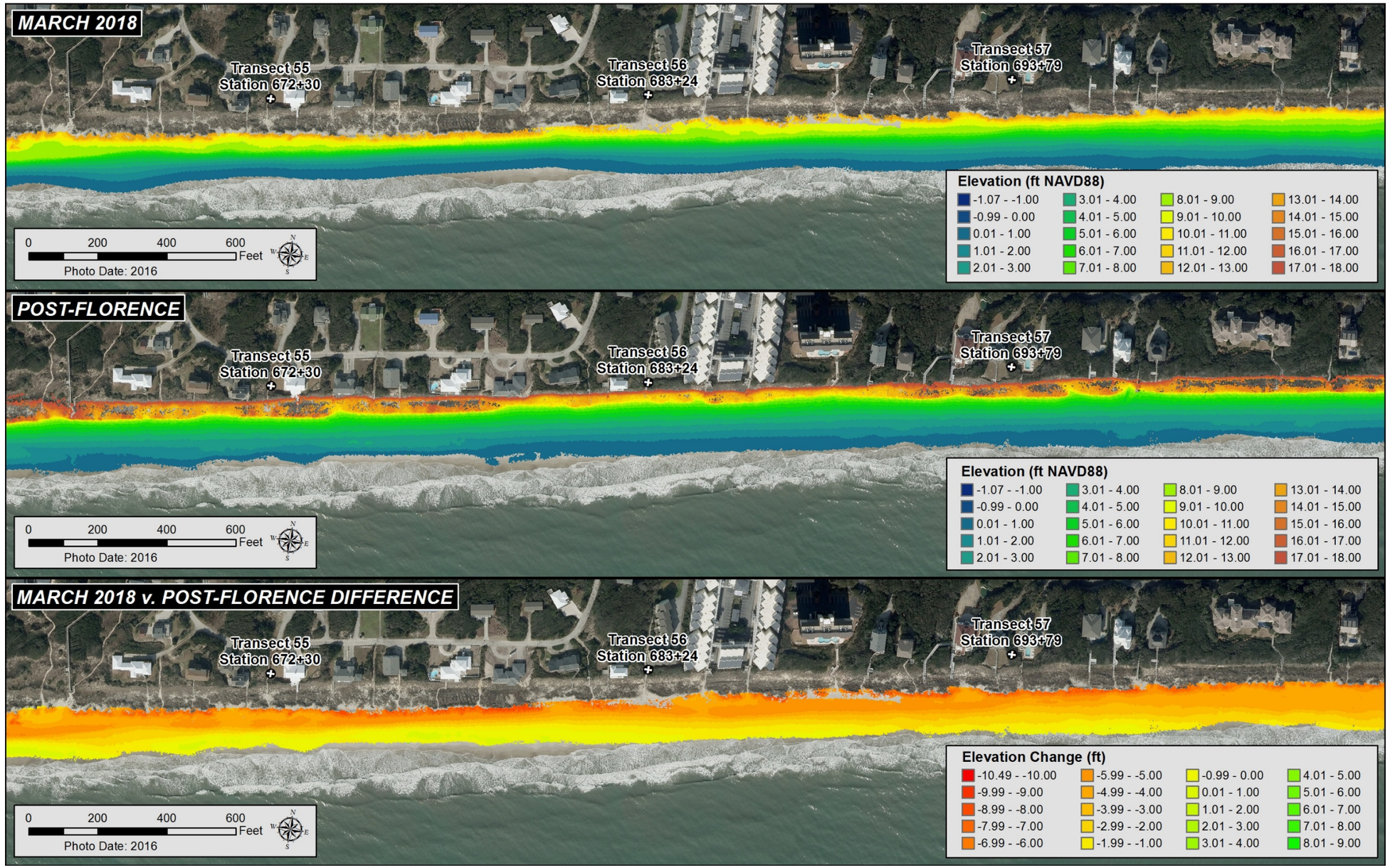


Figure C-27. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

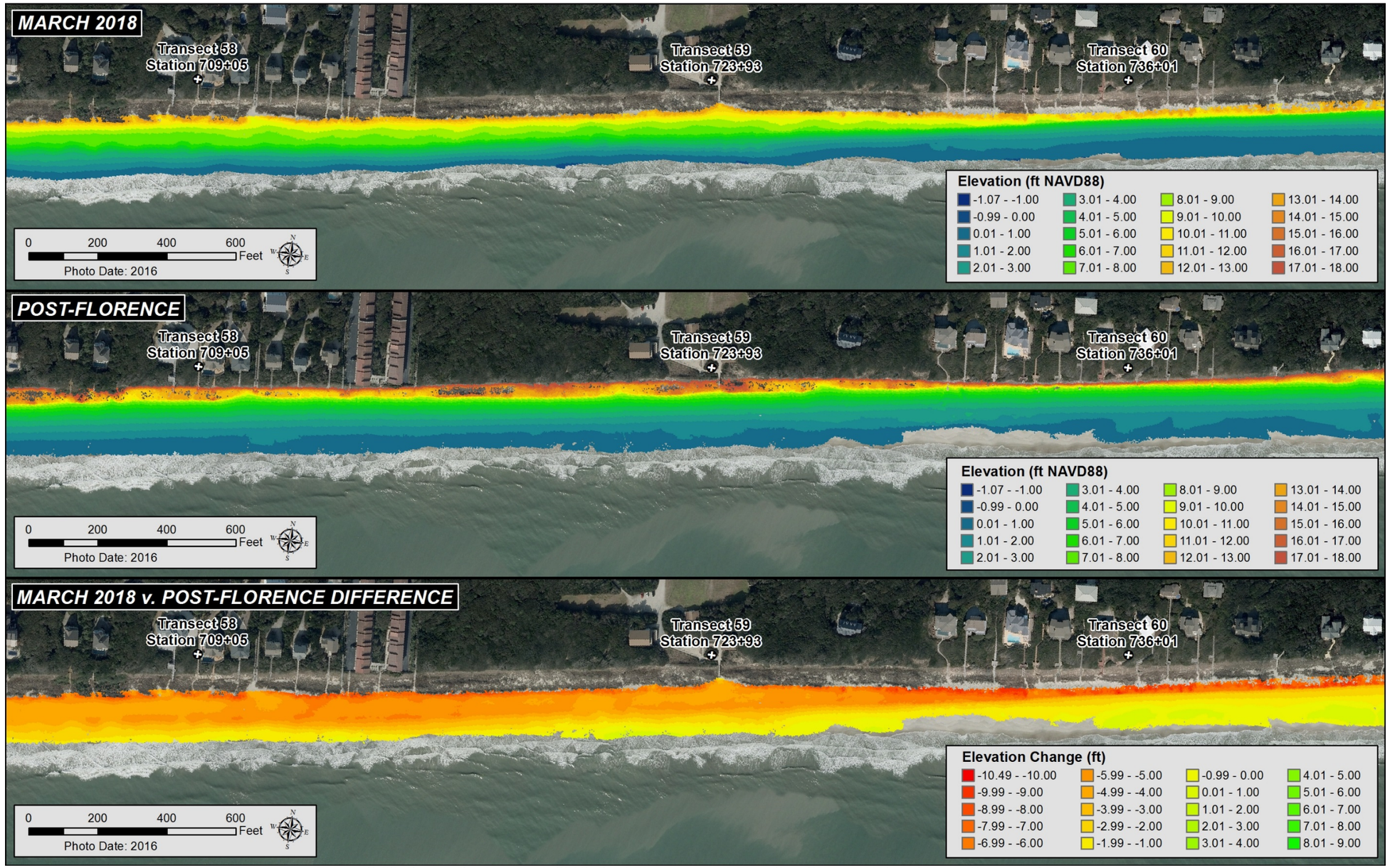


Figure C-28. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

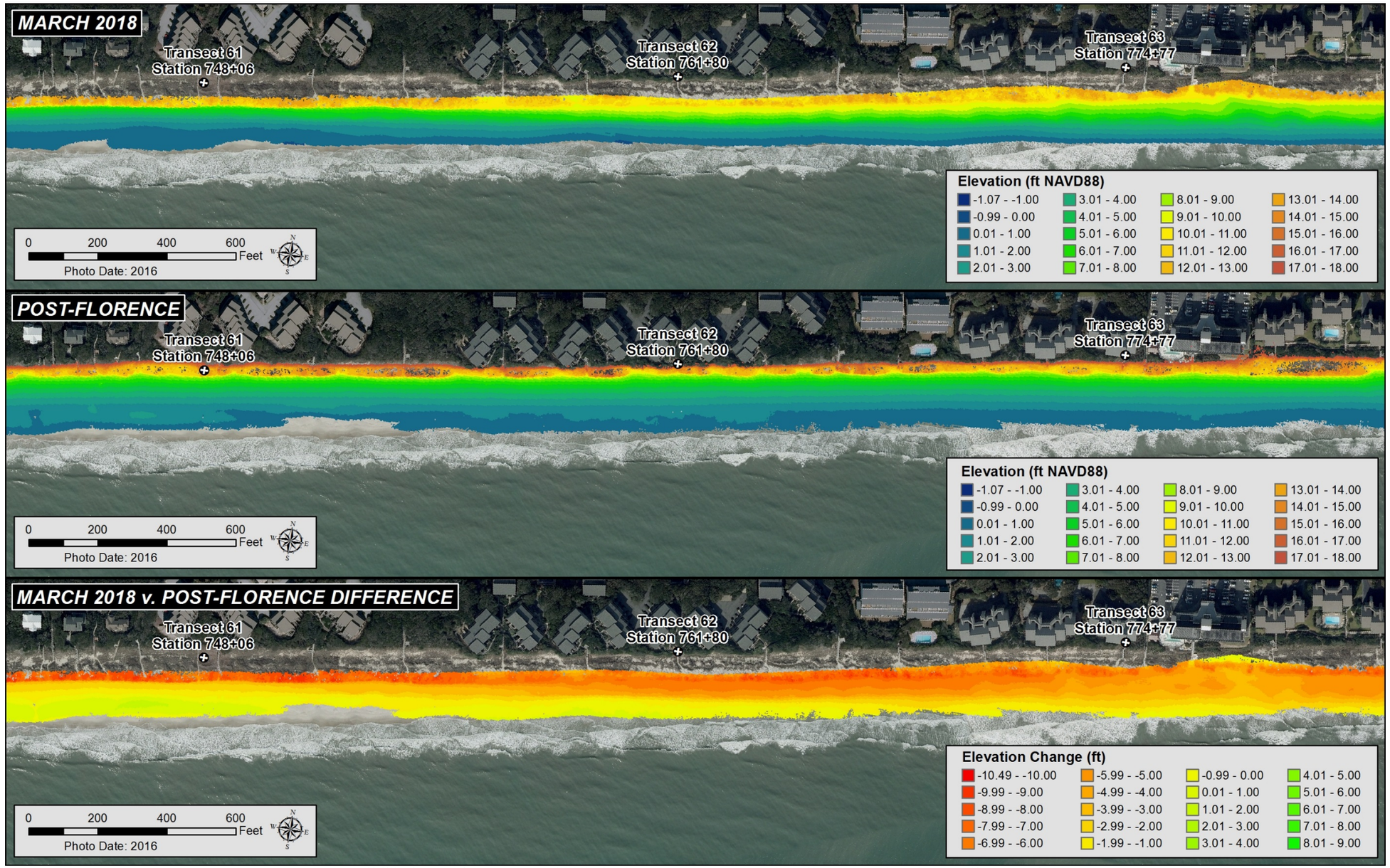


Figure C-29. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

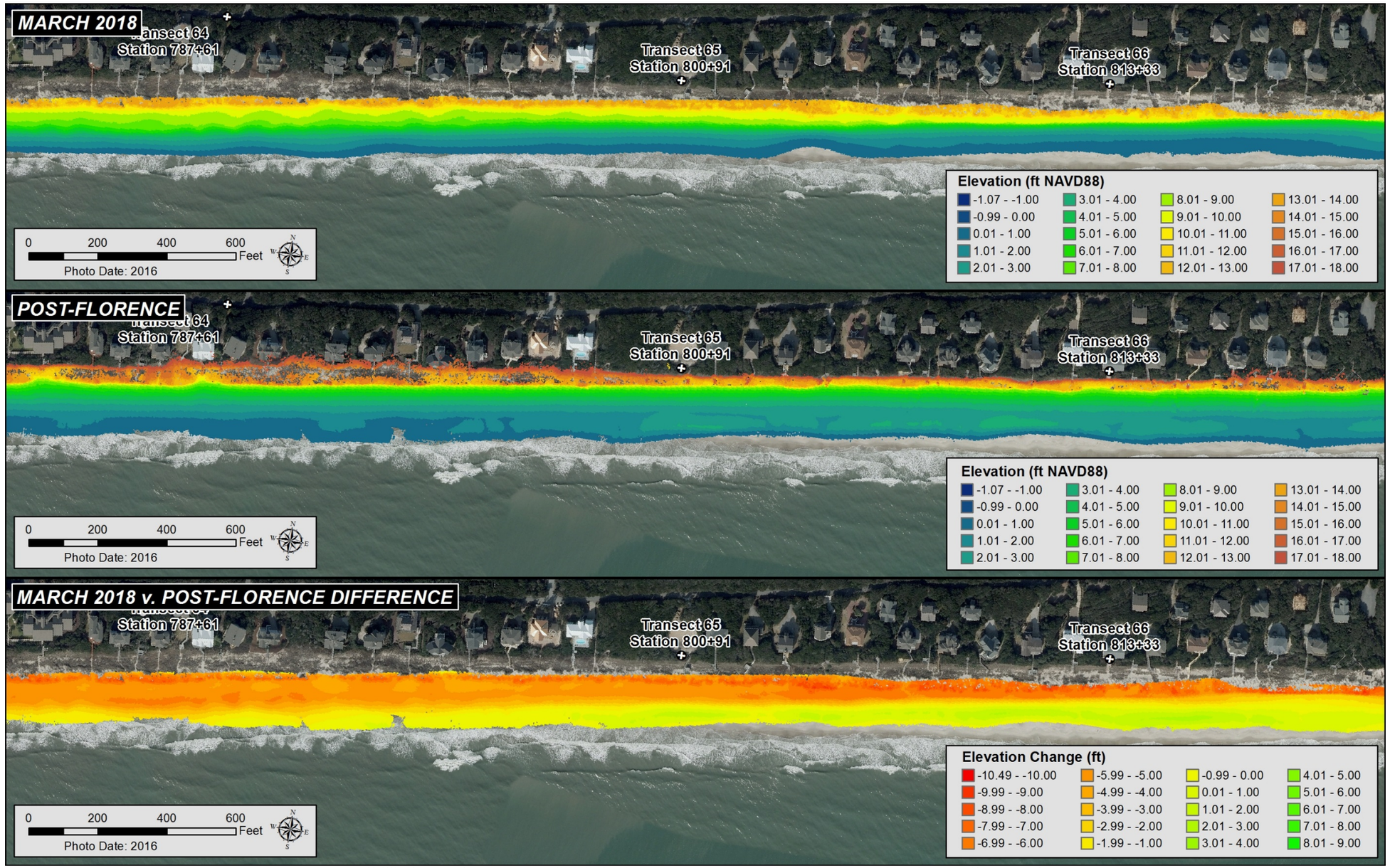


Figure C-30. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

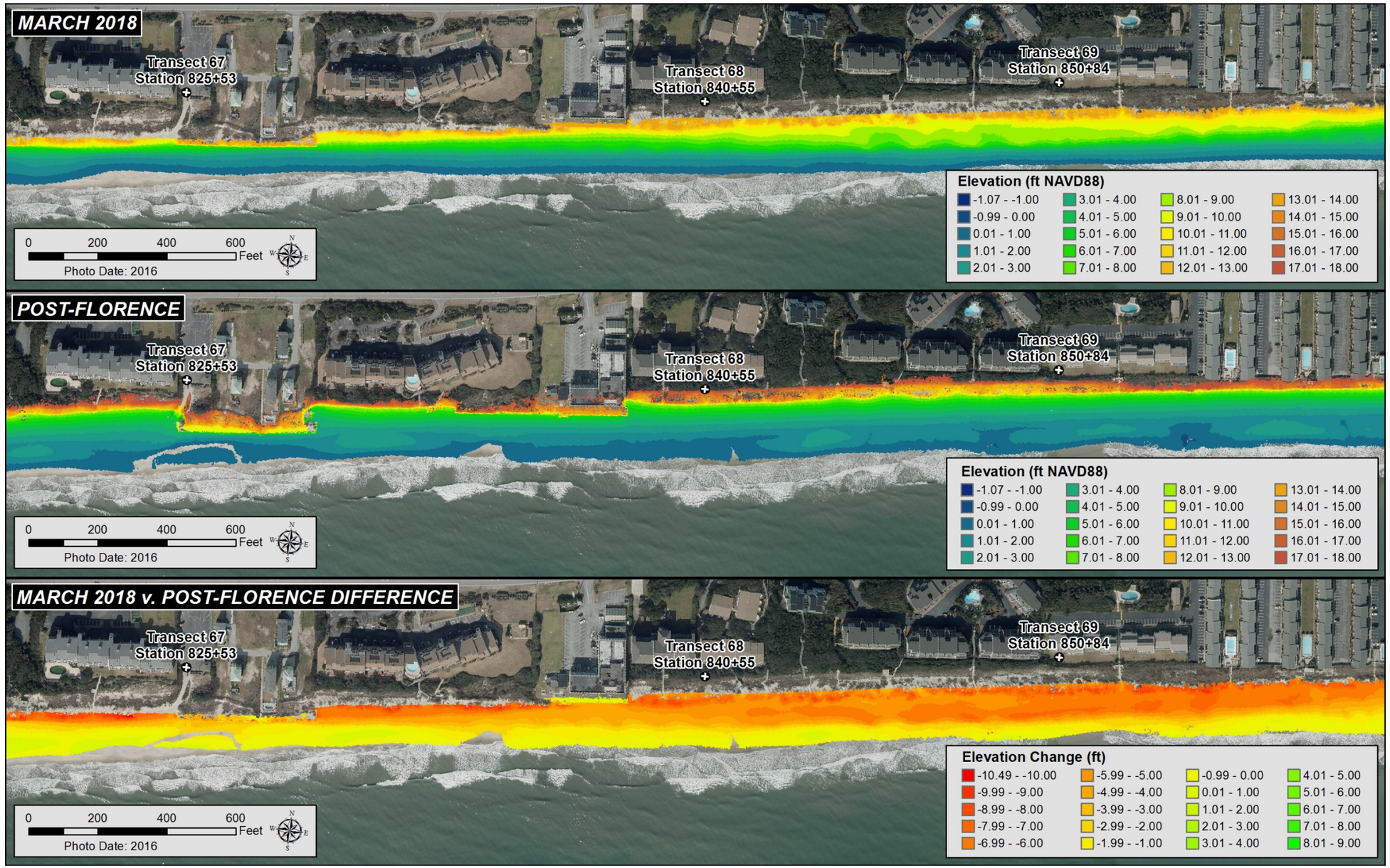


Figure C-31. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

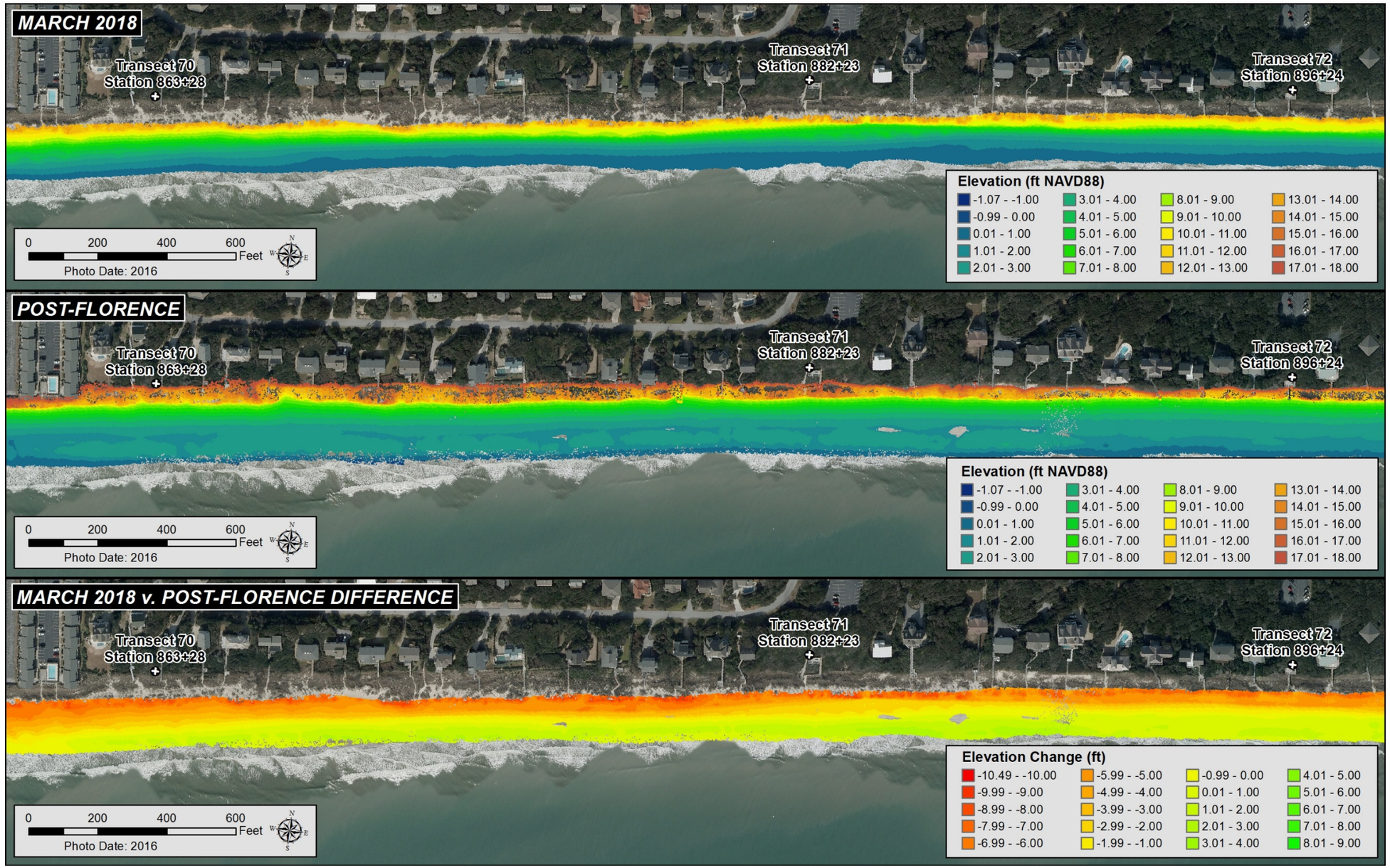


Figure C-32. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

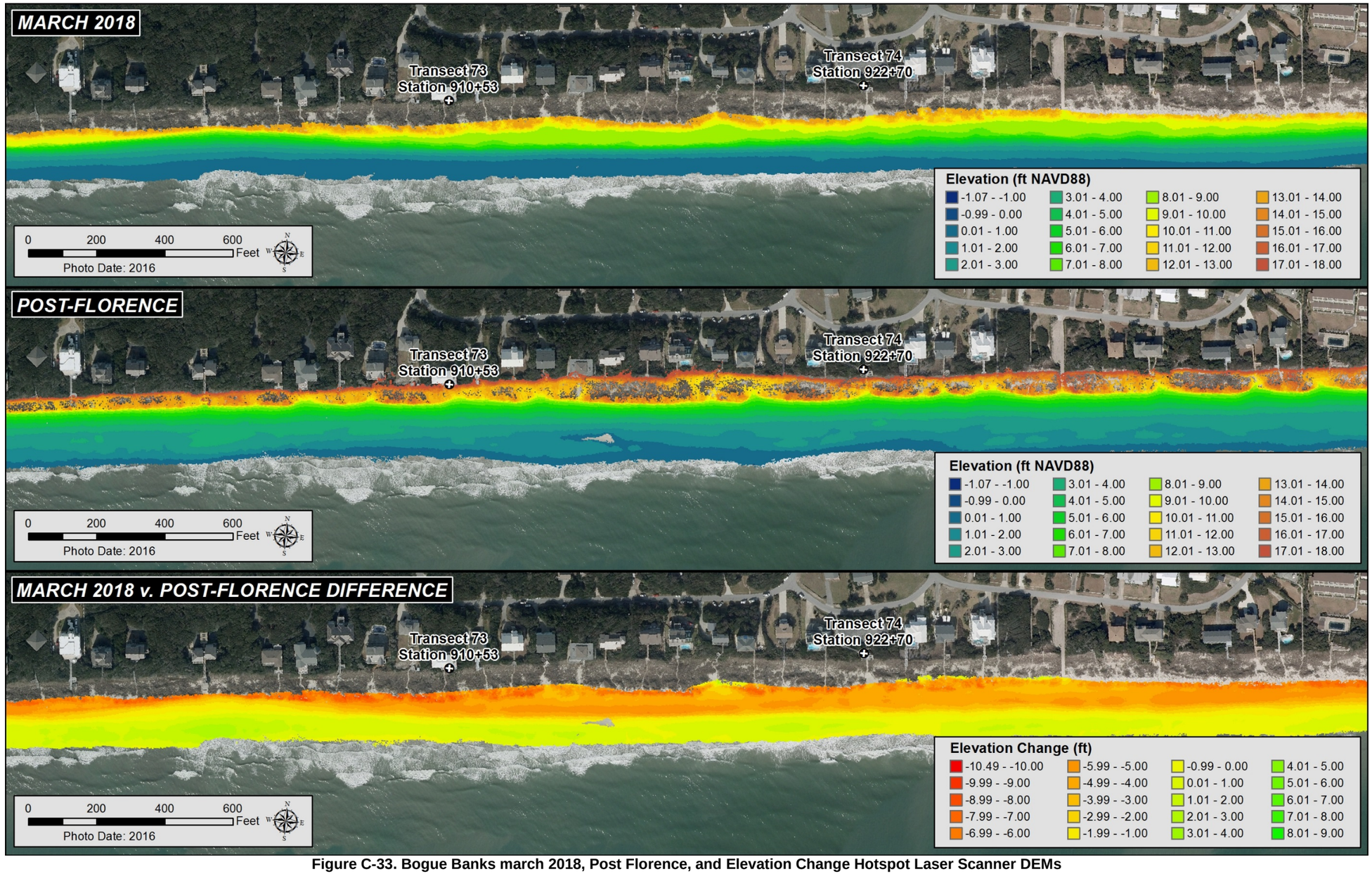


Figure C-33. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

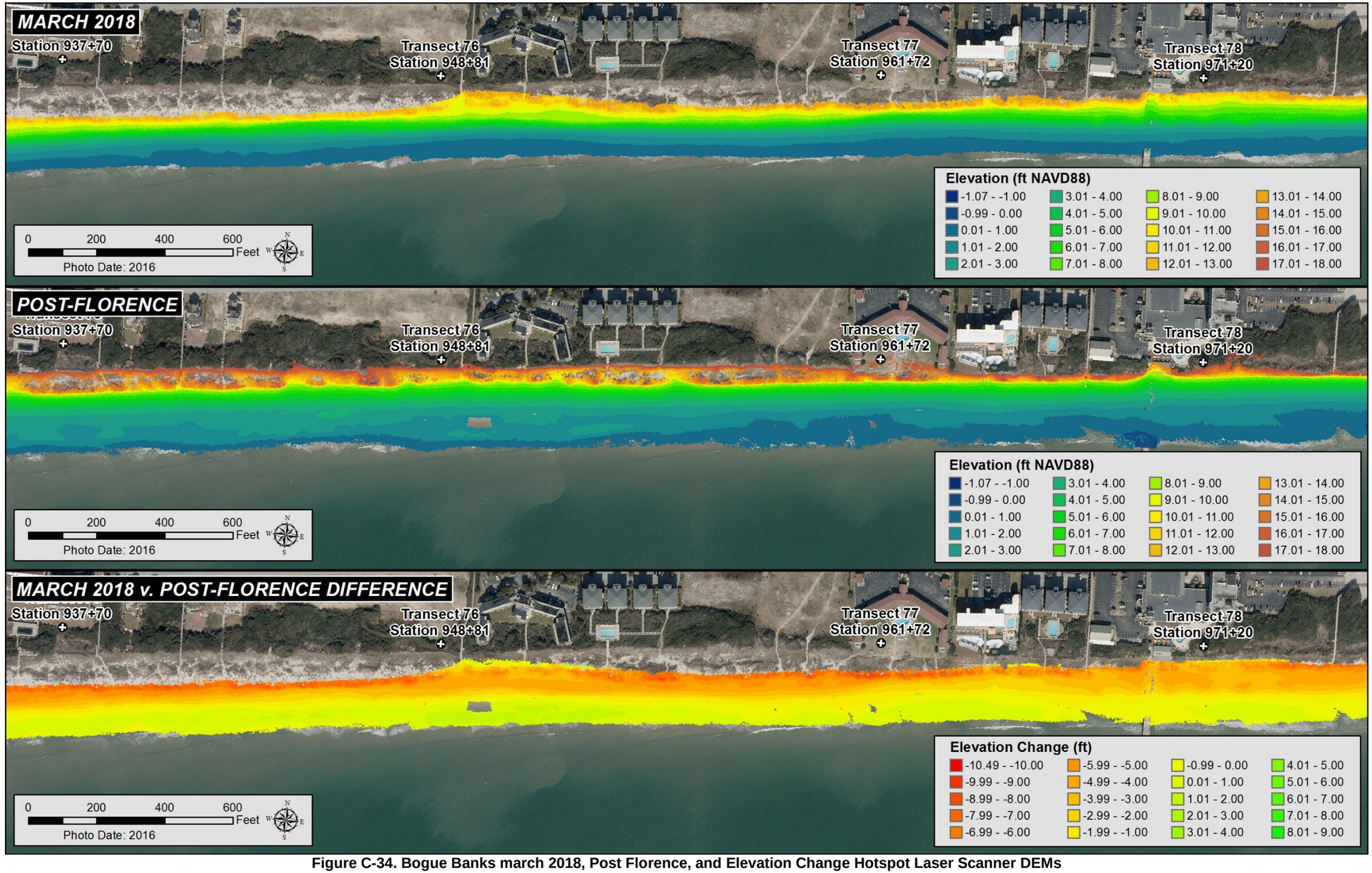


Figure C-34. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

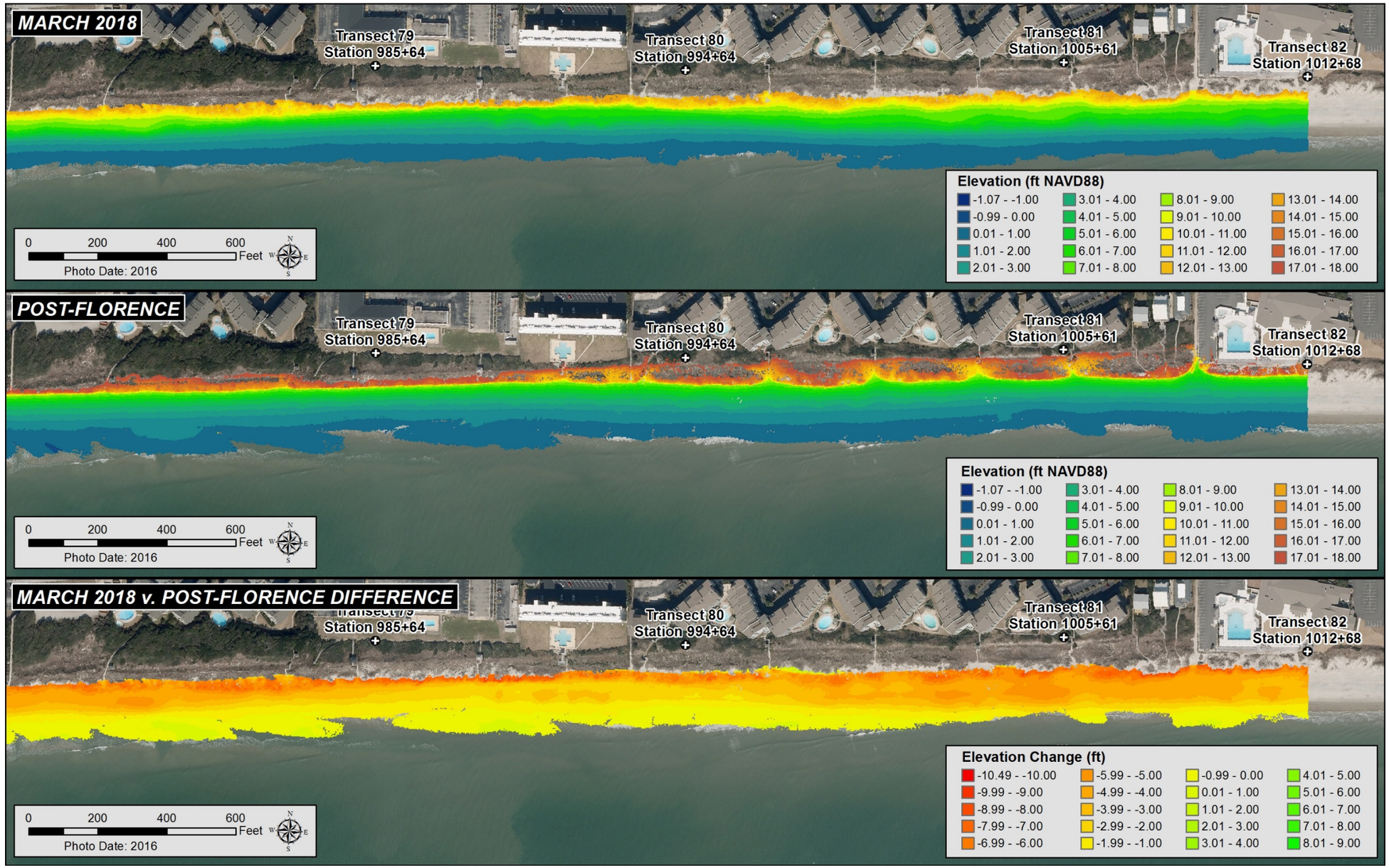


Figure C-35. Bogue Banks march 2018, Post Florence, and Elevation Change Hotspot Laser Scanner DEMs

APPENDIX D

Survey Profile Comparison Plots

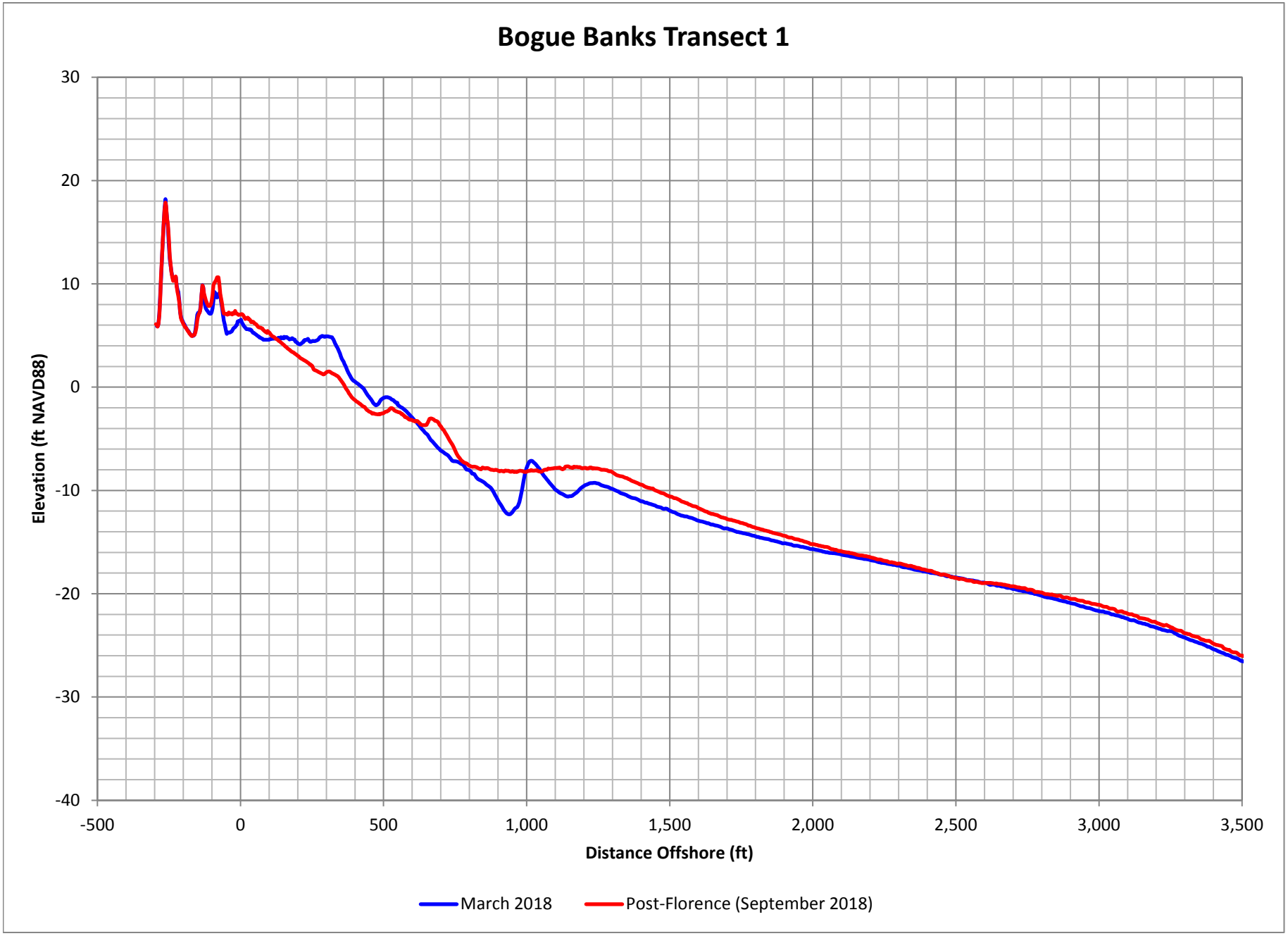


Figure D-1. Bogue Banks Profile Comparison Plot

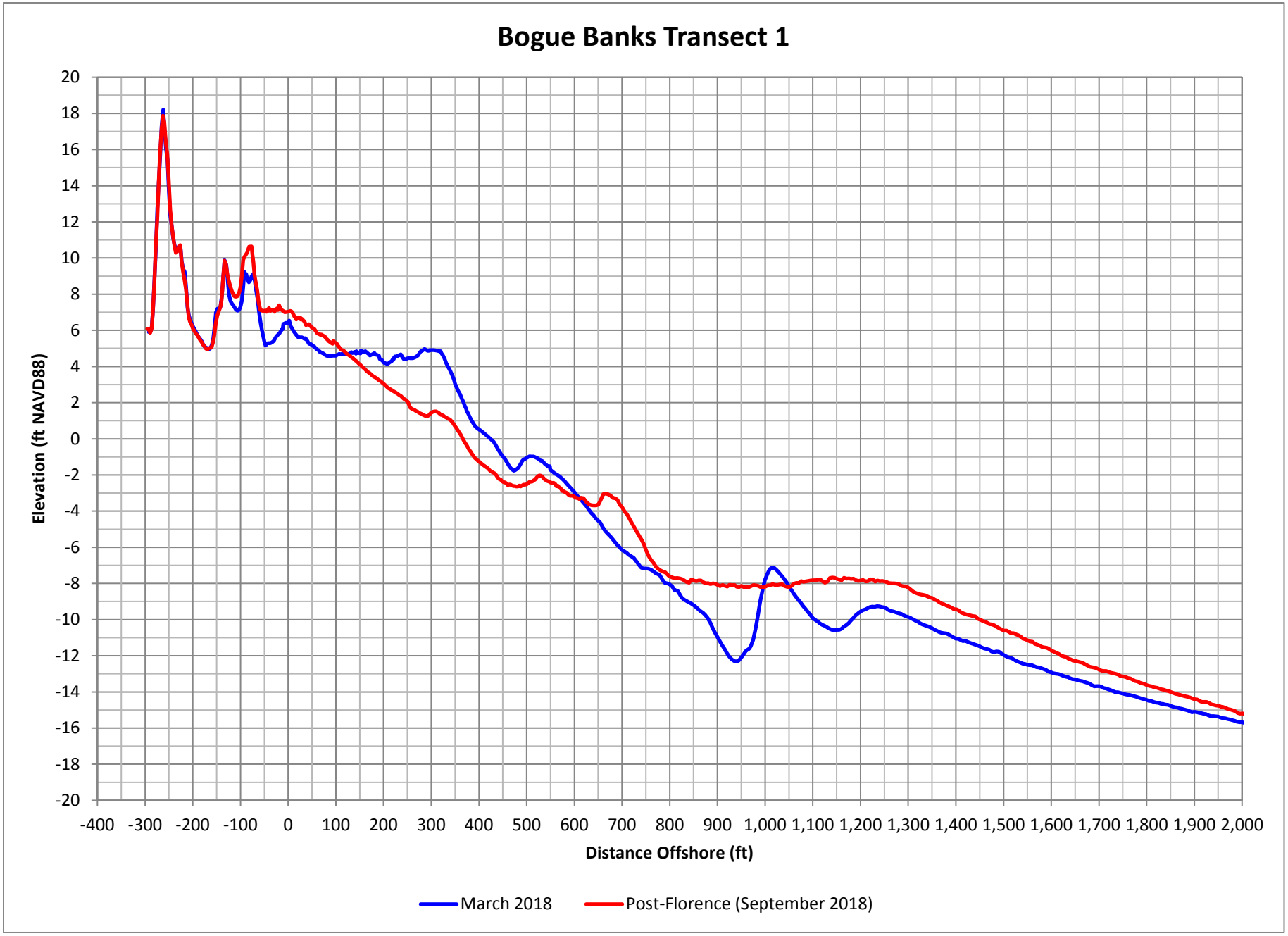


Figure D-2. Bogue Banks Profile Comparison Plot

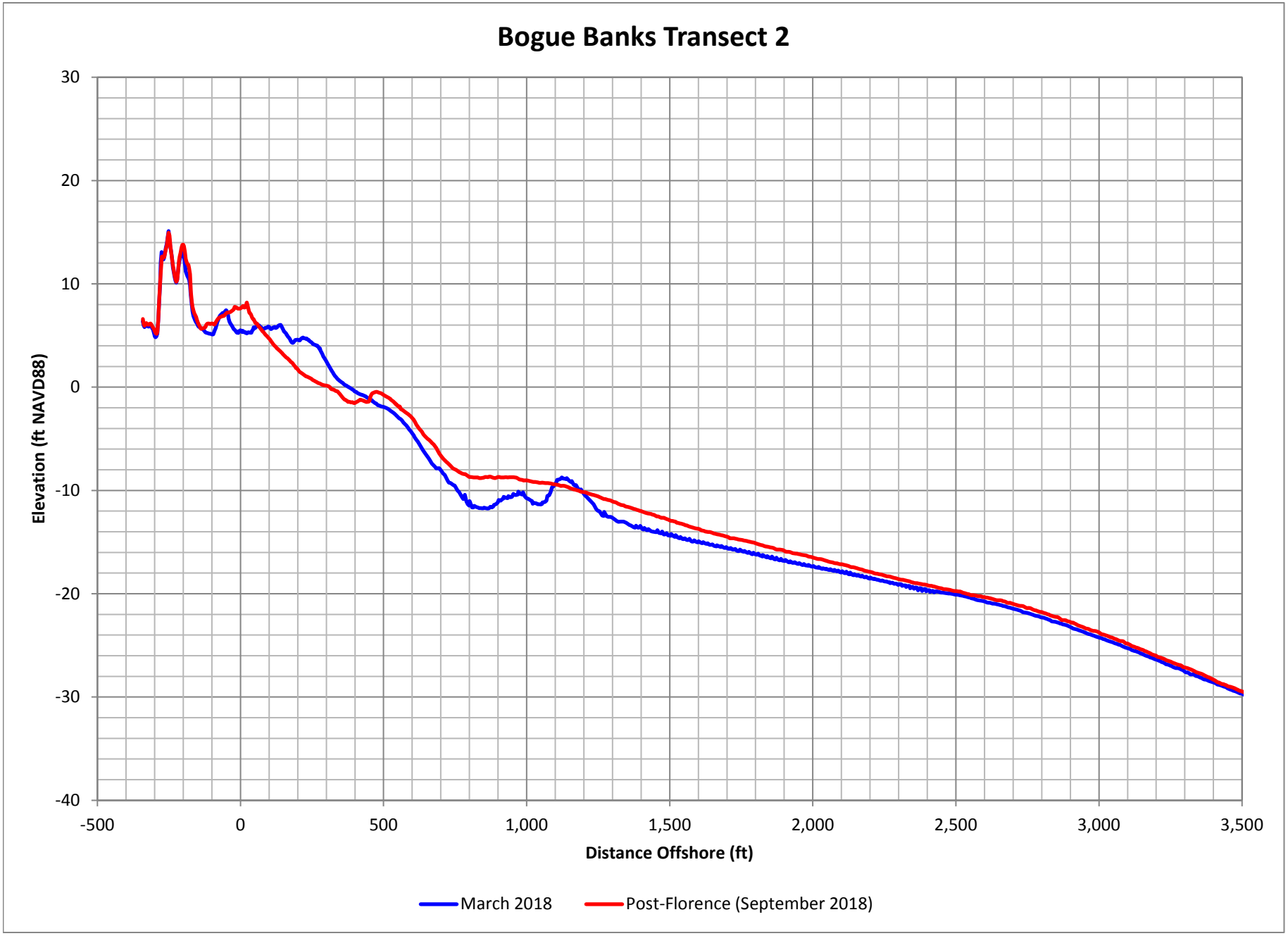


Figure D-3. Bogue Banks Profile Comparison Plot

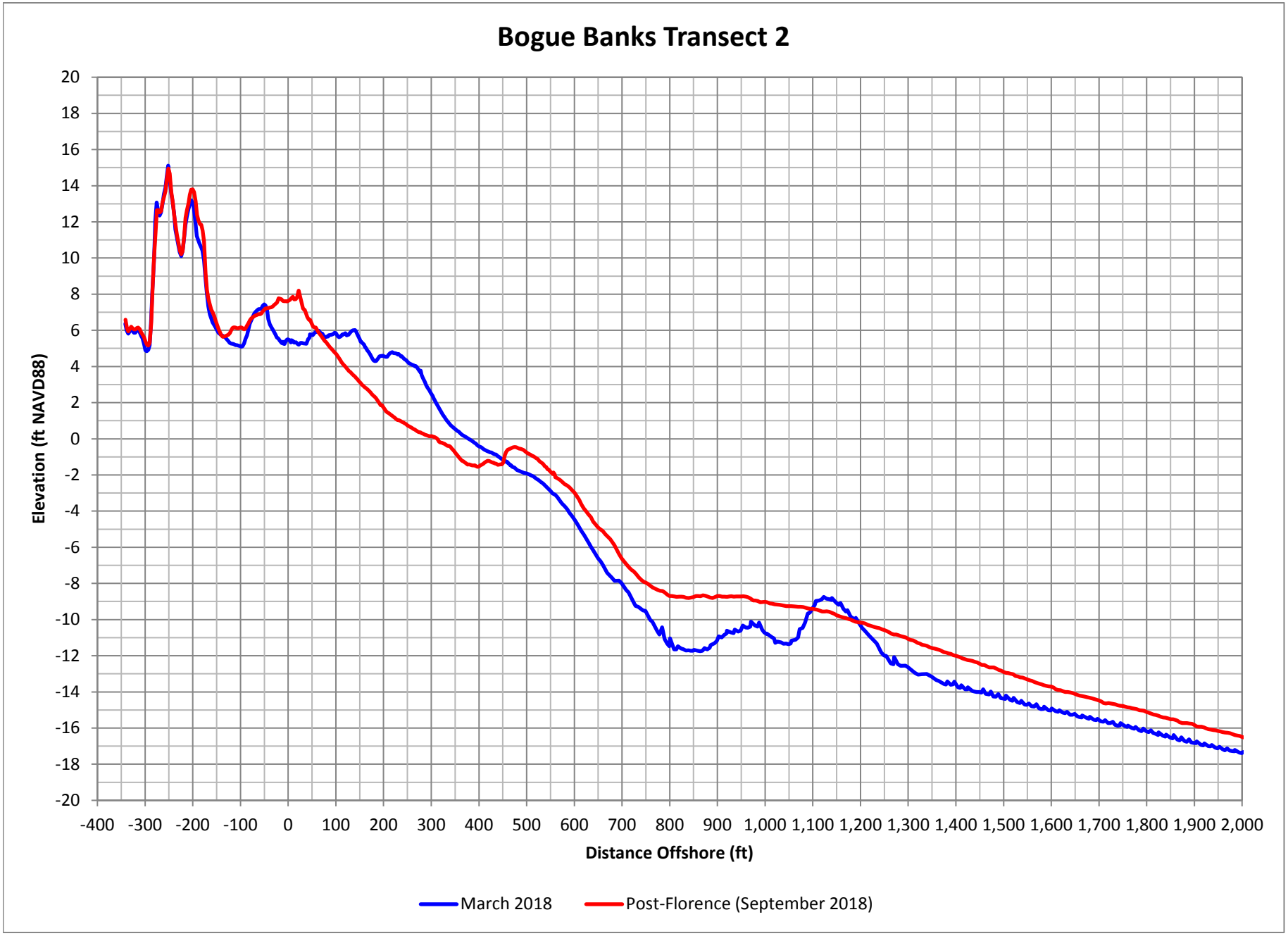


Figure D-4. Bogue Banks Profile Comparison Plot

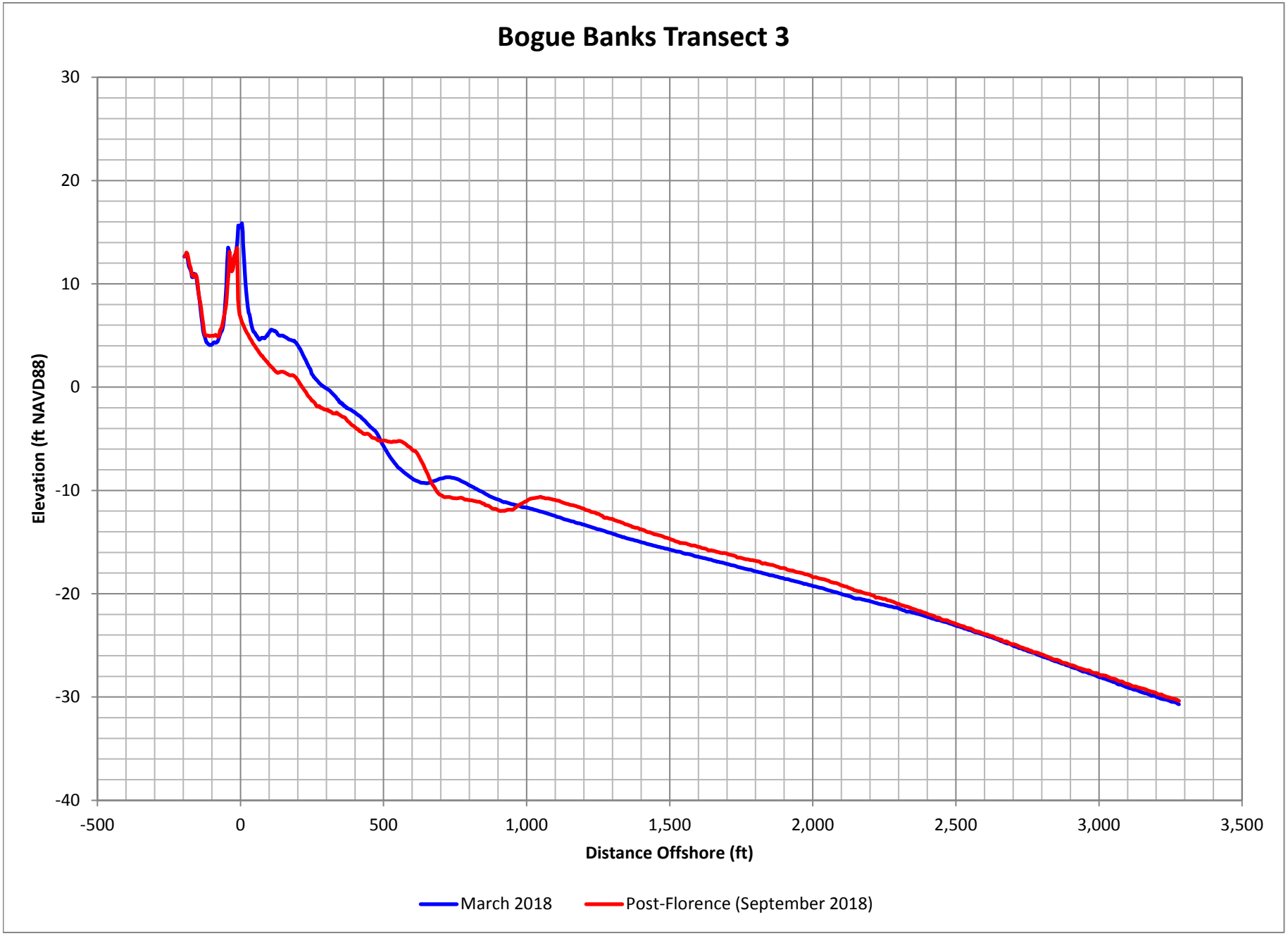


Figure D-5. Bogue Banks Profile Comparison Plot

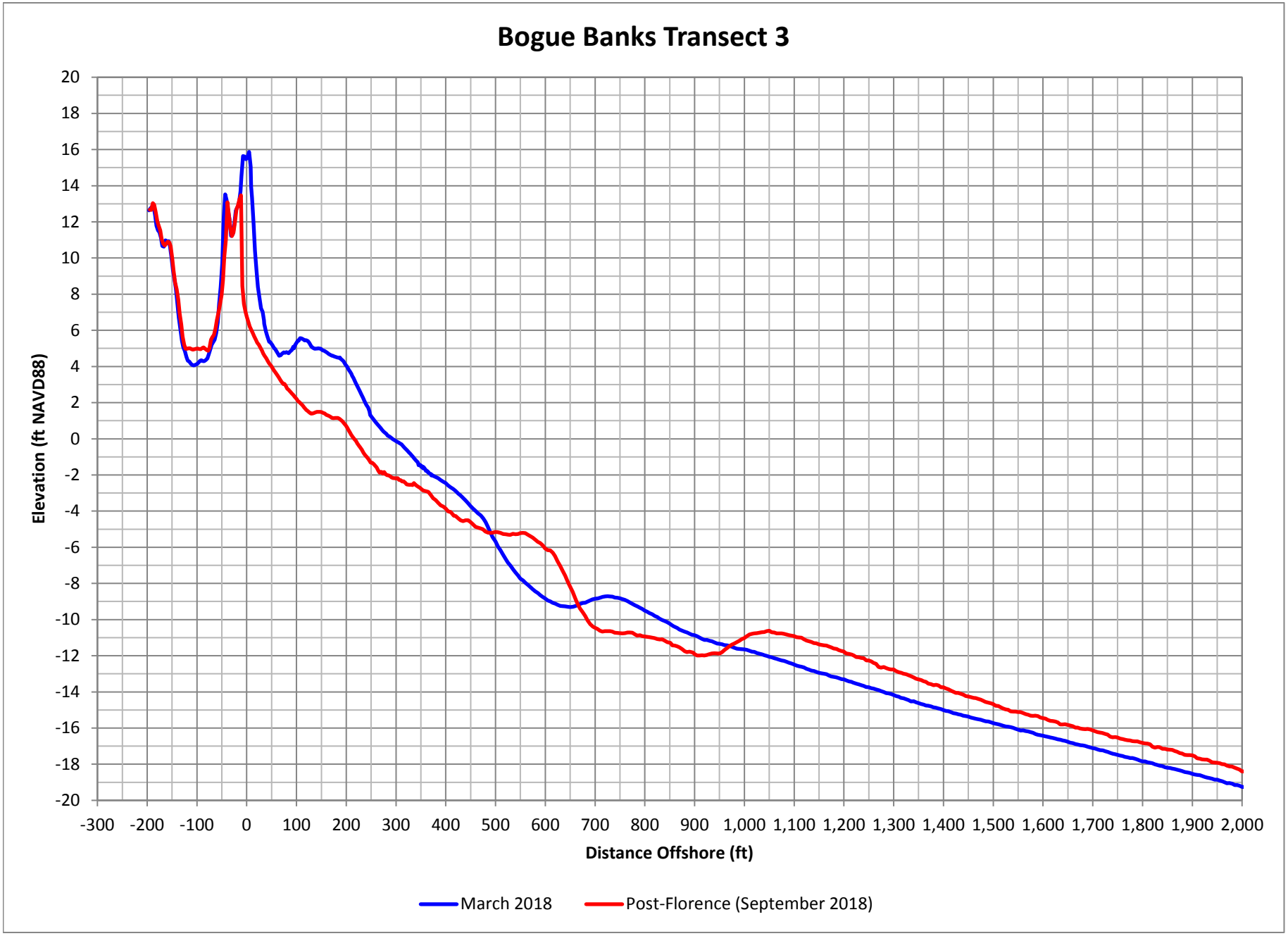


Figure D-6. Bogue Banks Profile Comparison Plot

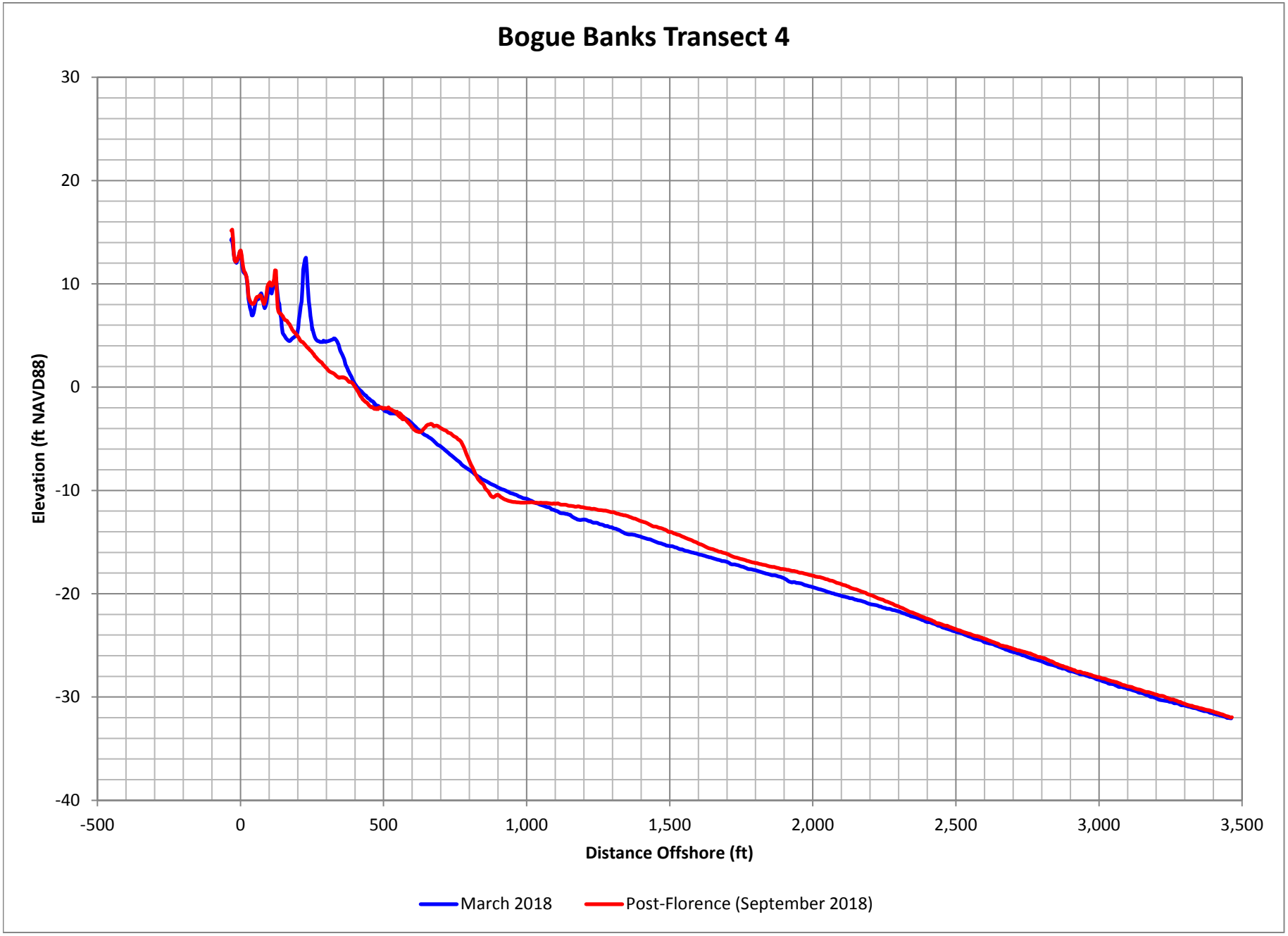


Figure D-7. Bogue Banks Profile Comparison Plot

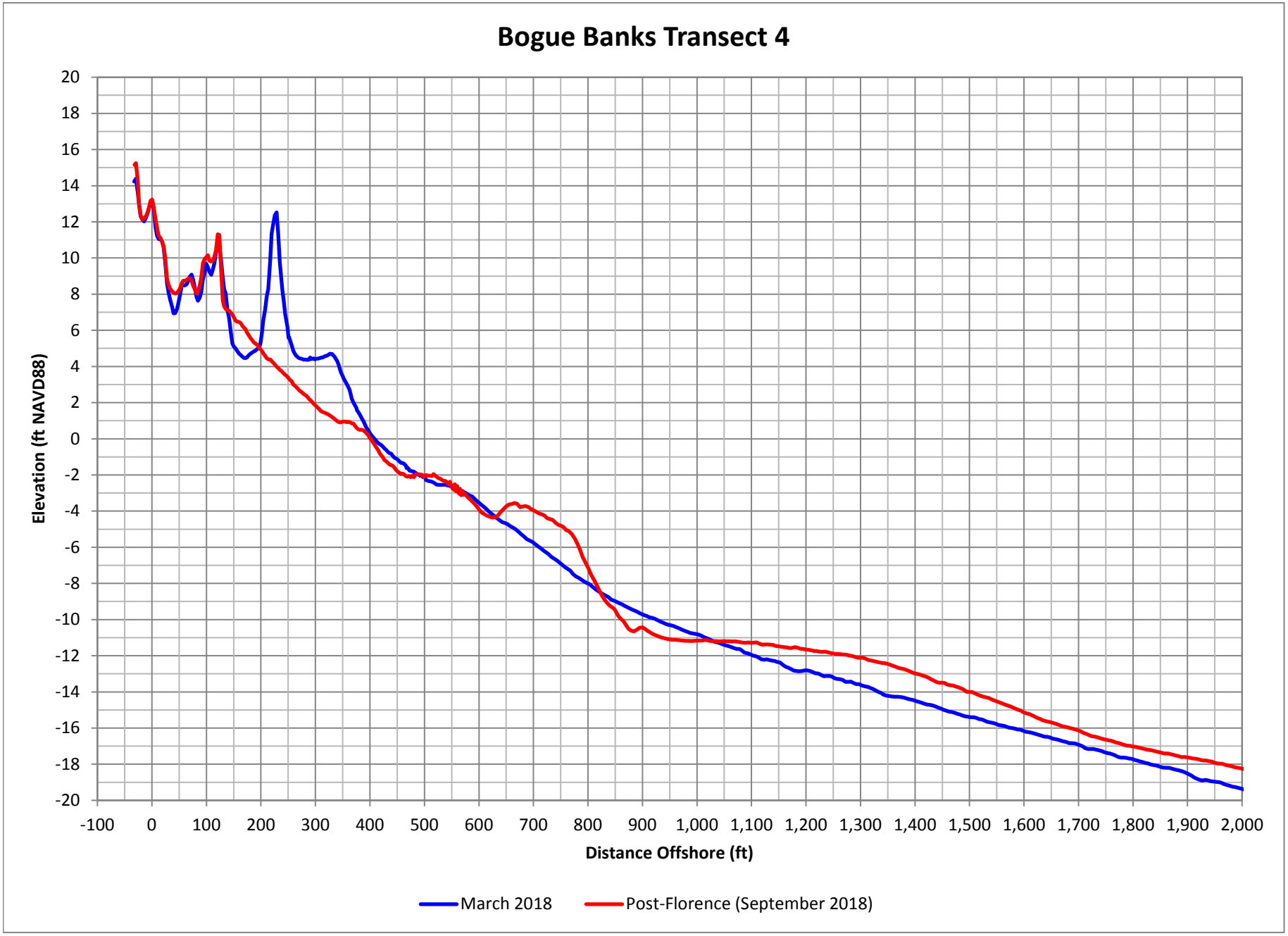


Figure D-8. Bogue Banks Profile Comparison Plot

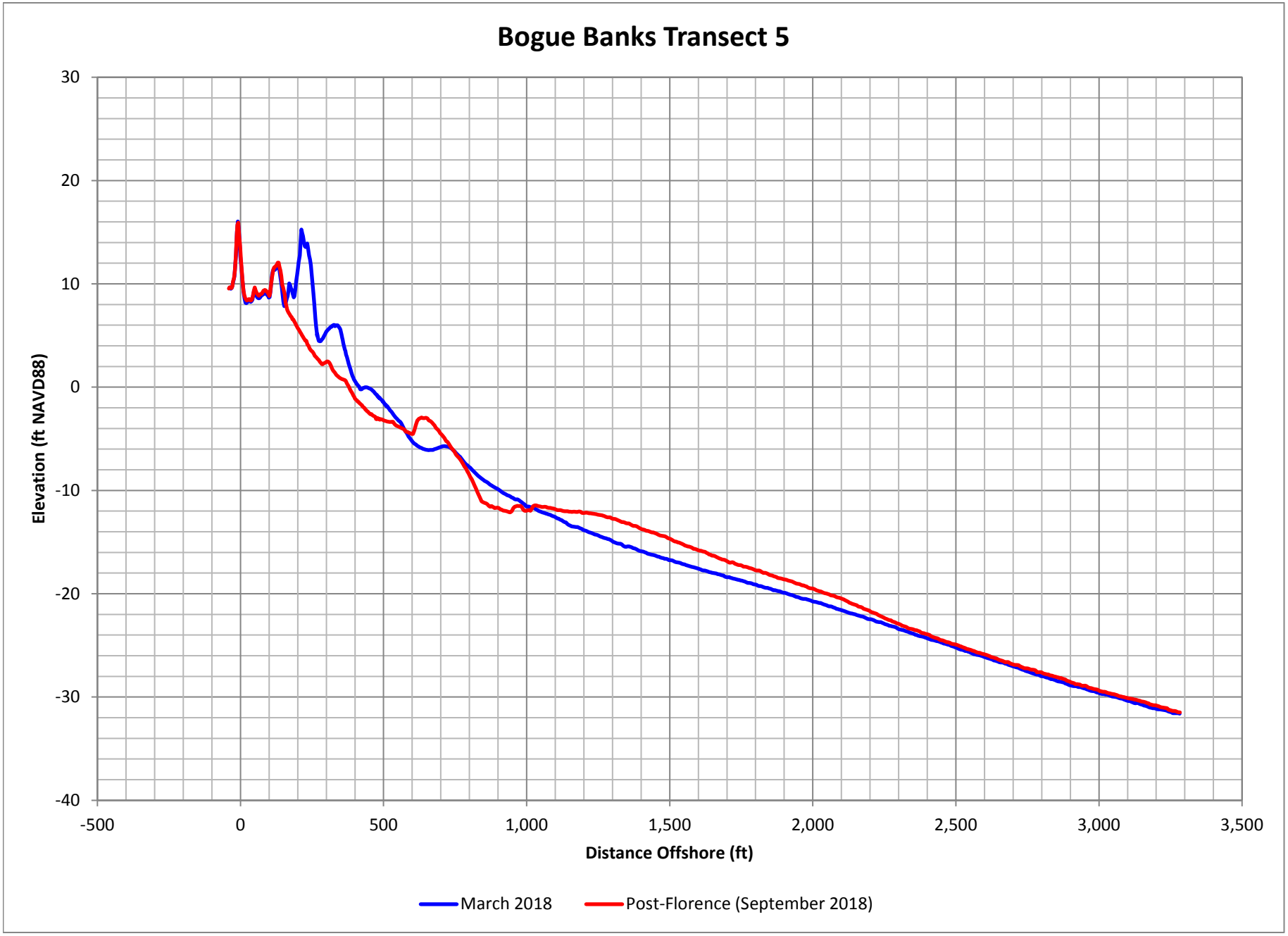


Figure D-9. Bogue Banks Profile Comparison Plot

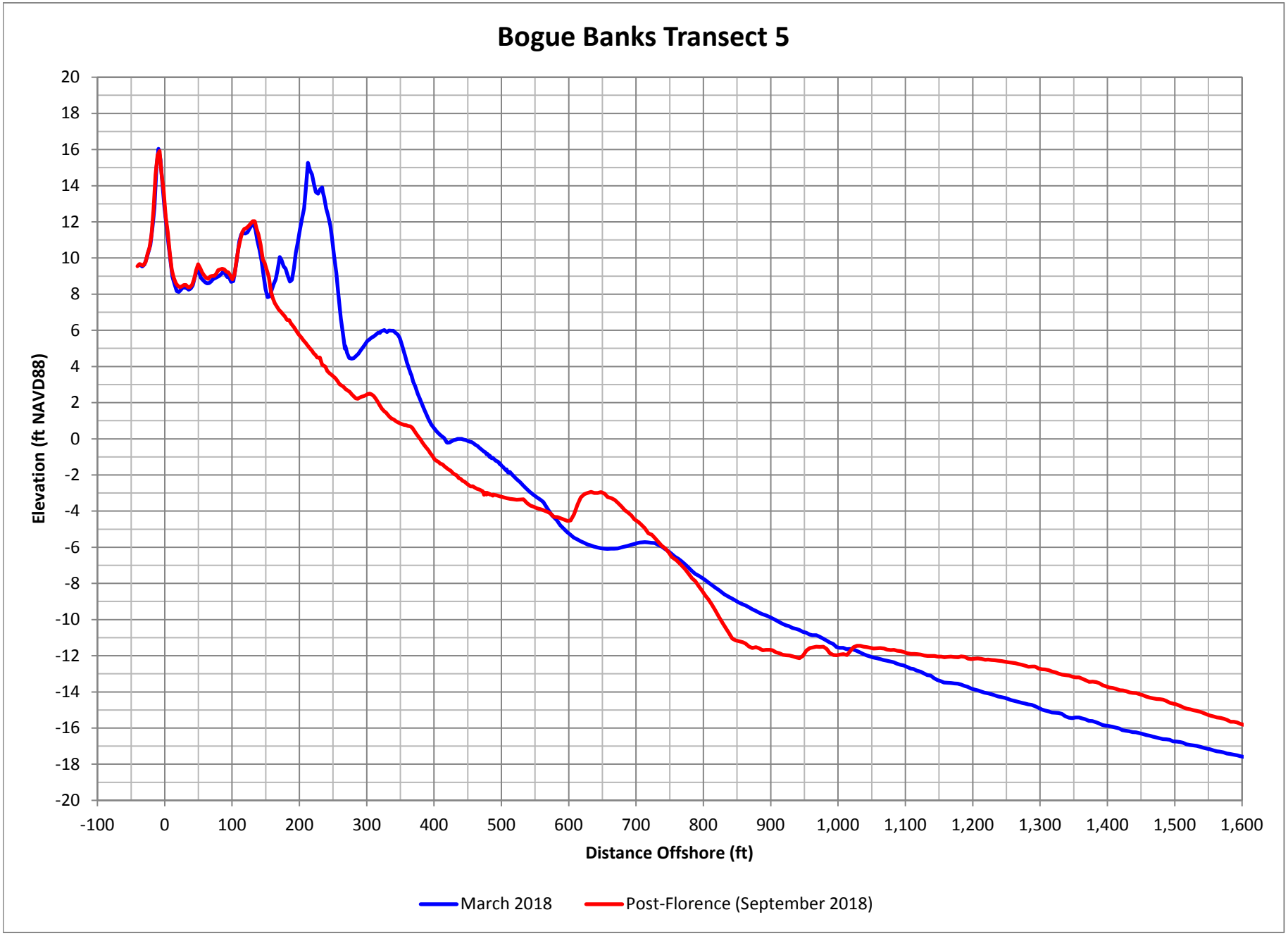


Figure D-10. Bogue Banks Profile Comparison Plot

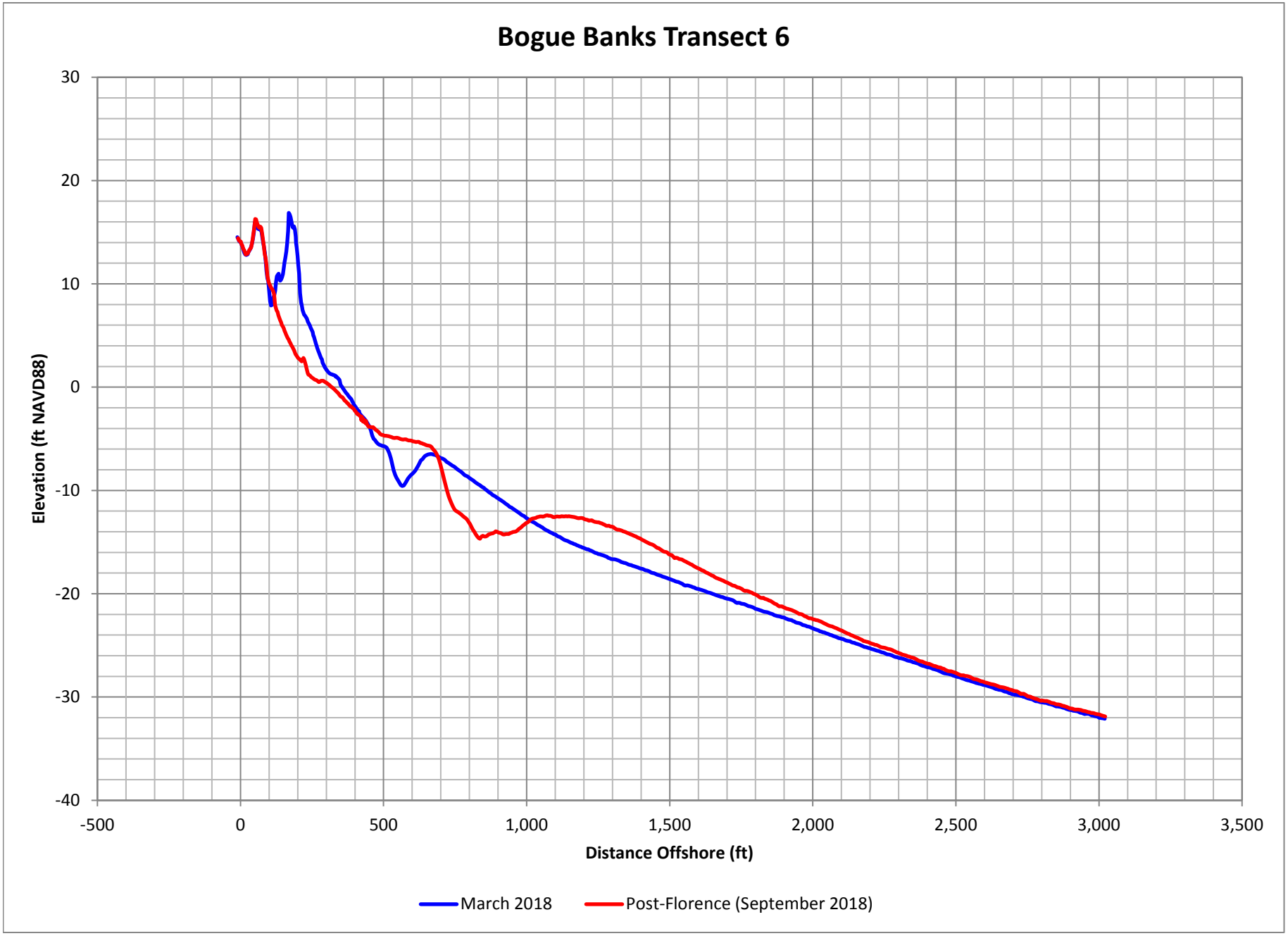


Figure D-11. Bogue Banks Profile Comparison Plot

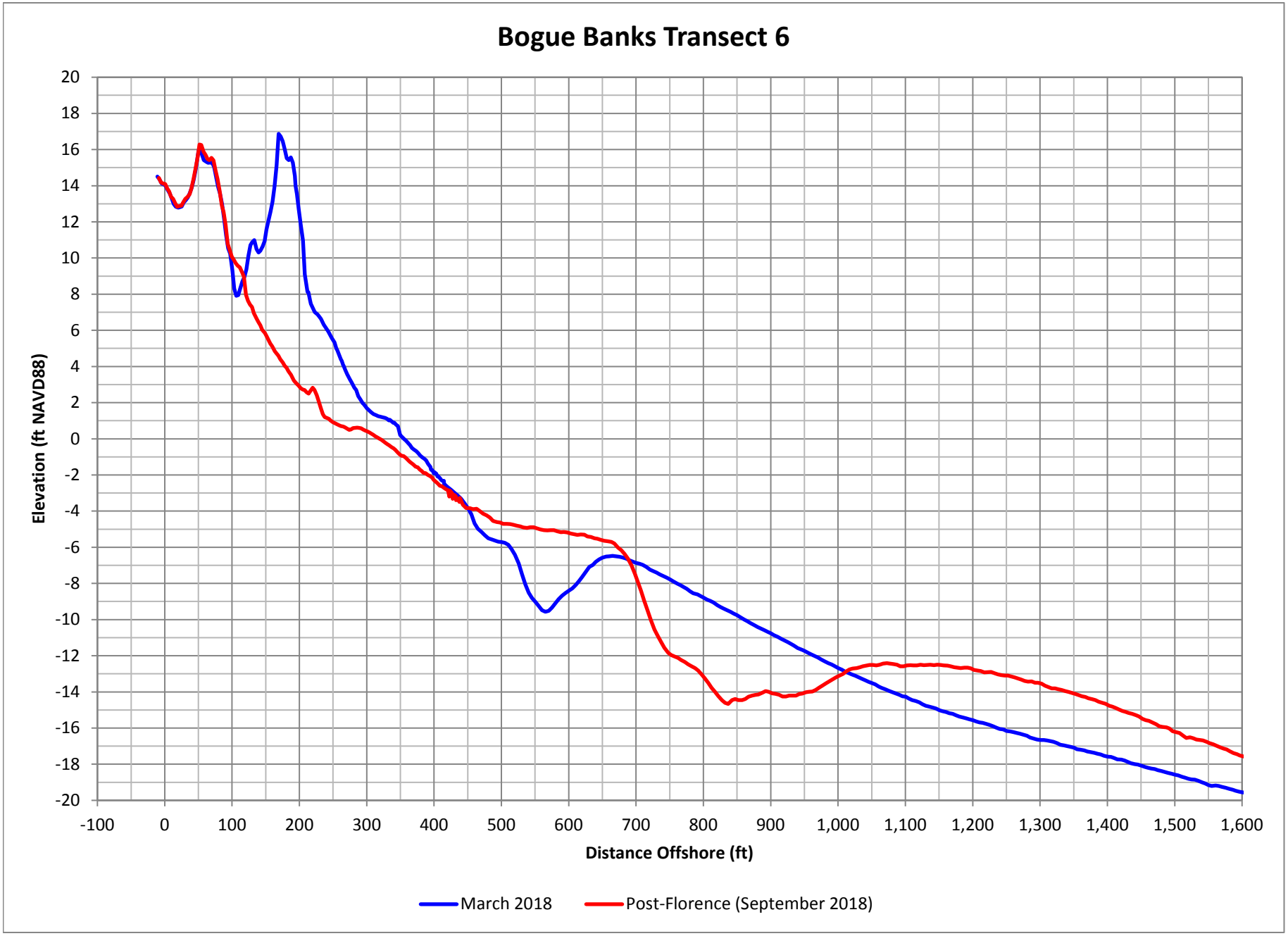


Figure D-12. Bogue Banks Profile Comparison Plot

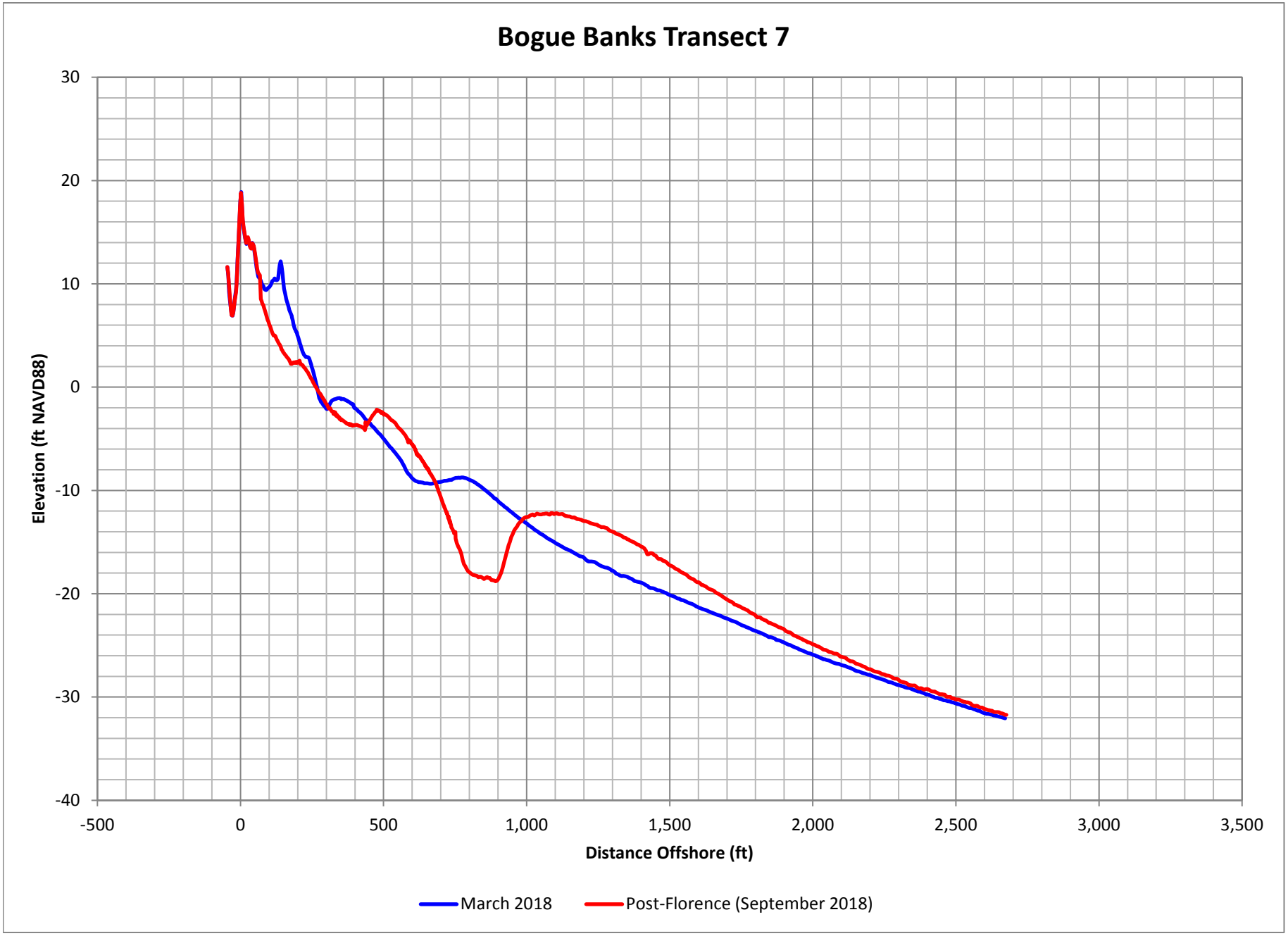
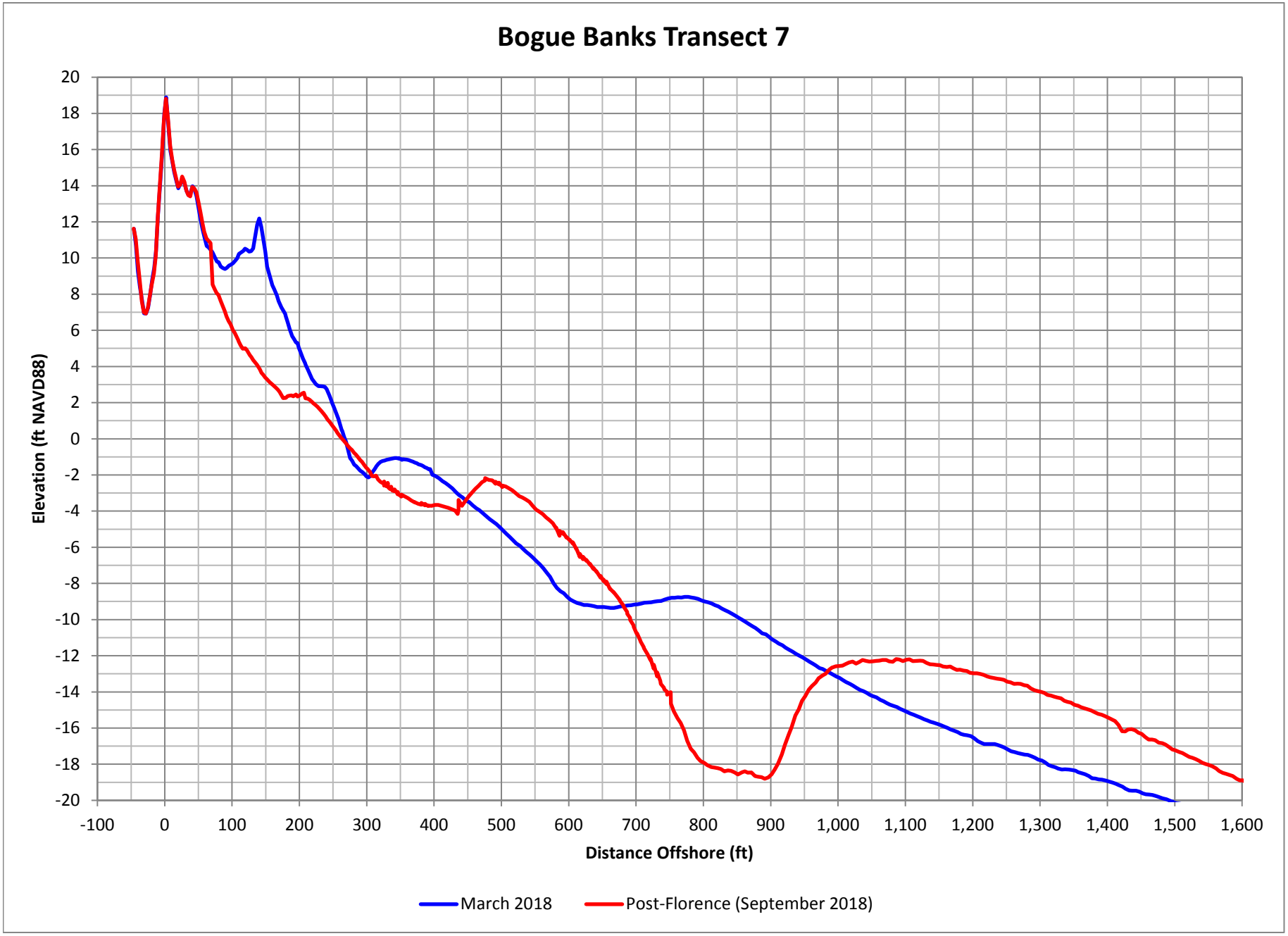


Figure D-13. Bogue Banks Profile Comparison Plot



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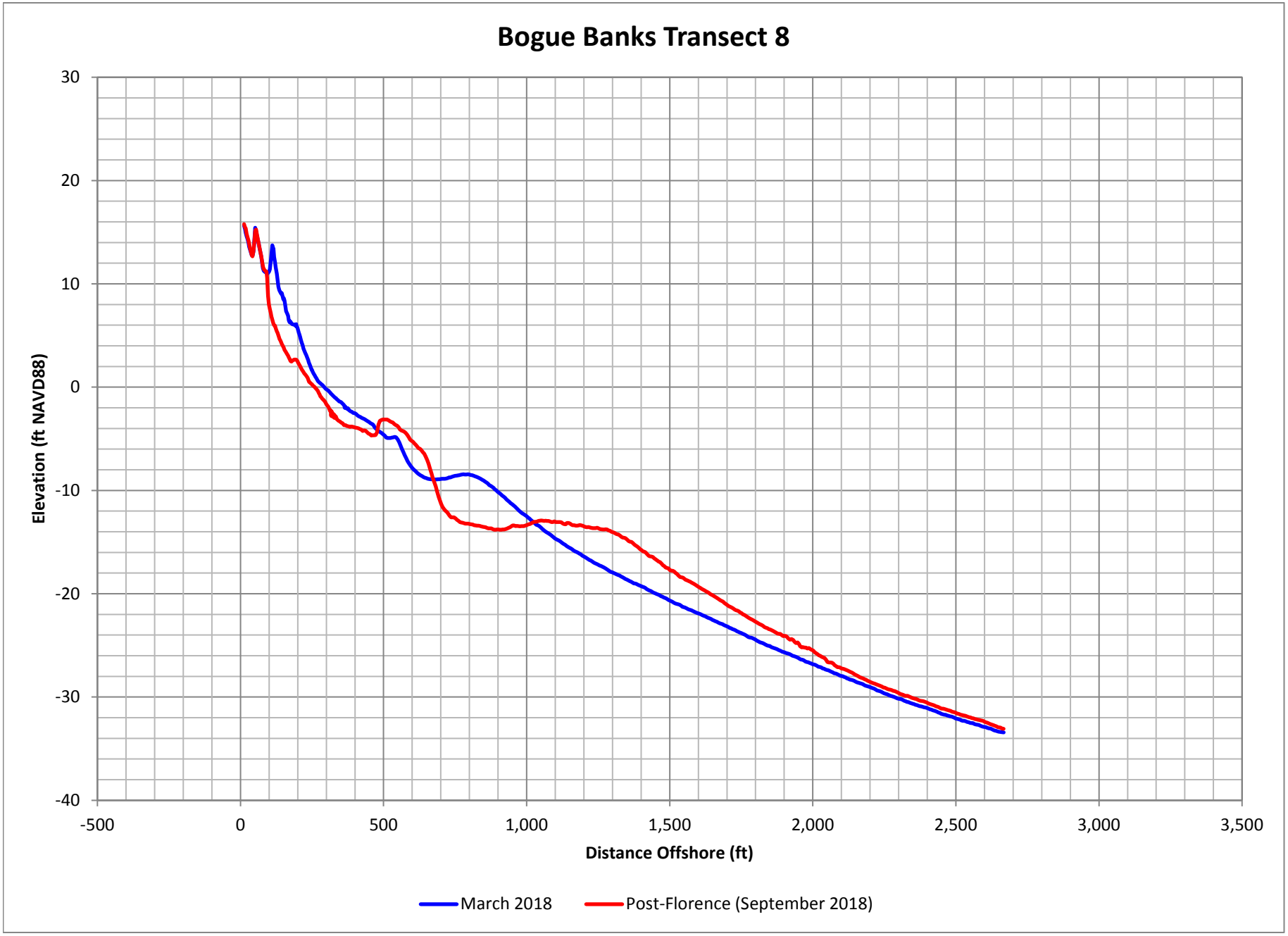

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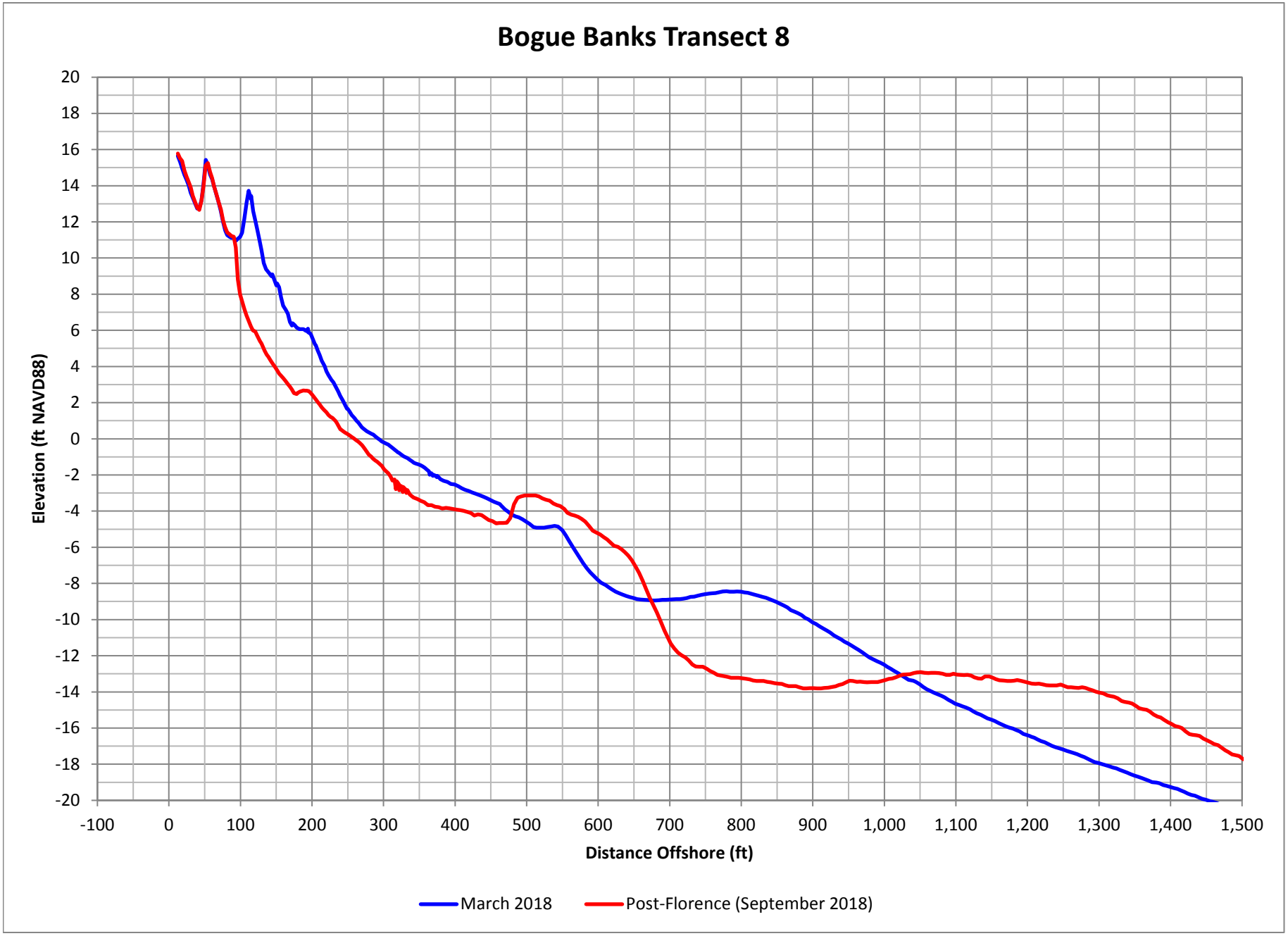

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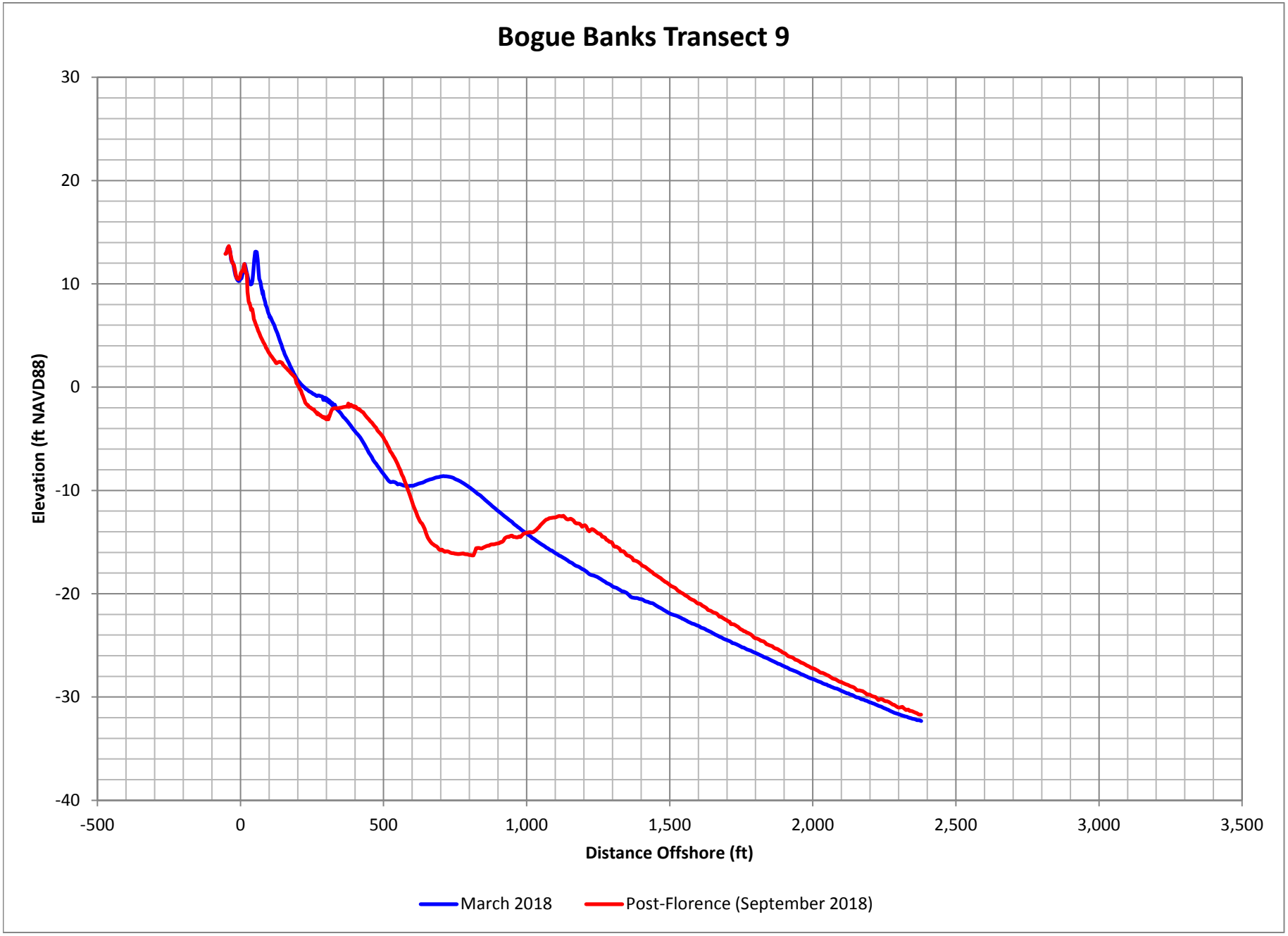
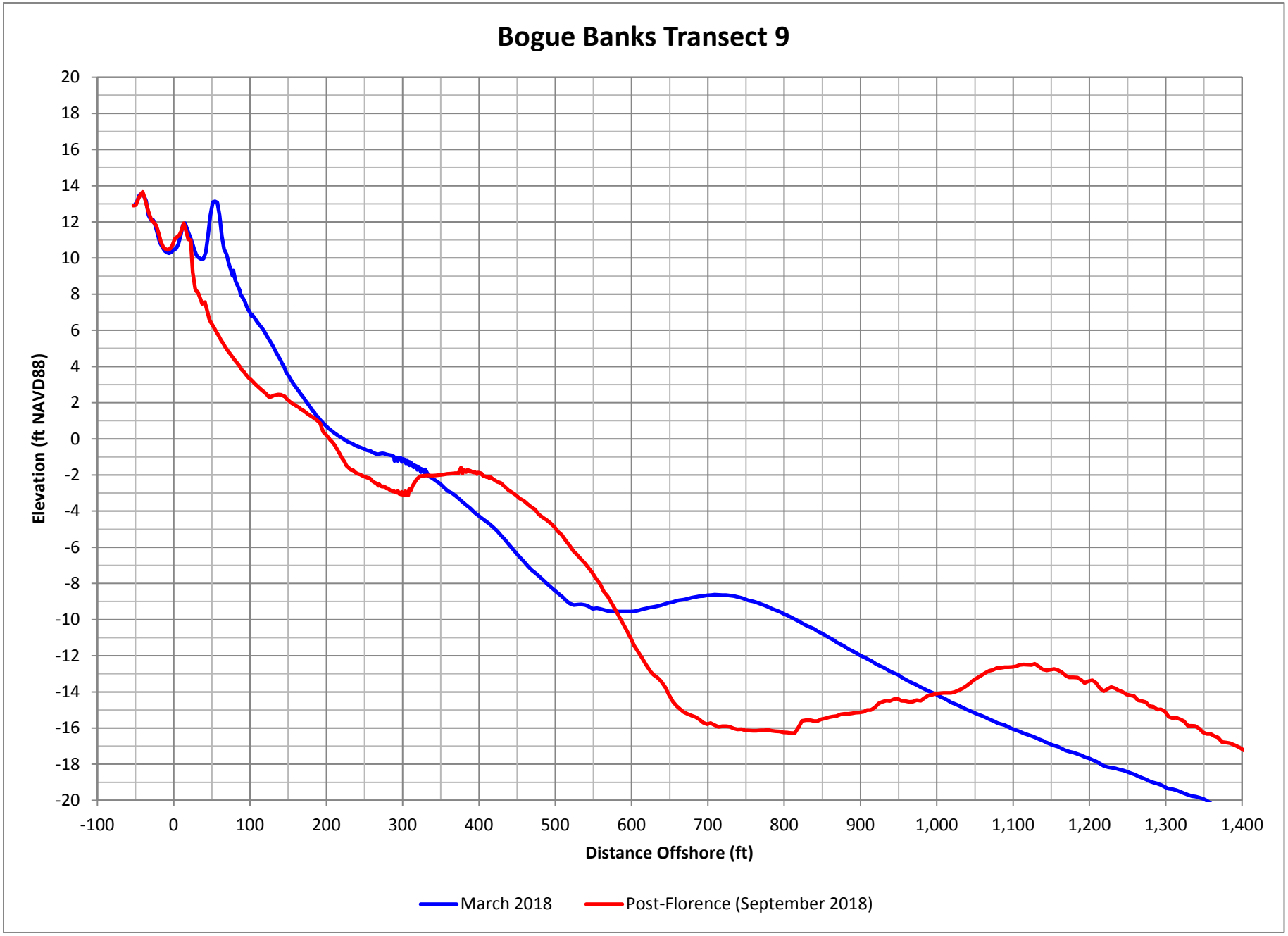


Figure D-17. Bogue Banks Profile Comparison Plot



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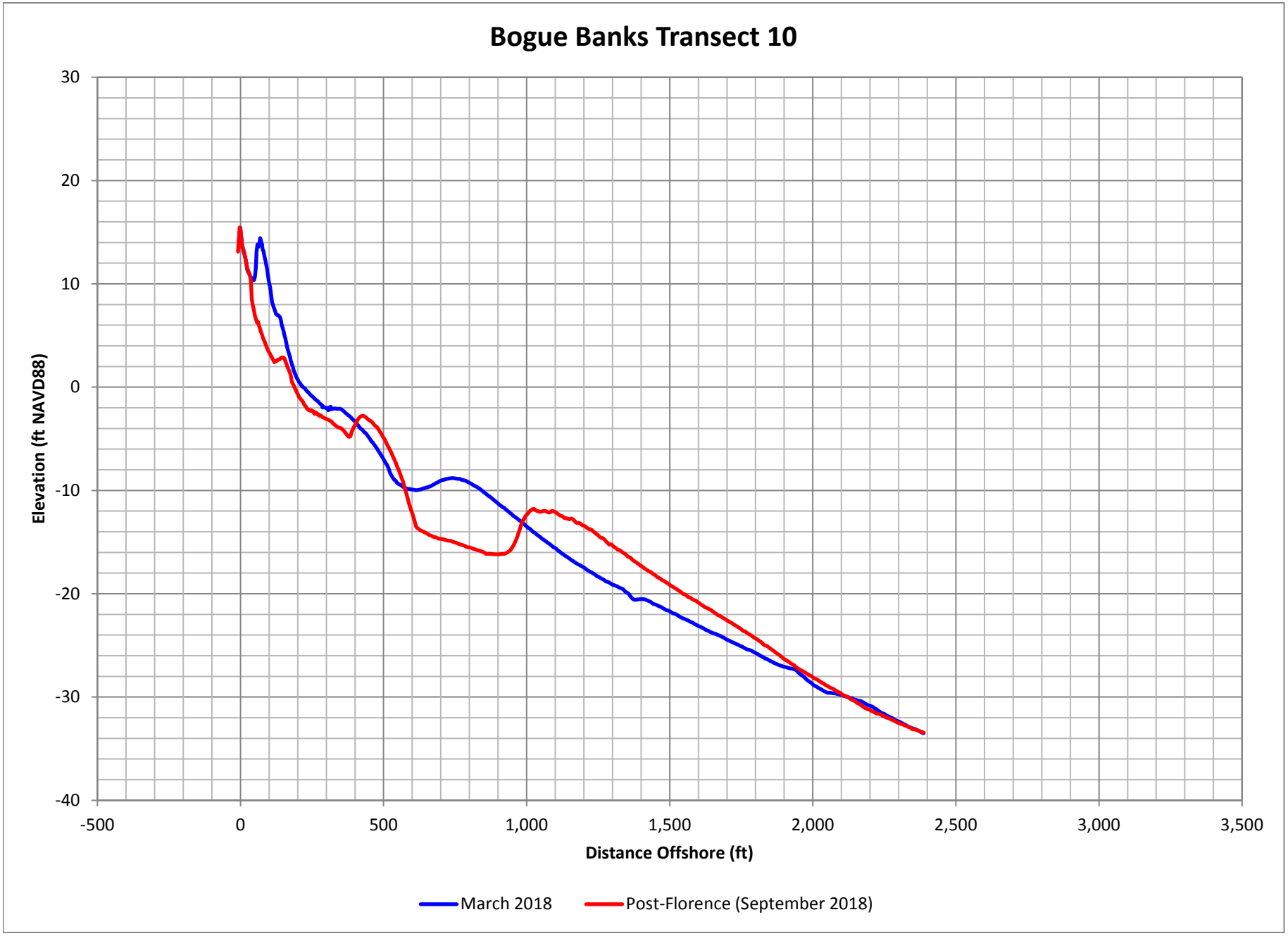

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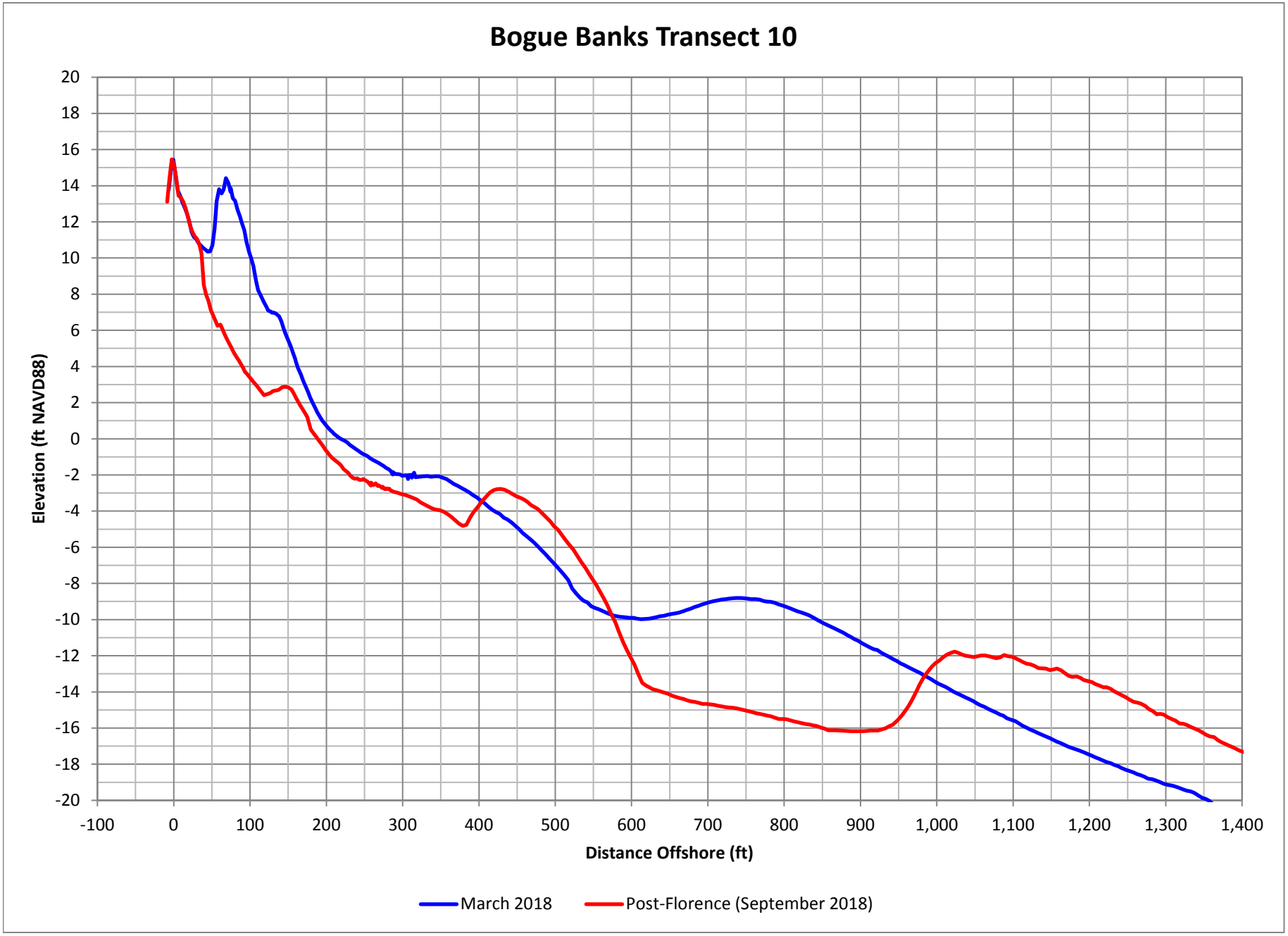

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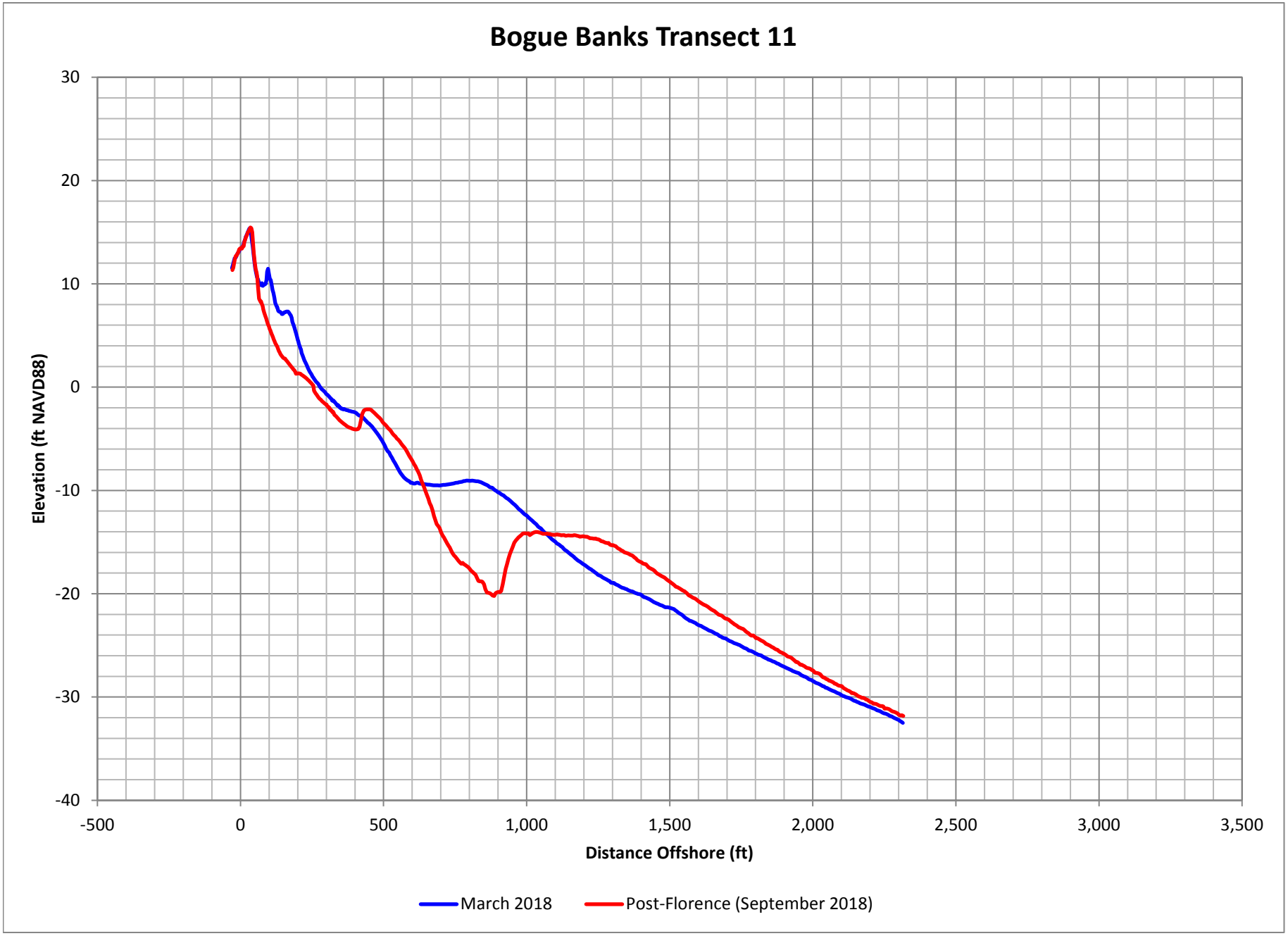

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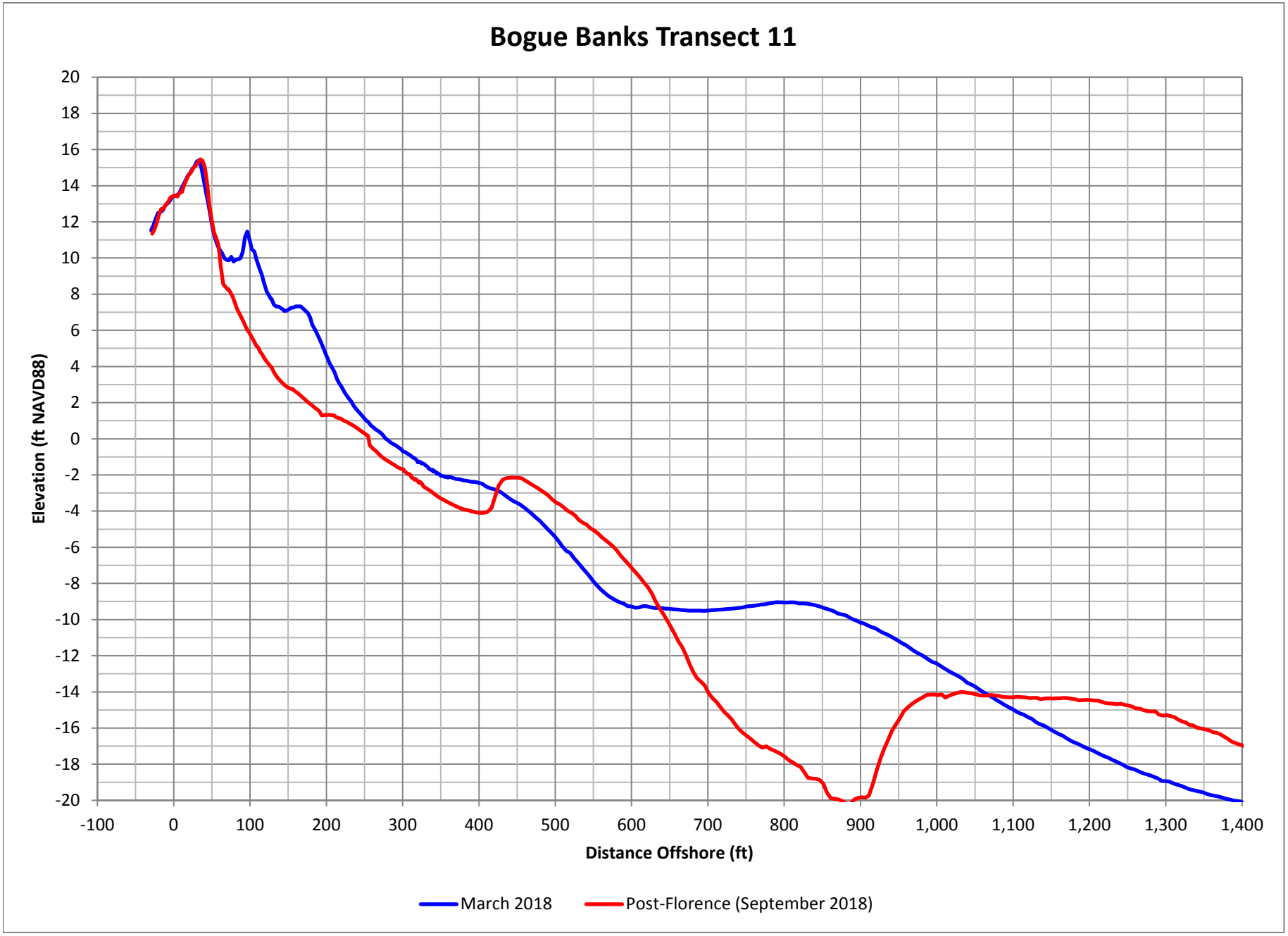

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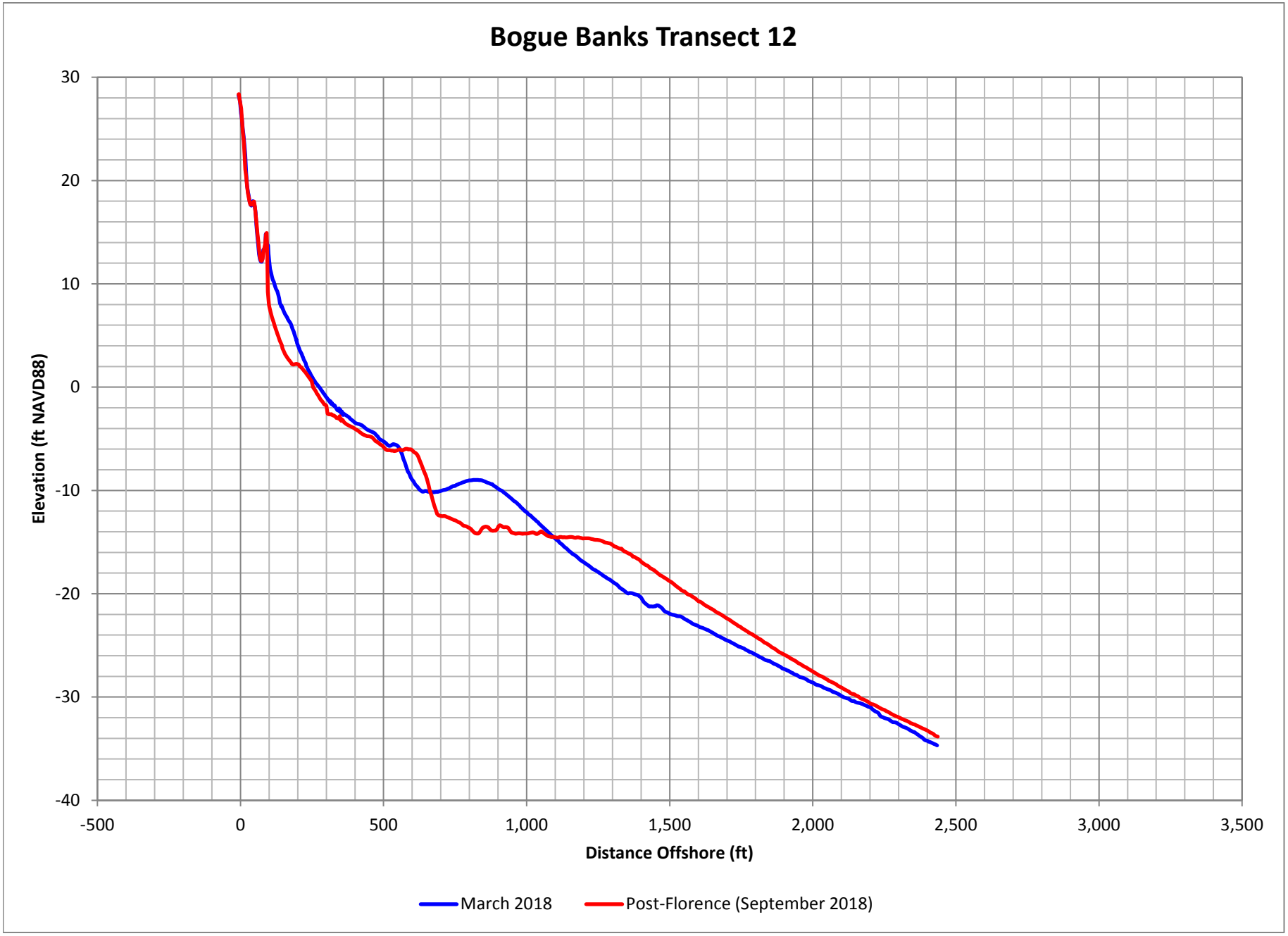

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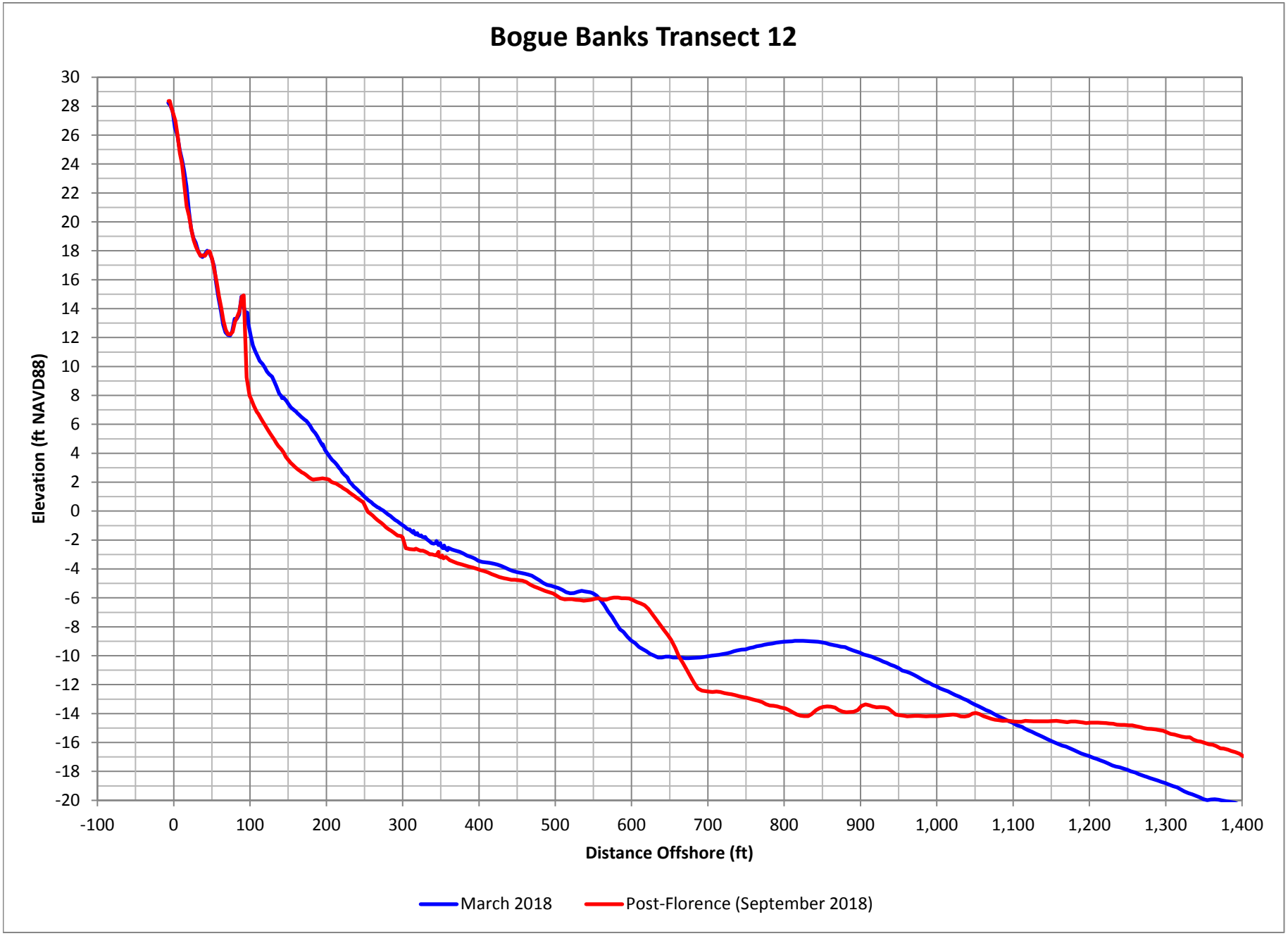

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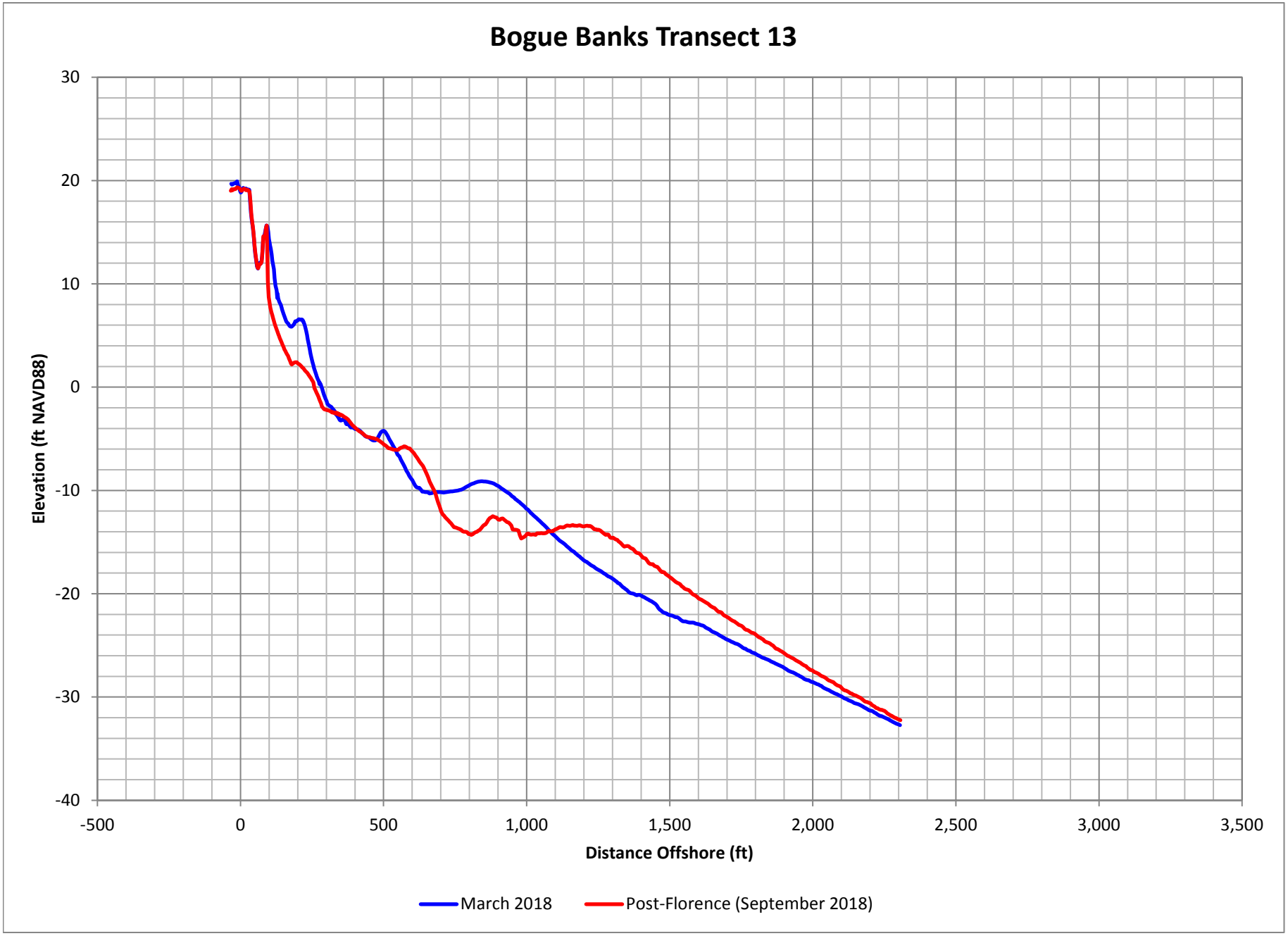

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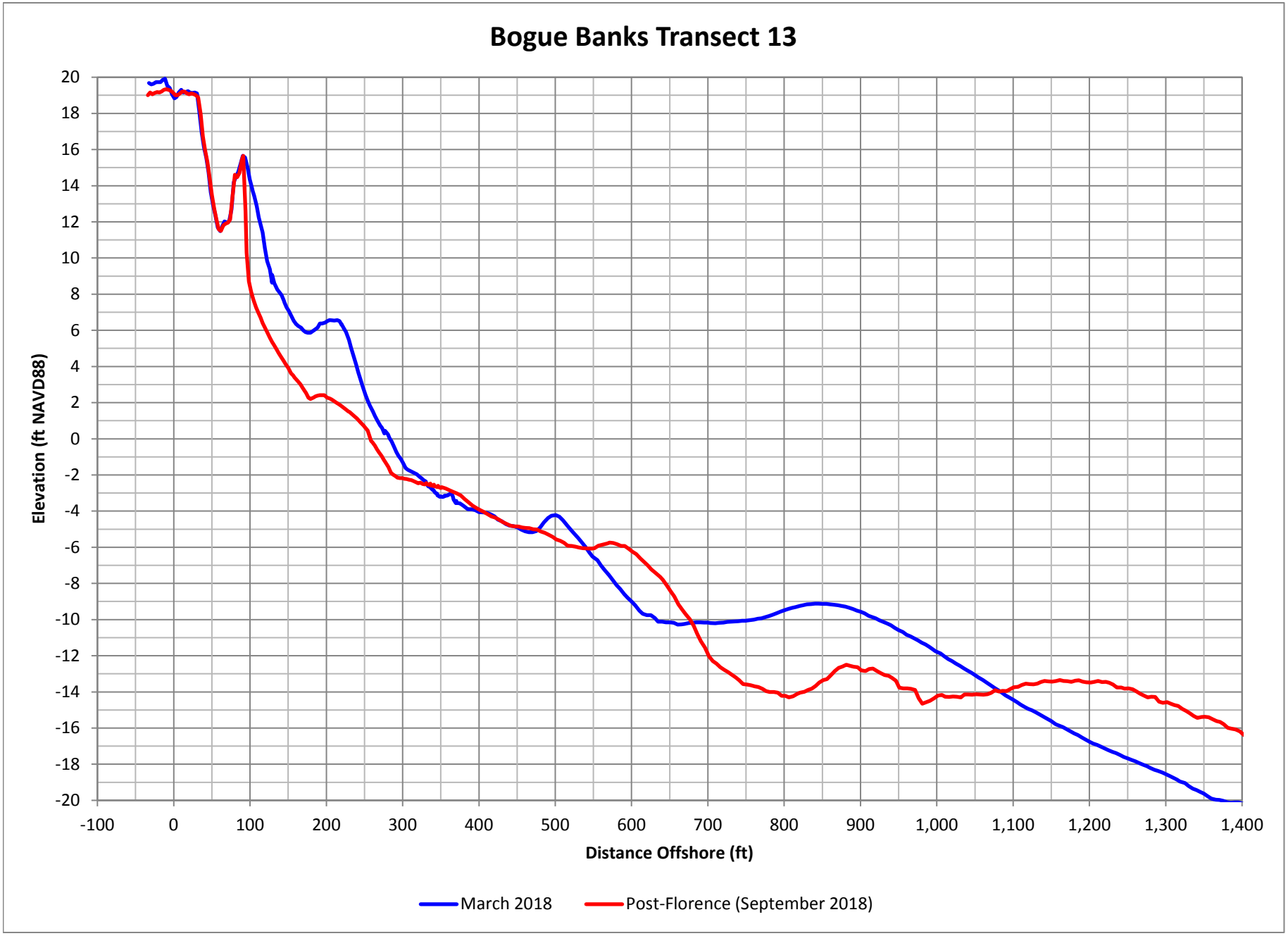
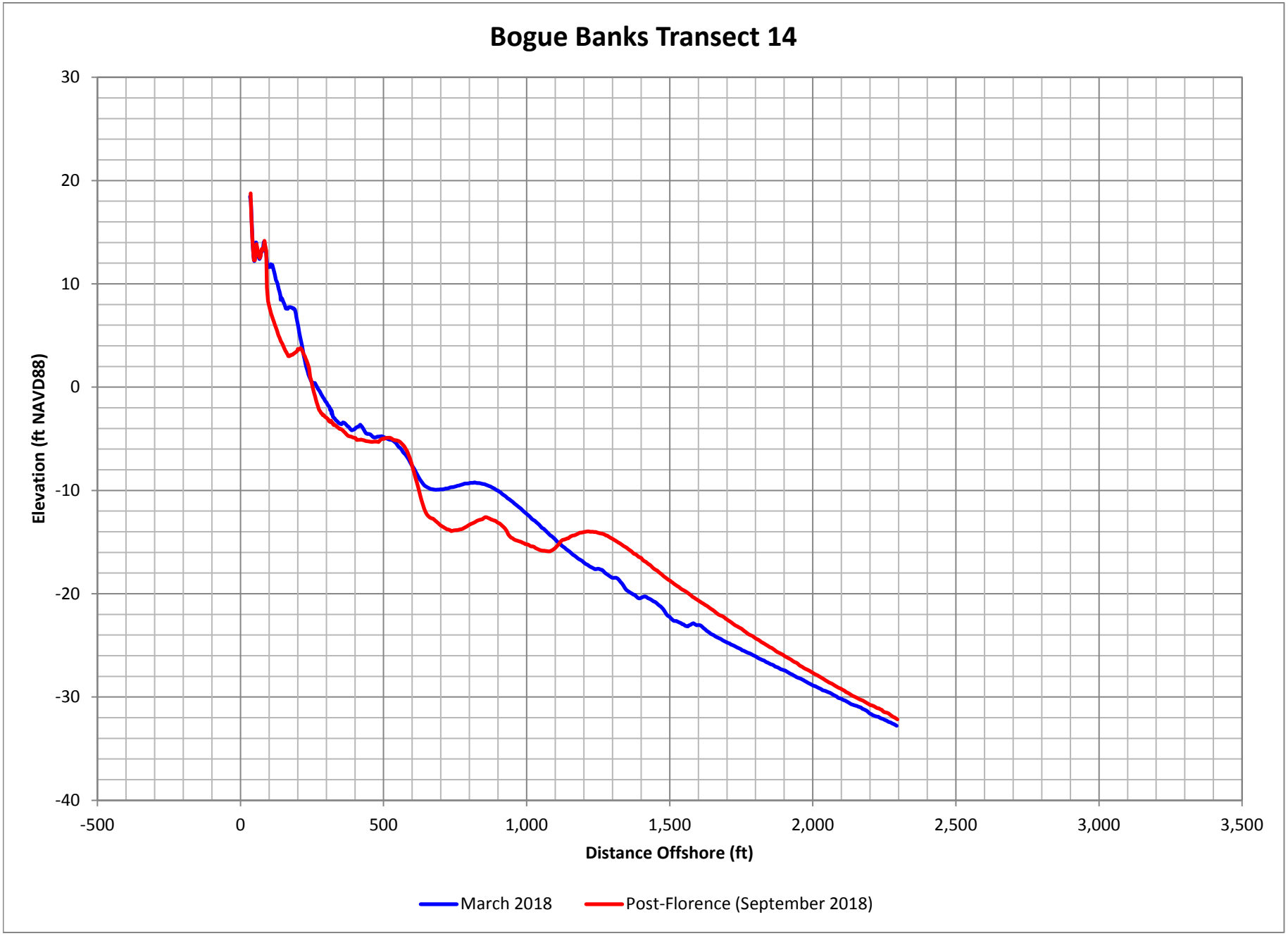


Figure D-26. Bogue Banks Profile Comparison Plot



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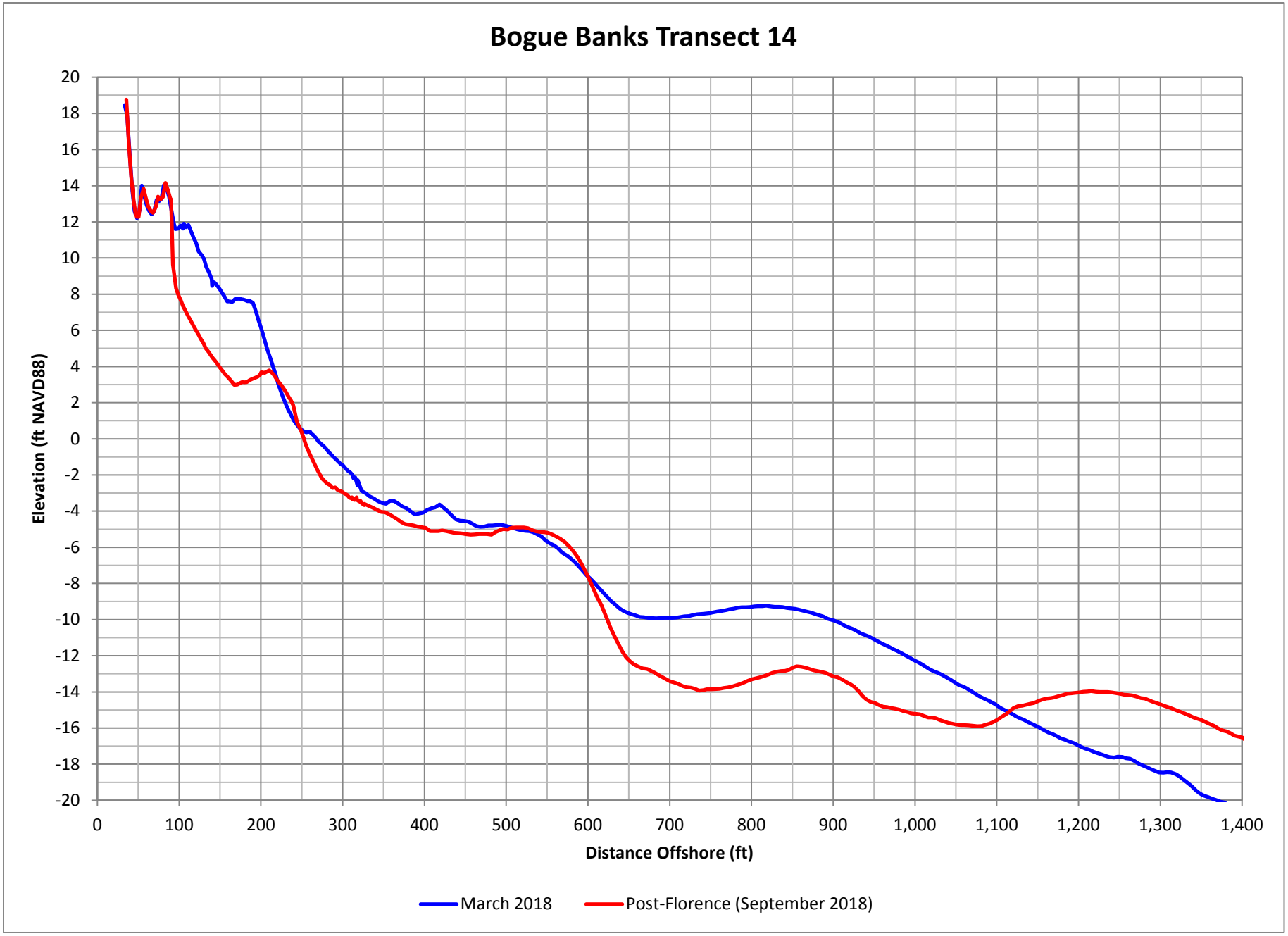

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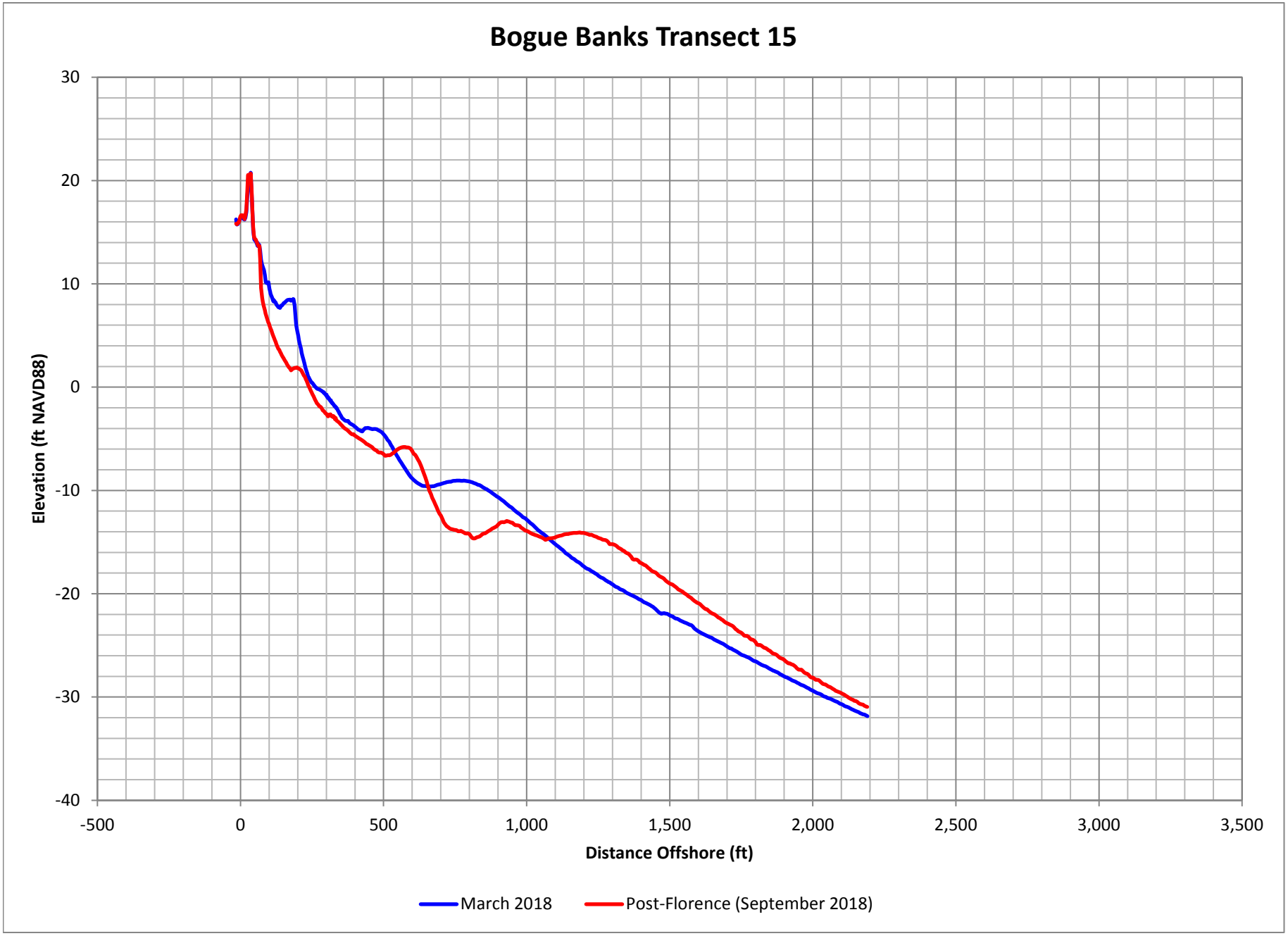

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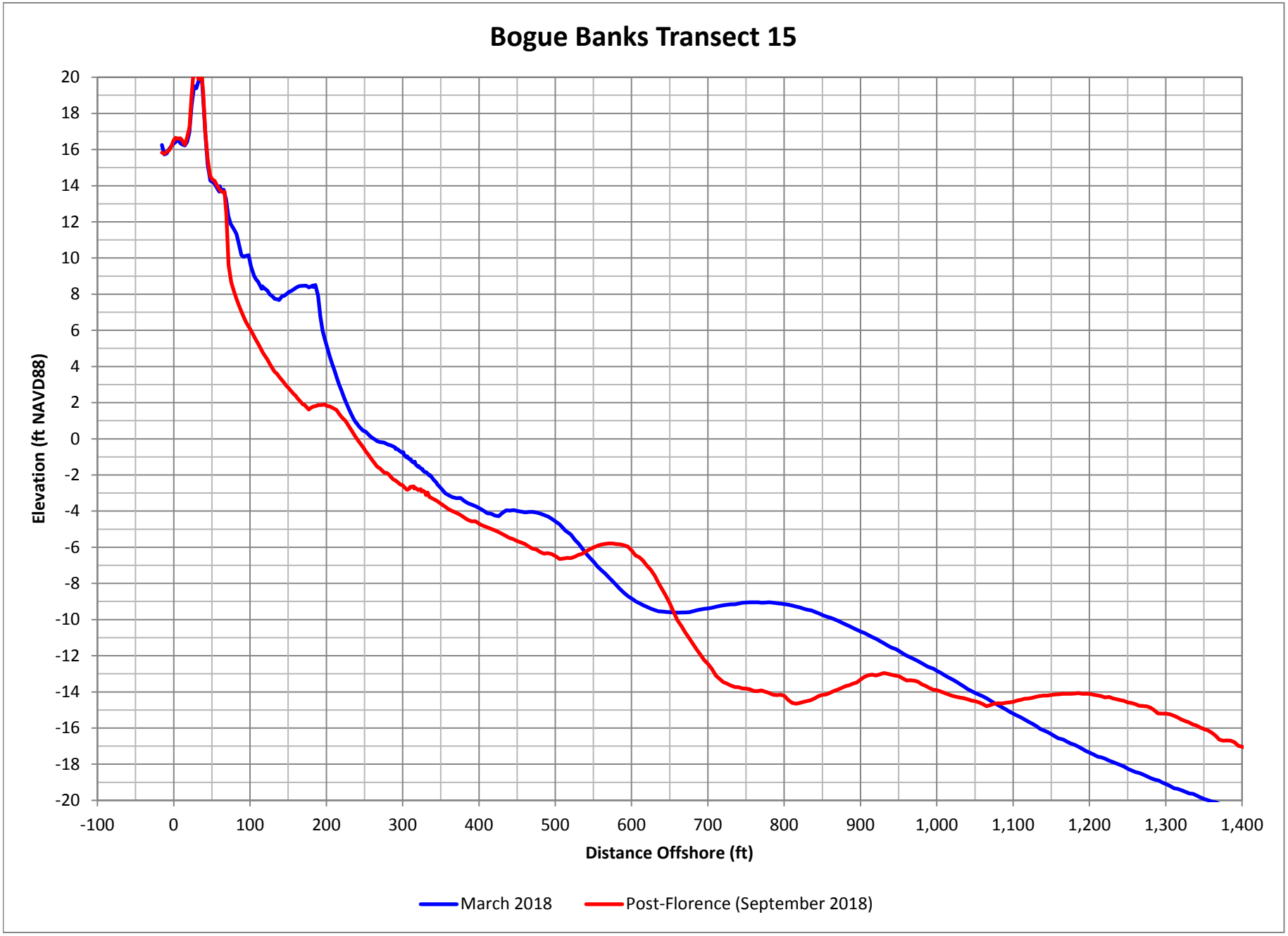
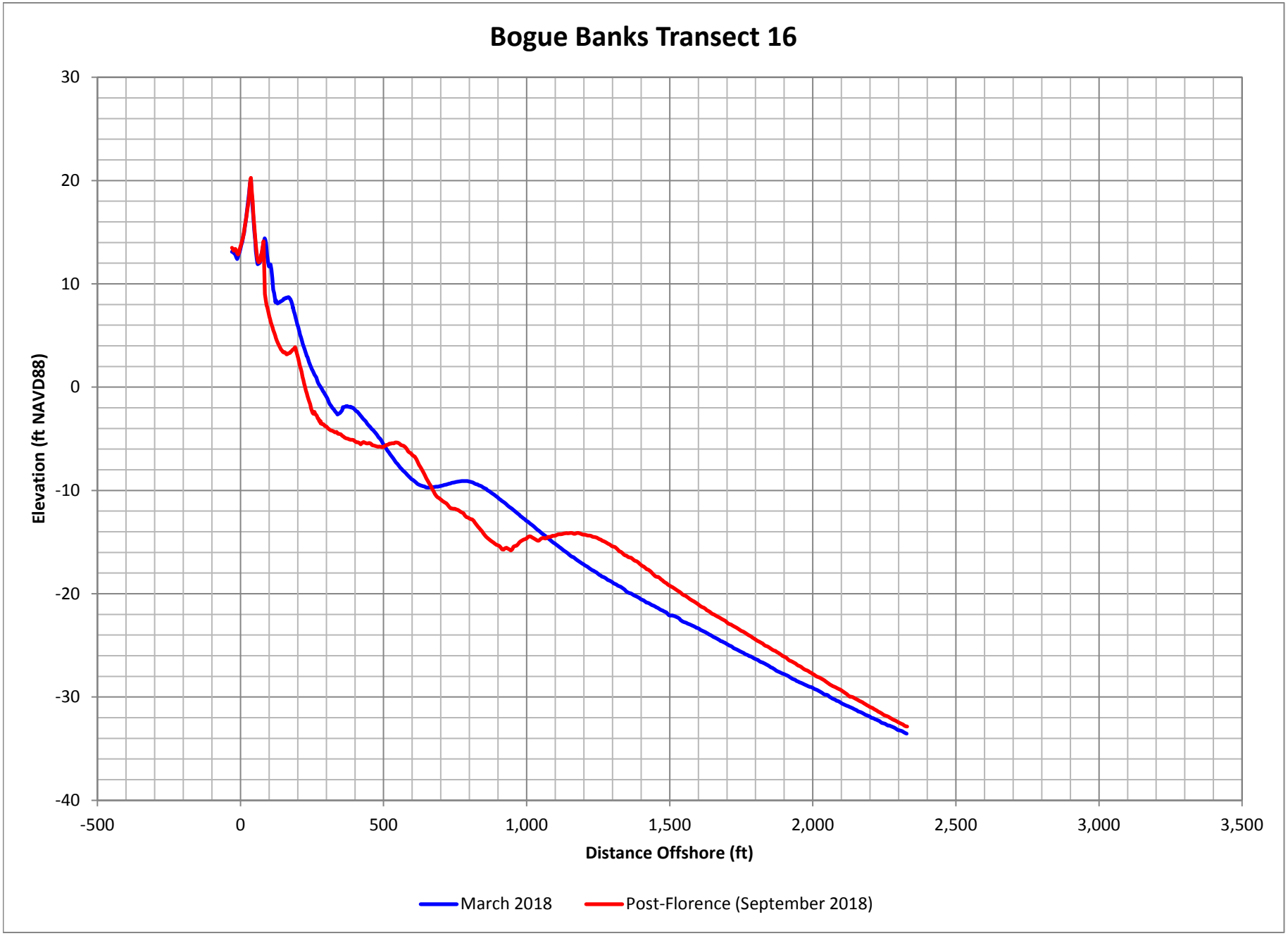


Figure D-30. Bogue Banks Profile Comparison Plot



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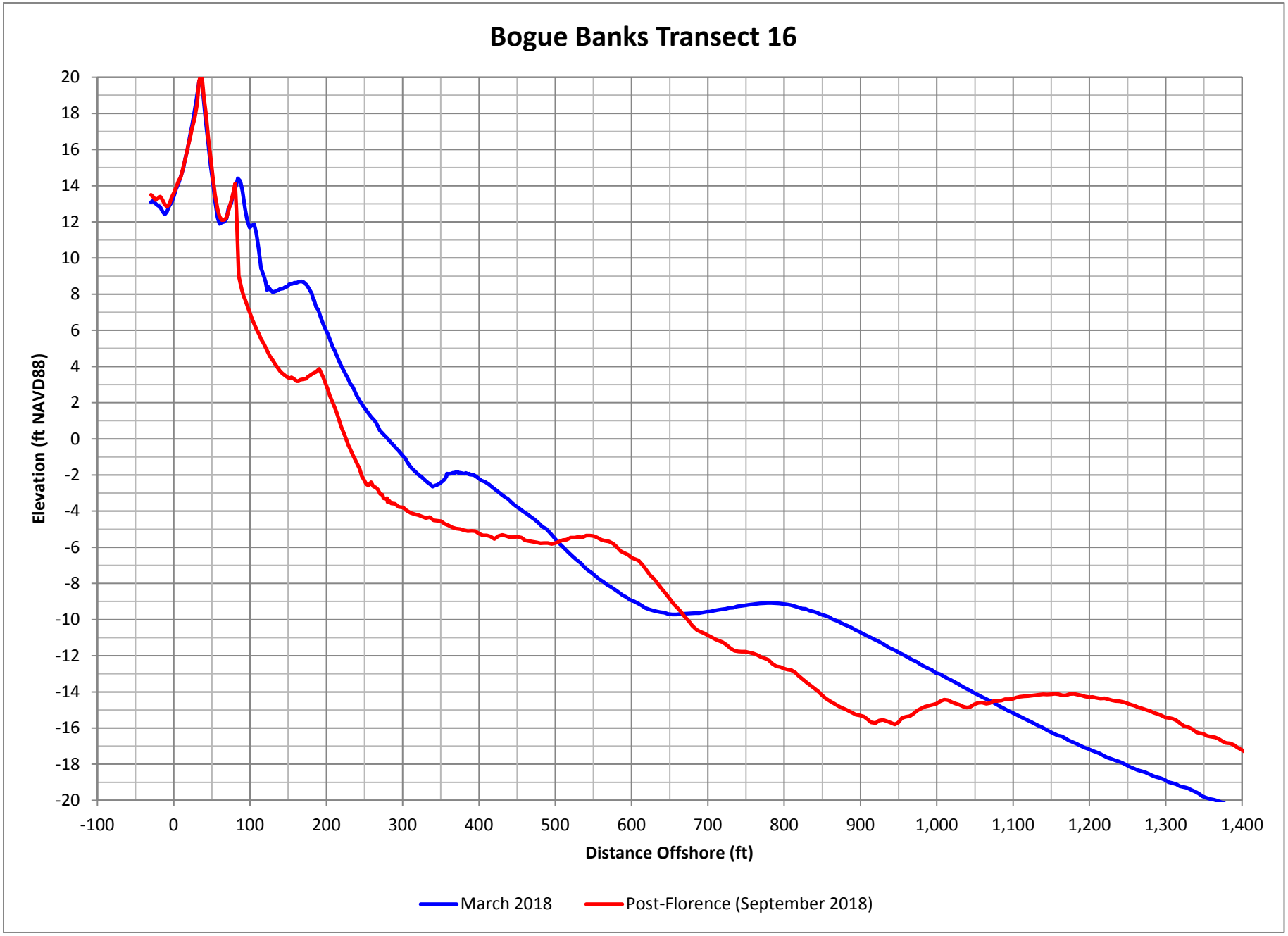

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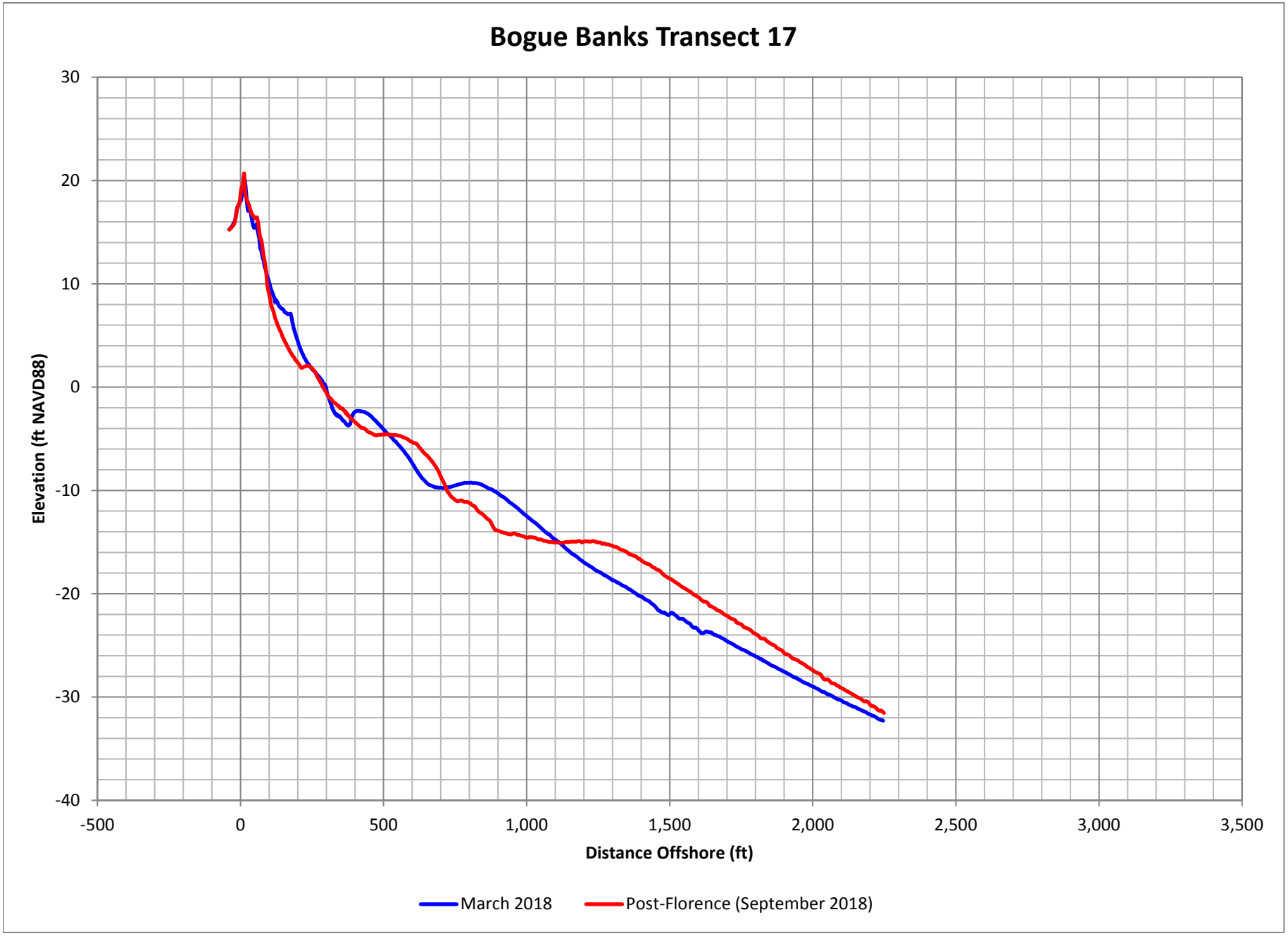

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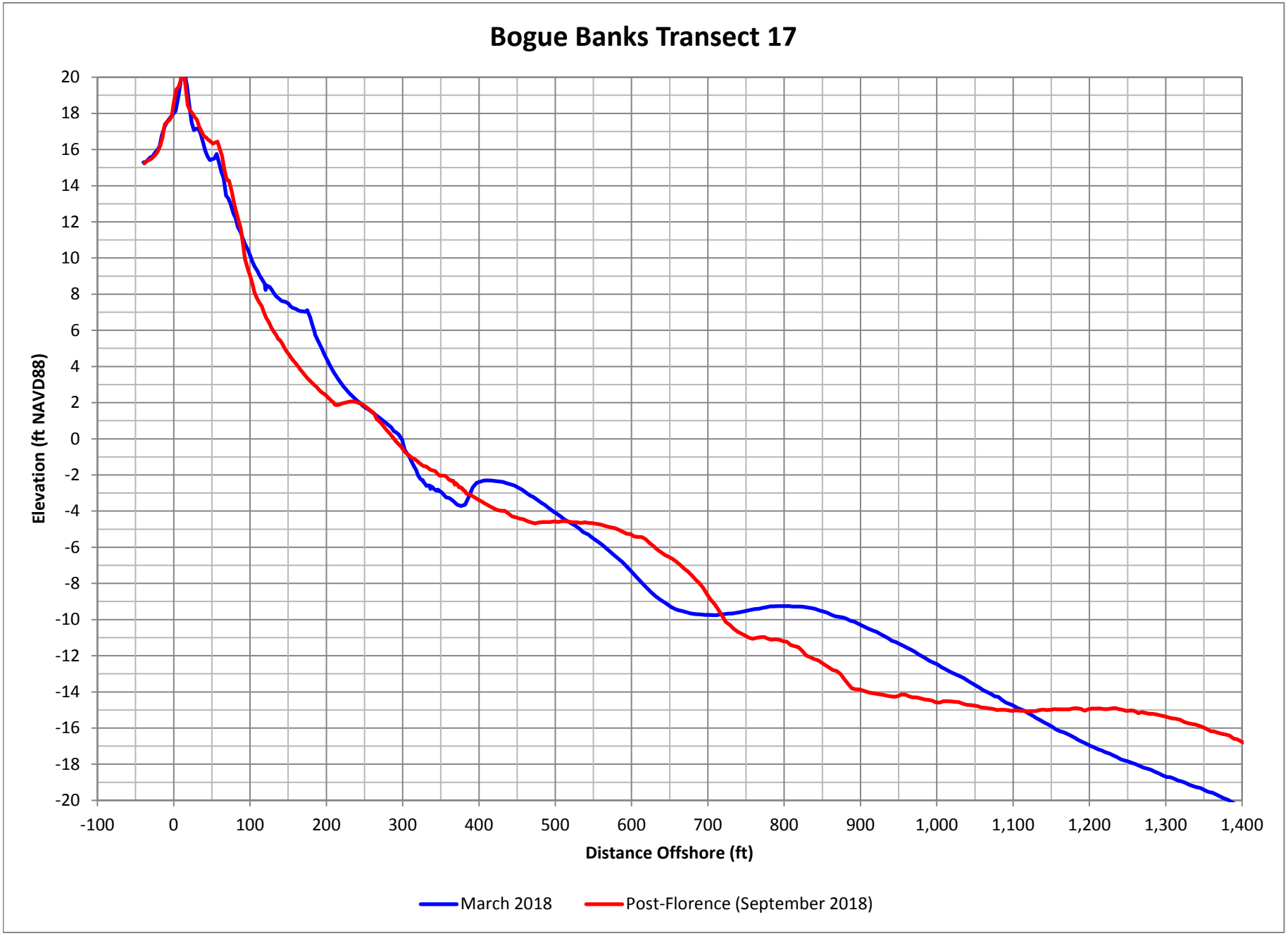

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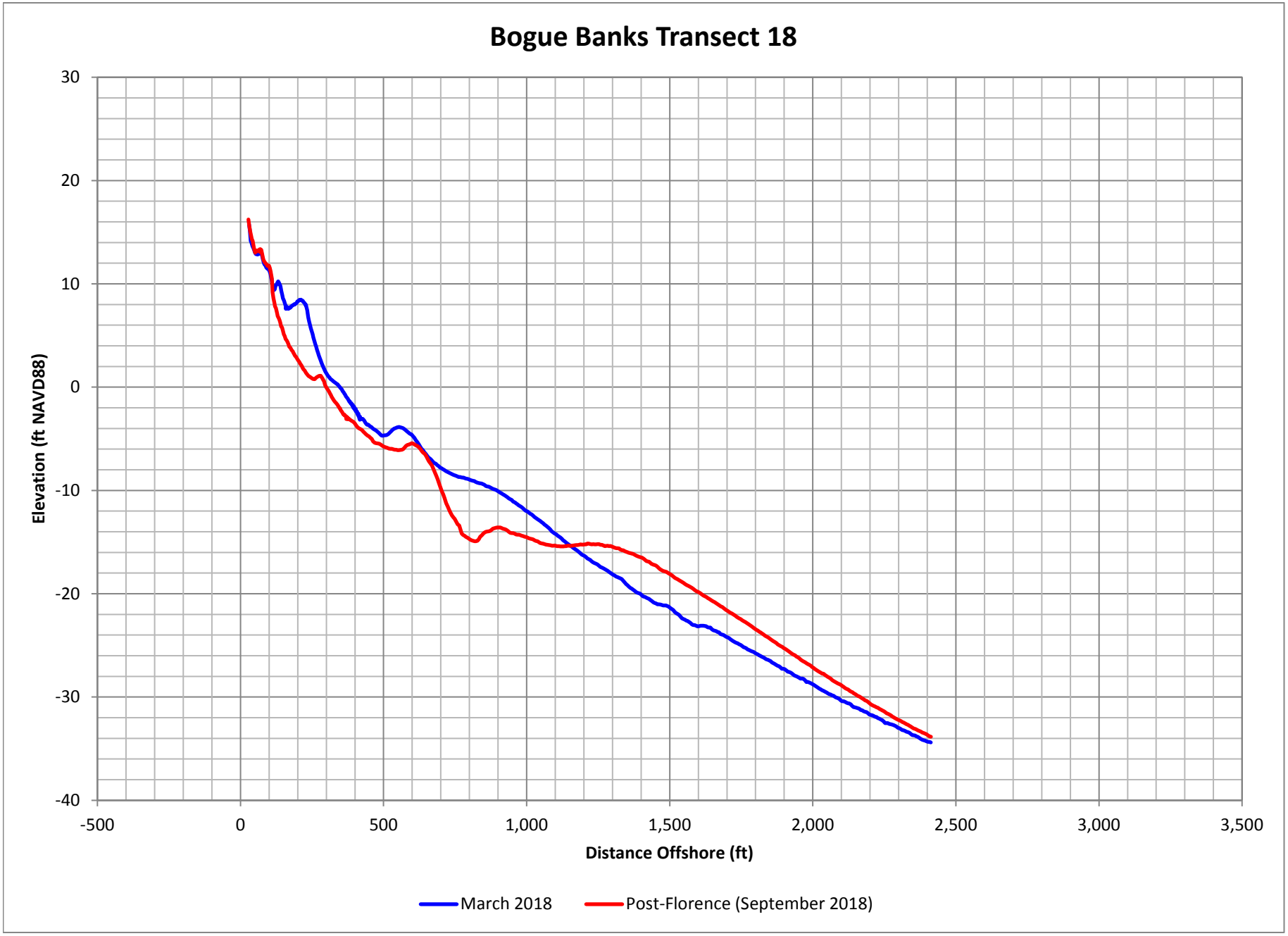

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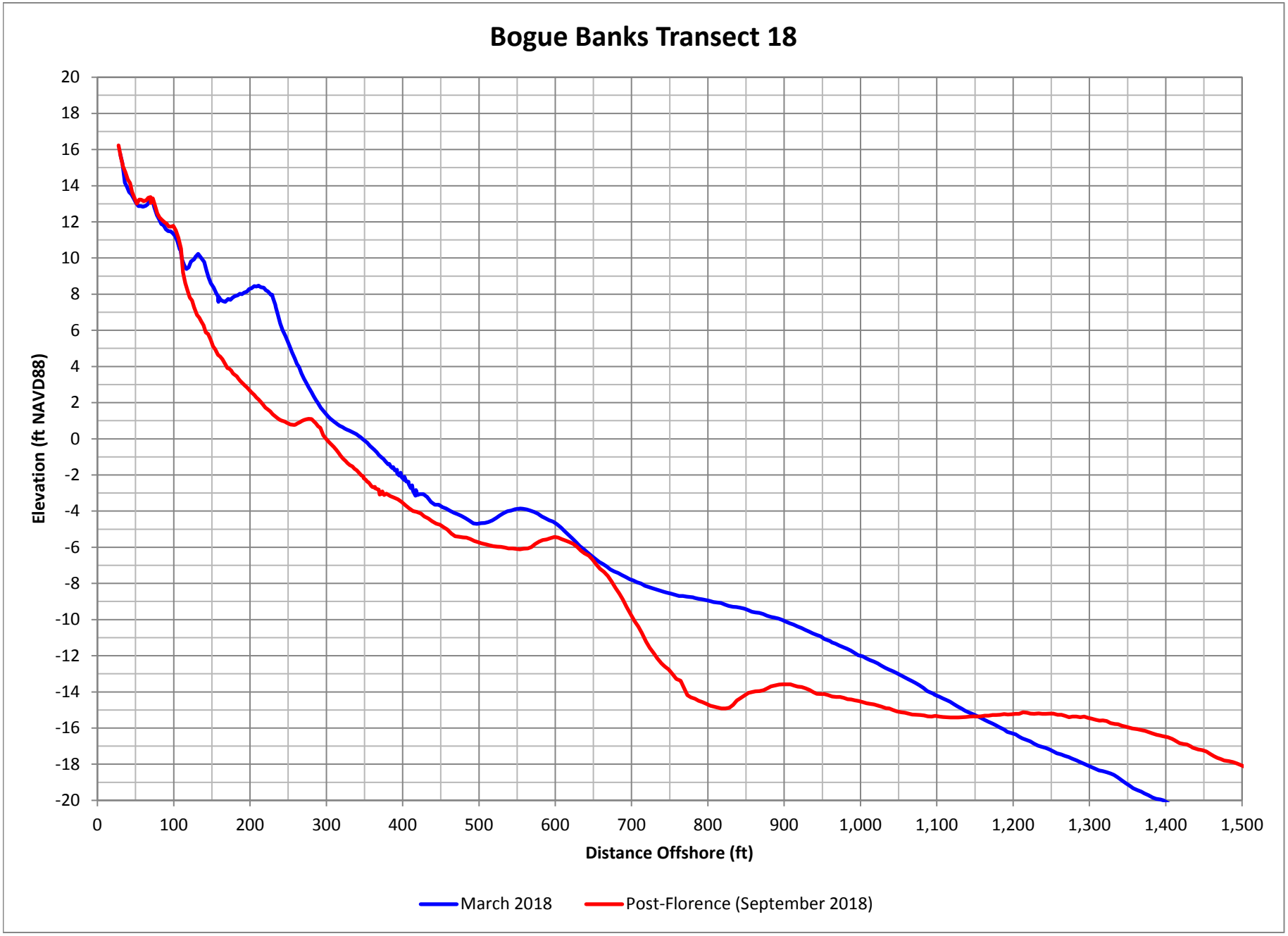


Figure D-36. Bogue Banks Profile Comparison Plot

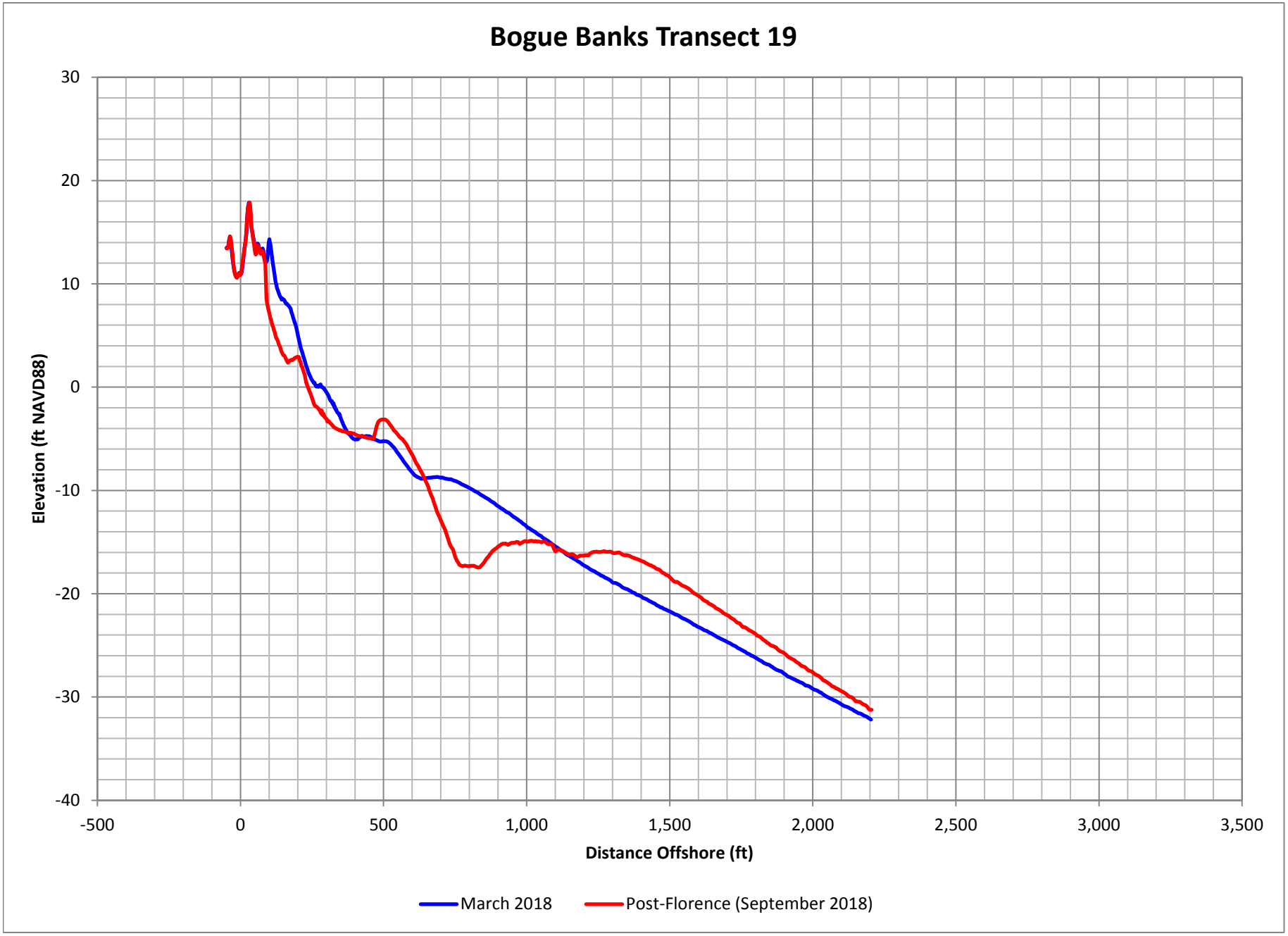


Figure D-37. Bogue Banks Profile Comparison Plot

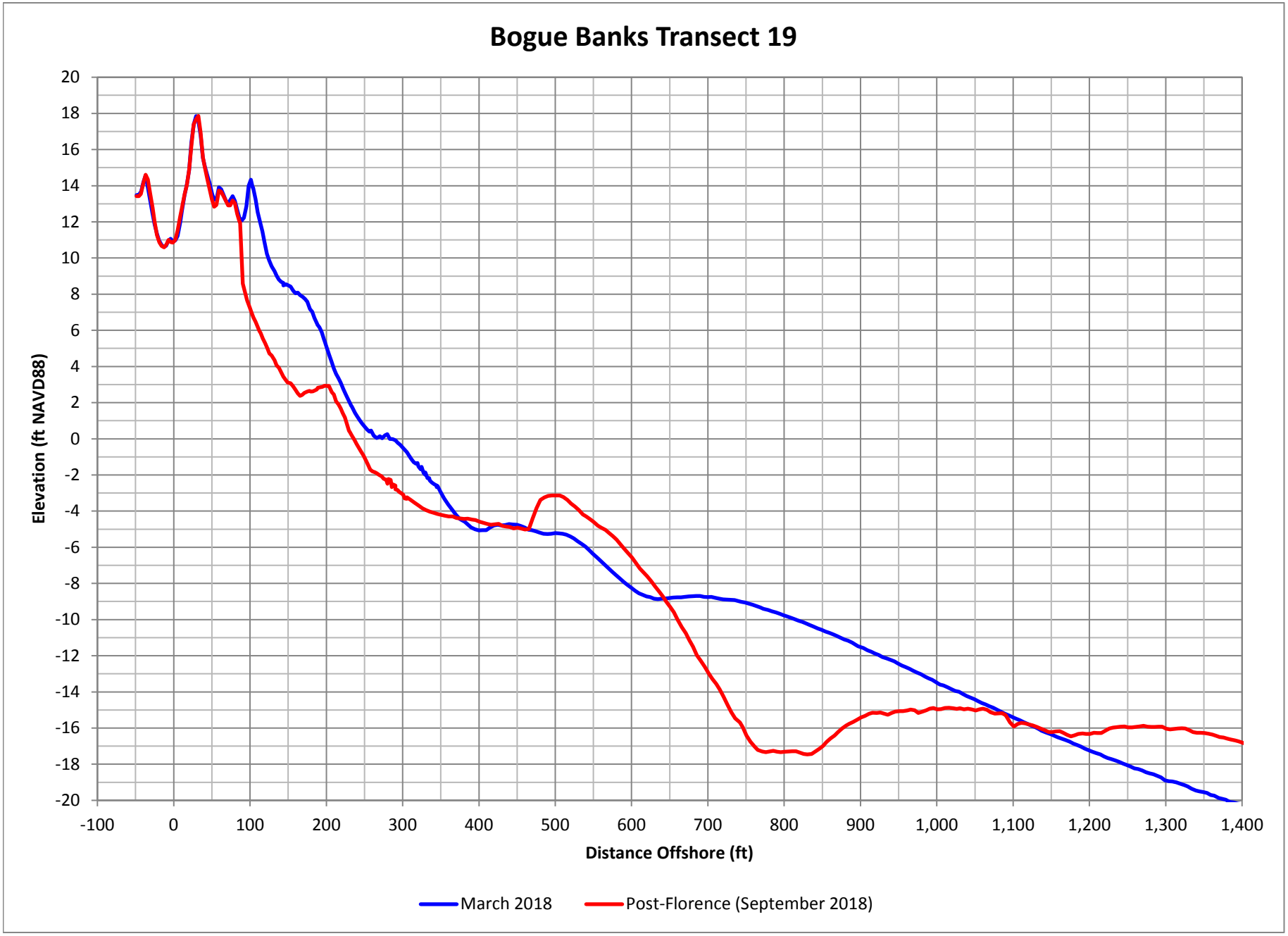


Figure D-38. Bogue Banks Profile Comparison Plot

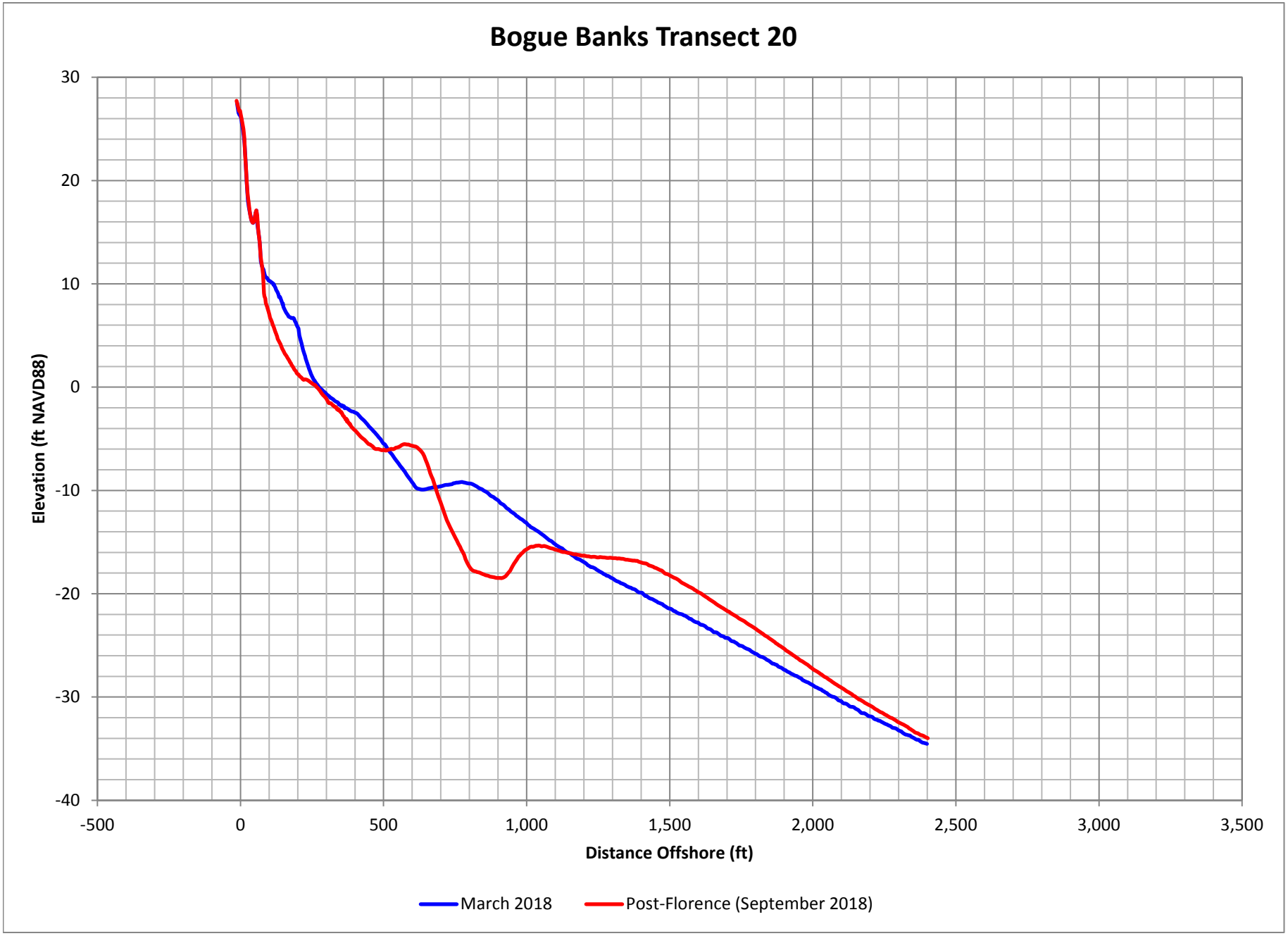


Figure D-39. Bogue Banks Profile Comparison Plot

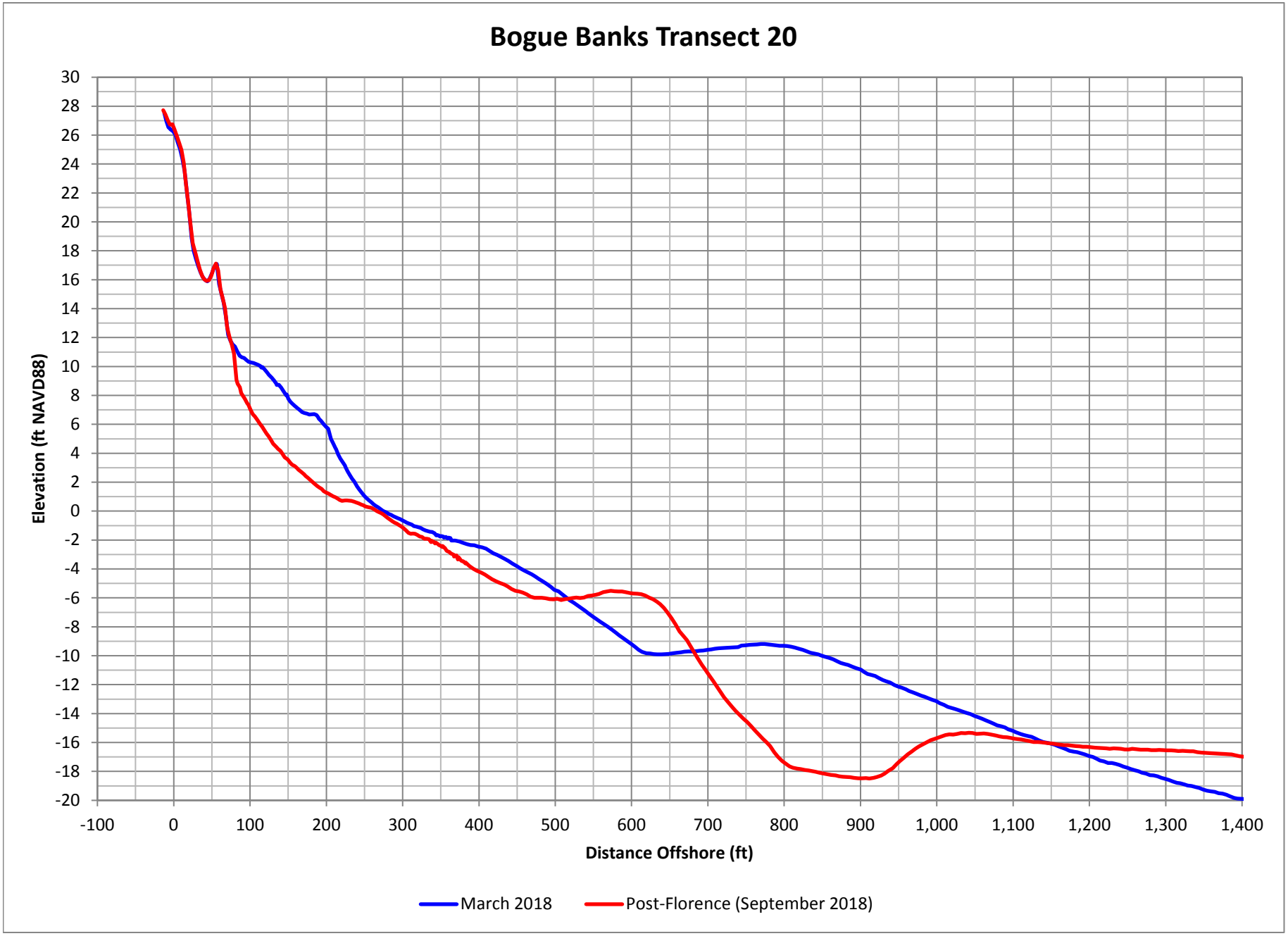


Figure D-40. Bogue Banks Profile Comparison Plot

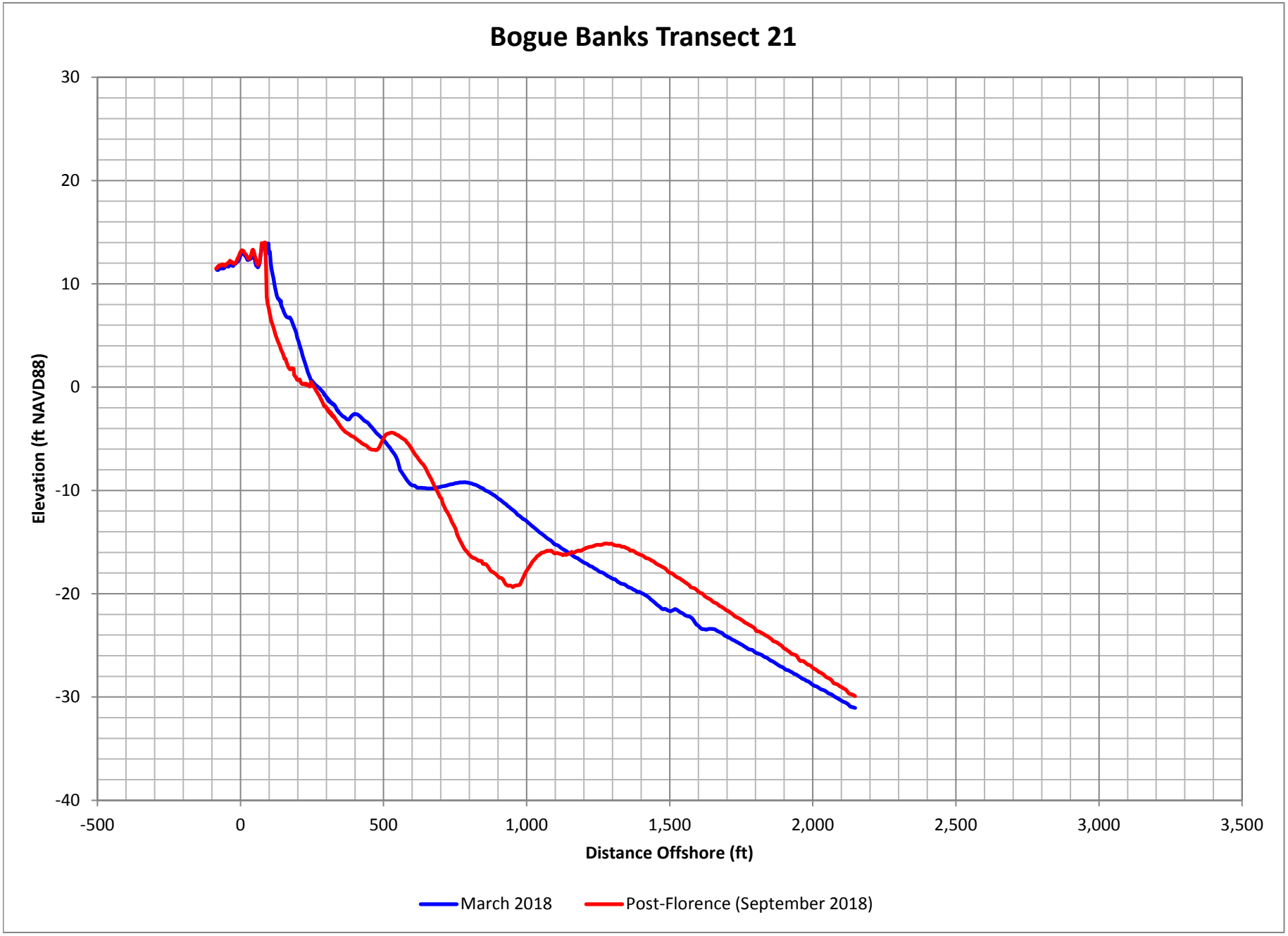


Figure D-41. Bogue Banks Profile Comparison Plot

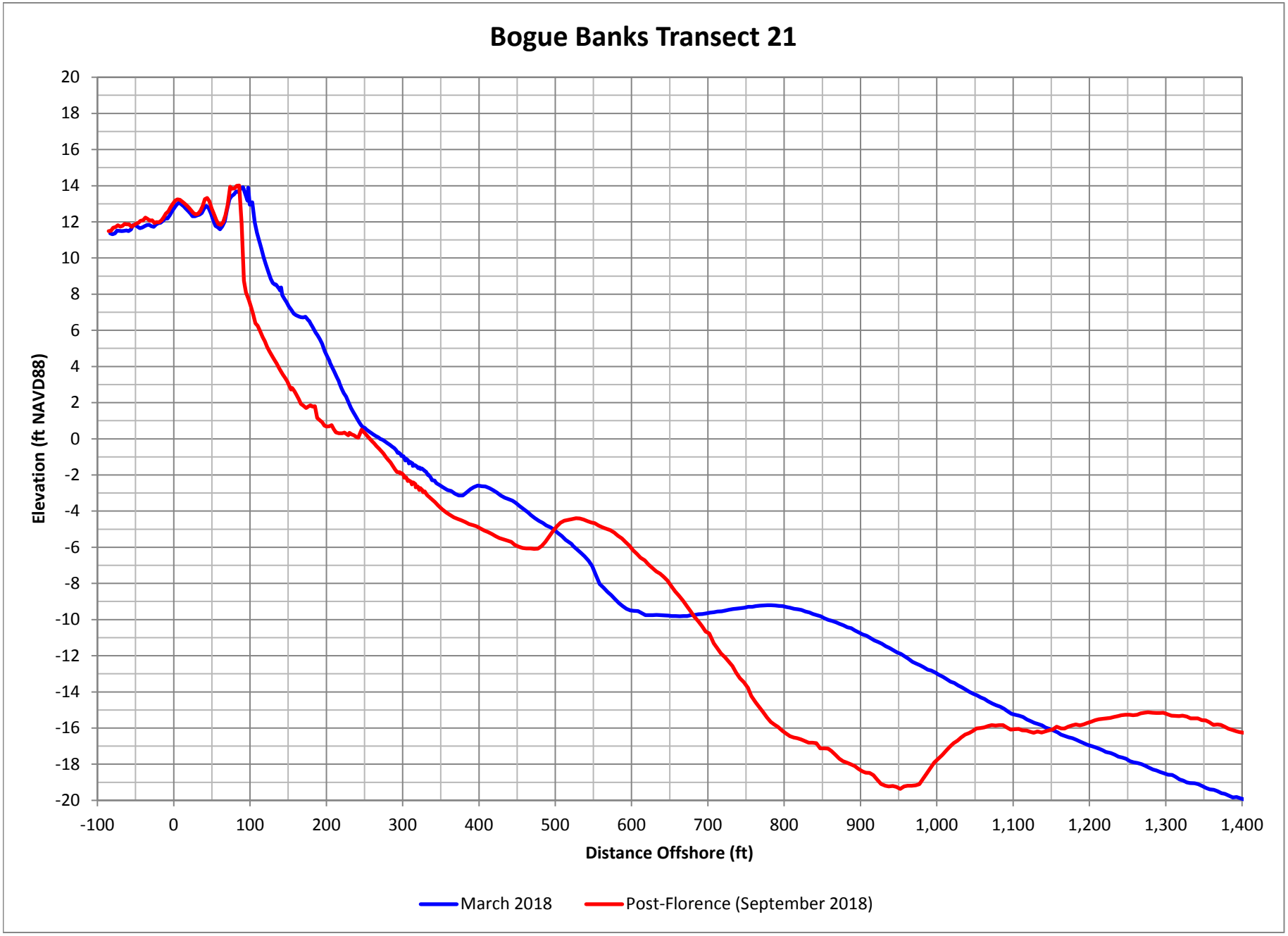


Figure D-42. Bogue Banks Profile Comparison Plot

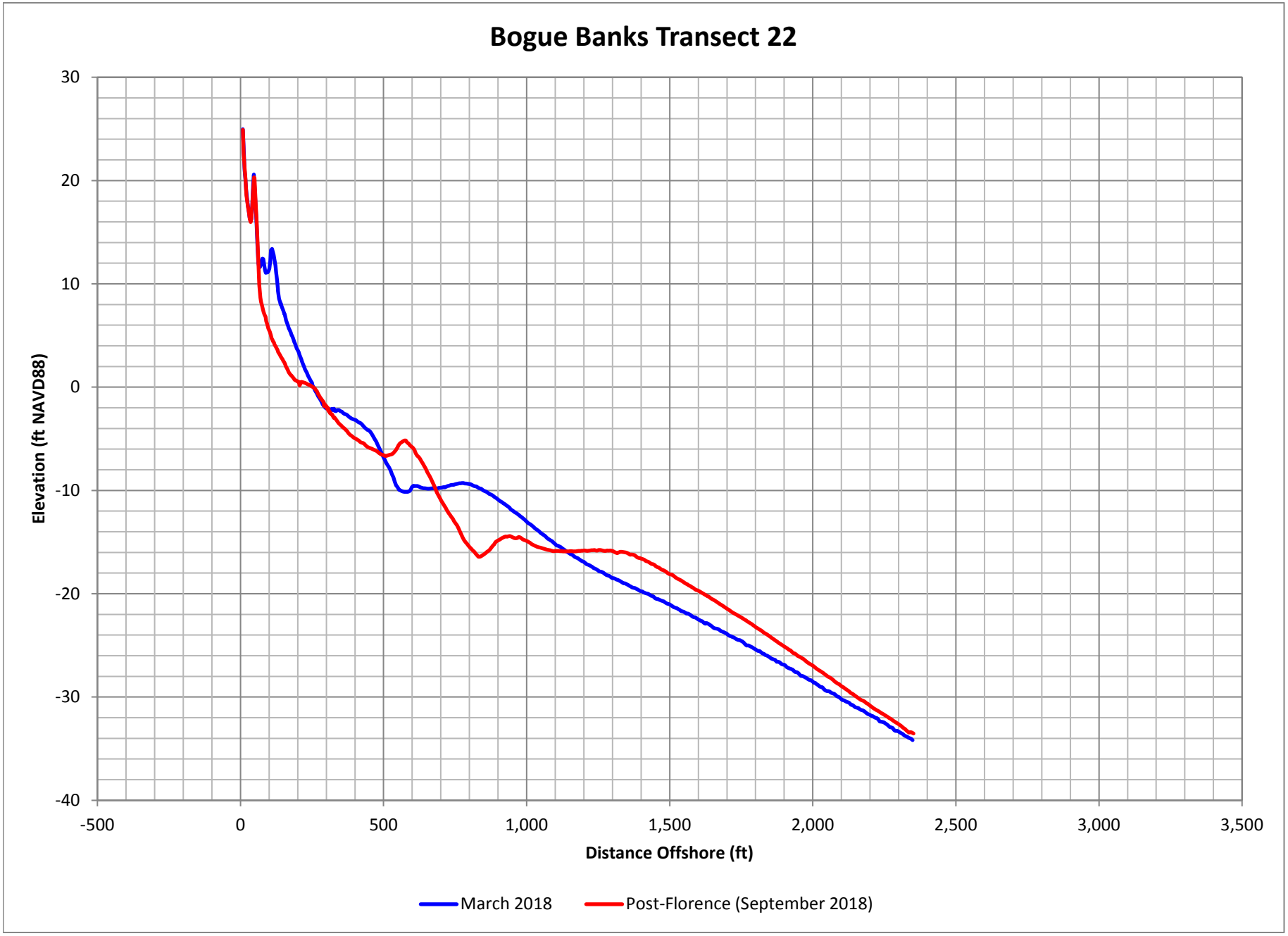


Figure D-43. Bogue Banks Profile Comparison Plot

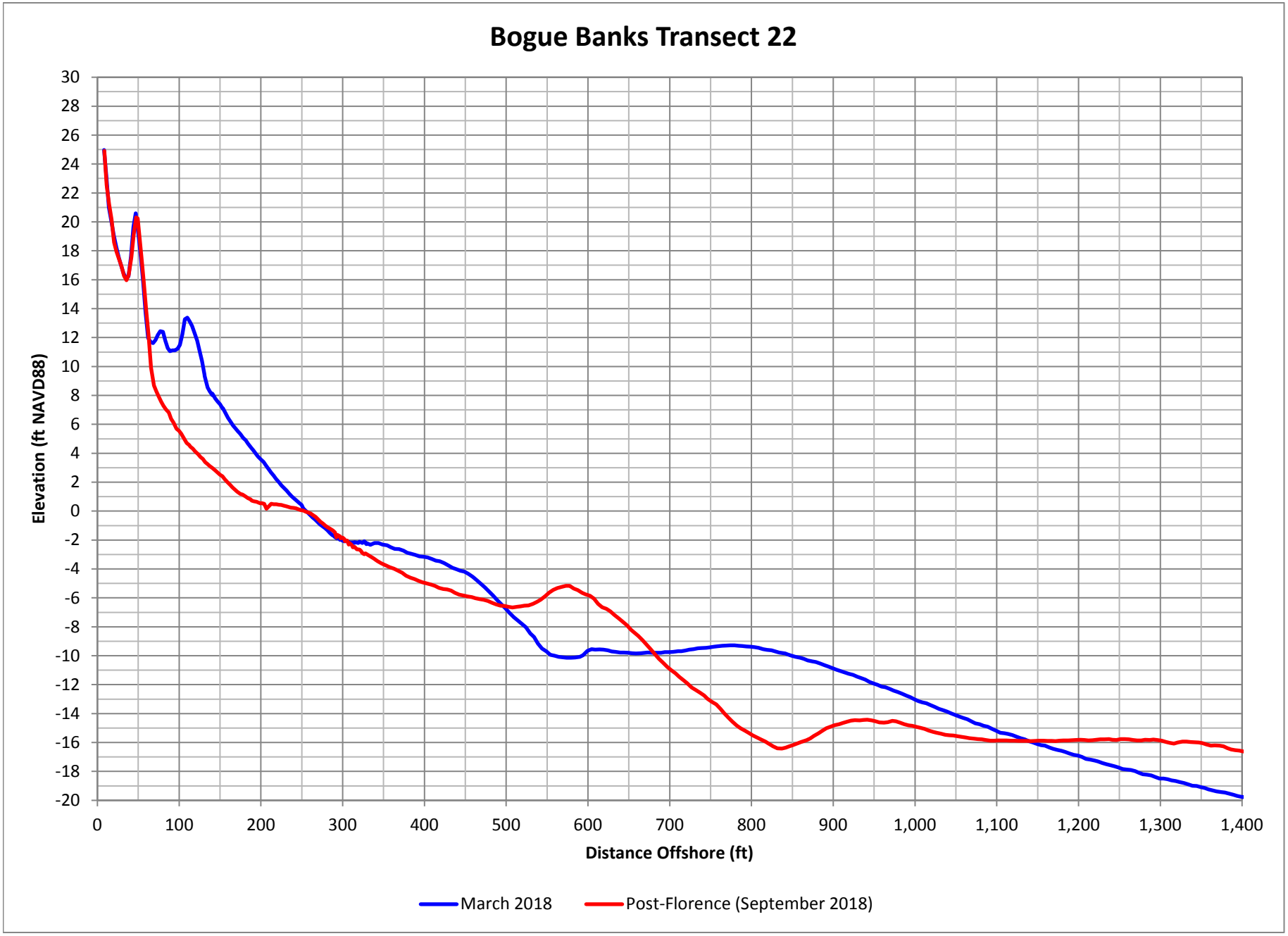


Figure D-44. Bogue Banks Profile Comparison Plot

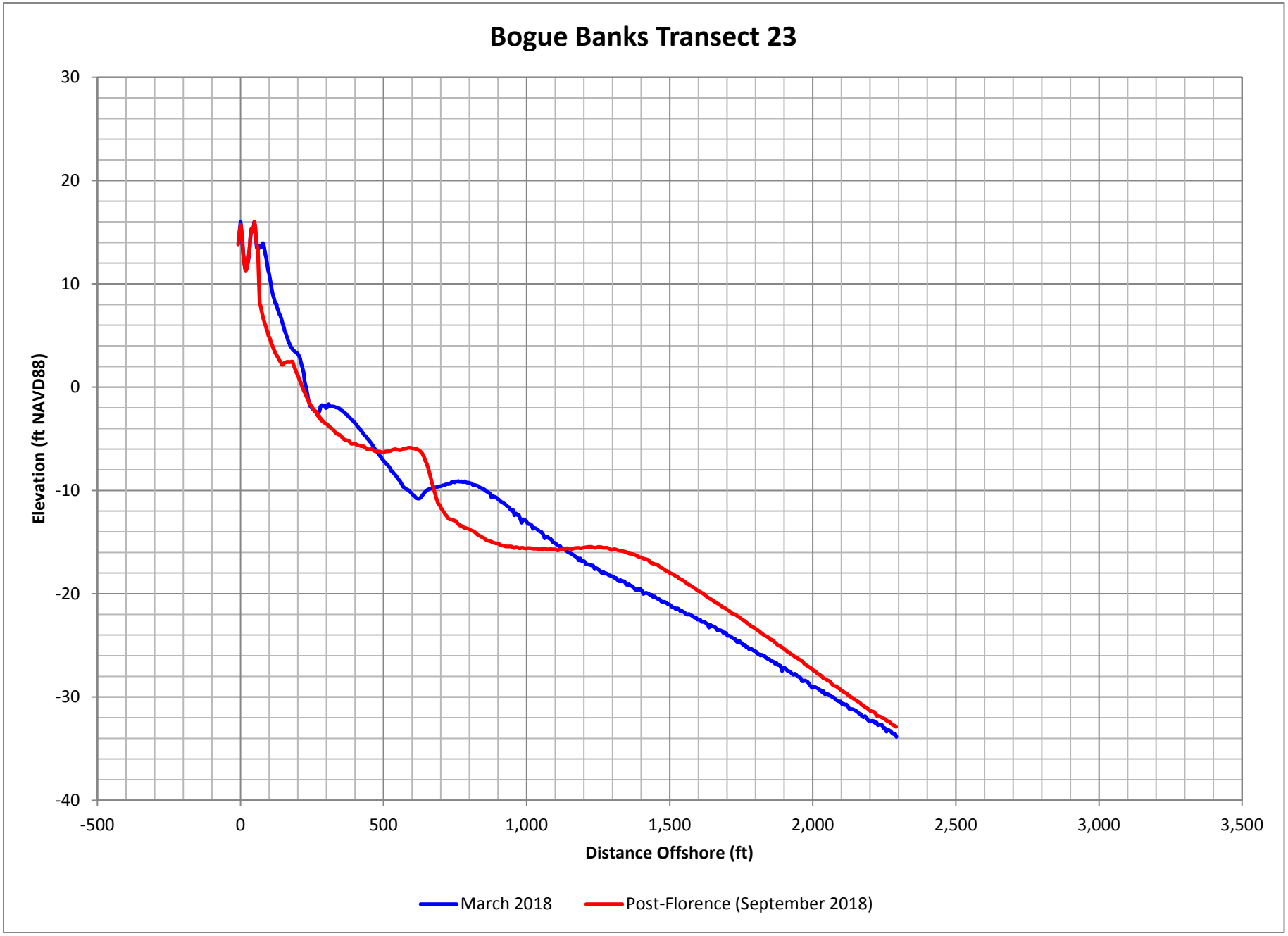


Figure D-45. Bogue Banks Profile Comparison Plot

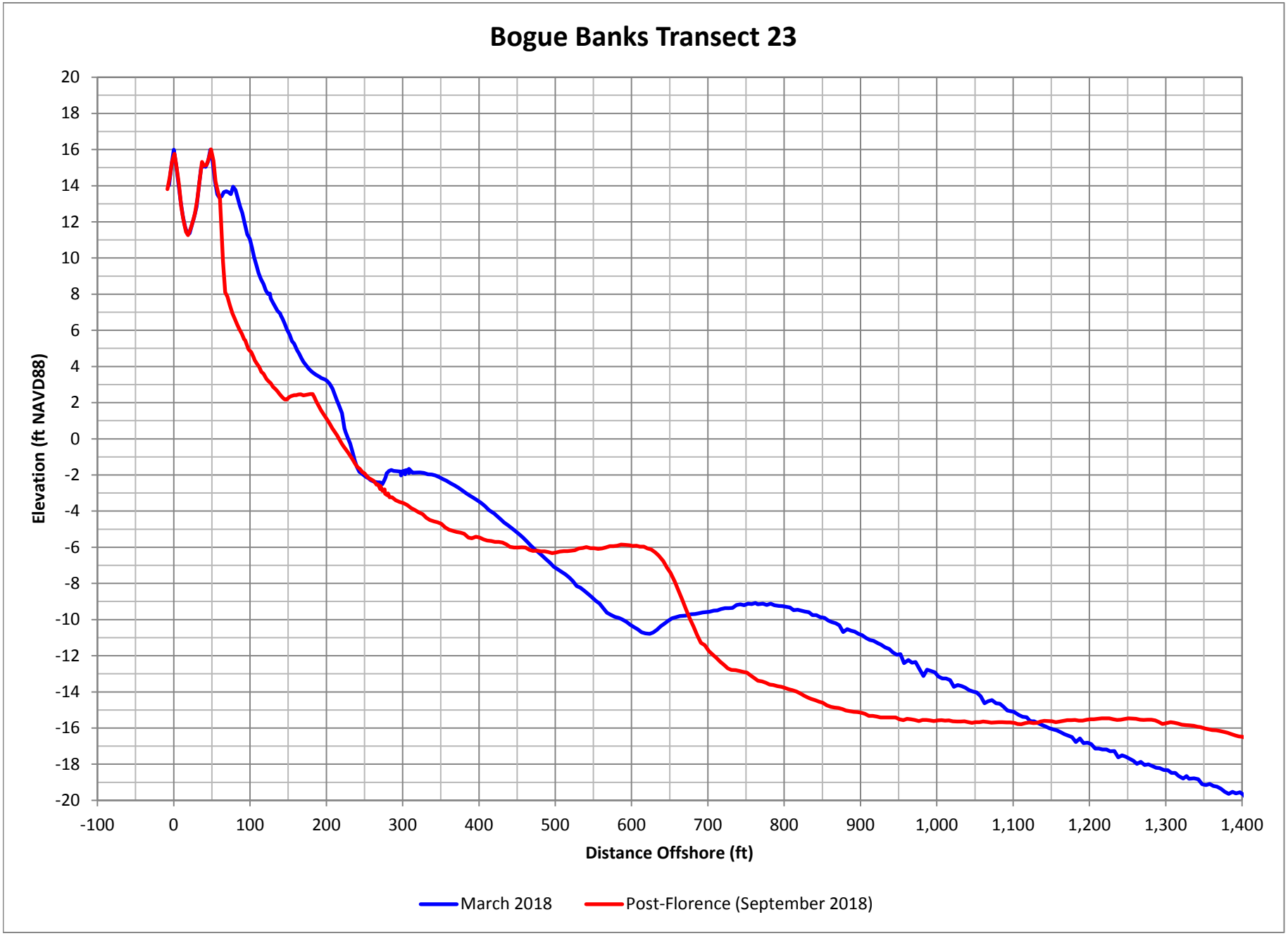


Figure D-46. Bogue Banks Profile Comparison Plot

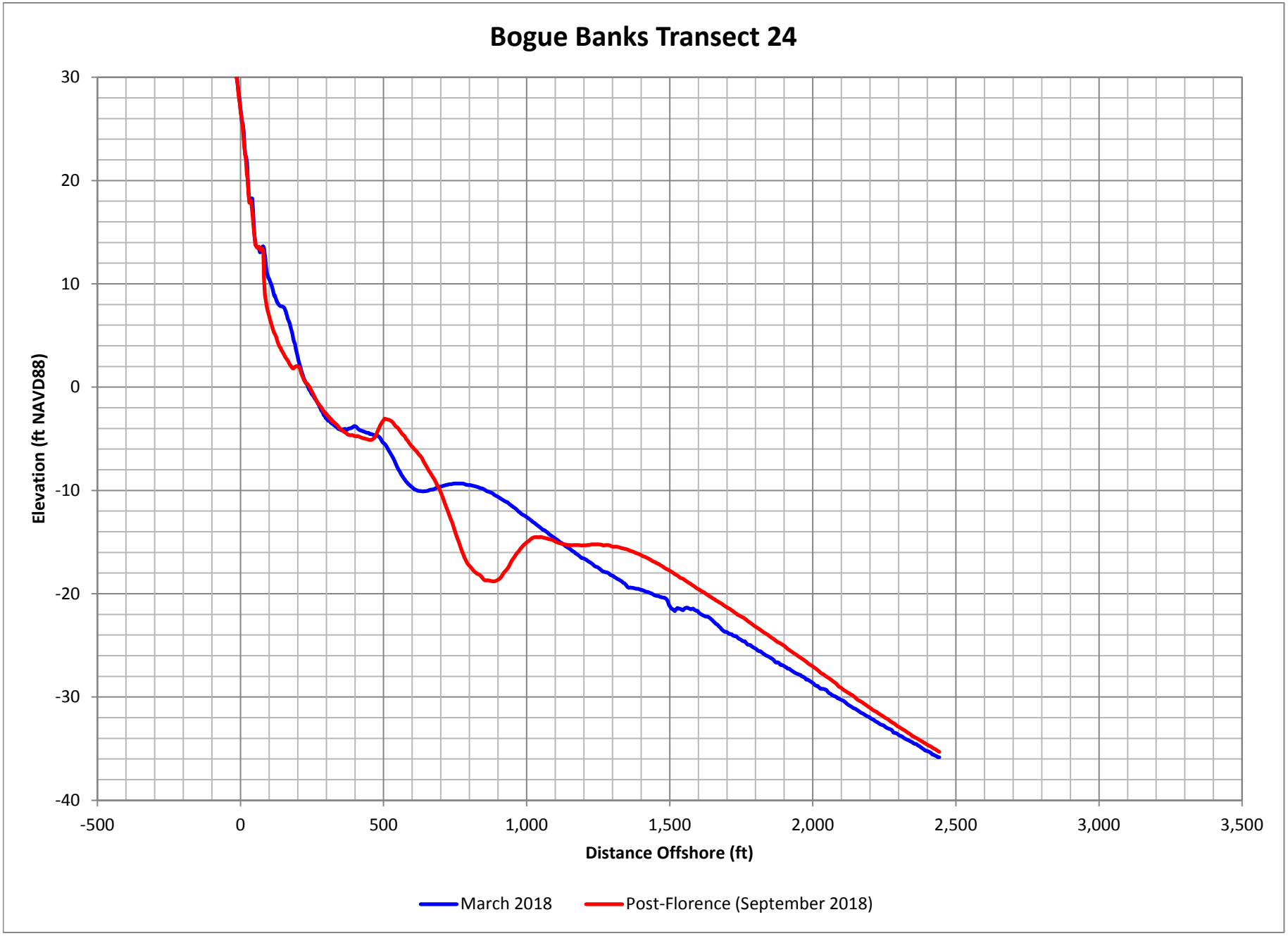


Figure D-47. Bogue Banks Profile Comparison Plot

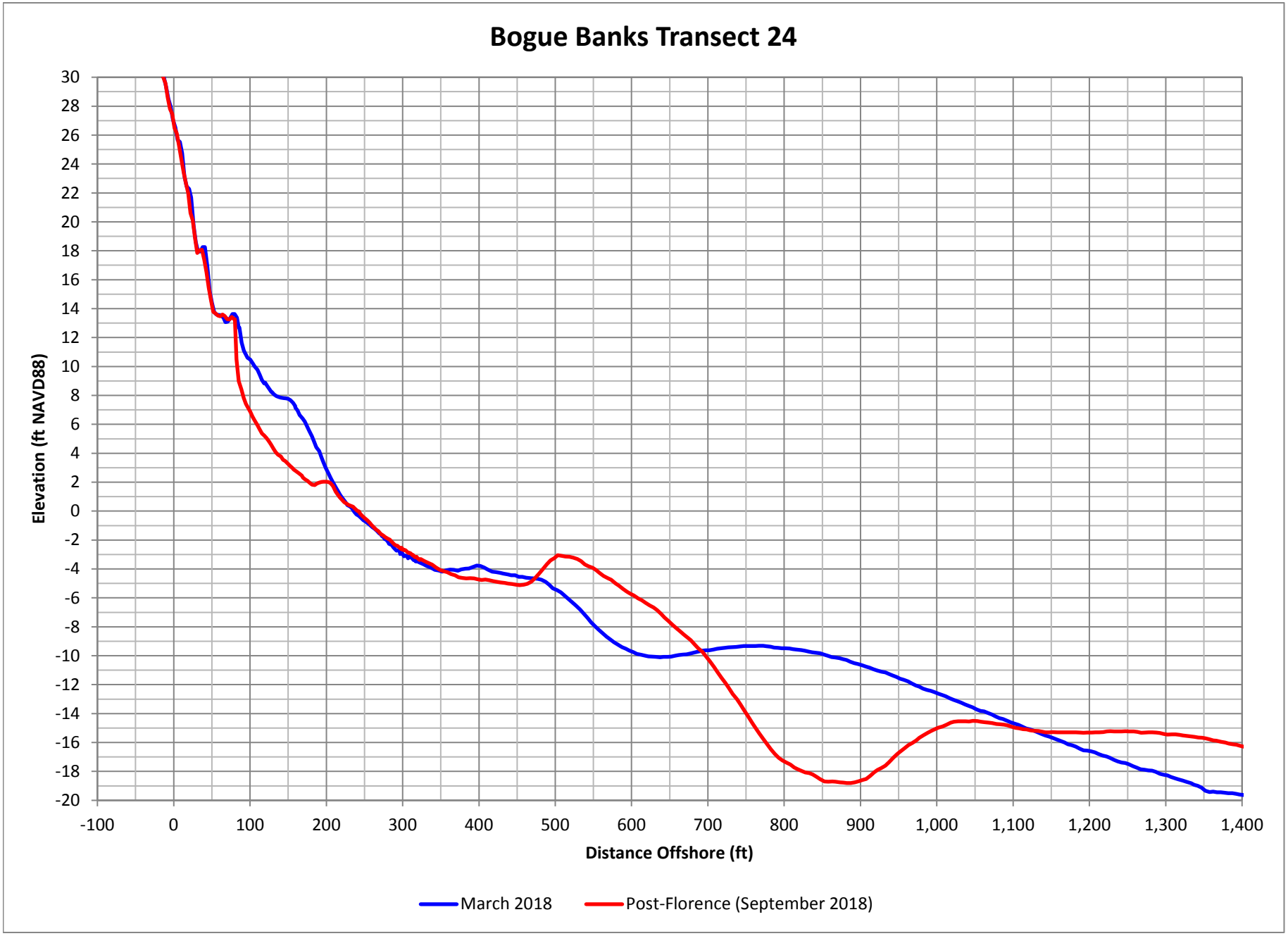


Figure D-48. Bogue Banks Profile Comparison Plot

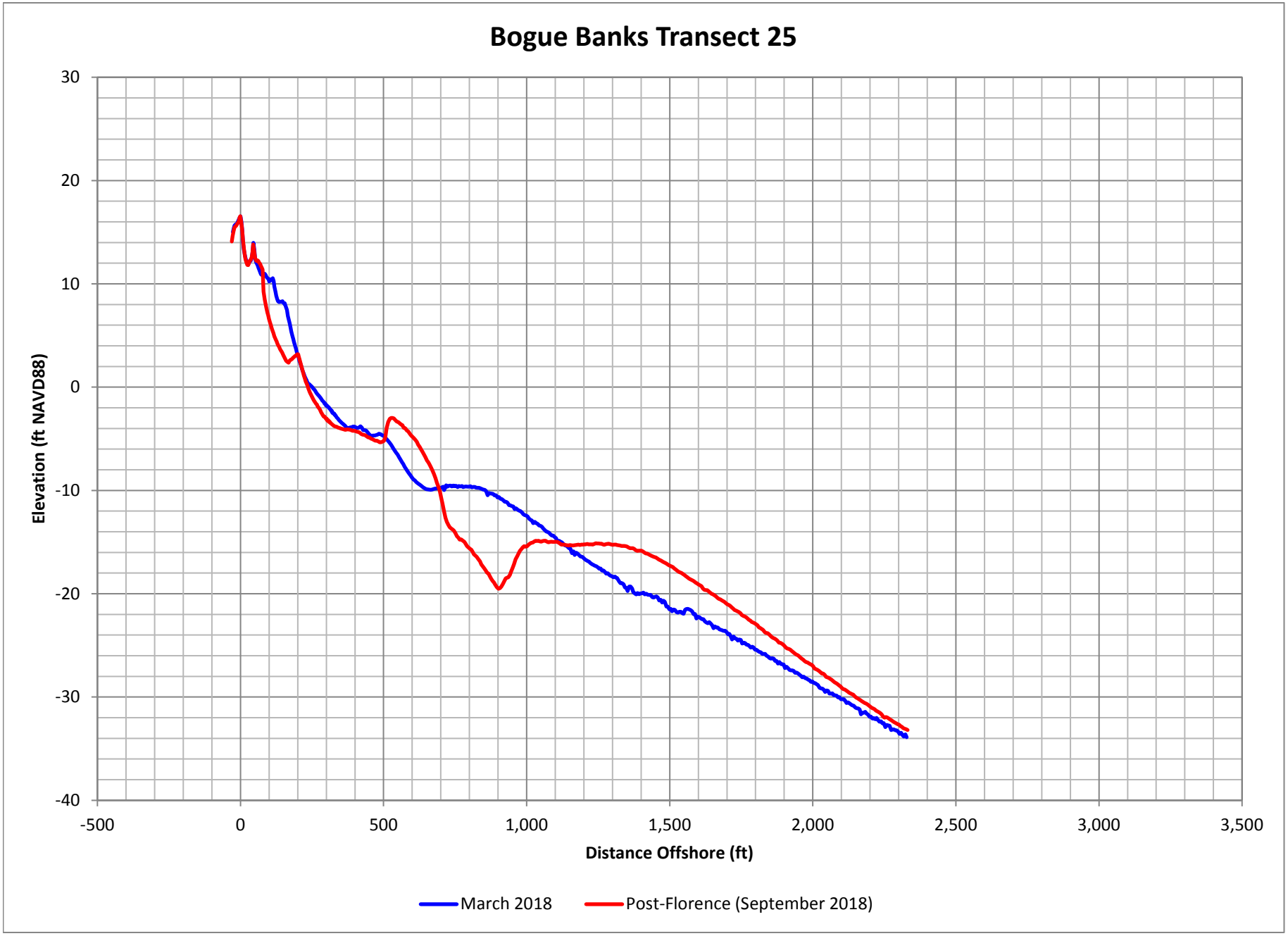


Figure D-49. Bogue Banks Profile Comparison Plot

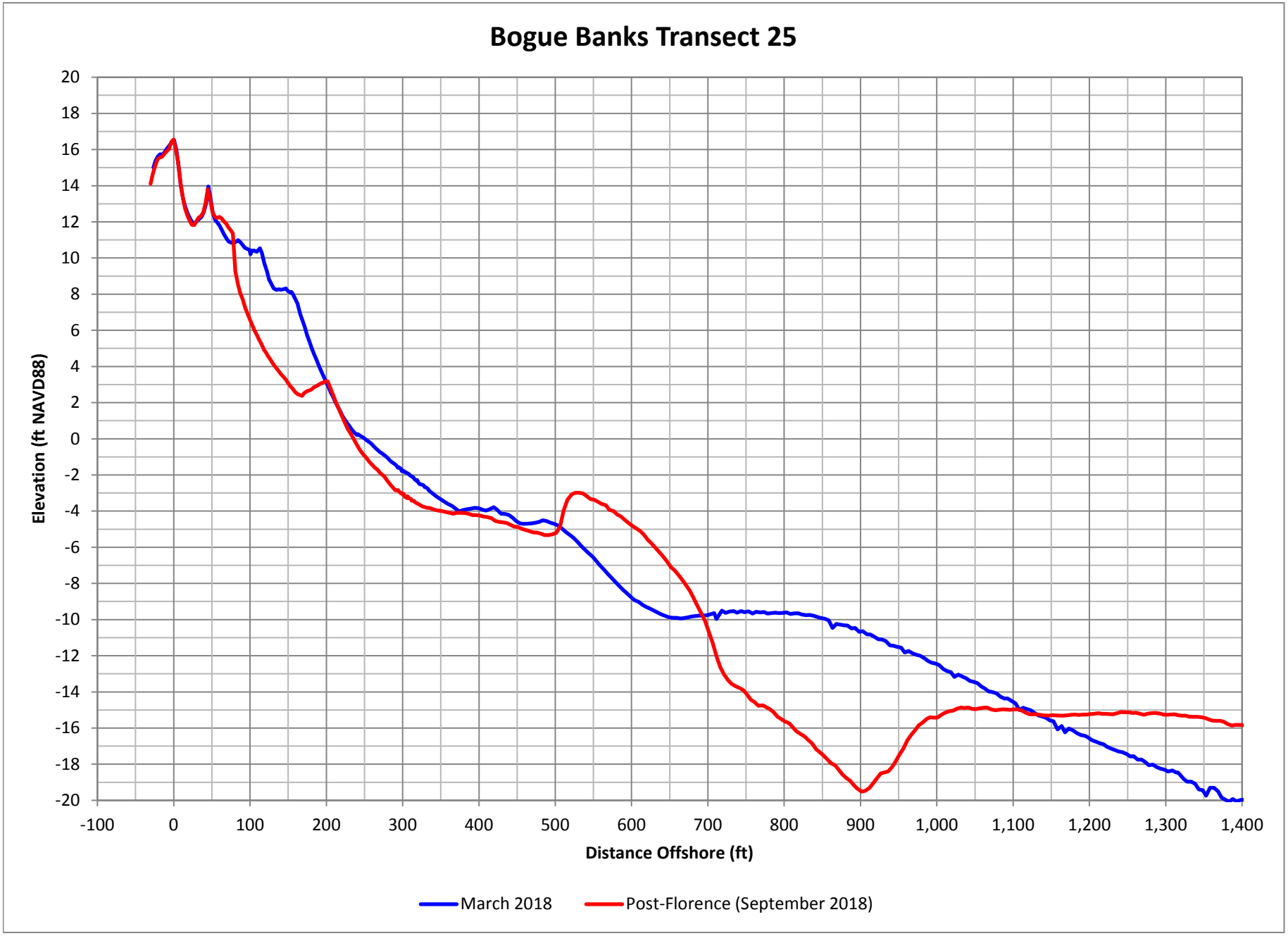


Figure D-50. Bogue Banks Profile Comparison Plot

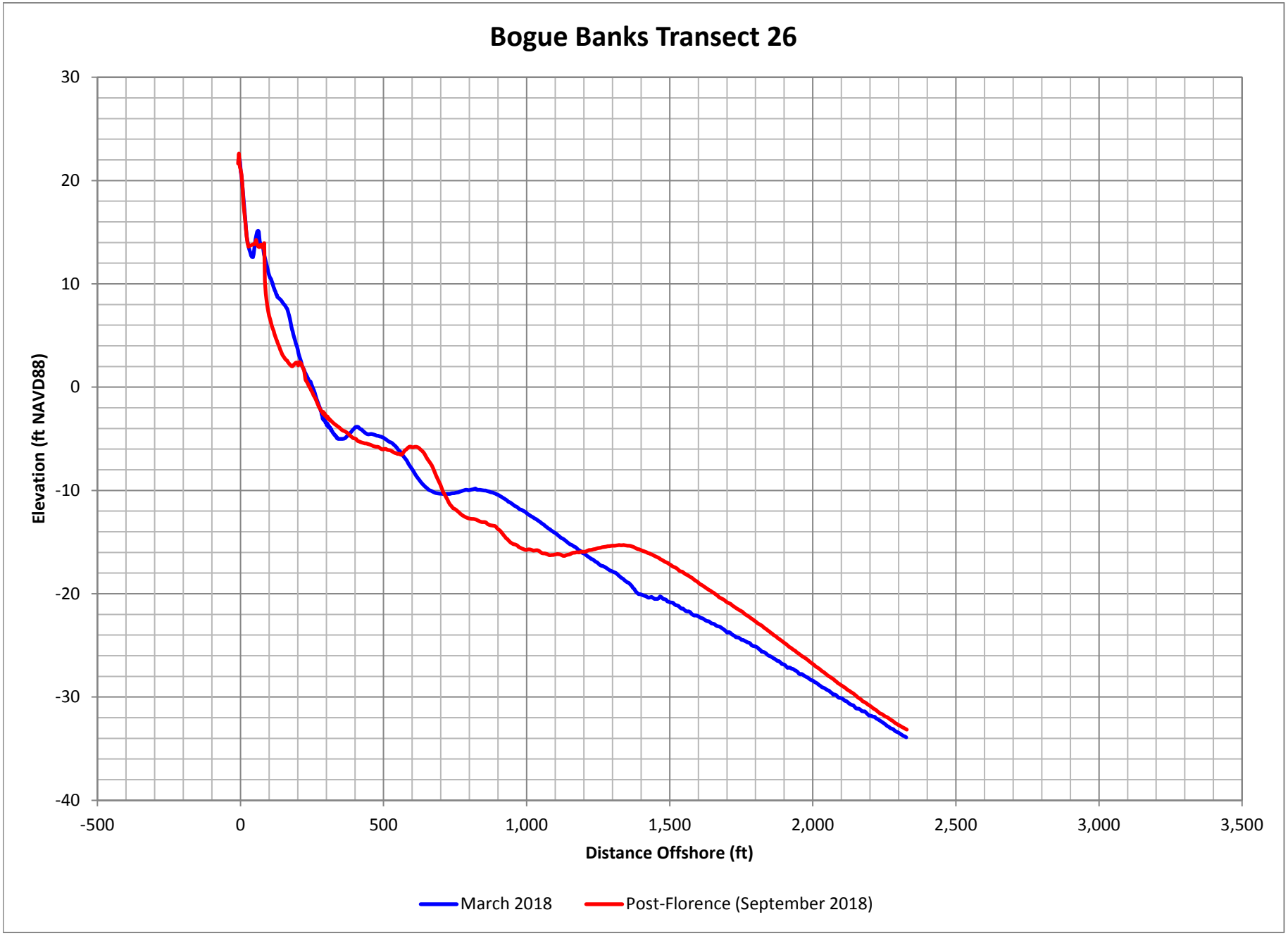


Figure D-51. Bogue Banks Profile Comparison Plot

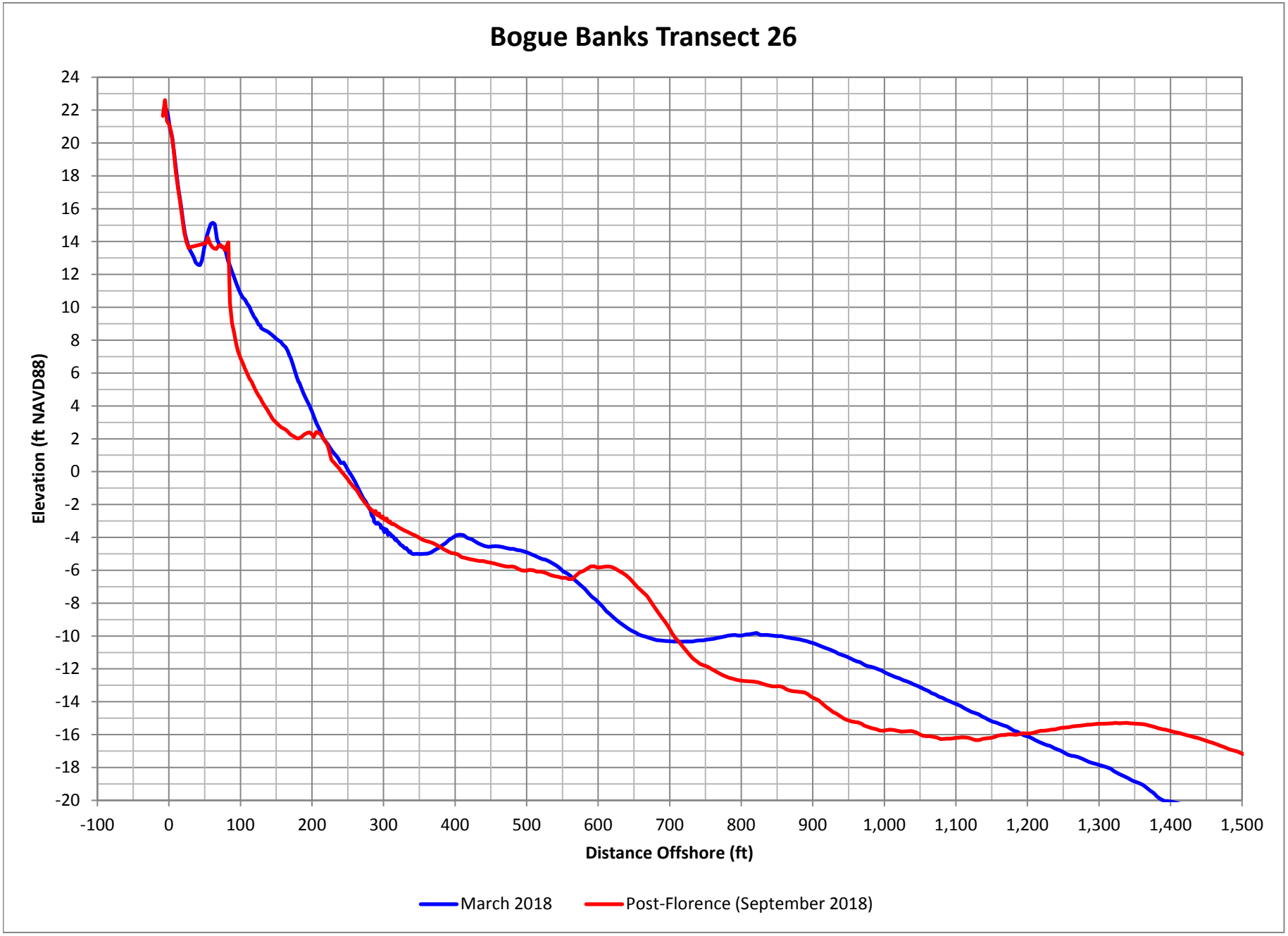


Figure D-52. Bogue Banks Profile Comparison Plot

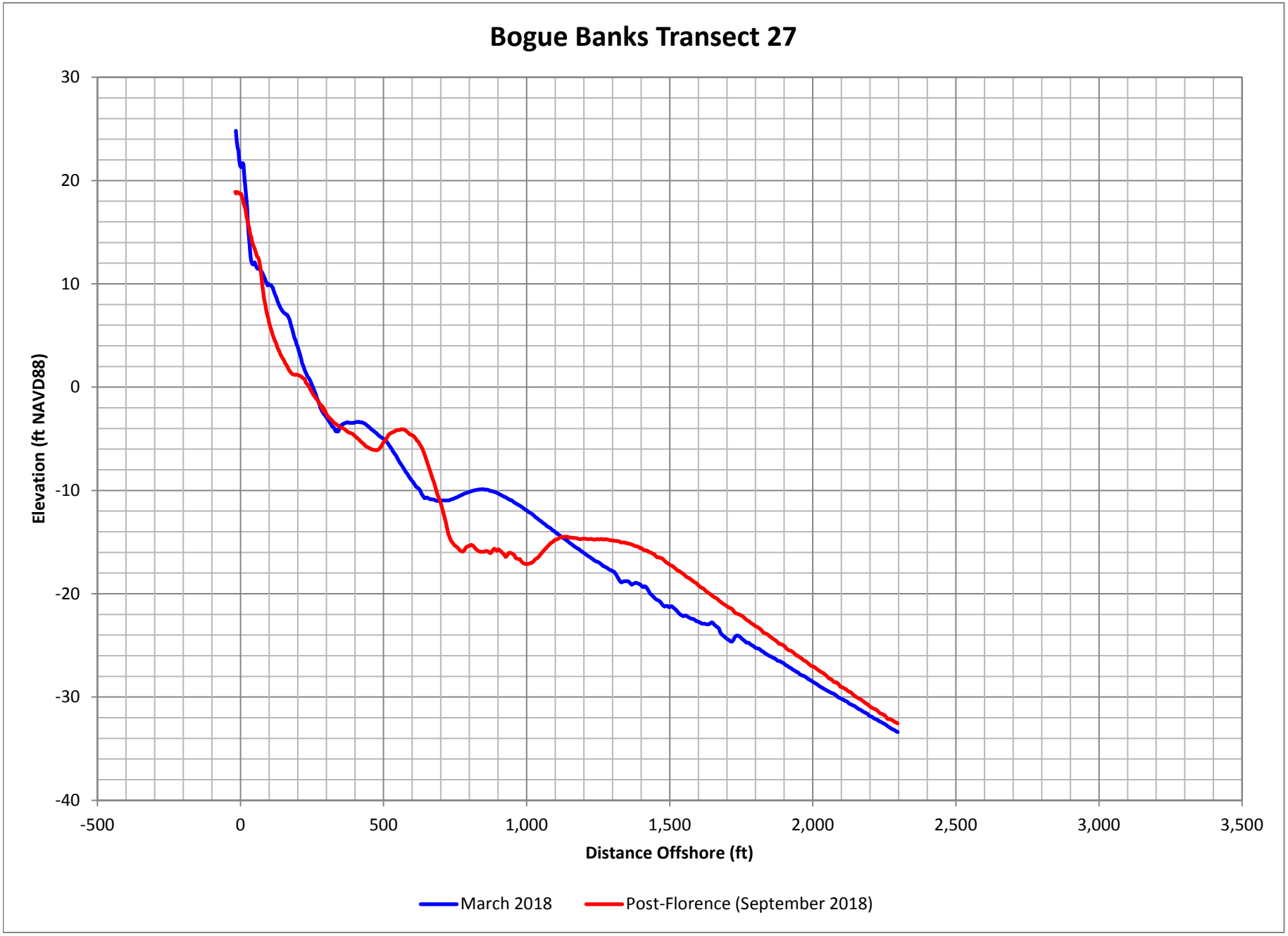


Figure D-53. Bogue Banks Profile Comparison Plot

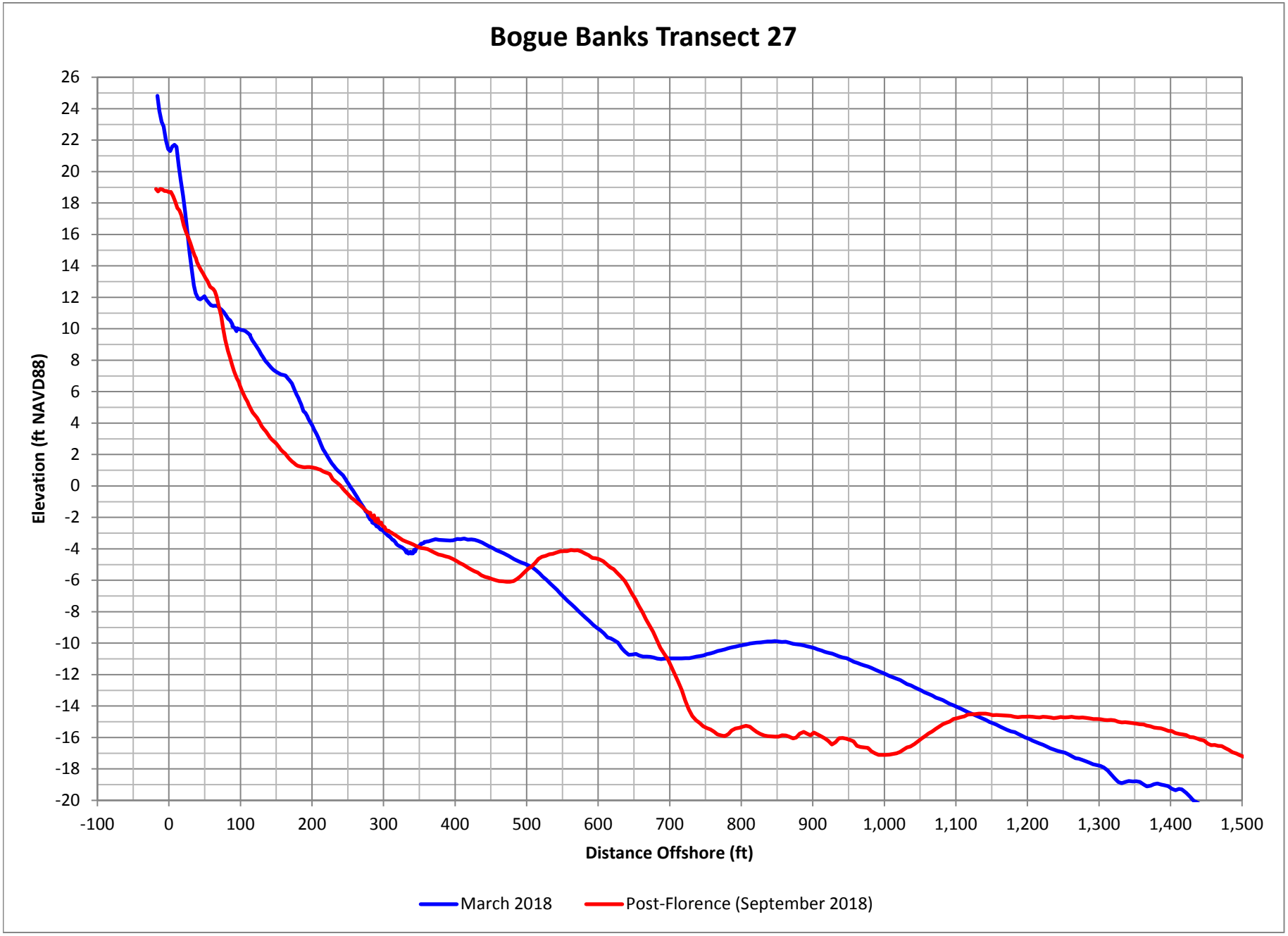


Figure D-54. Bogue Banks Profile Comparison Plot

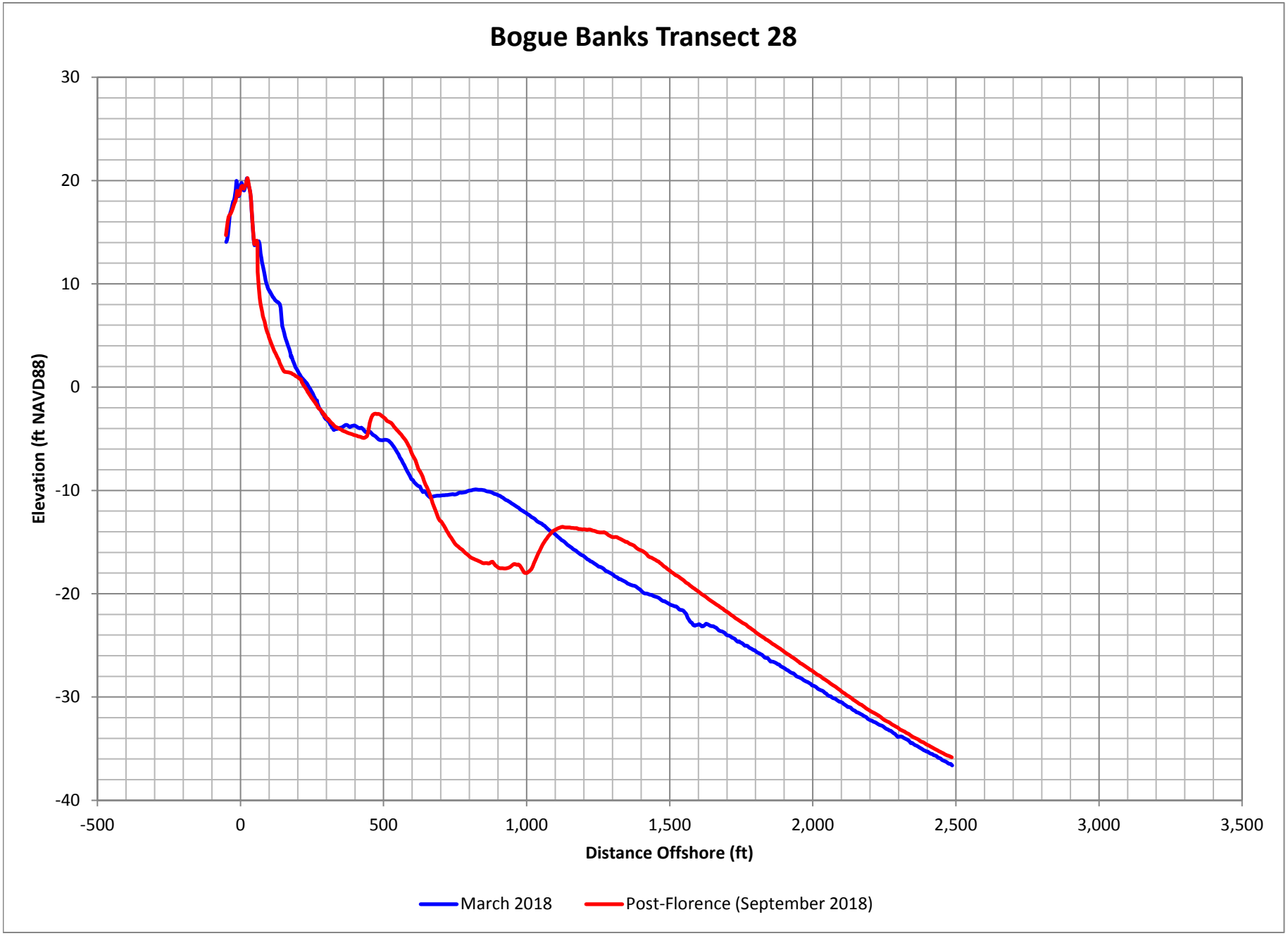


Figure D-55. Bogue Banks Profile Comparison Plot

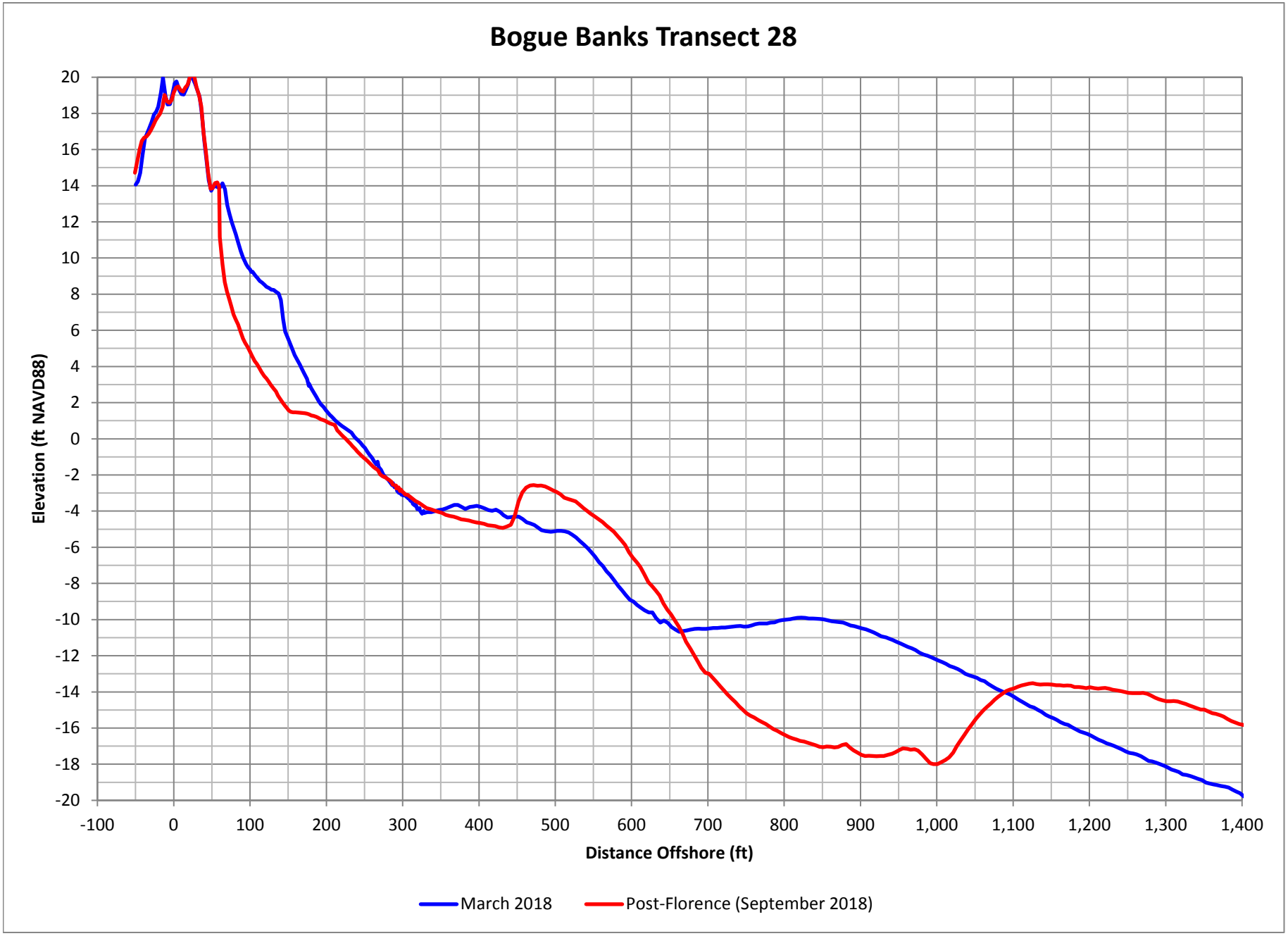


Figure D-56. Bogue Banks Profile Comparison Plot

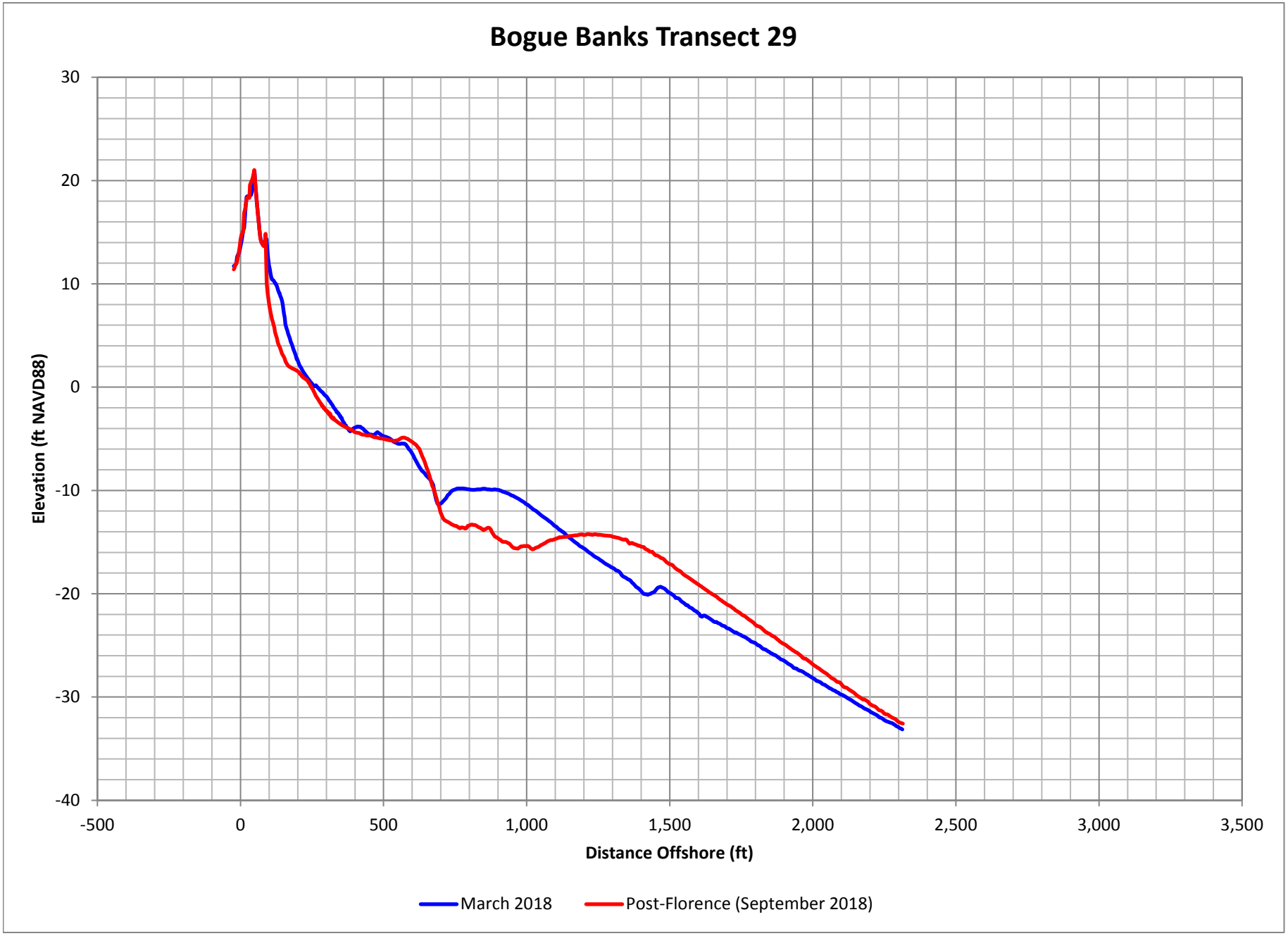


Figure D-57. Bogue Banks Profile Comparison Plot

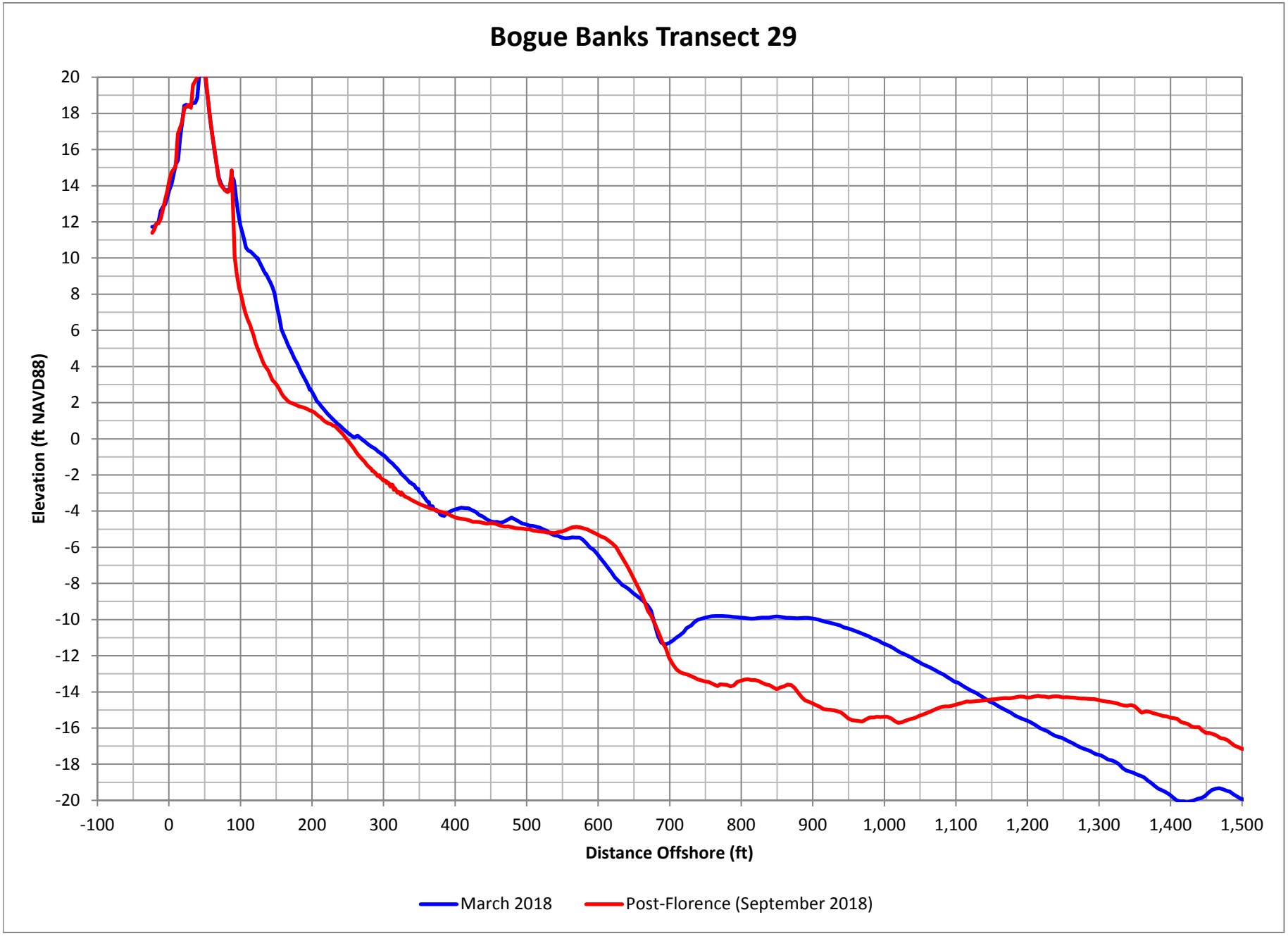


Figure D-58. Bogue Banks Profile Comparison Plot

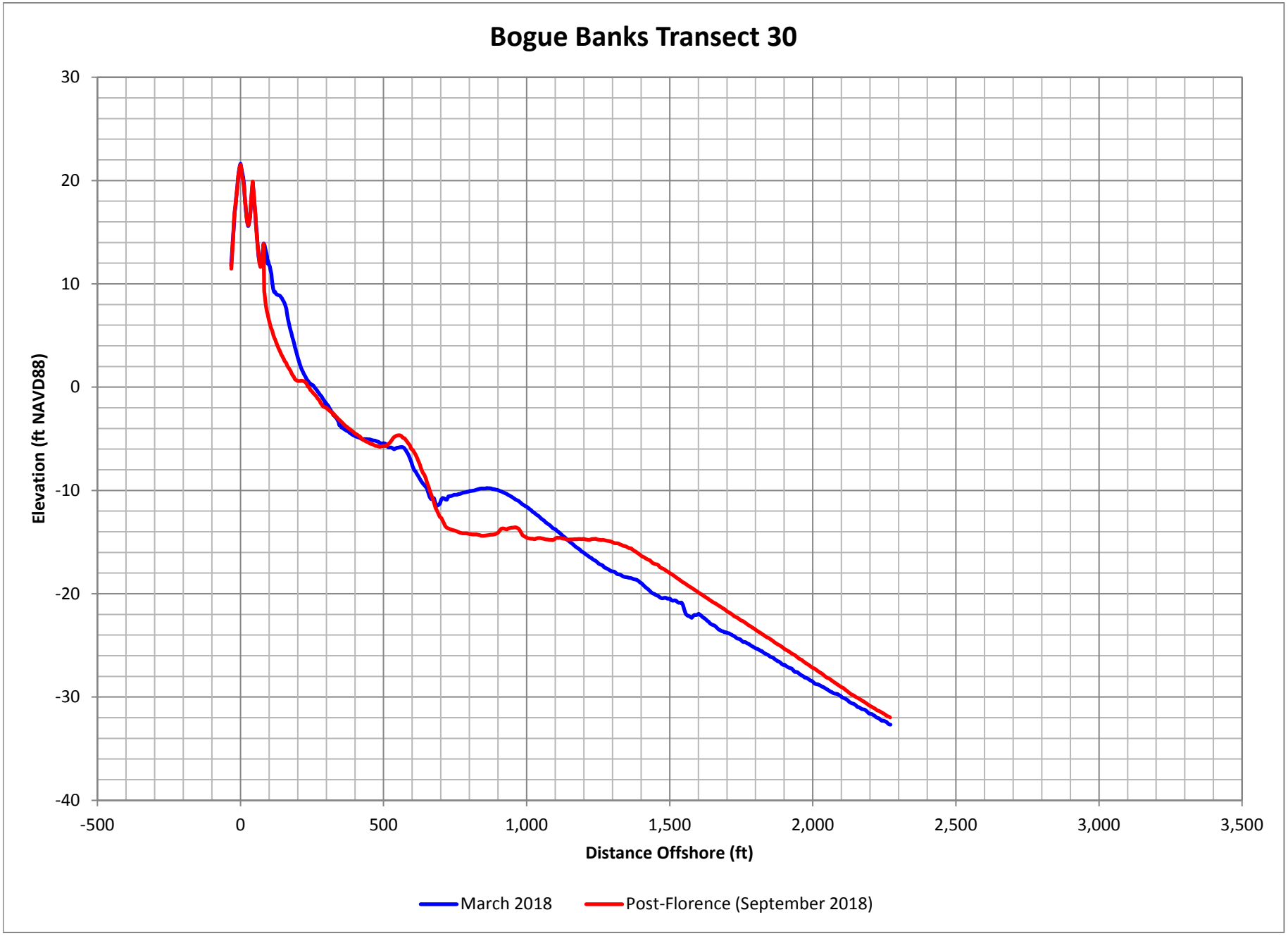


Figure D-59. Bogue Banks Profile Comparison Plot

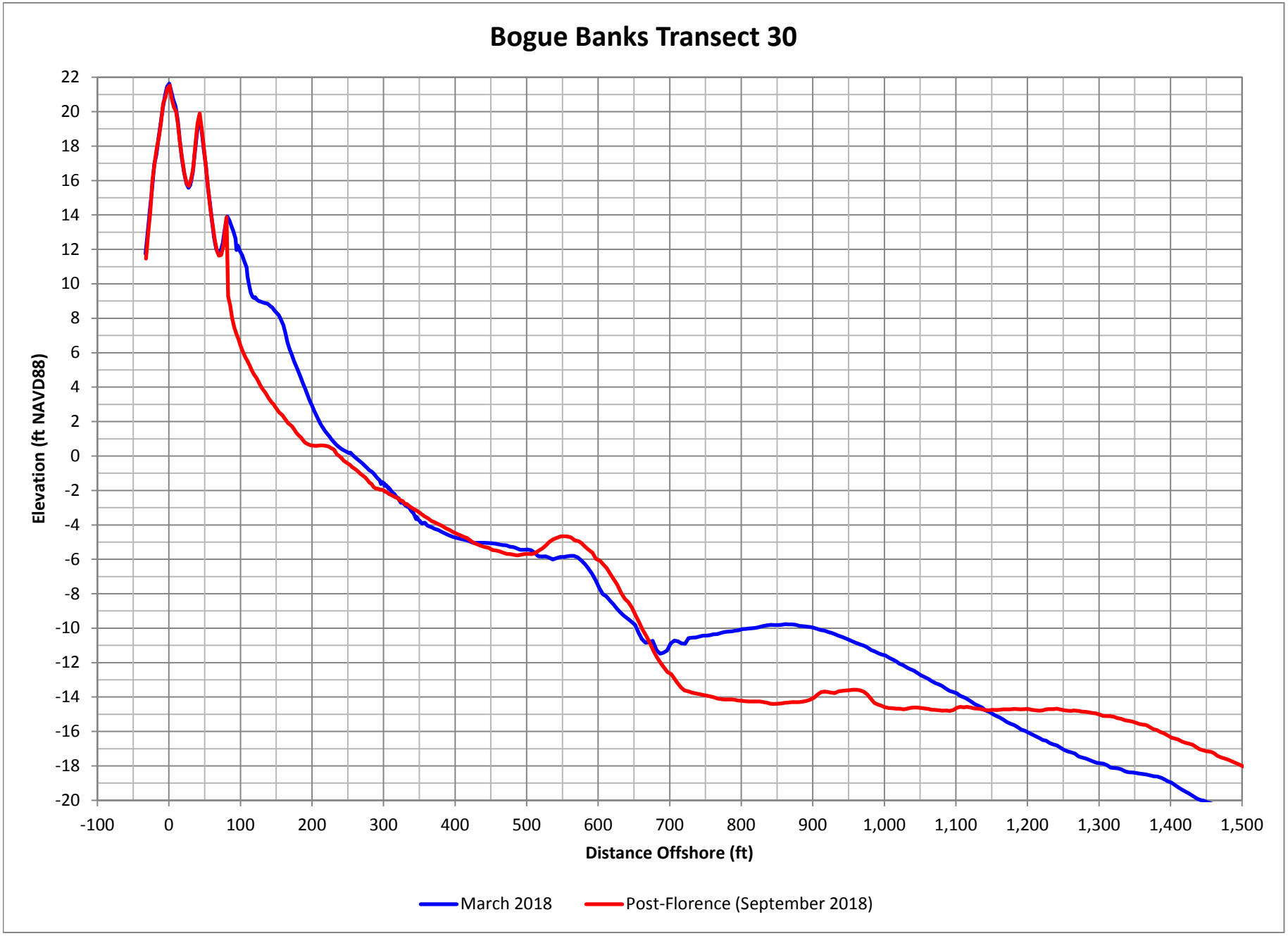


Figure D-60. Bogue Banks Profile Comparison Plot

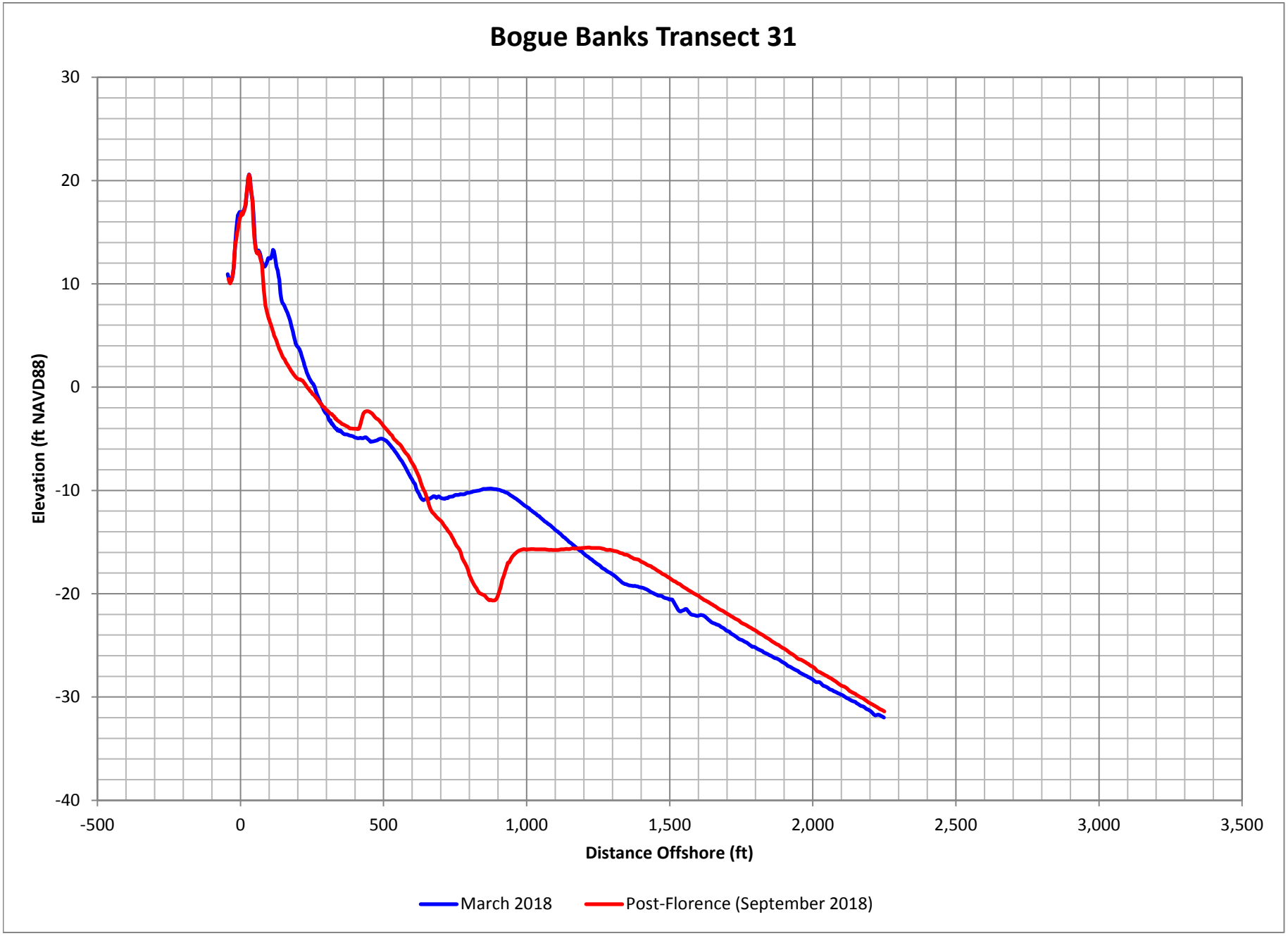


Figure D-61. Bogue Banks Profile Comparison Plot

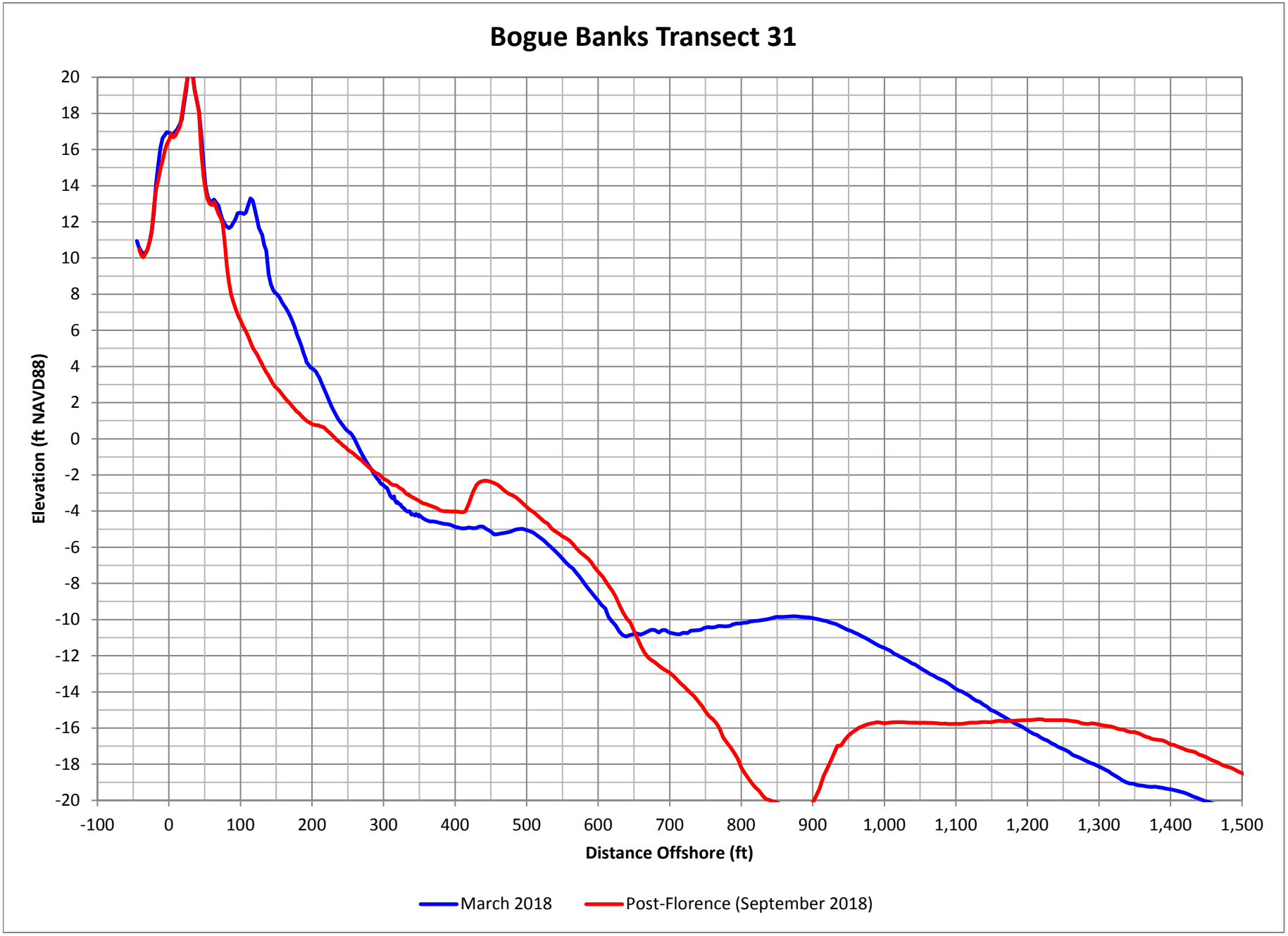


Figure D-62. Bogue Banks Profile Comparison Plot

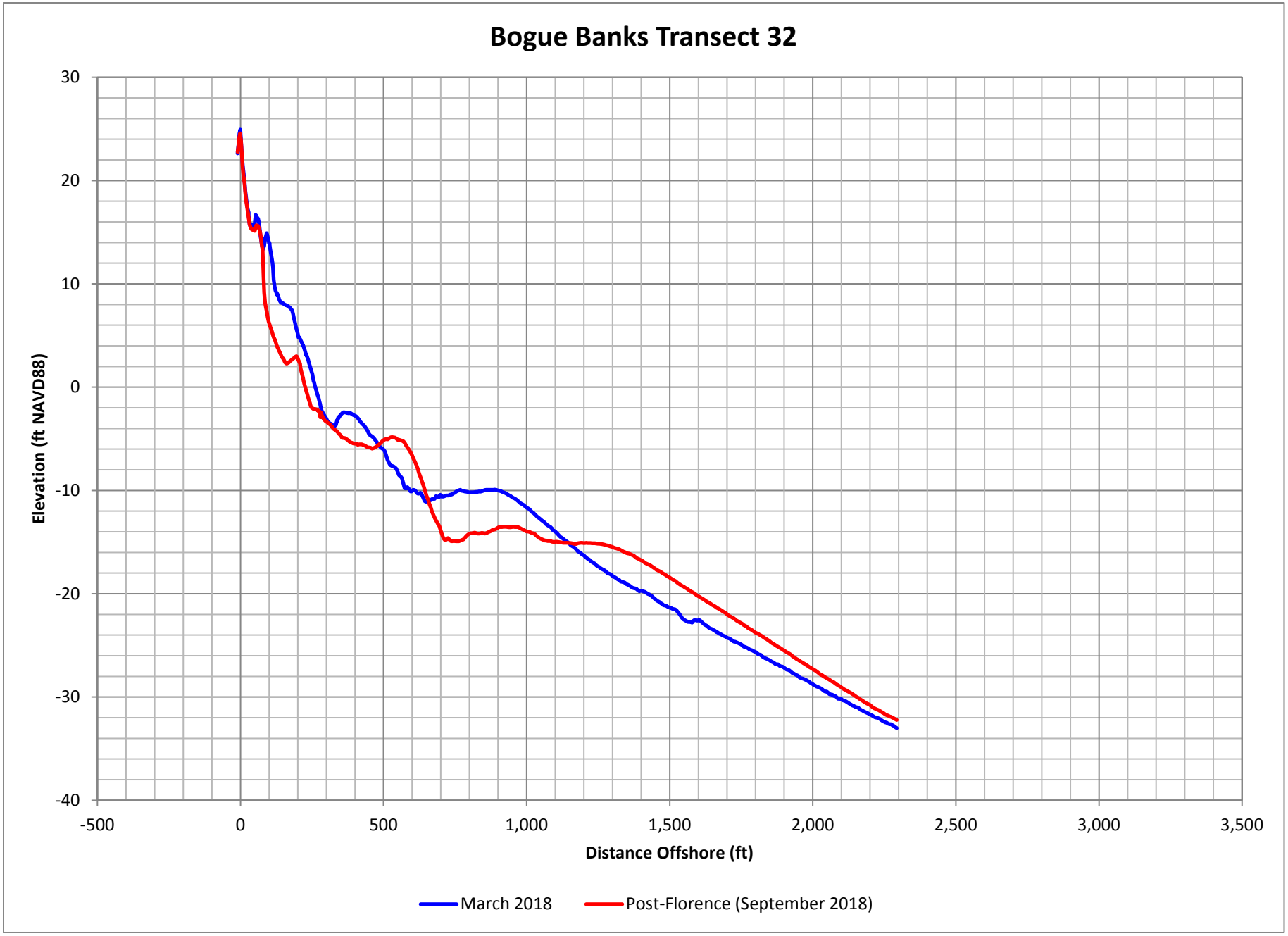


Figure D-63. Bogue Banks Profile Comparison Plot

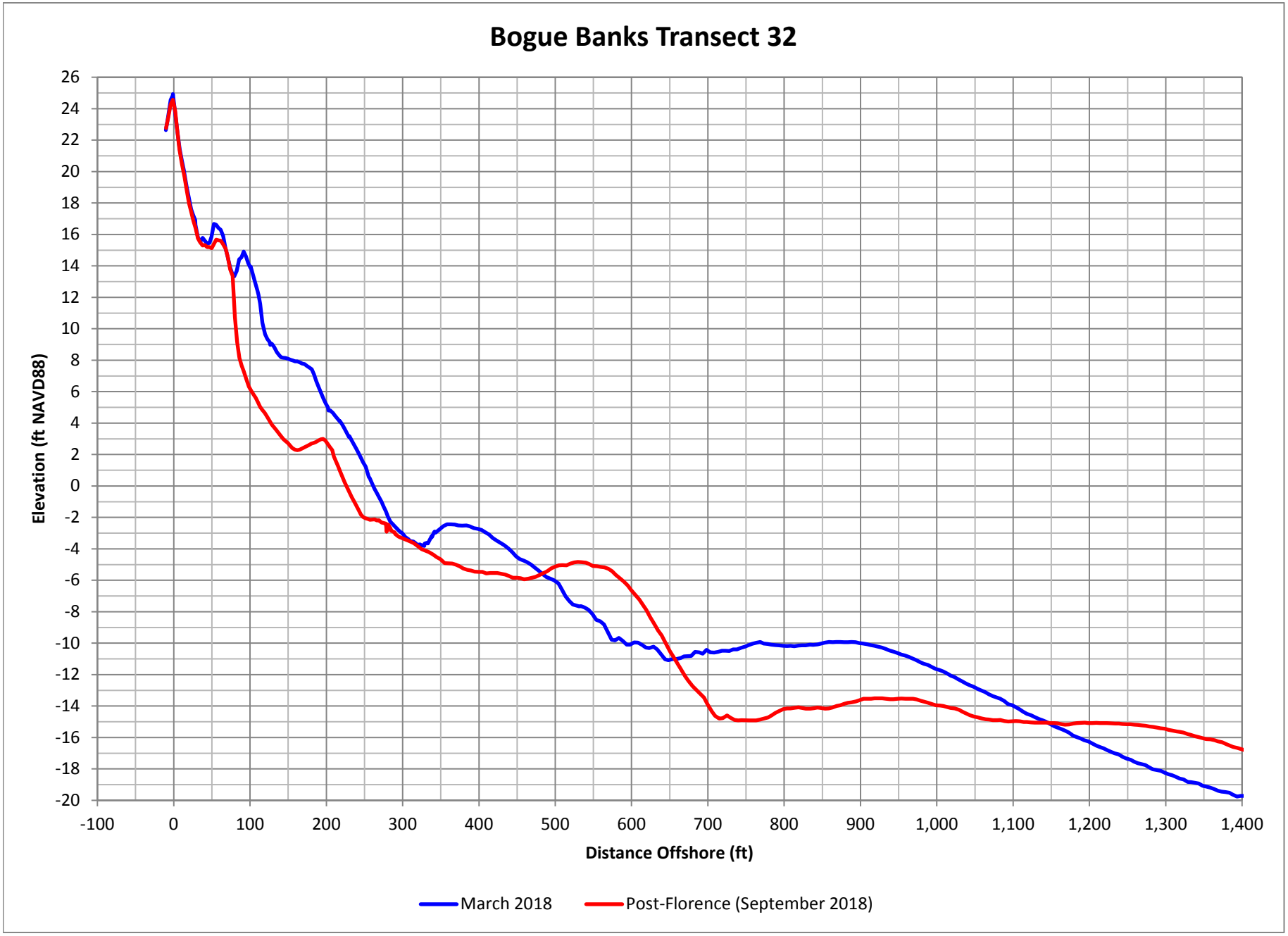


Figure D-64. Bogue Banks Profile Comparison Plot

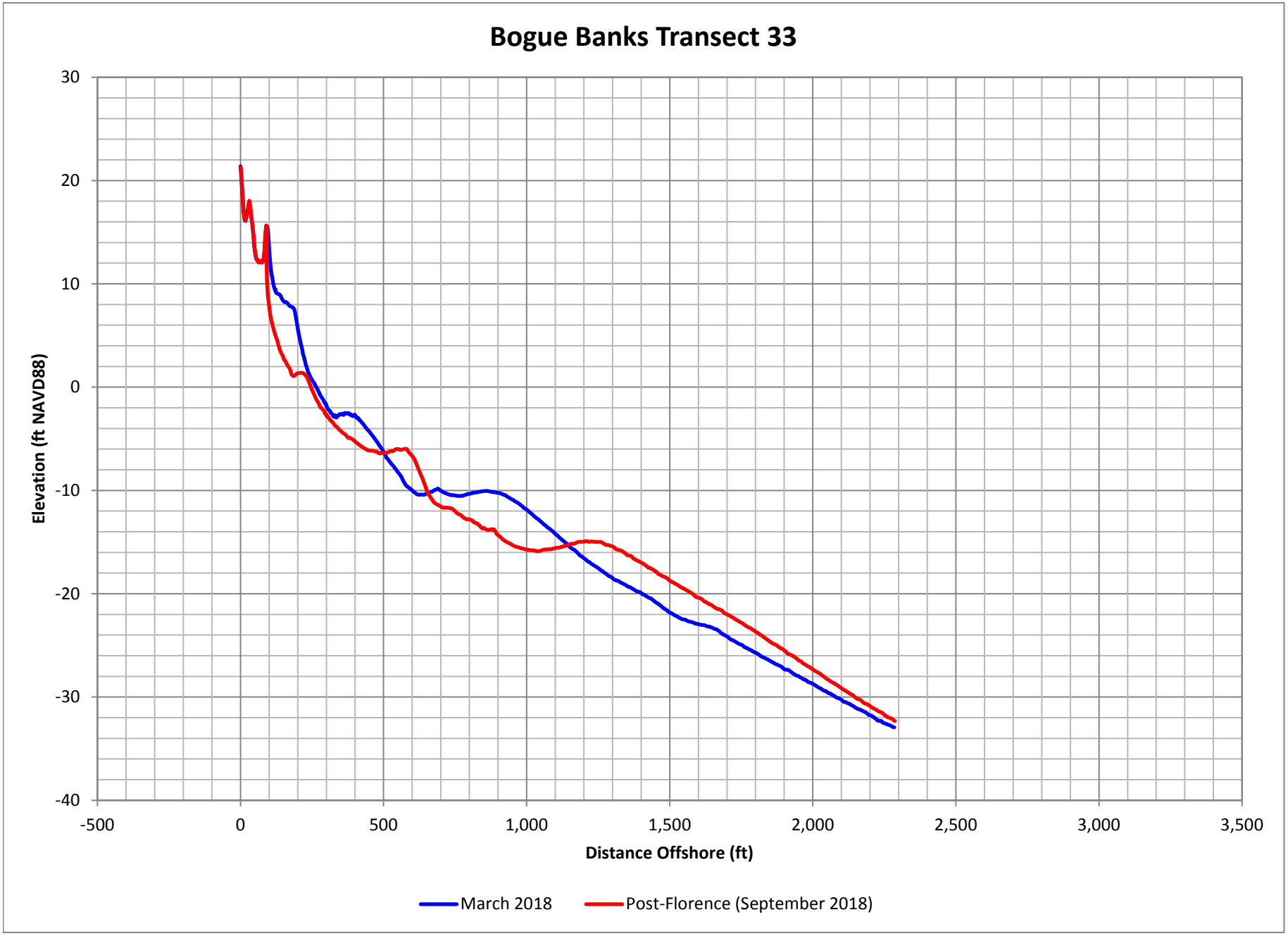


Figure D-65. Bogue Banks Profile Comparison Plot

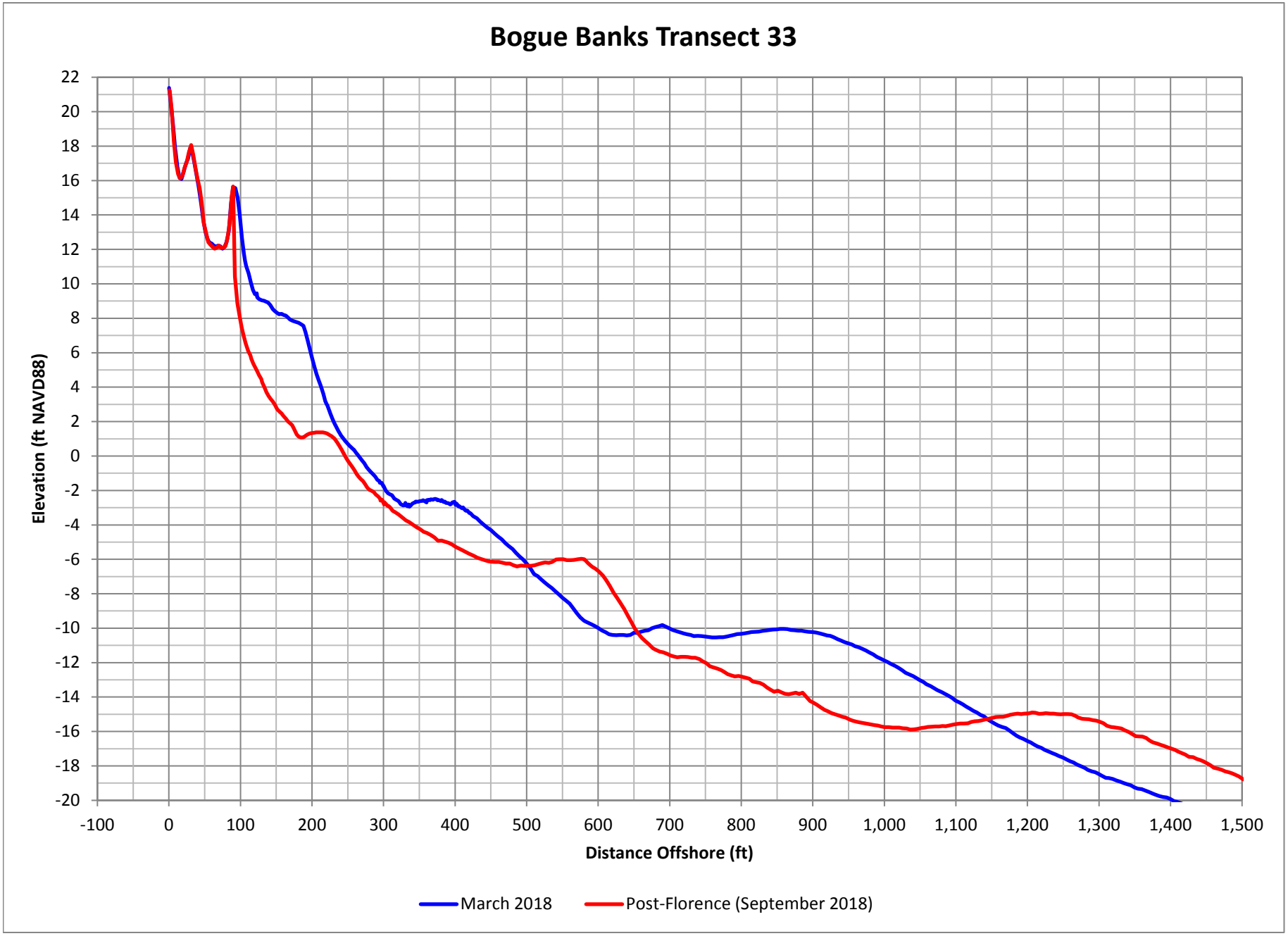


Figure D-66. Bogue Banks Profile Comparison Plot

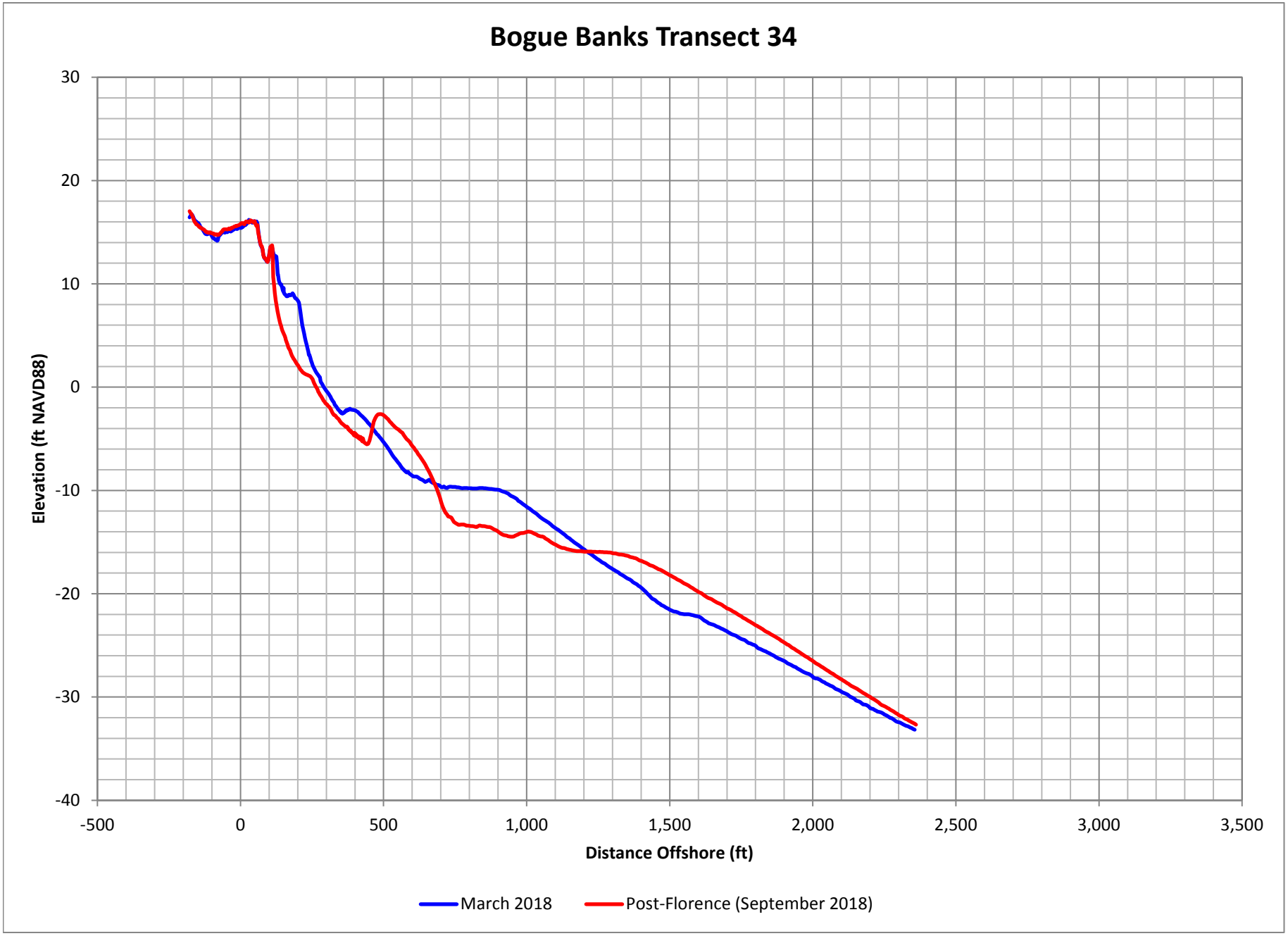


Figure D-67. Bogue Banks Profile Comparison Plot

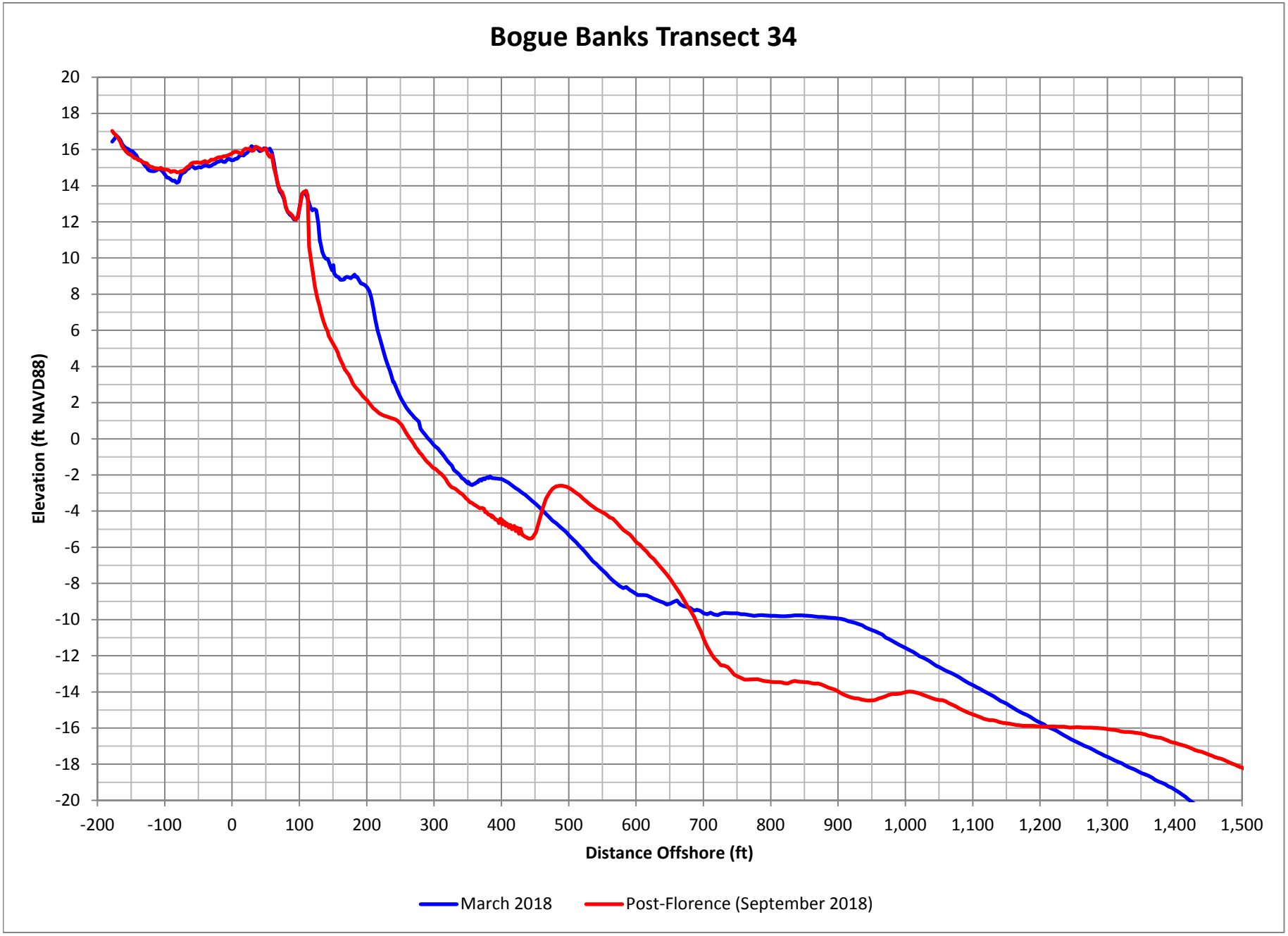


Figure D-68. Bogue Banks Profile Comparison Plot

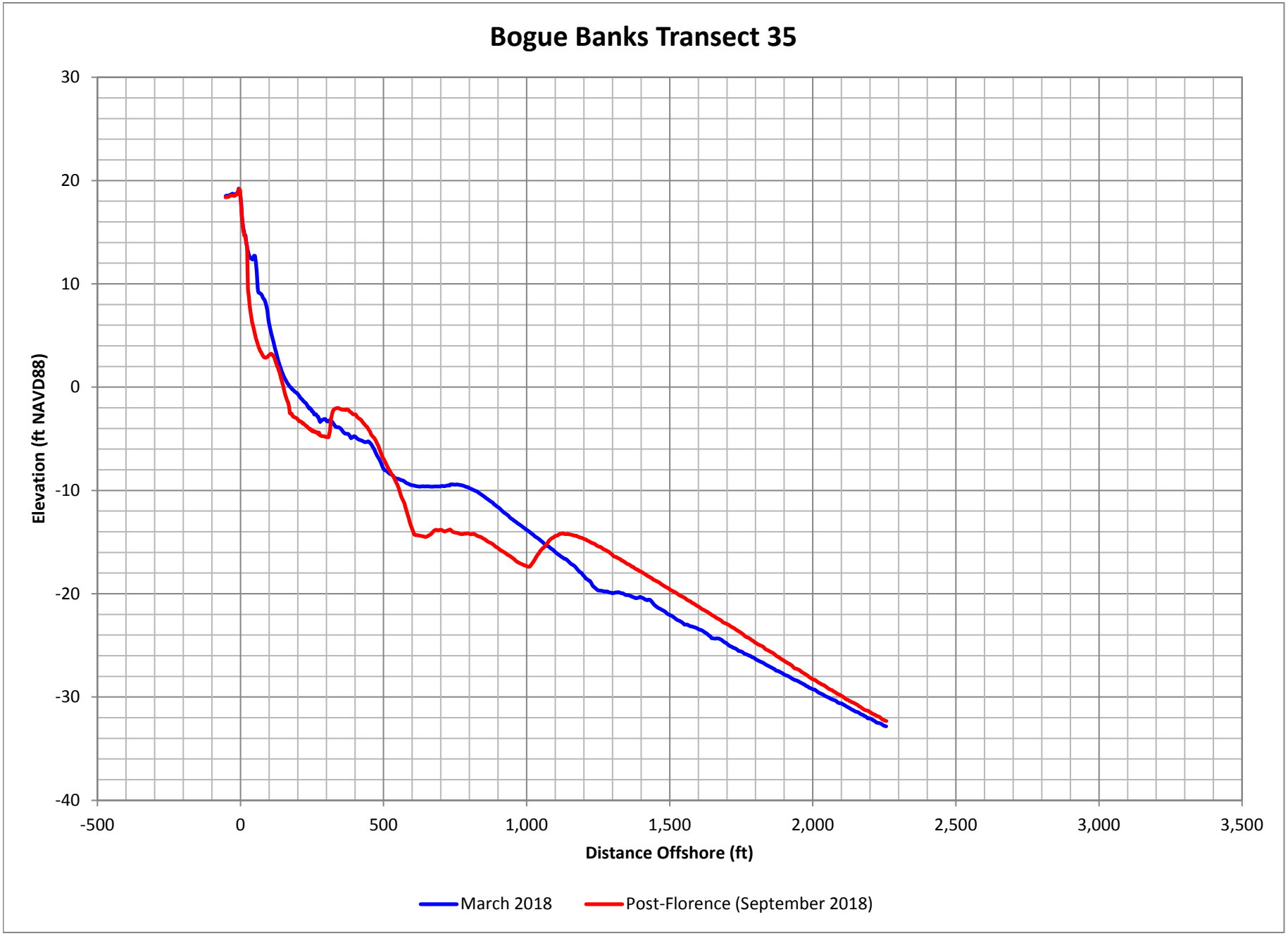


Figure D-69. Bogue Banks Profile Comparison Plot

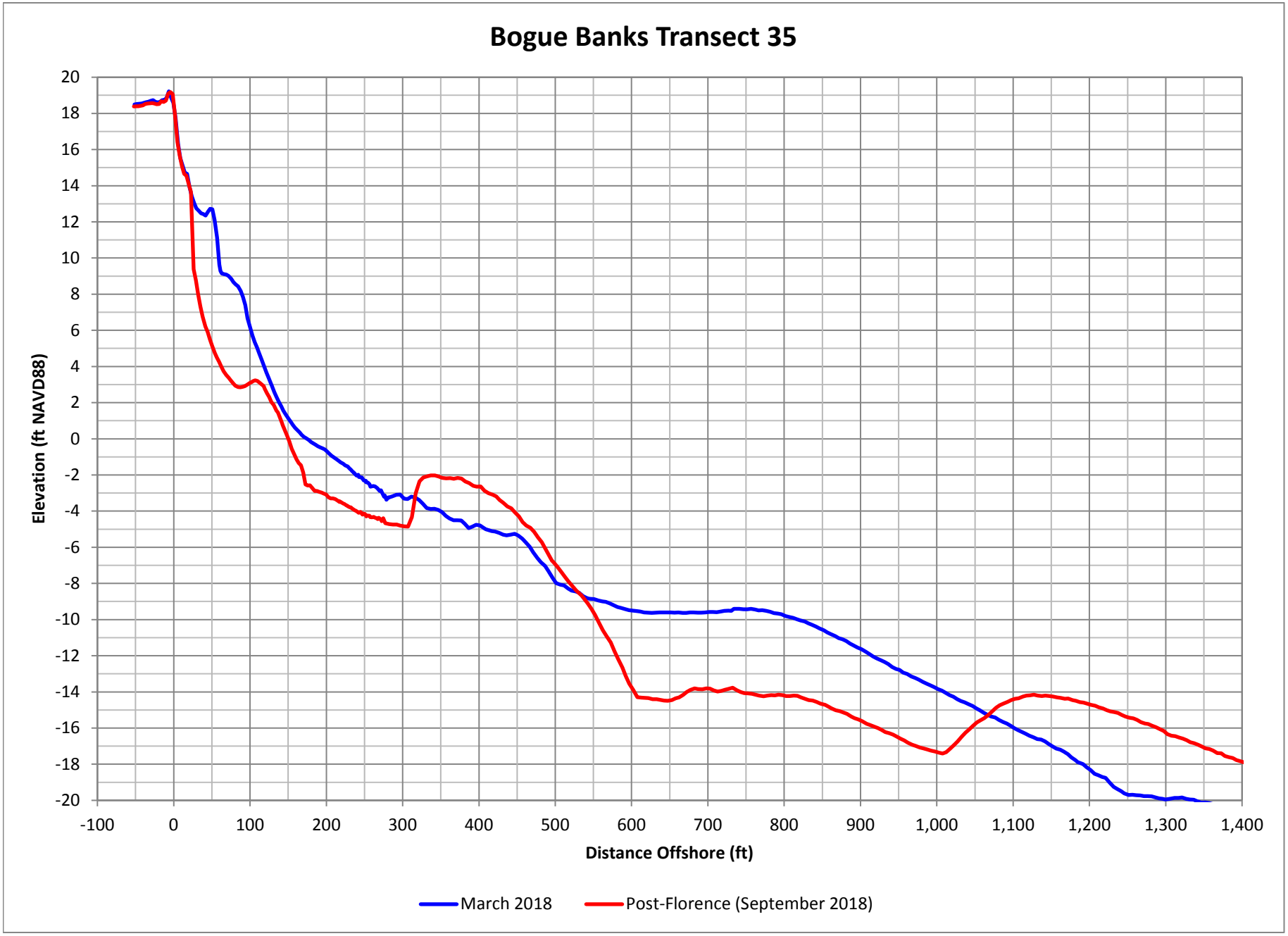


Figure D-70. Bogue Banks Profile Comparison Plot

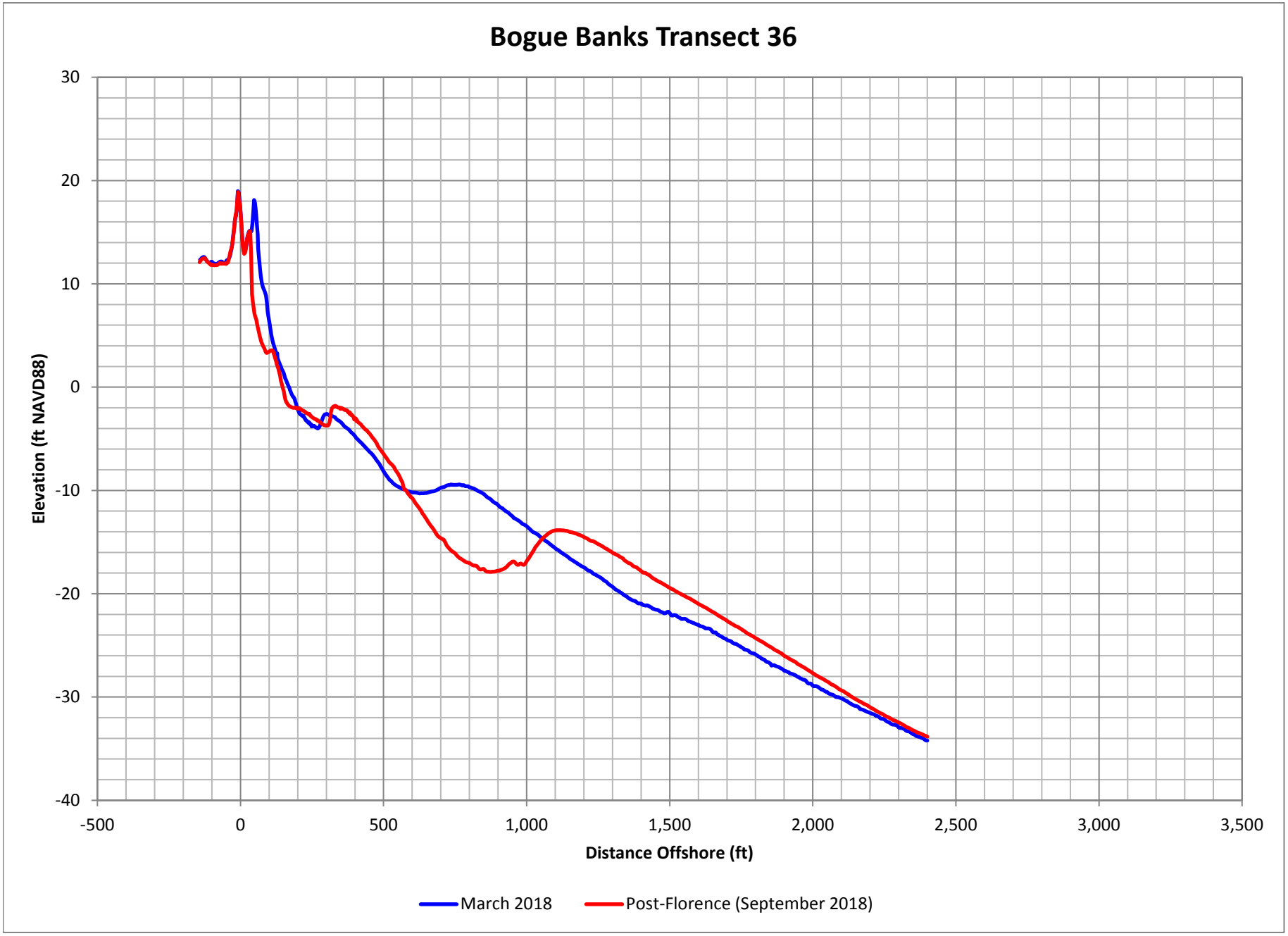


Figure D-71. Bogue Banks Profile Comparison Plot

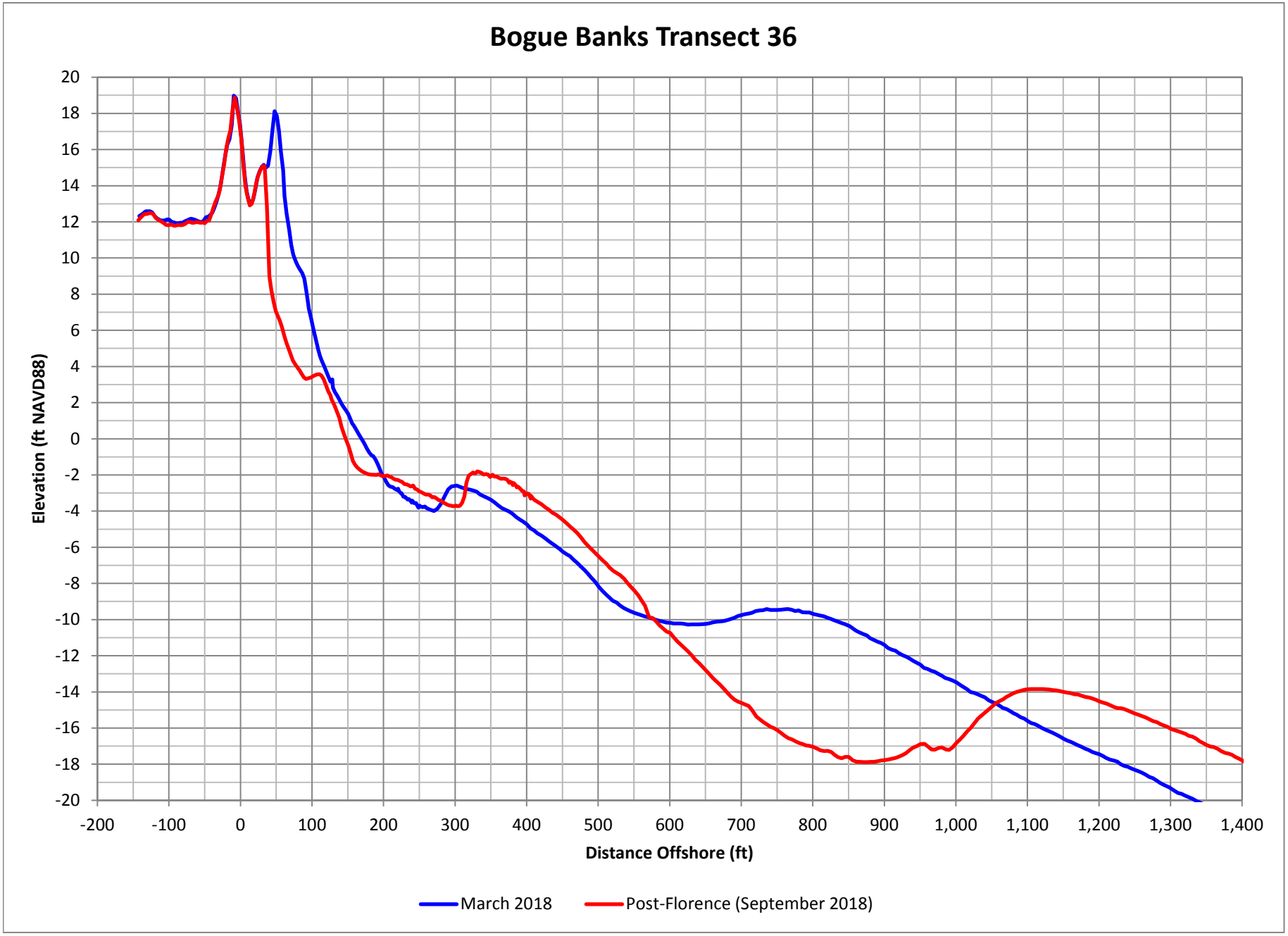


Figure D-72. Bogue Banks Profile Comparison Plot

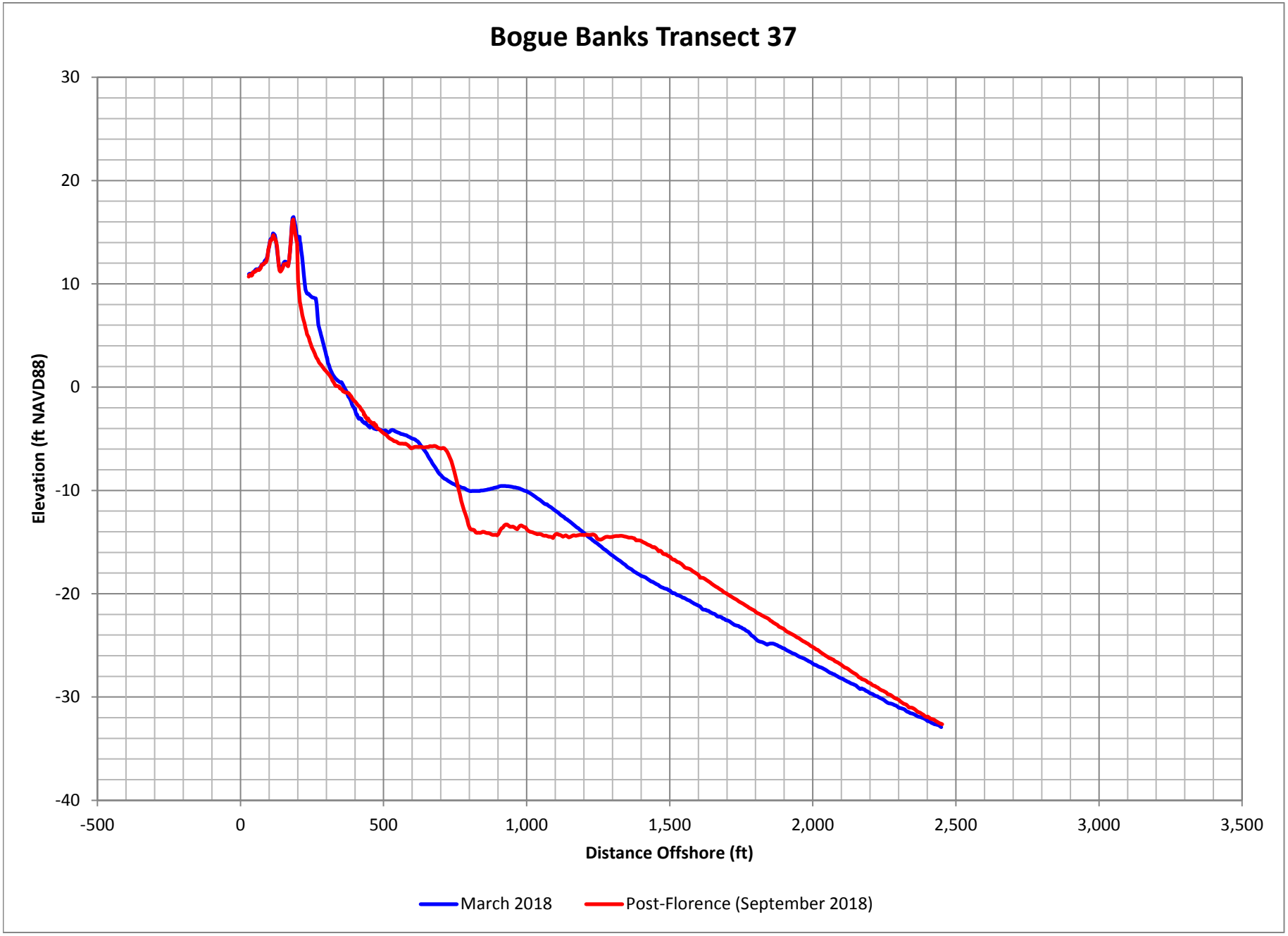


Figure D-73. Bogue Banks Profile Comparison Plot

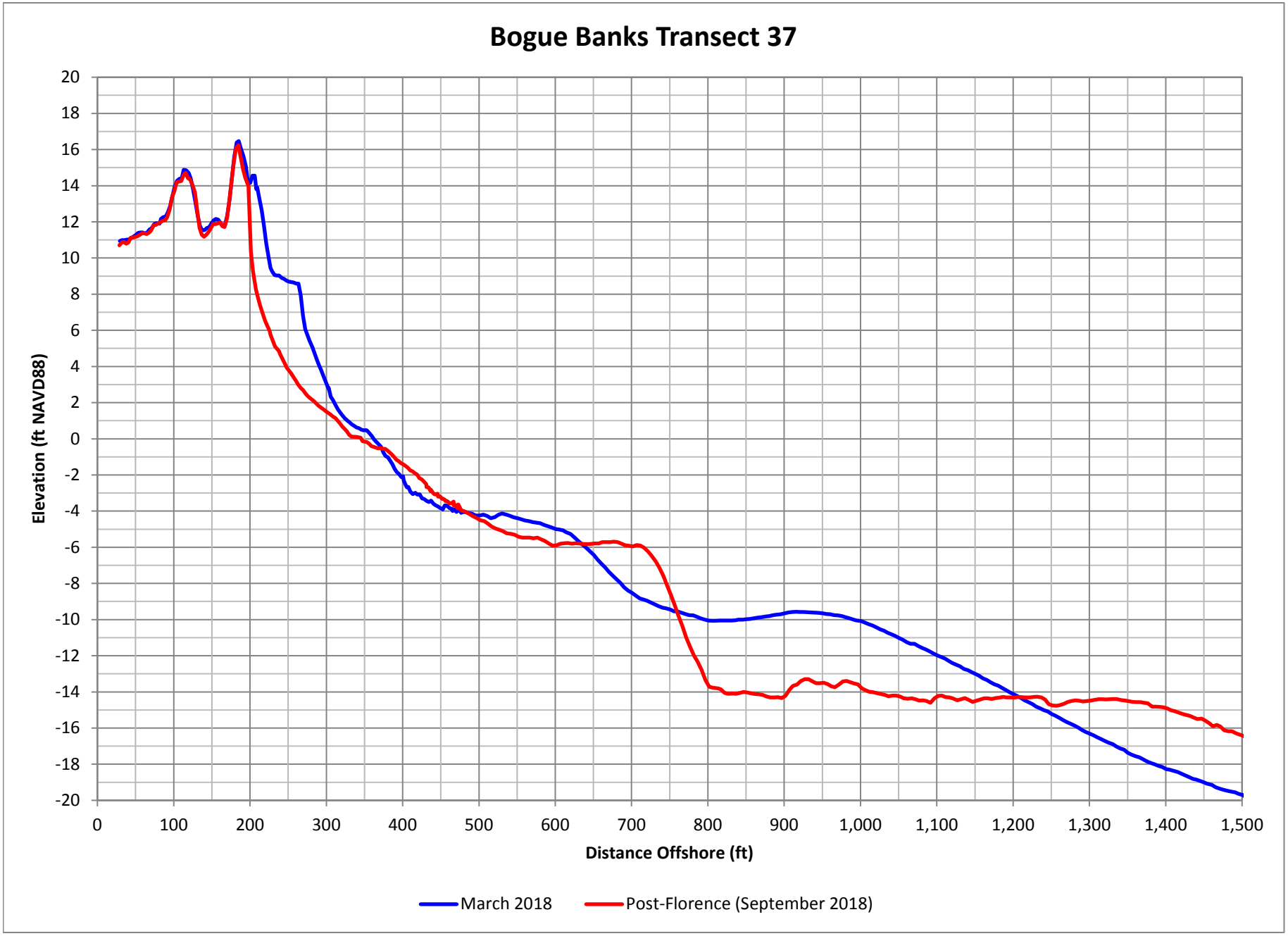


Figure D-74. Bogue Banks Profile Comparison Plot

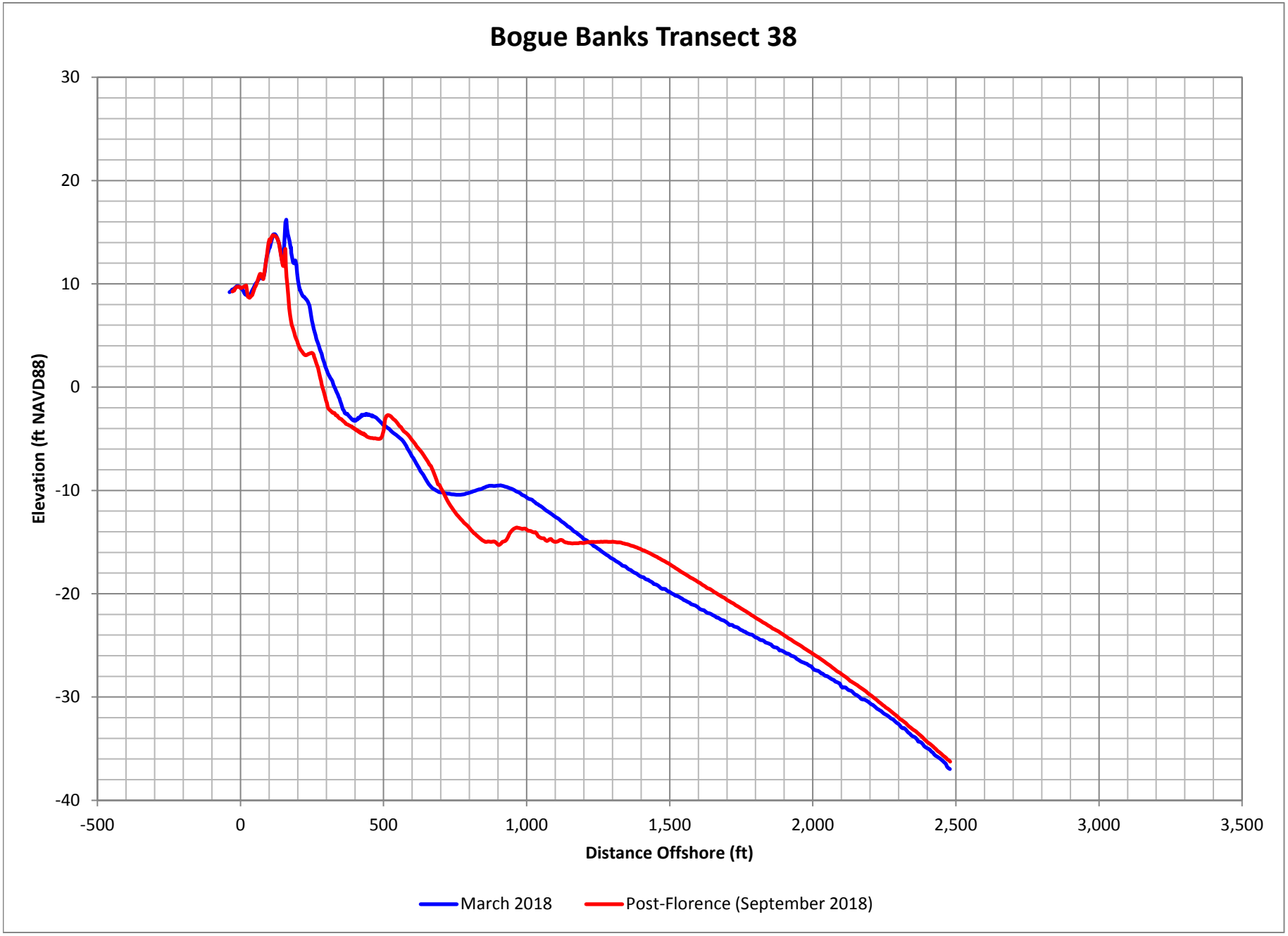


Figure D-75. Bogue Banks Profile Comparison Plot

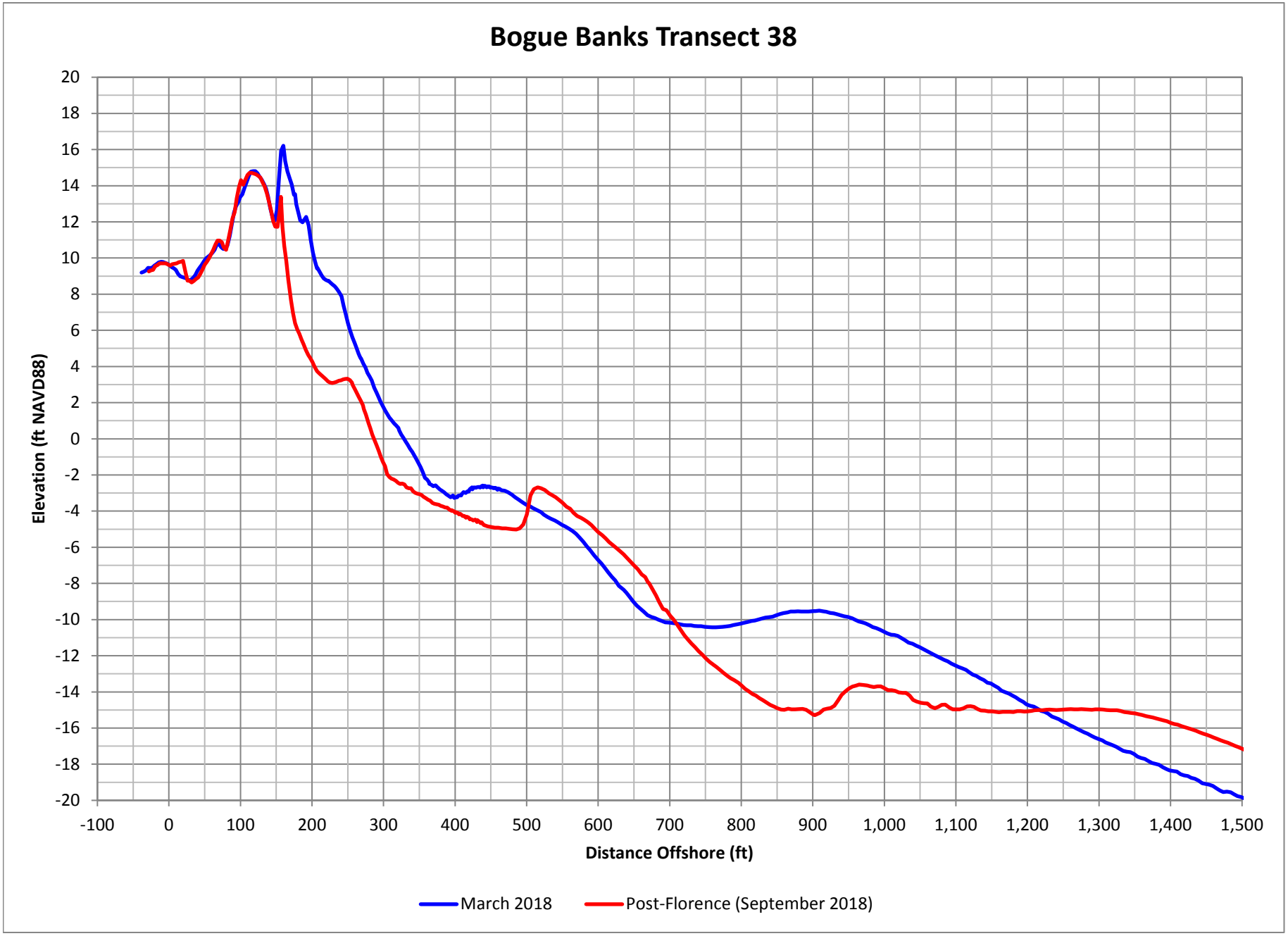


Figure D-76. Bogue Banks Profile Comparison Plot

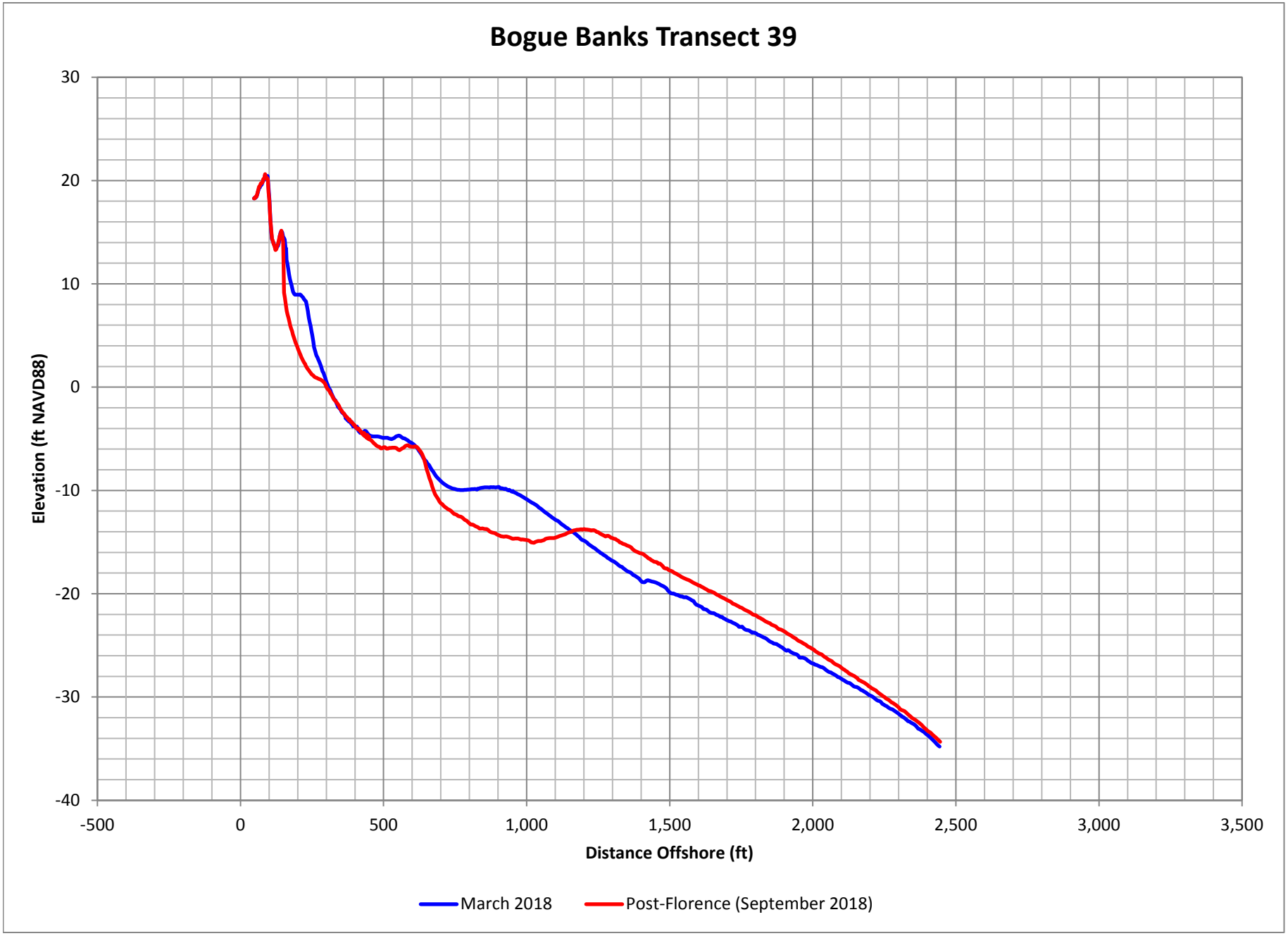


Figure D-77. Bogue Banks Profile Comparison Plot

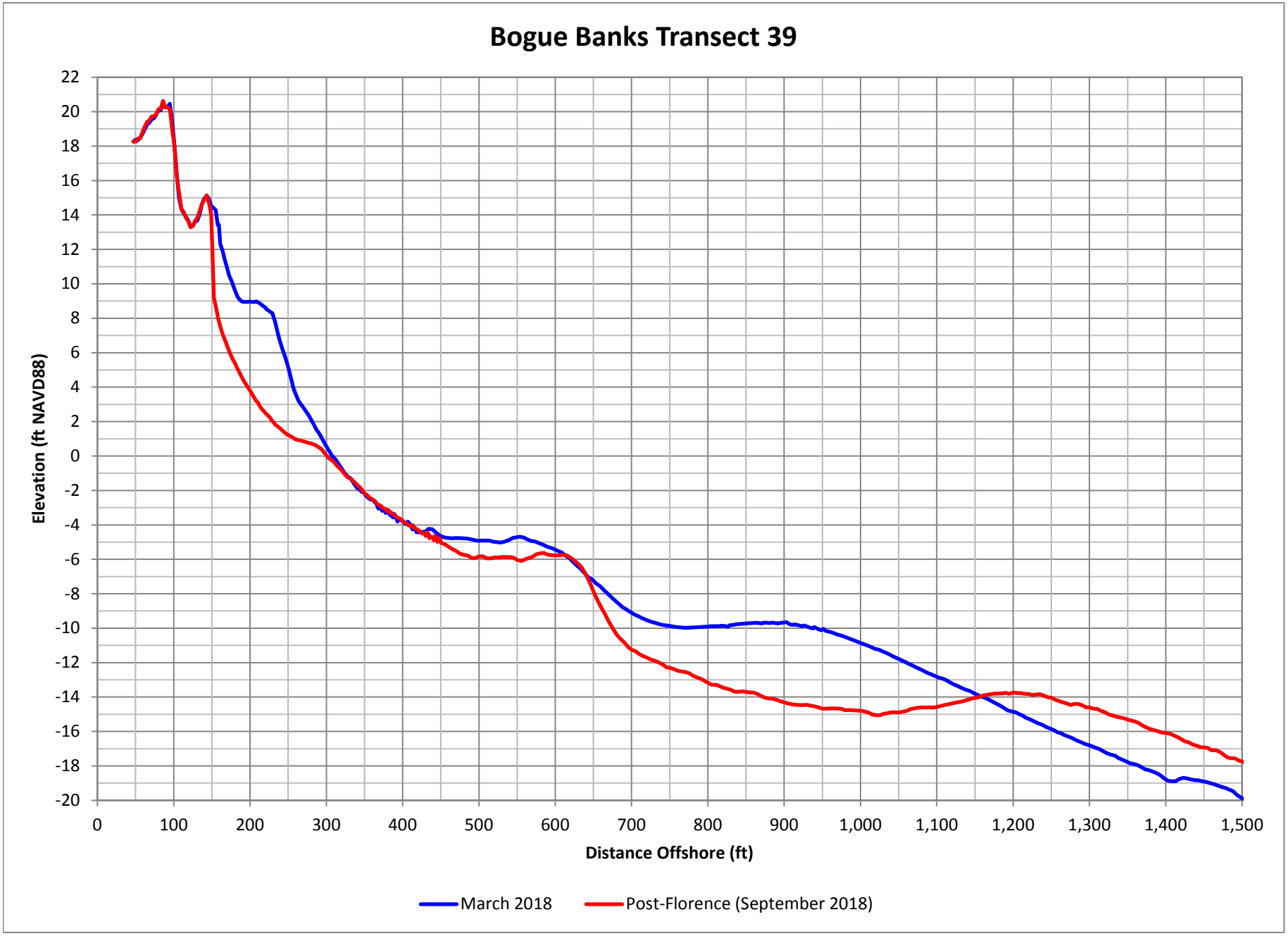


Figure D-78. Bogue Banks Profile Comparison Plot

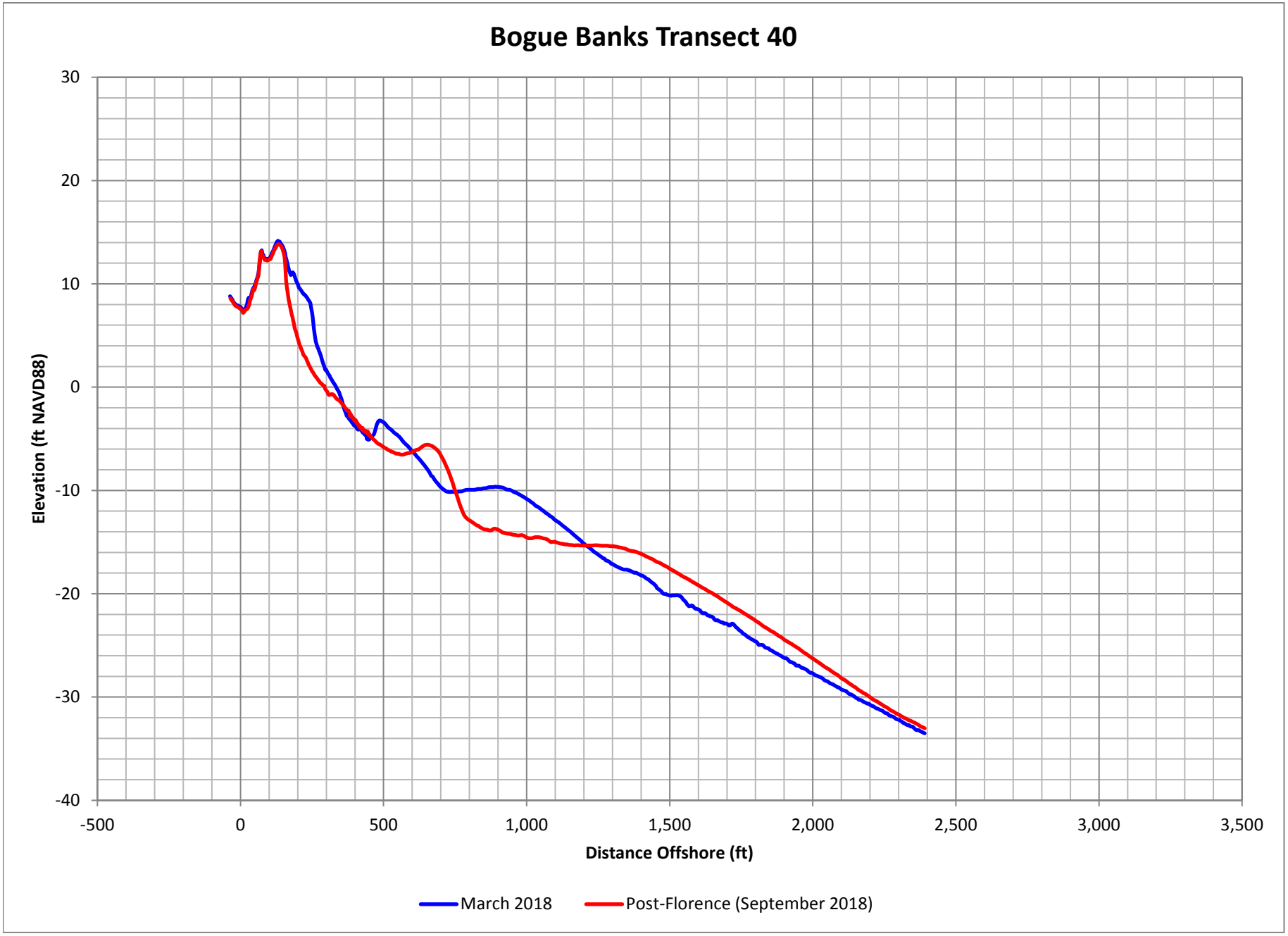


Figure D-79. Bogue Banks Profile Comparison Plot

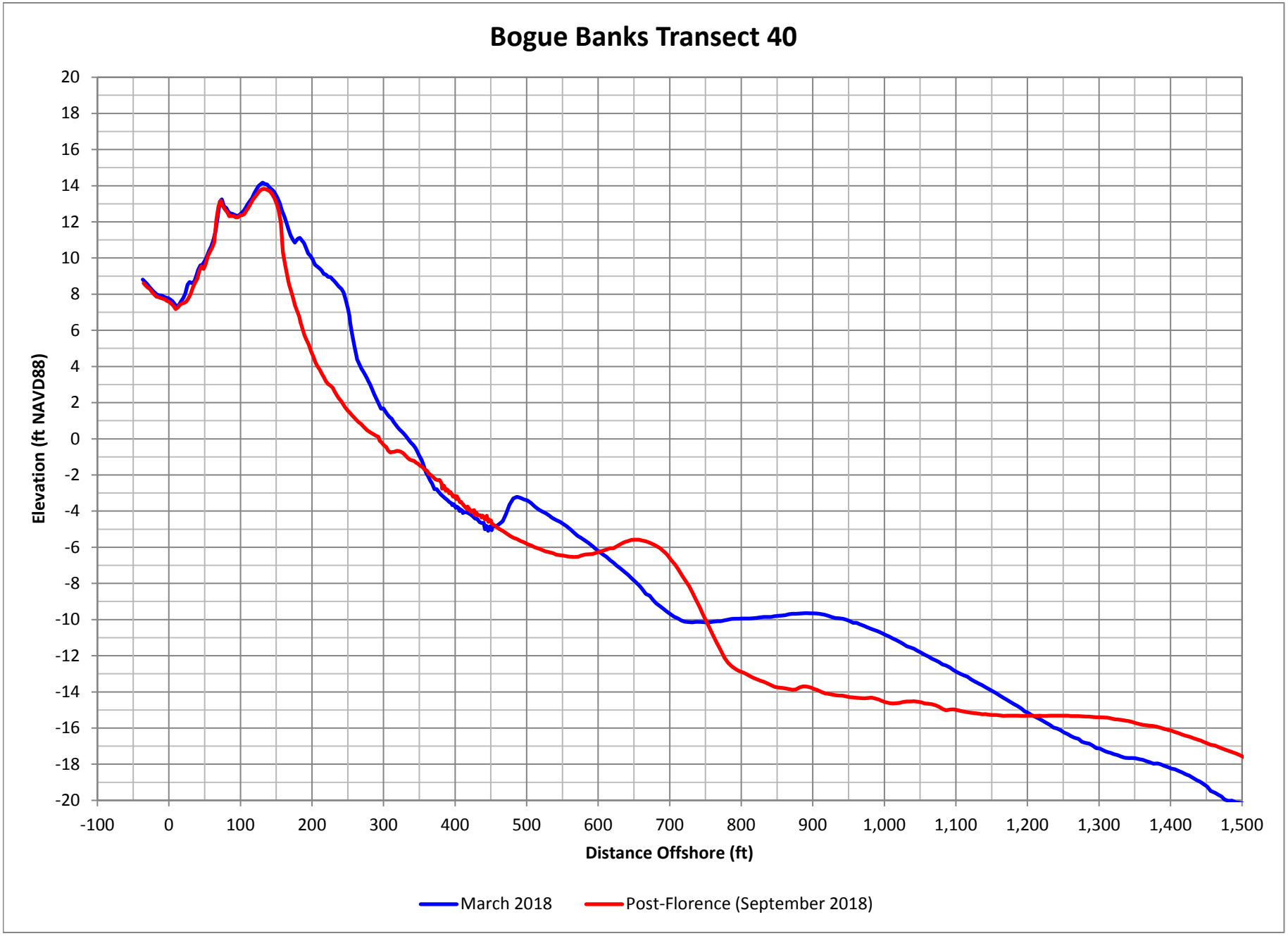


Figure D-80. Bogue Banks Profile Comparison Plot

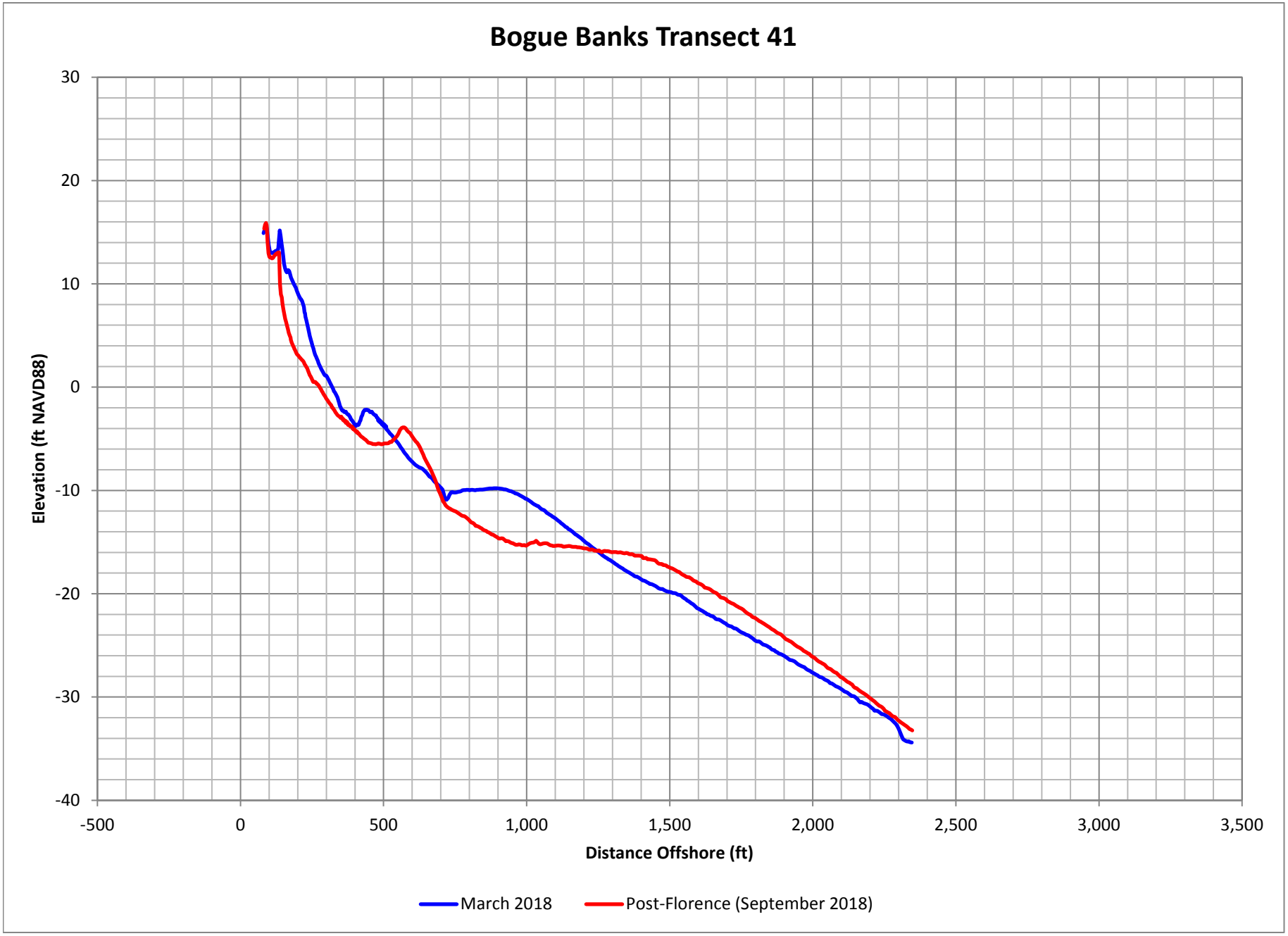


Figure D-81. Bogue Banks Profile Comparison Plot

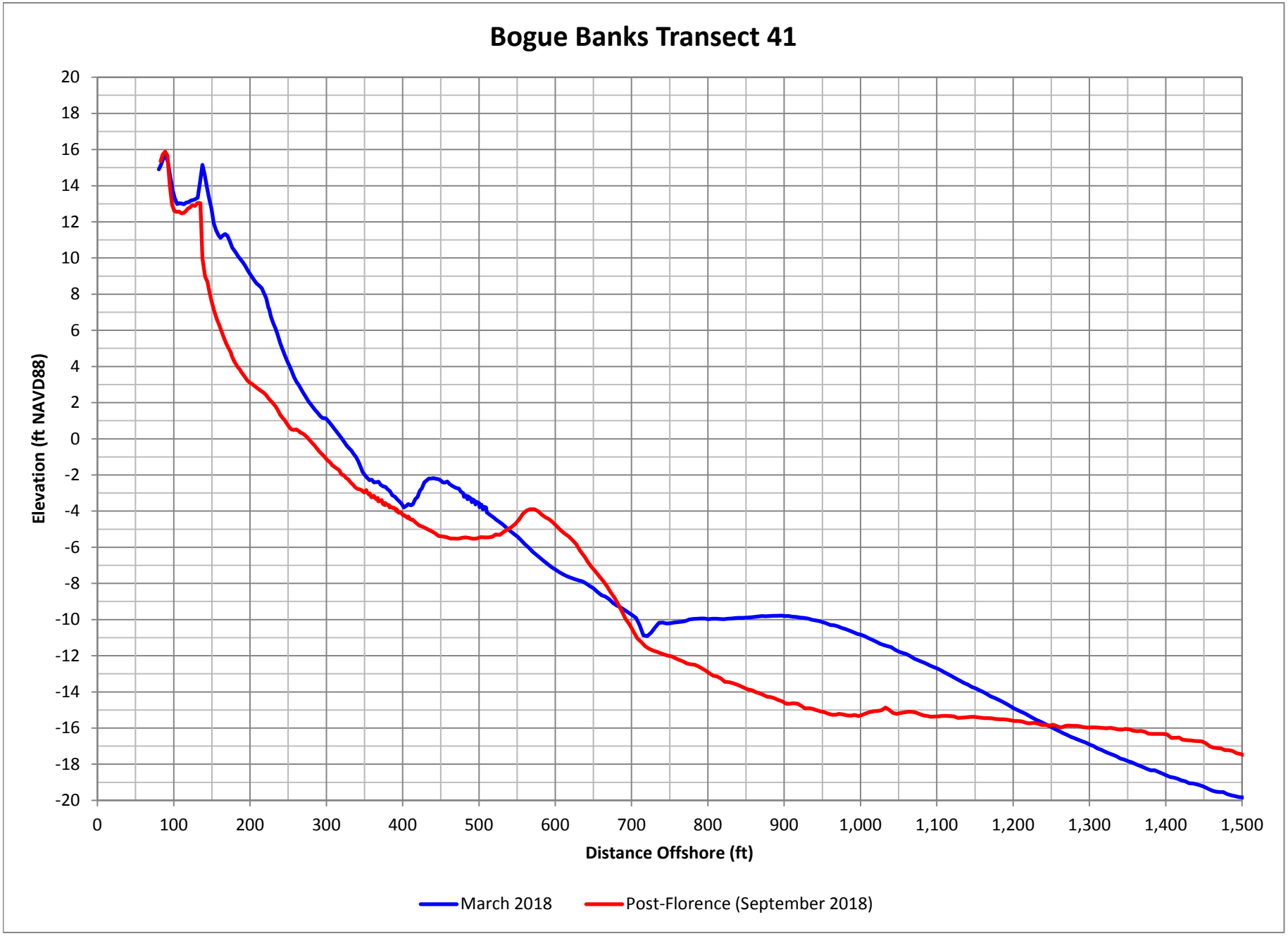


Figure D-82. Bogue Banks Profile Comparison Plot

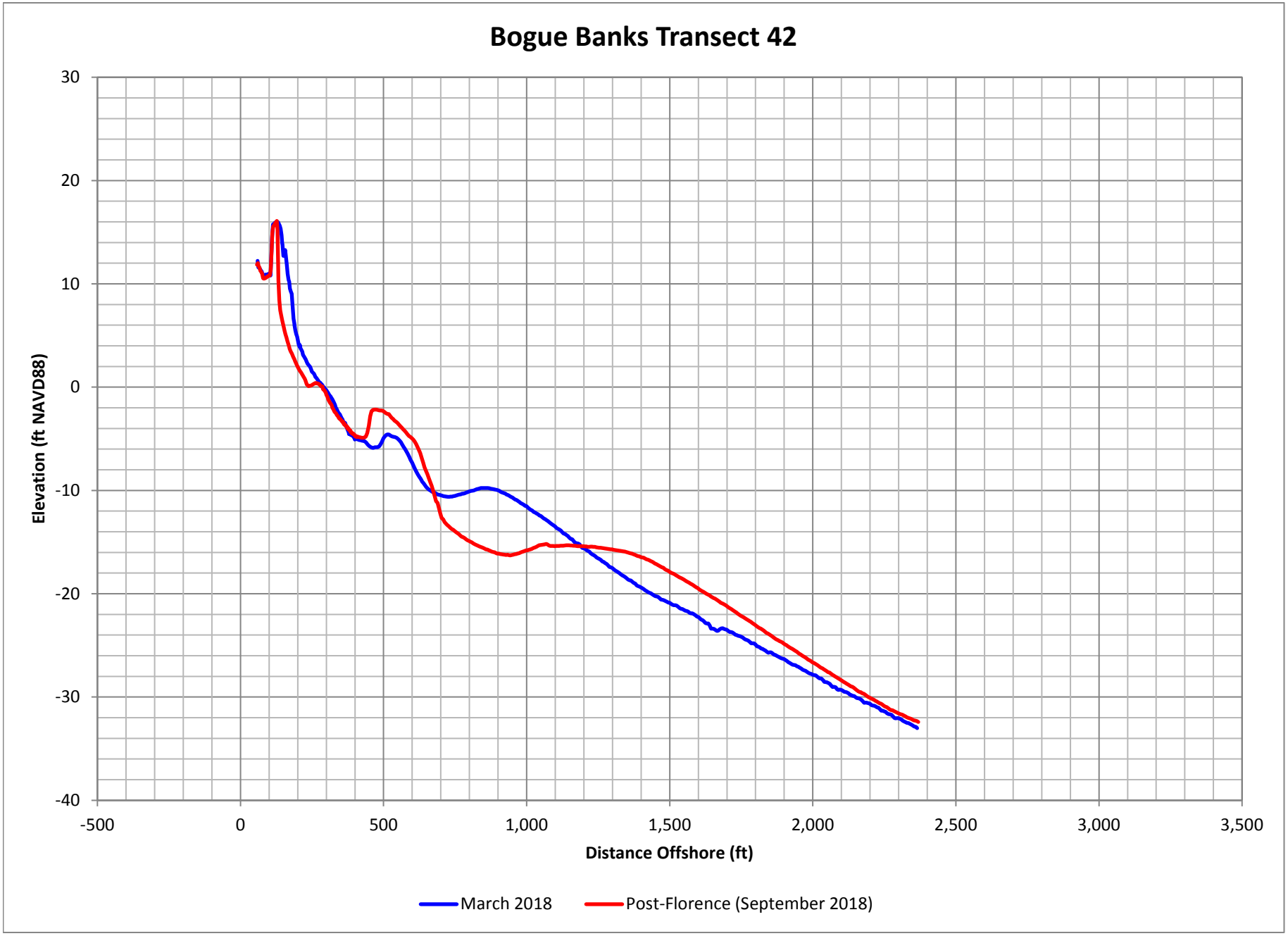


Figure D-83. Bogue Banks Profile Comparison Plot

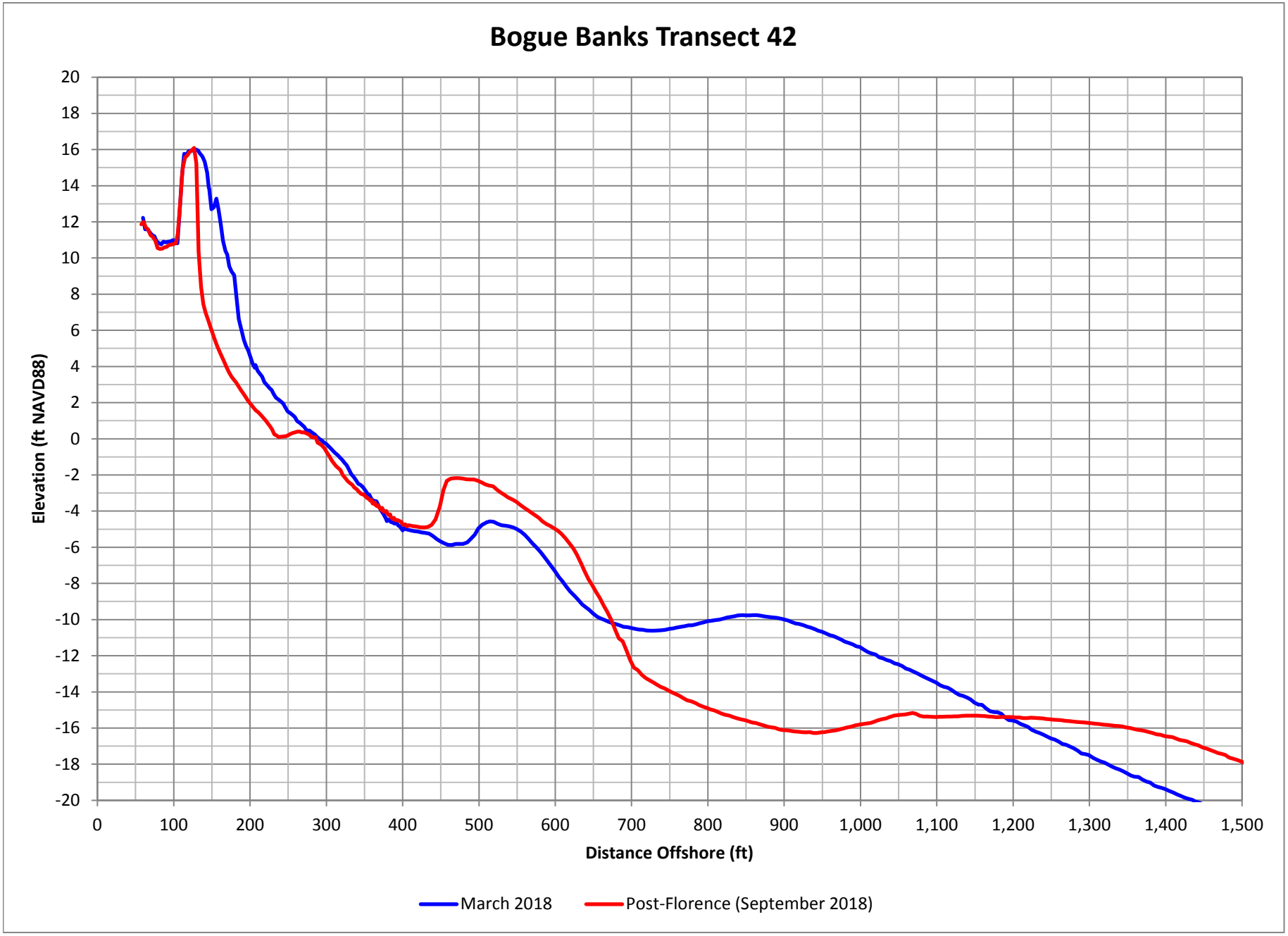


Figure D-84. Bogue Banks Profile Comparison Plot

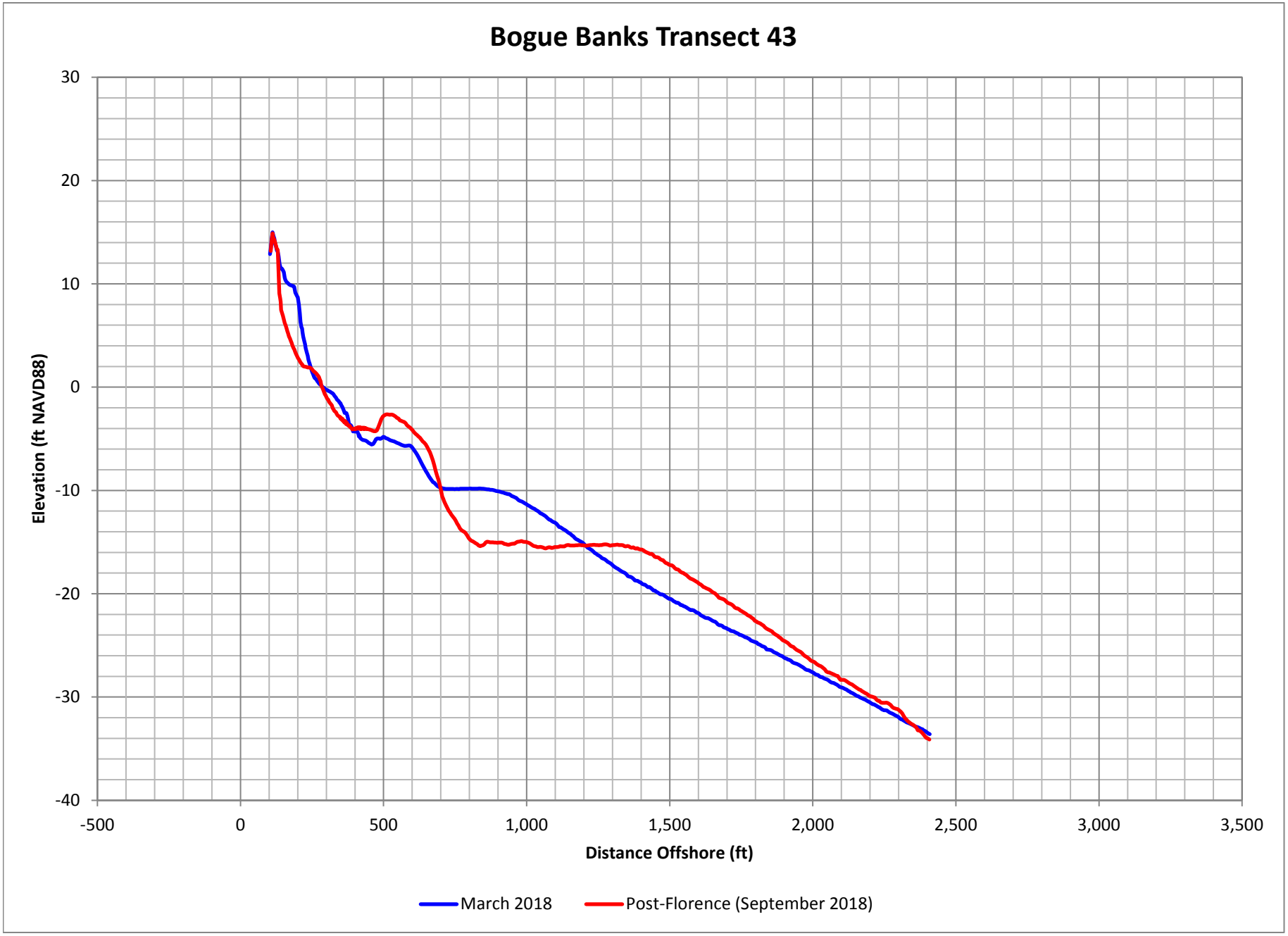


Figure D-85. Bogue Banks Profile Comparison Plot

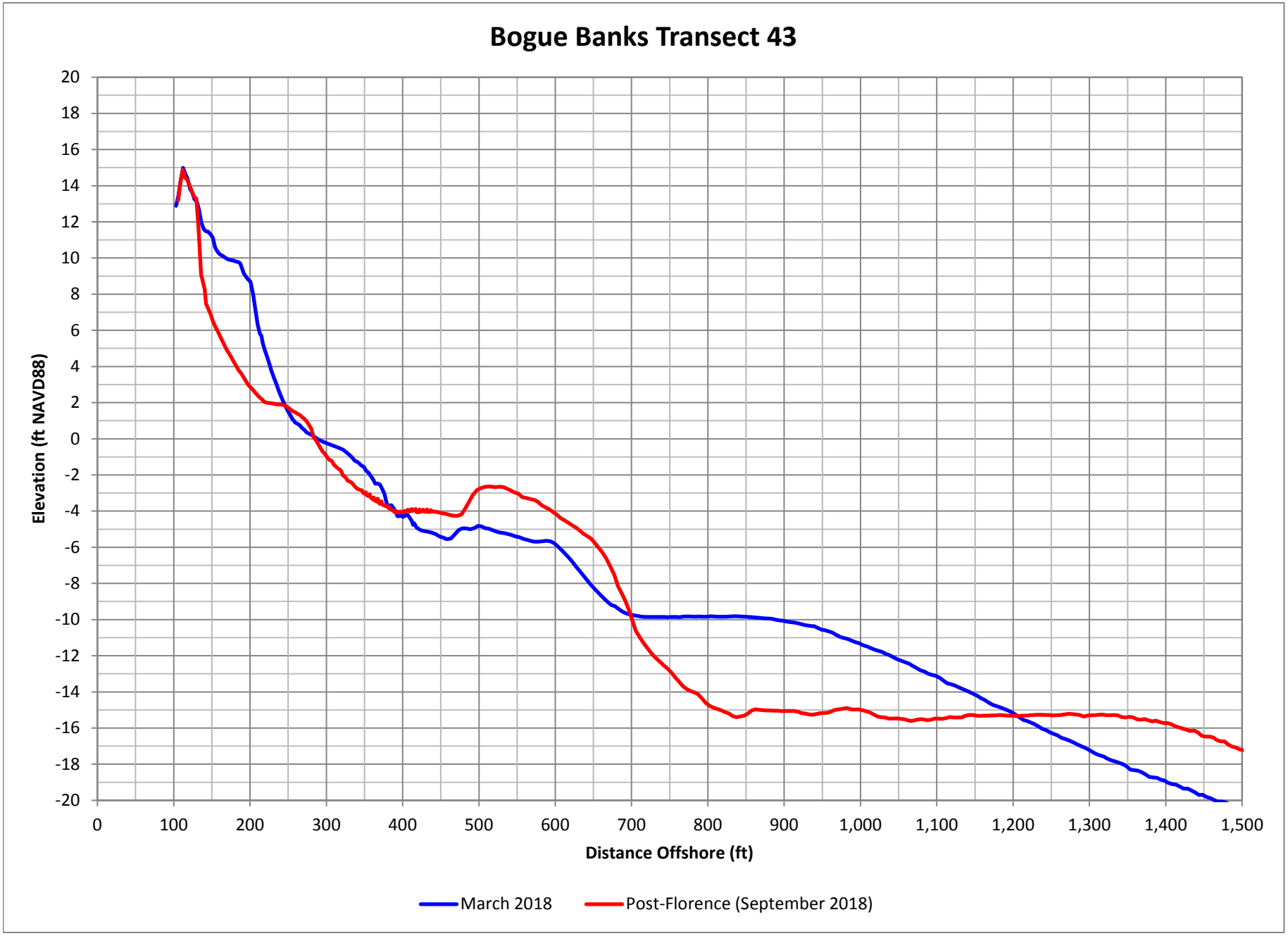


Figure D-86. Bogue Banks Profile Comparison Plot

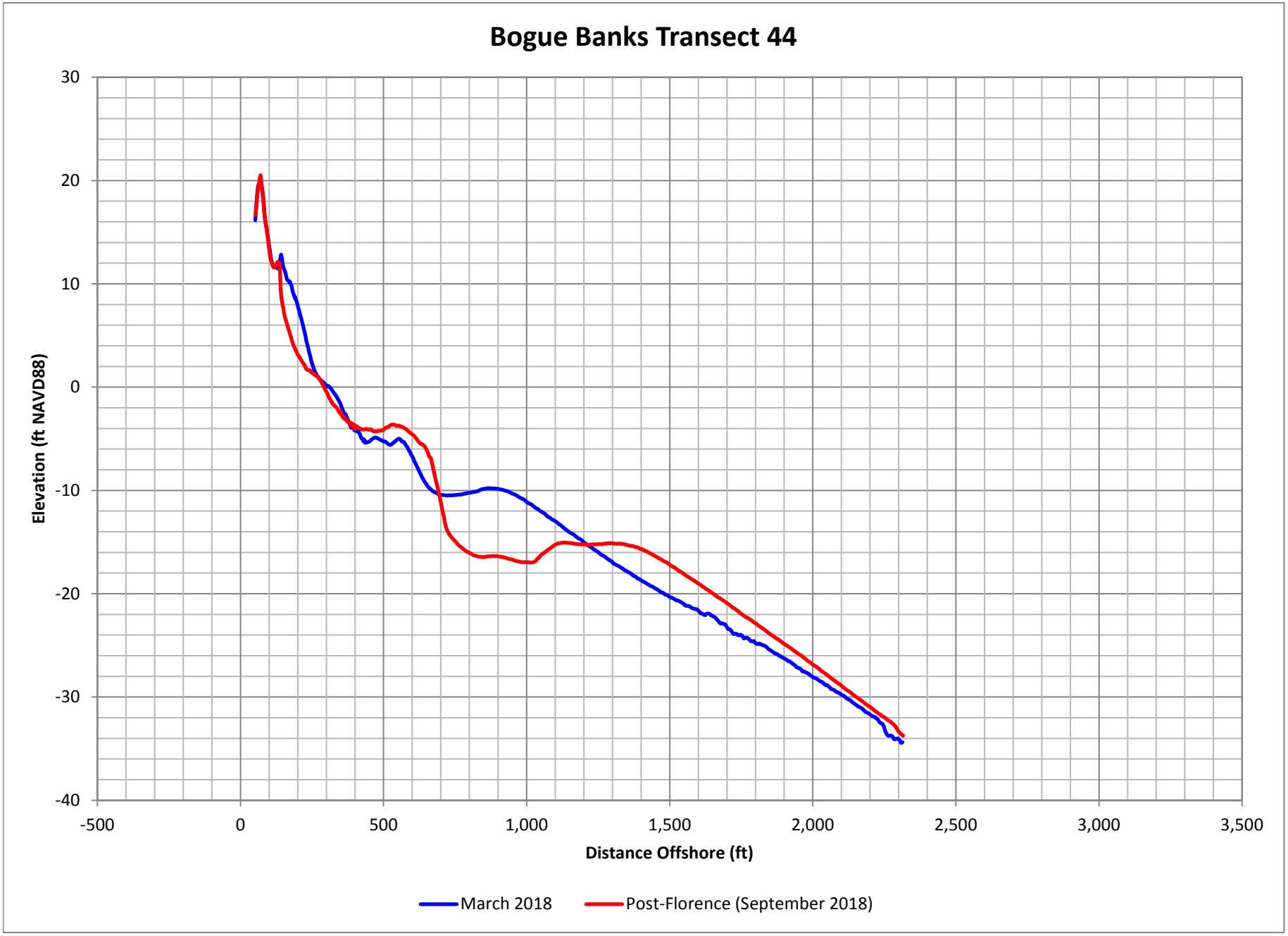


Figure D-87. Bogue Banks Profile Comparison Plot

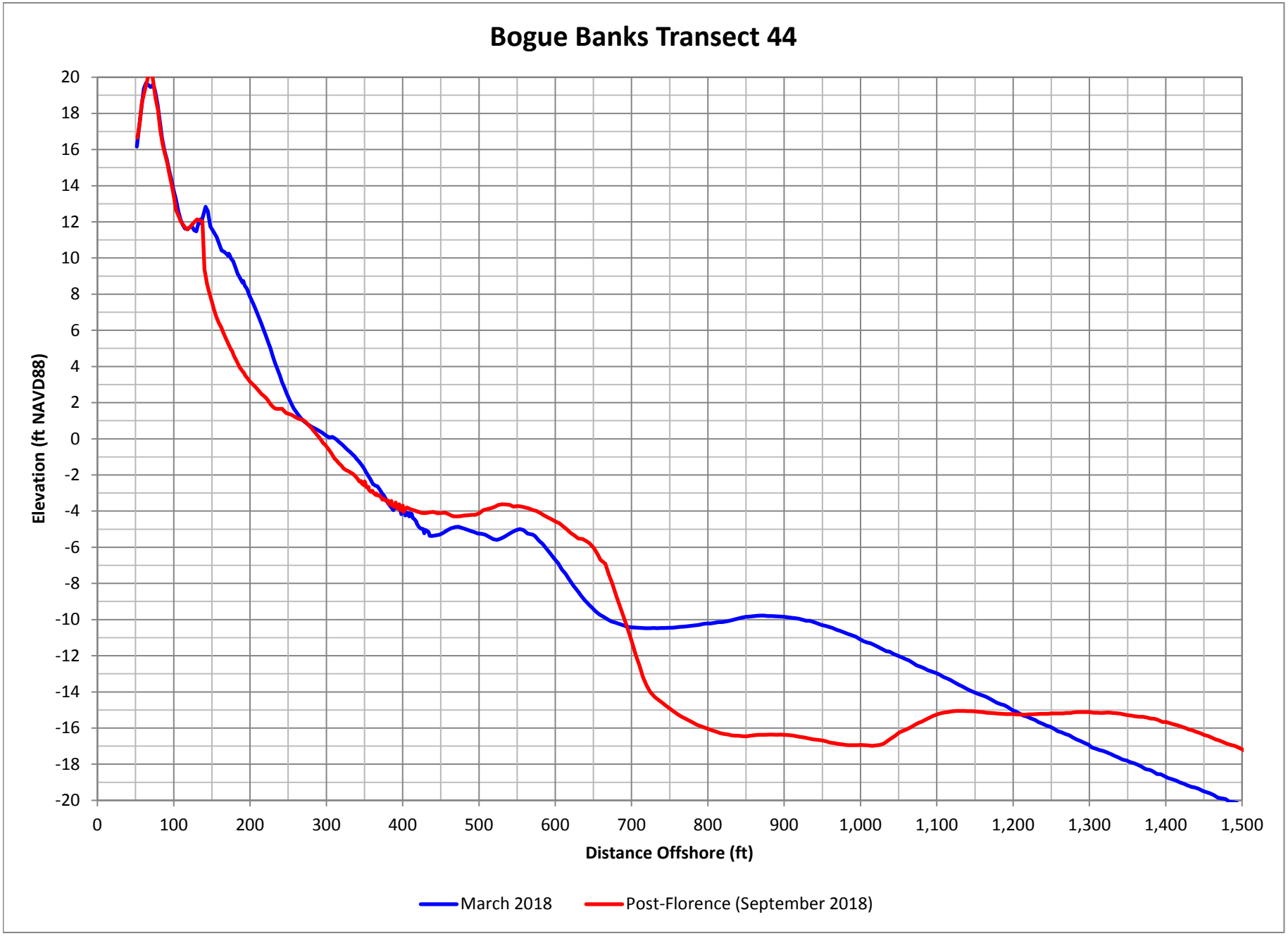


Figure D-88. Bogue Banks Profile Comparison Plot

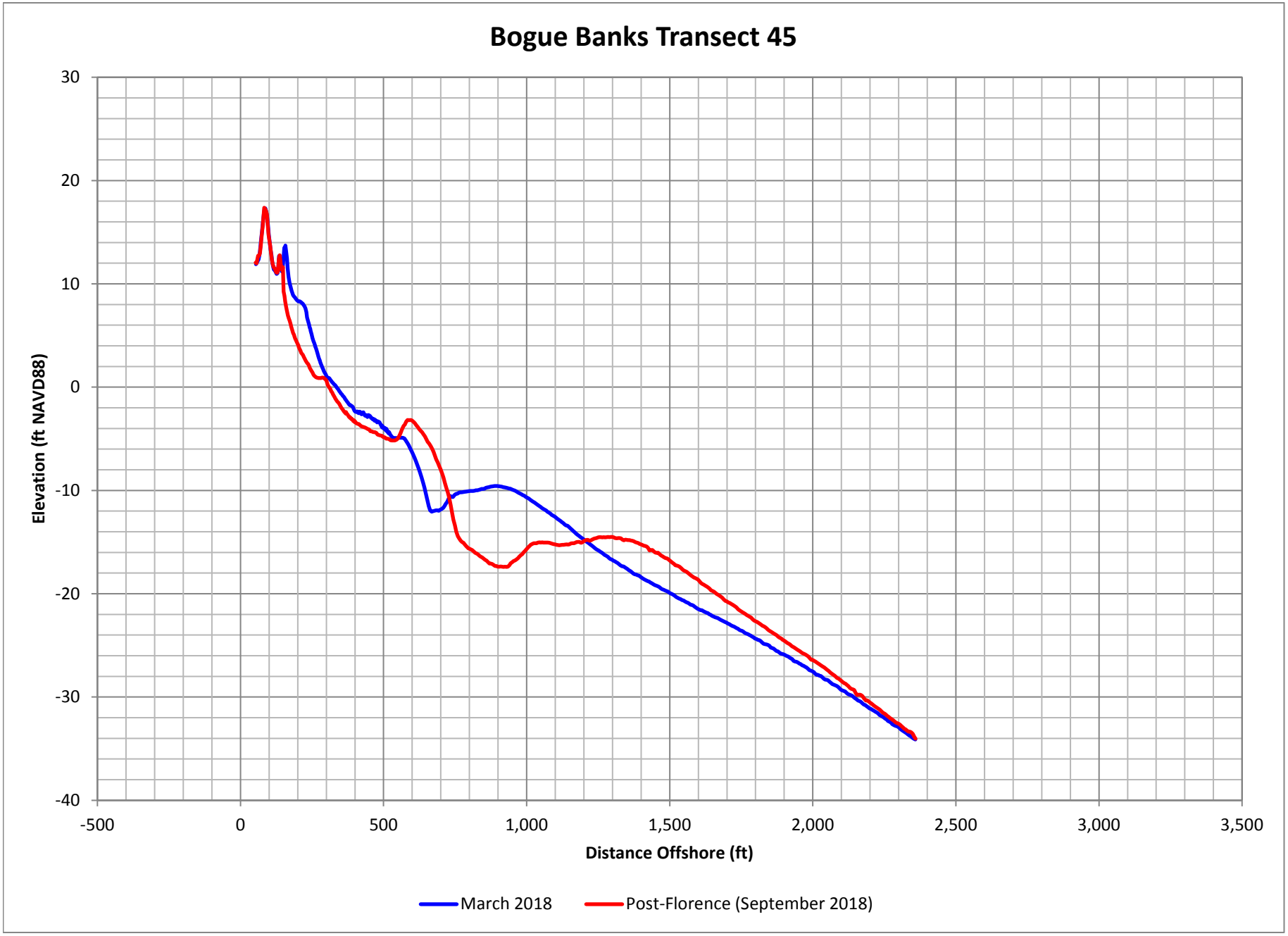


Figure D-89. Bogue Banks Profile Comparison Plot

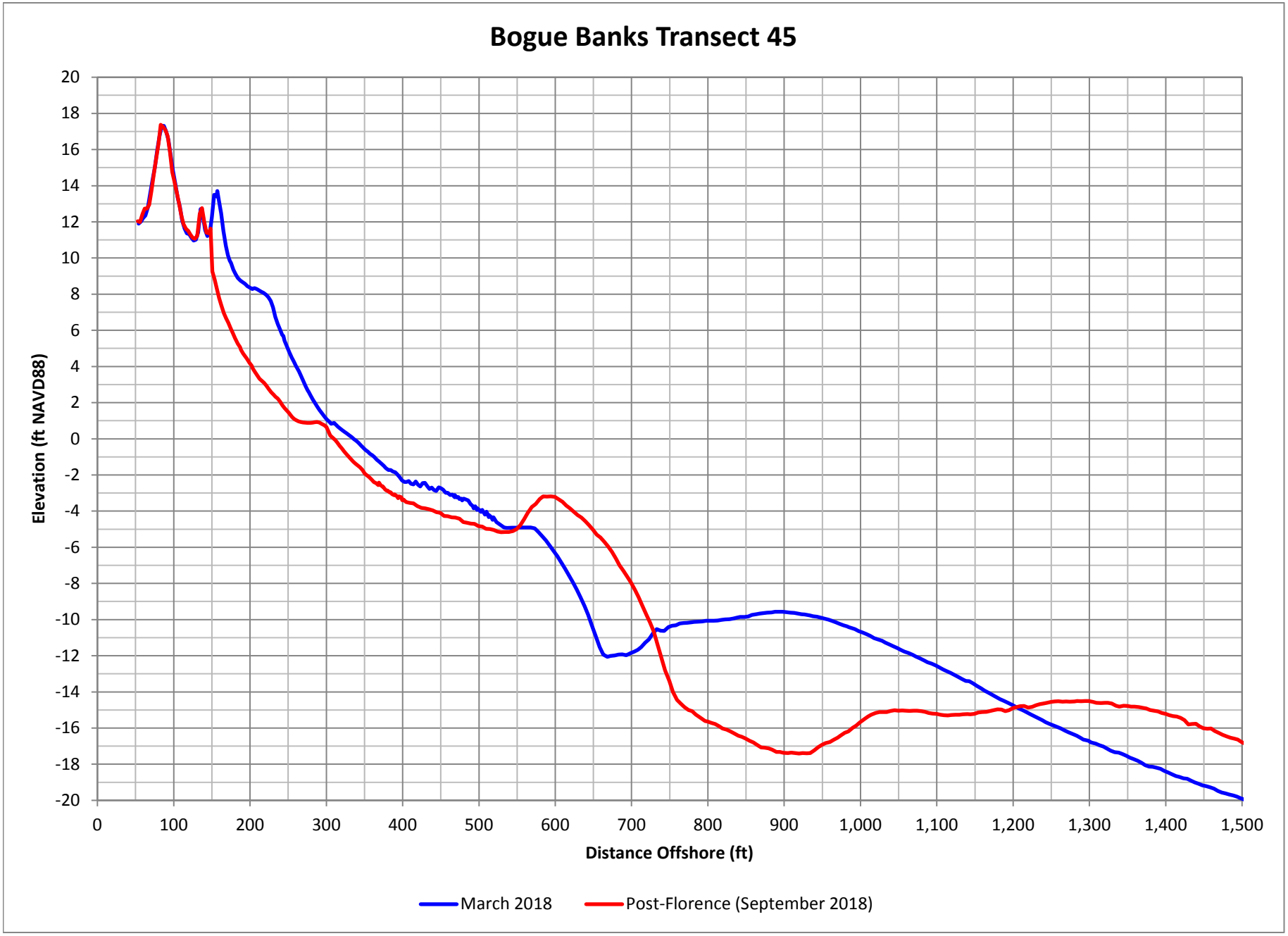


Figure D-90. Bogue Banks Profile Comparison Plot

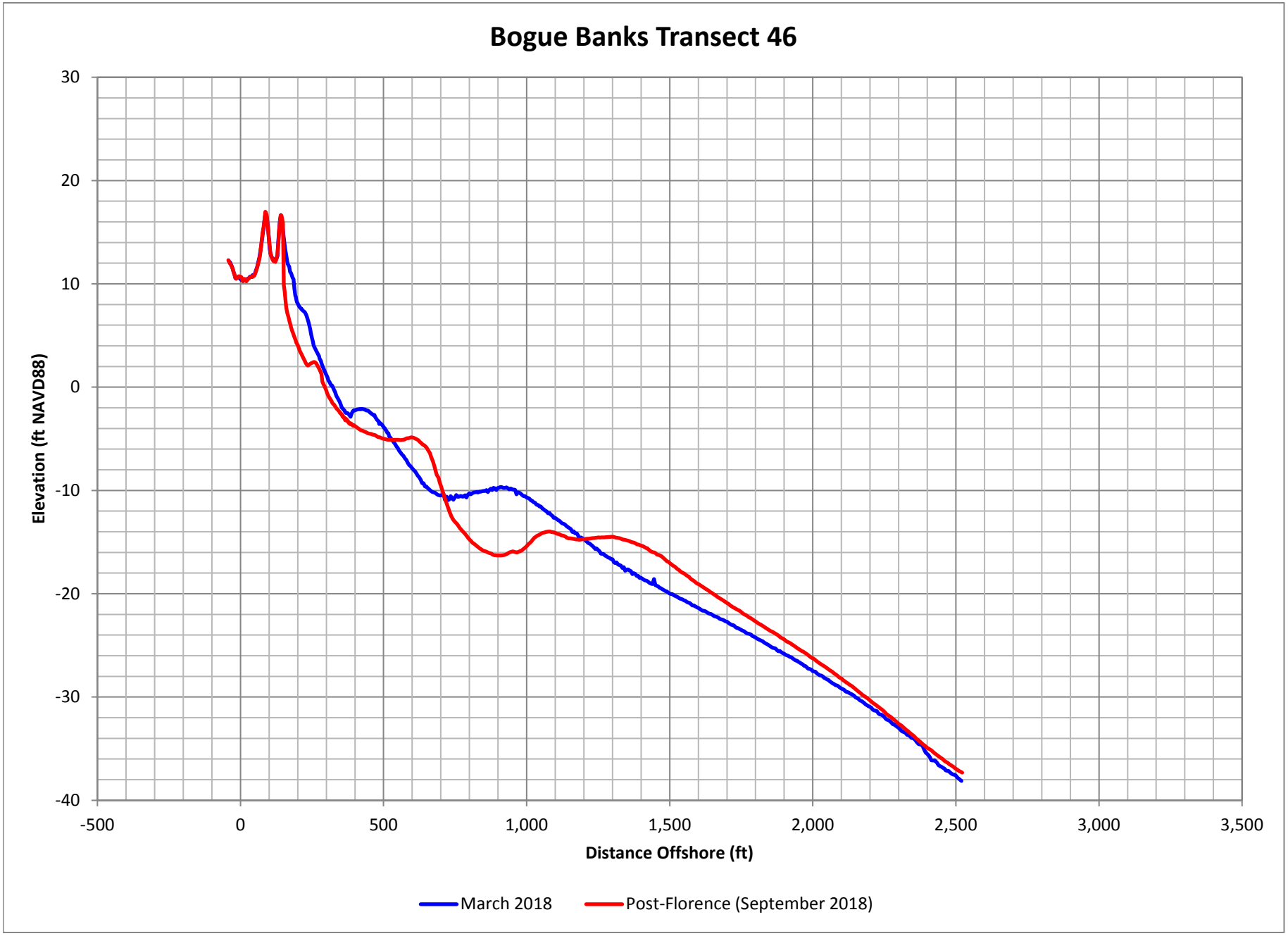


Figure D-91. Bogue Banks Profile Comparison Plot

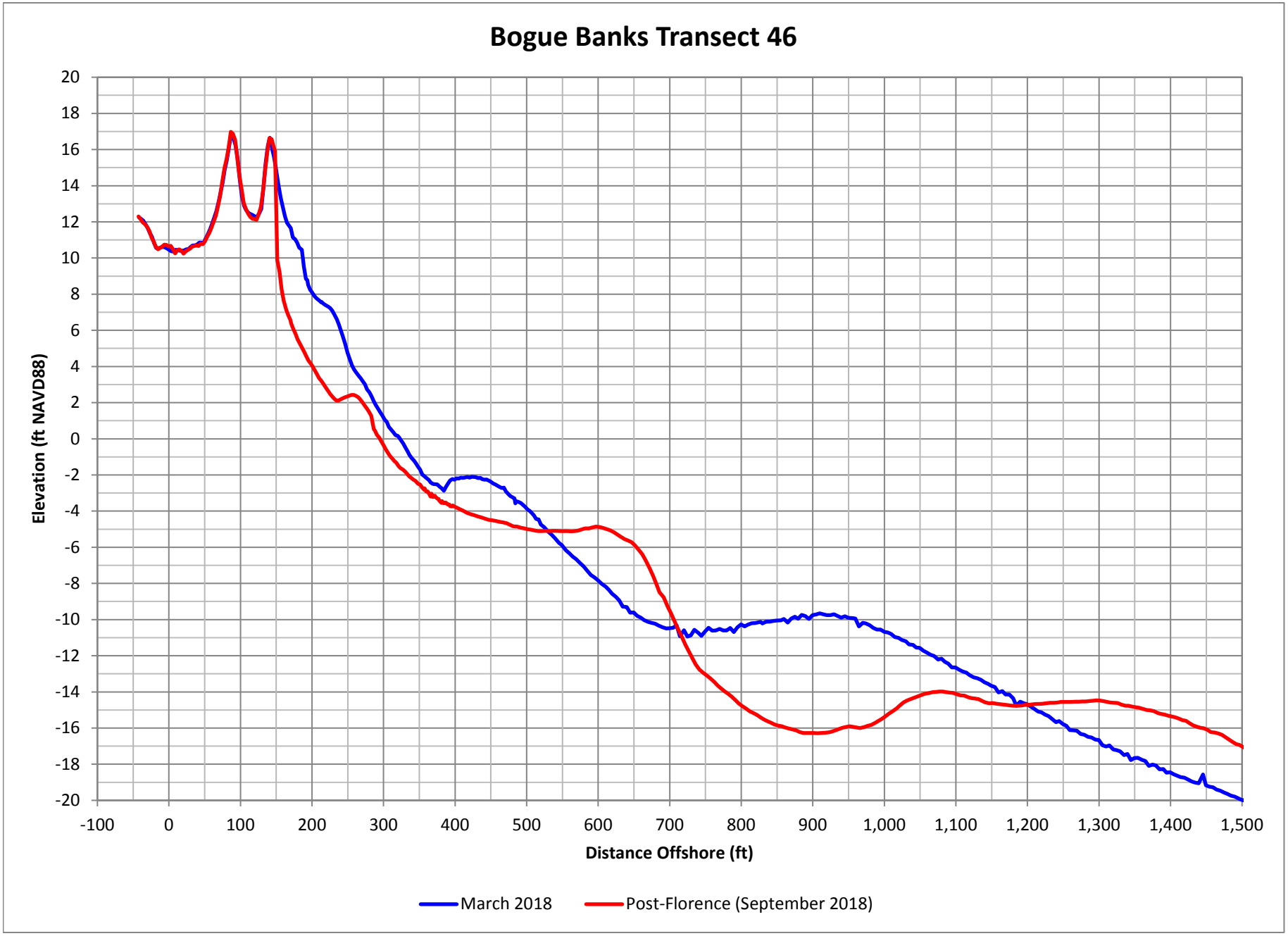


Figure D-92. Bogue Banks Profile Comparison Plot

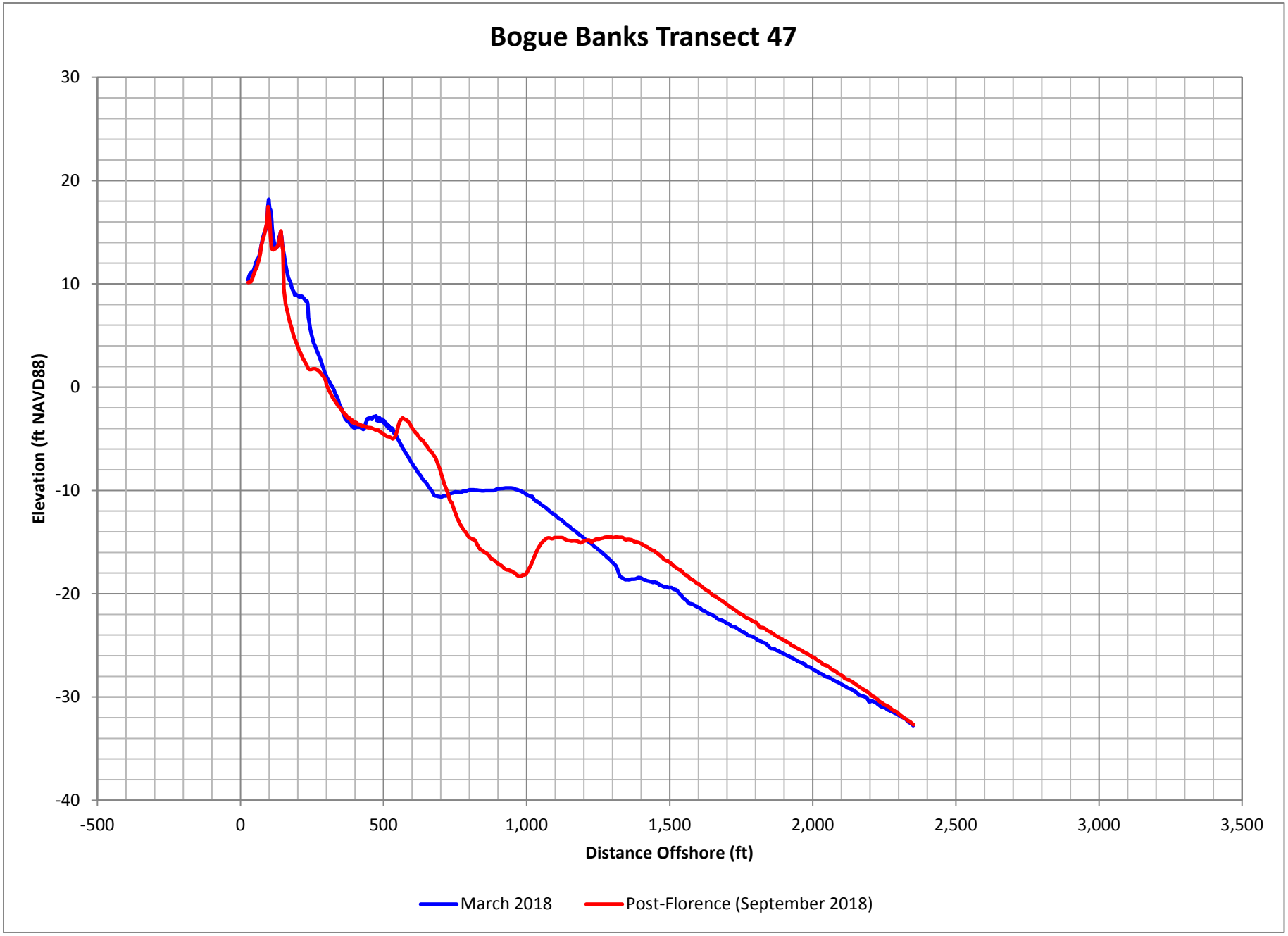


Figure D-93. Bogue Banks Profile Comparison Plot

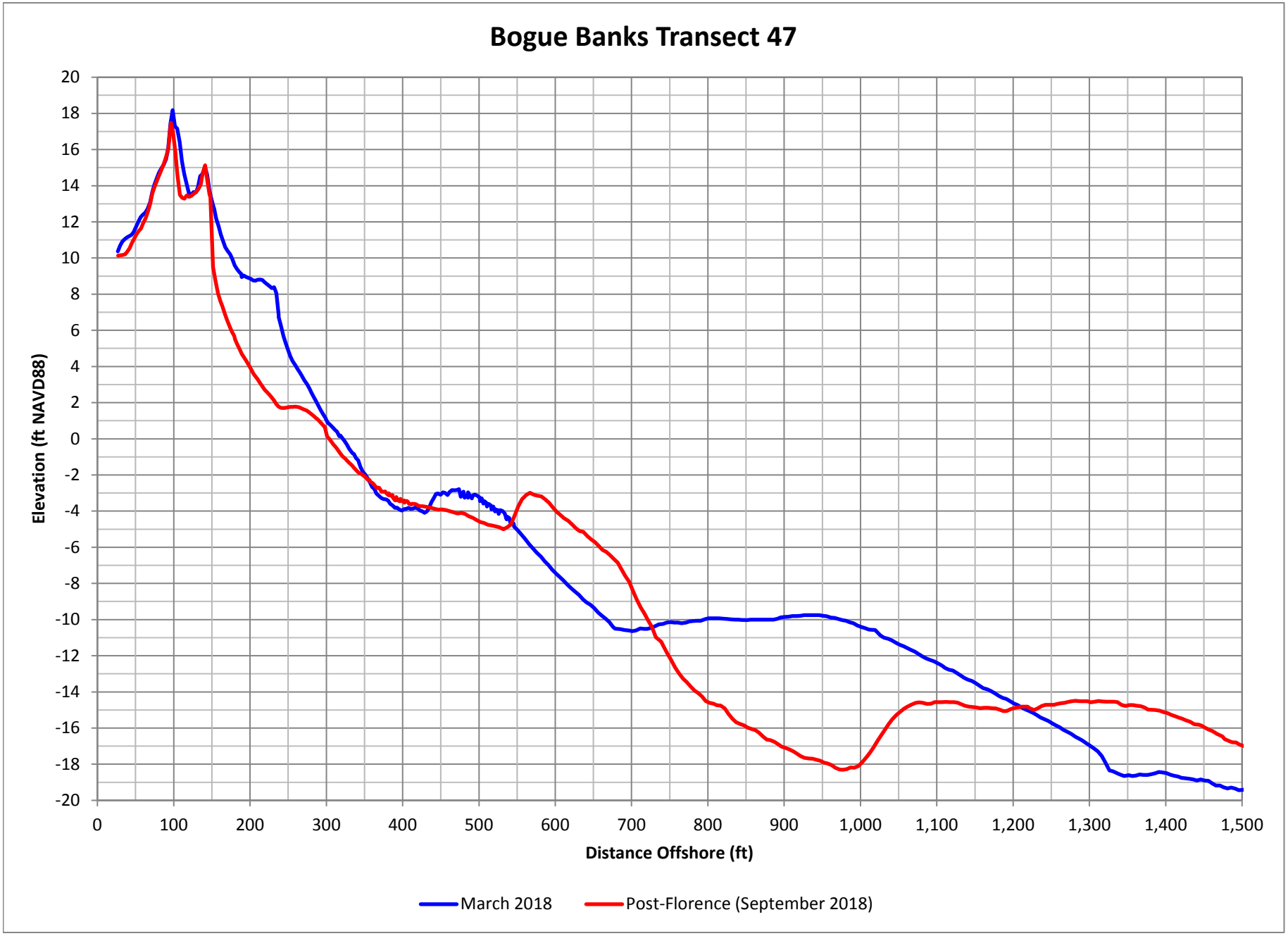


Figure D-94. Bogue Banks Profile Comparison Plot

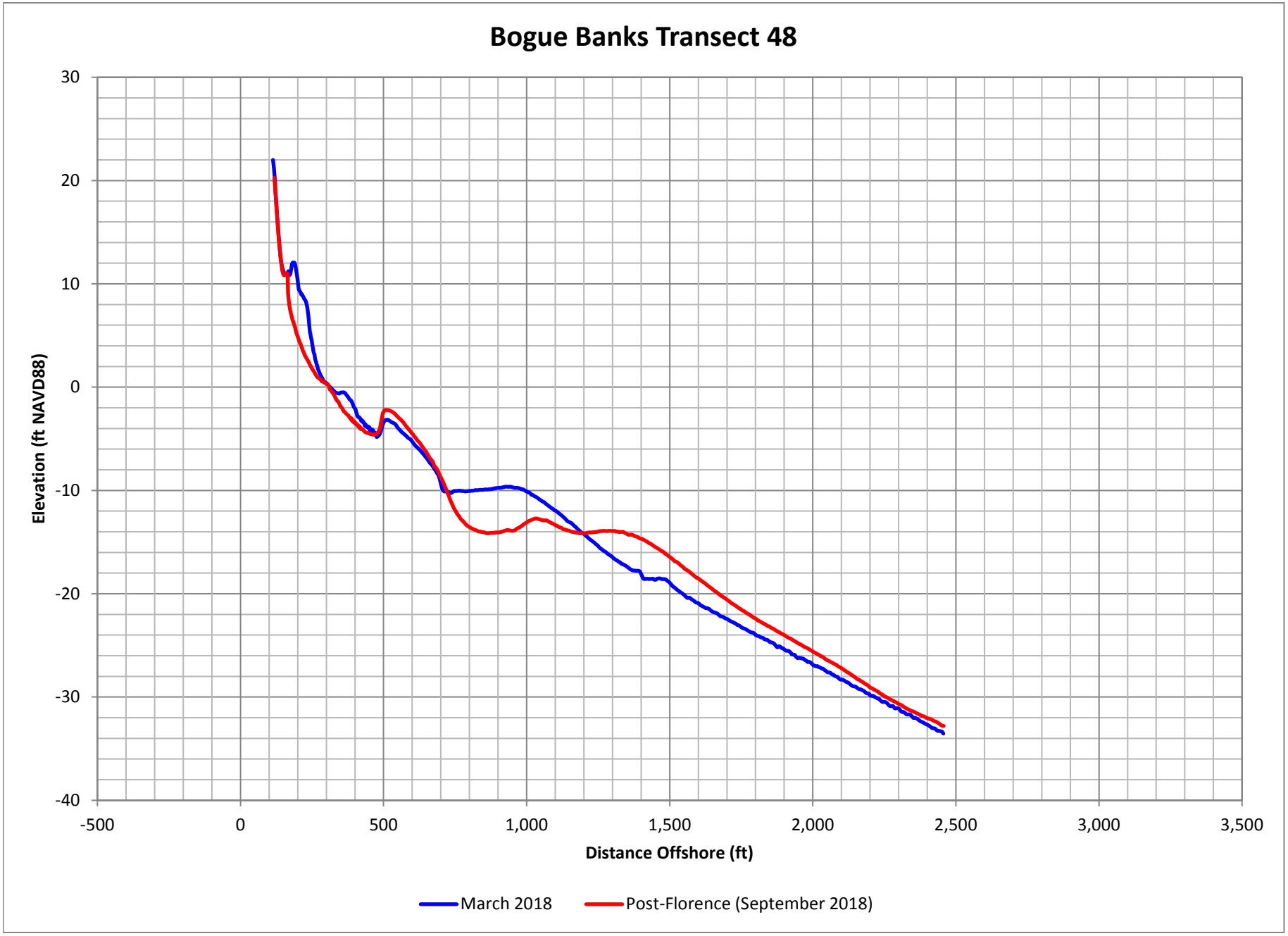


Figure D-95. Bogue Banks Profile Comparison Plot

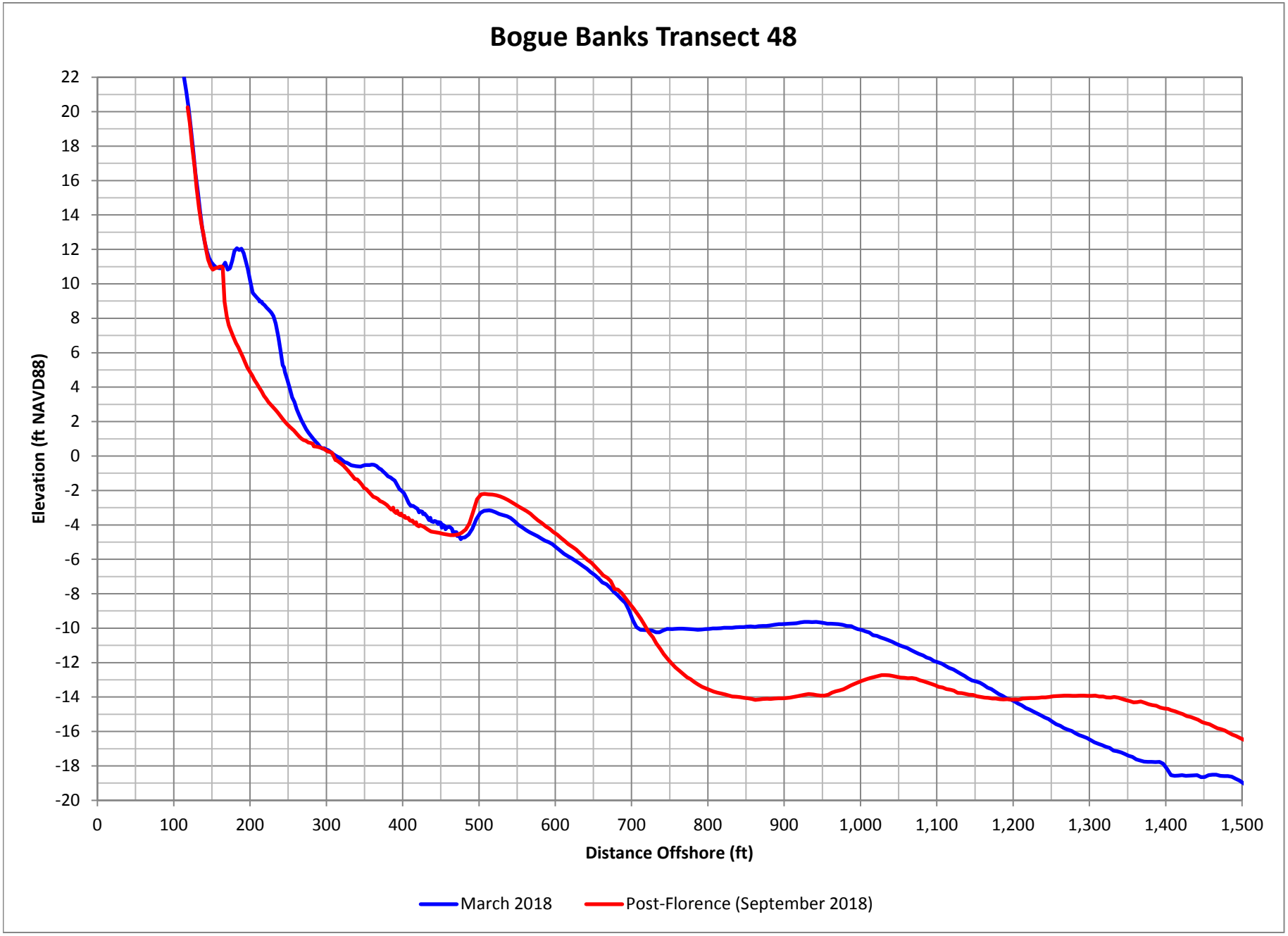


Figure D-96. Bogue Banks Profile Comparison Plot

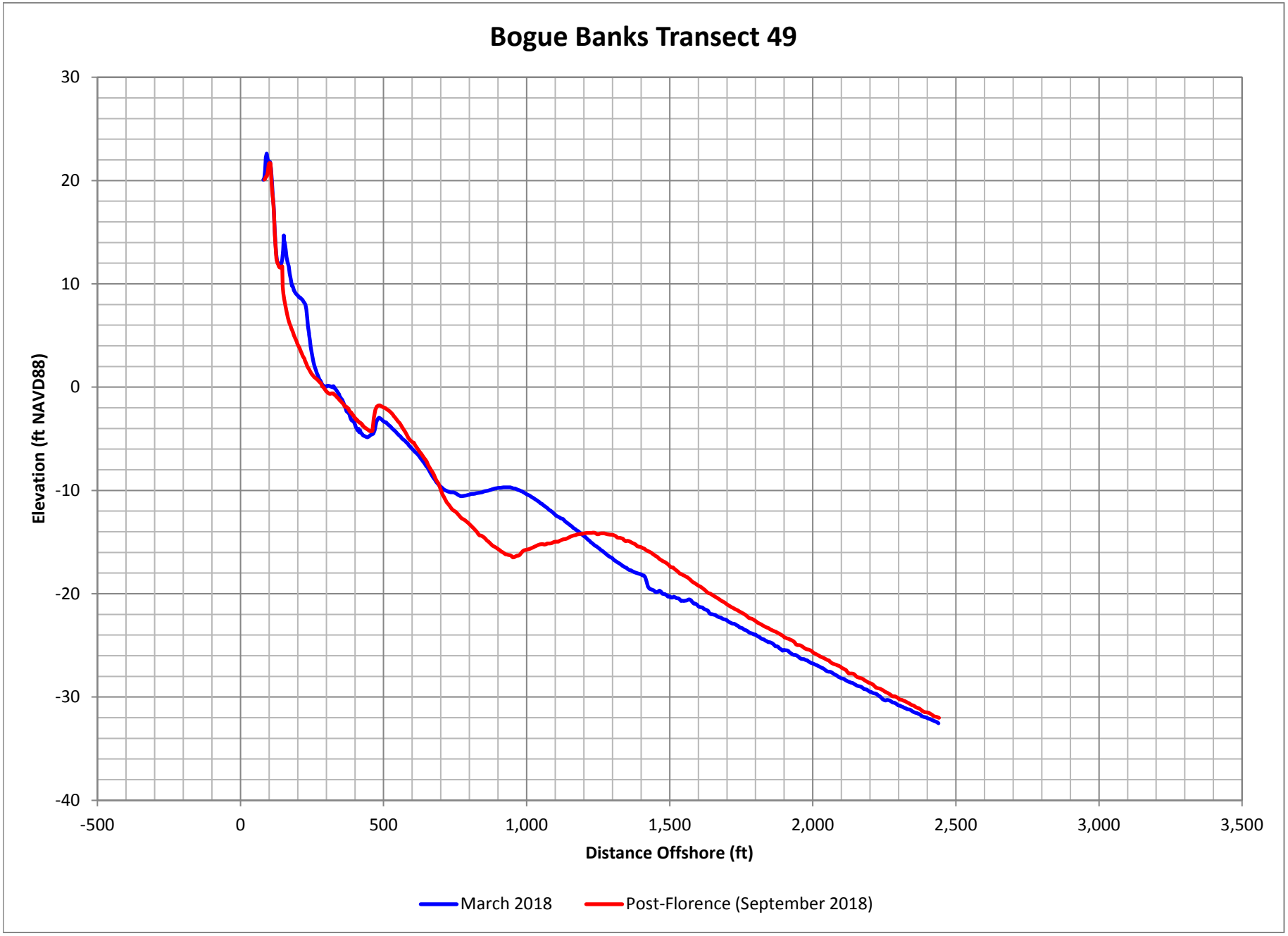


Figure D-97. Bogue Banks Profile Comparison Plot

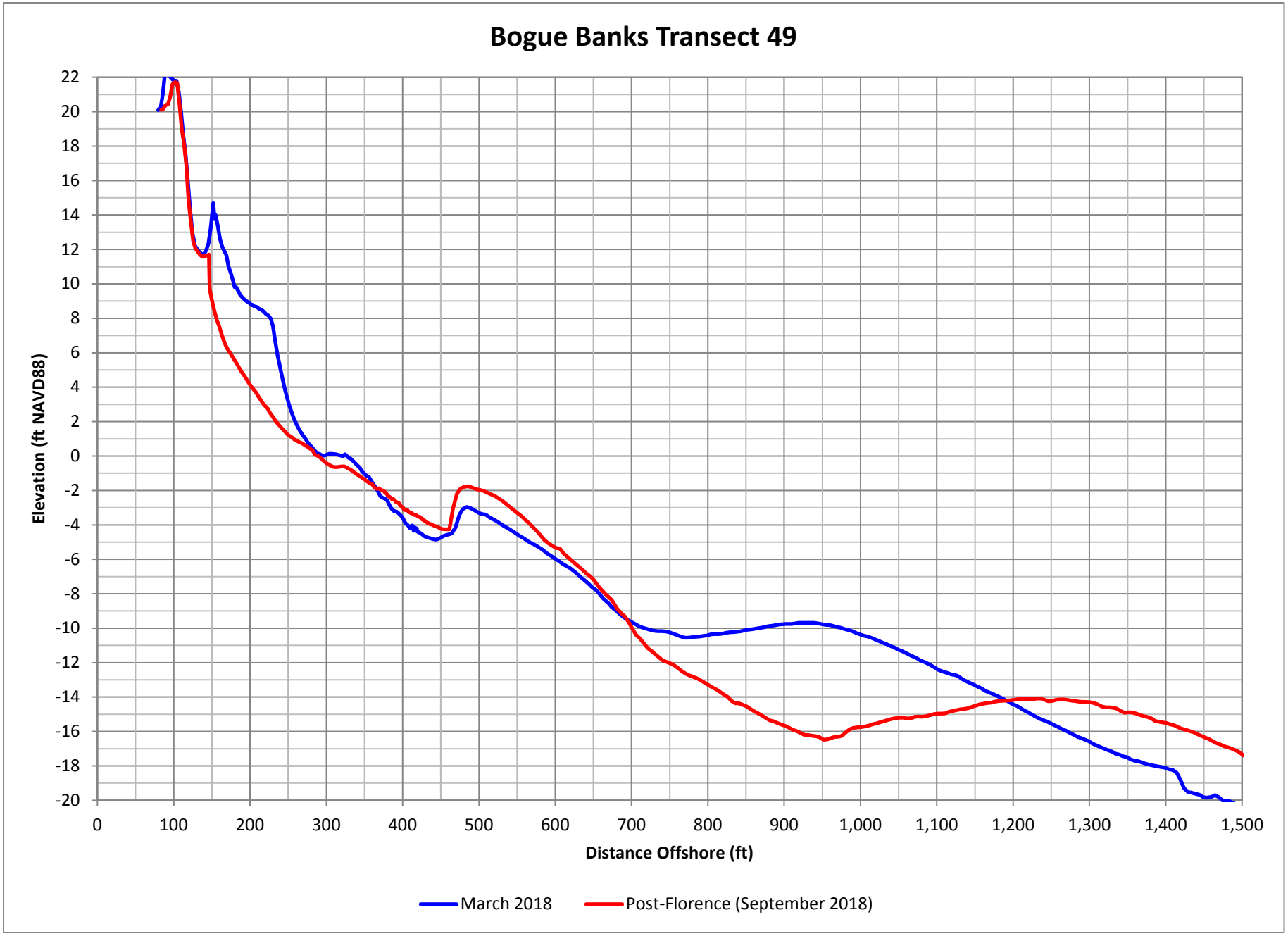


Figure D-98. Bogue Banks Profile Comparison Plot

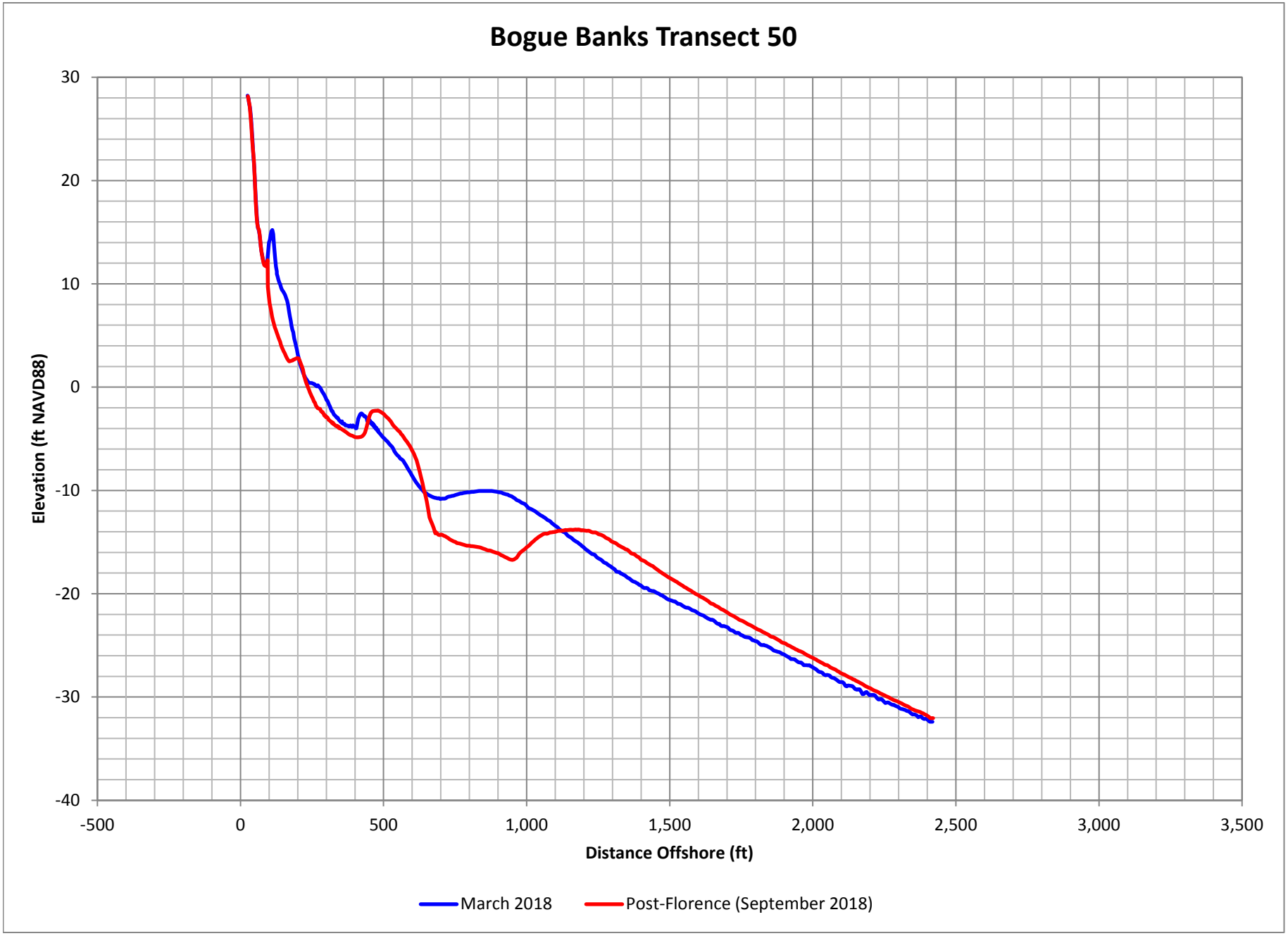


Figure D-99. Bogue Banks Profile Comparison Plot

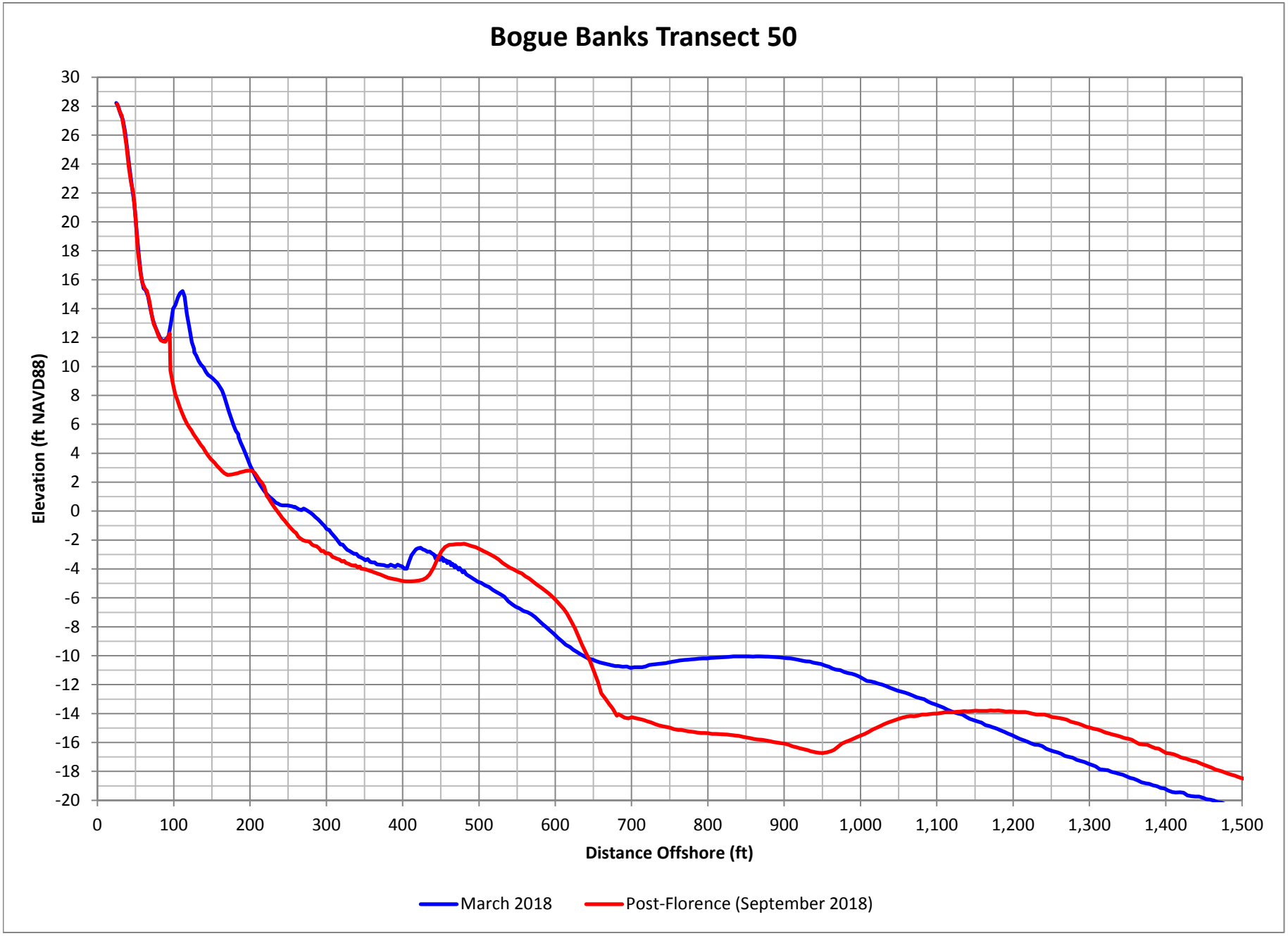


Figure D-100. Bogue Banks Profile Comparison Plot

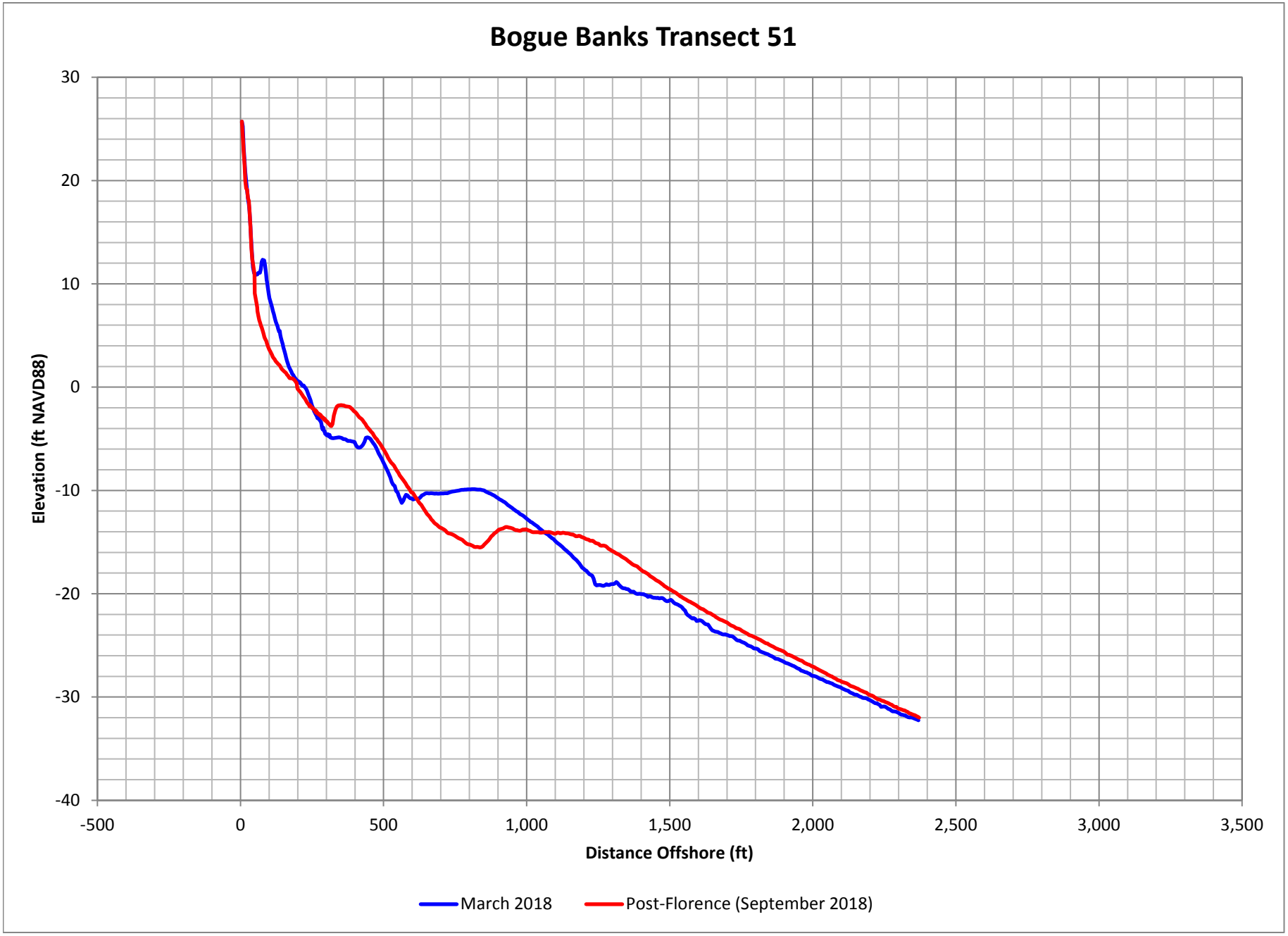


Figure D-101. Bogue Banks Profile Comparison Plot

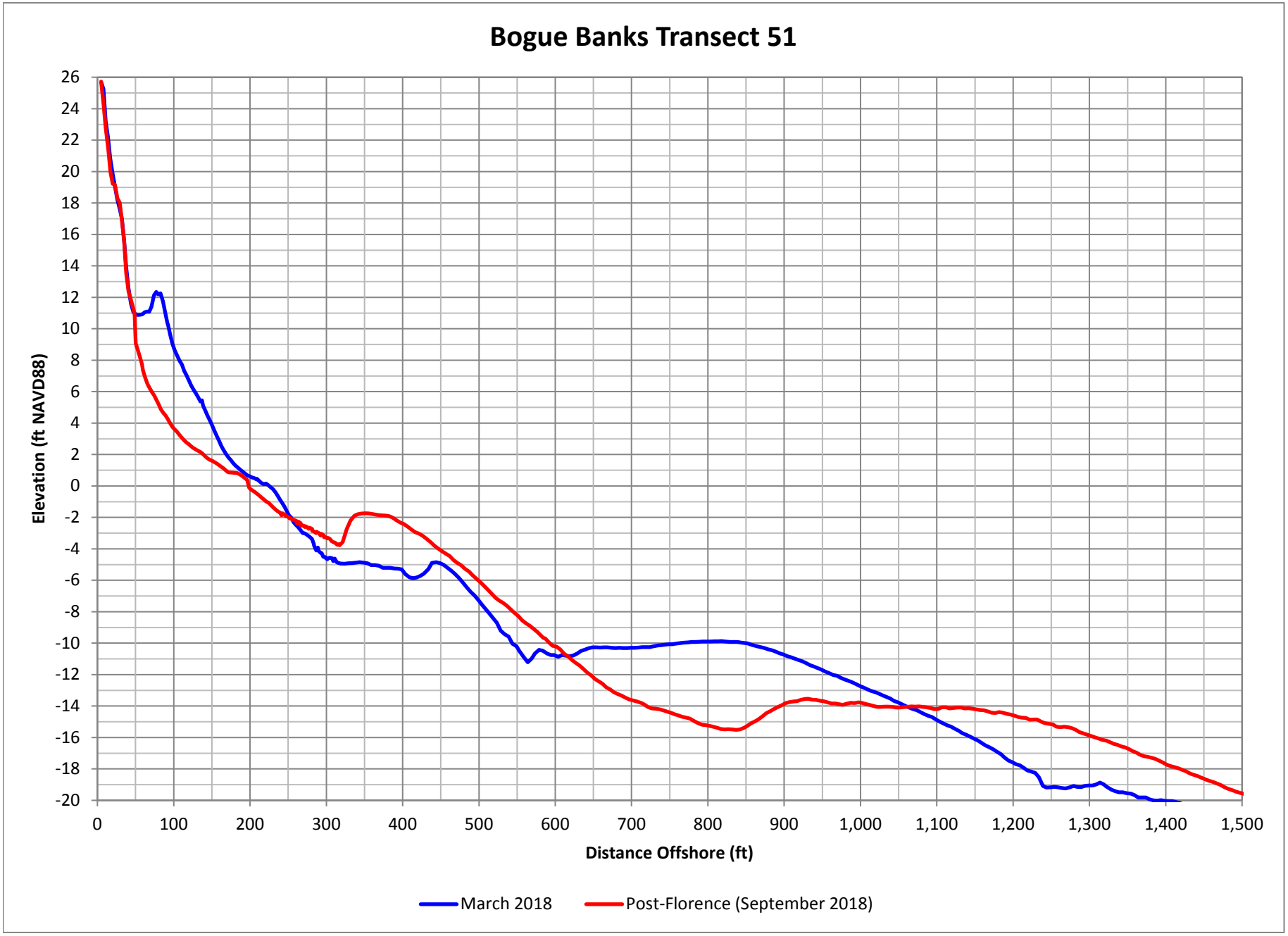


Figure D-102. Bogue Banks Profile Comparison Plot

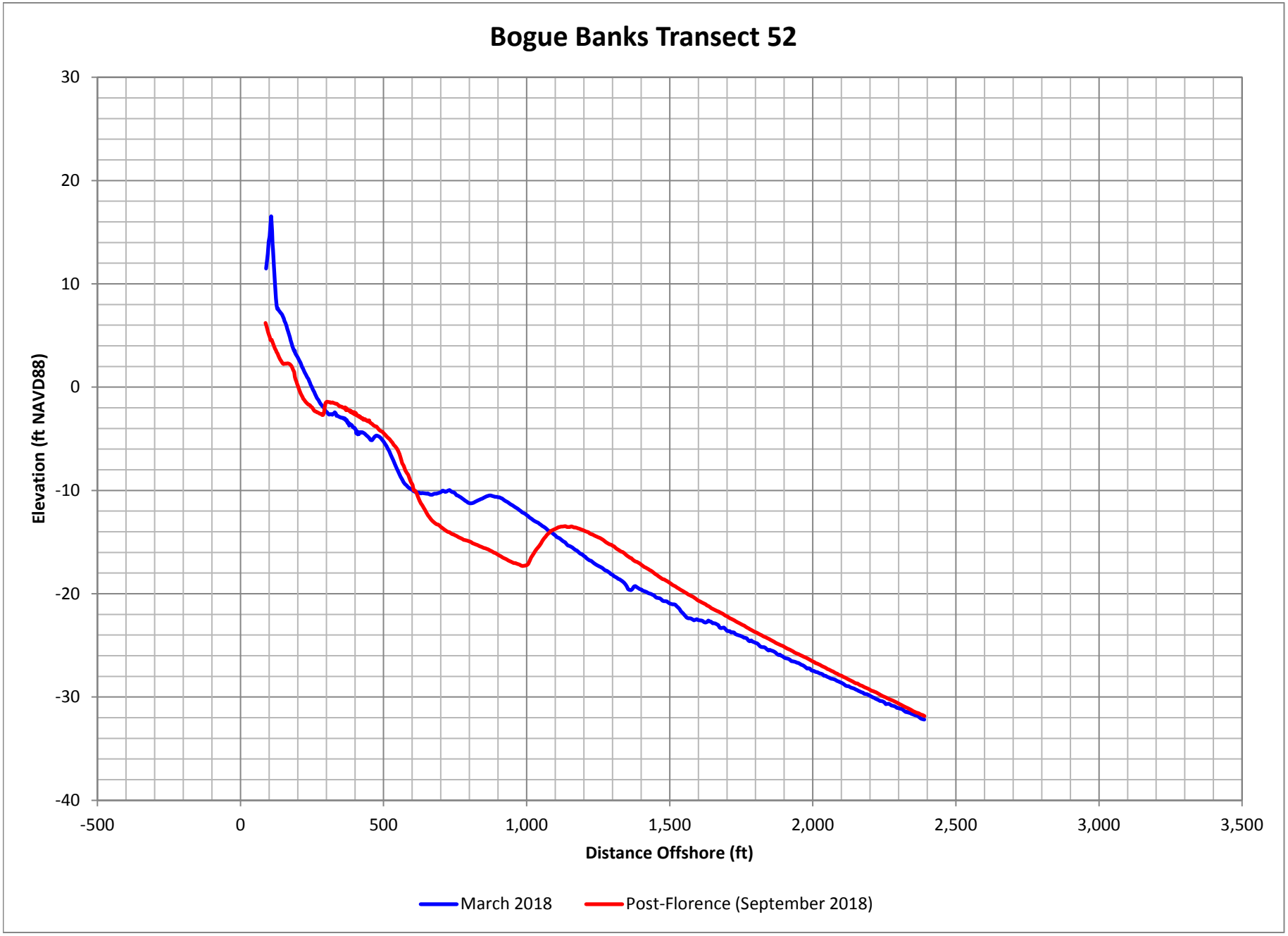


Figure D-103. Bogue Banks Profile Comparison Plot

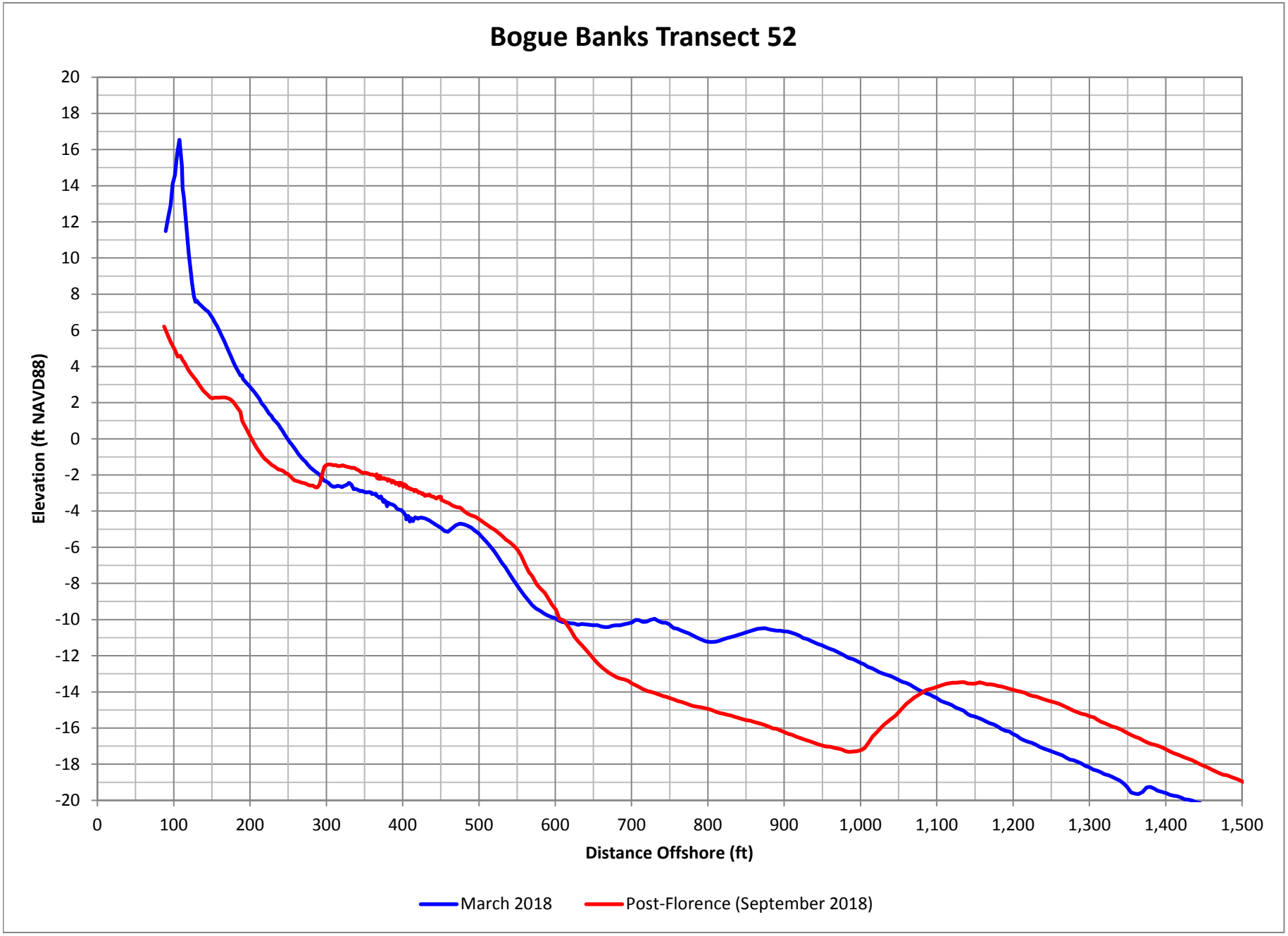


Figure D-104. Bogue Banks Profile Comparison Plot

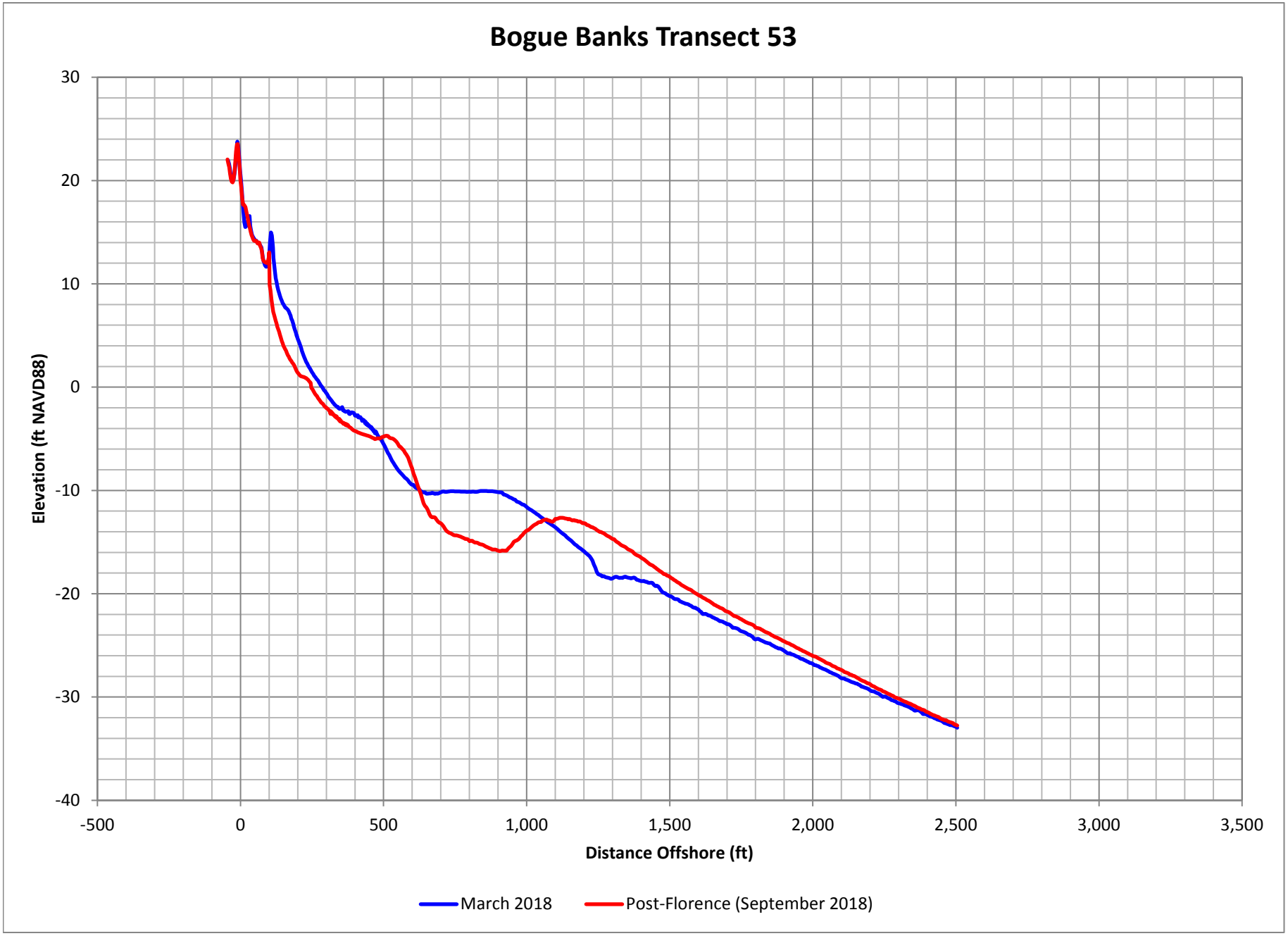


Figure D-105. Bogue Banks Profile Comparison Plot

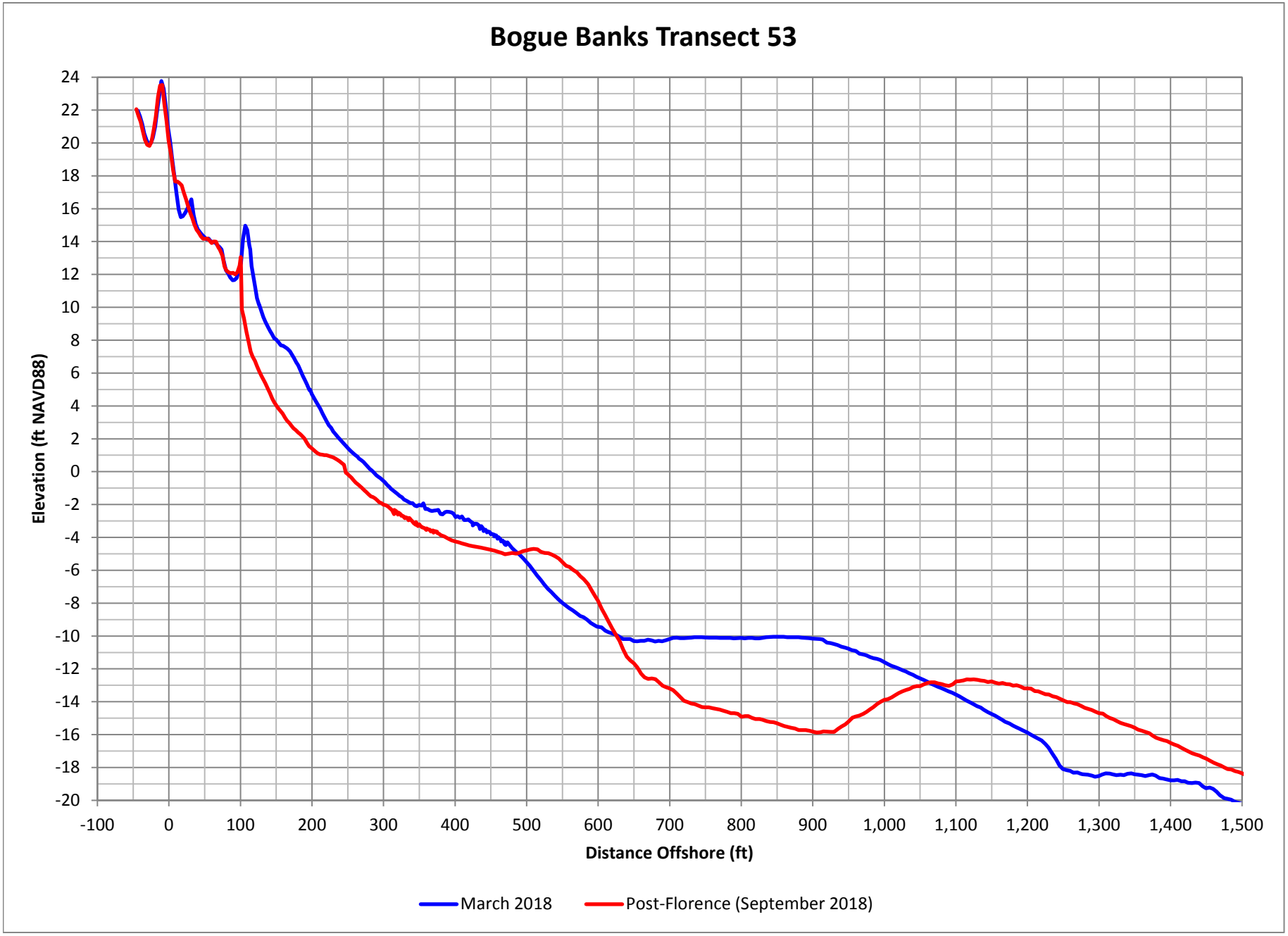


Figure D-106. Bogue Banks Profile Comparison Plot

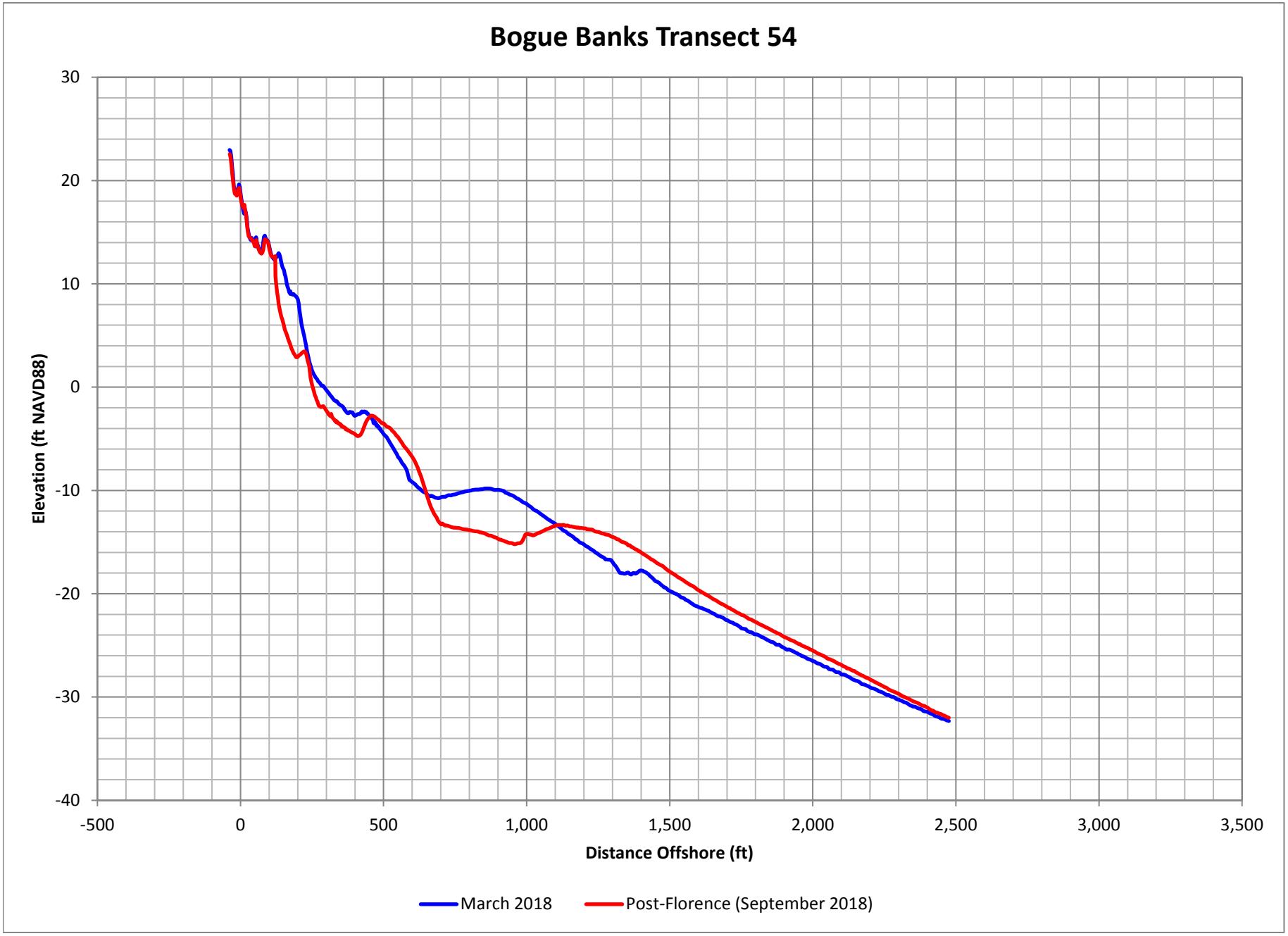


Figure D-107. Bogue Banks Profile Comparison Plot

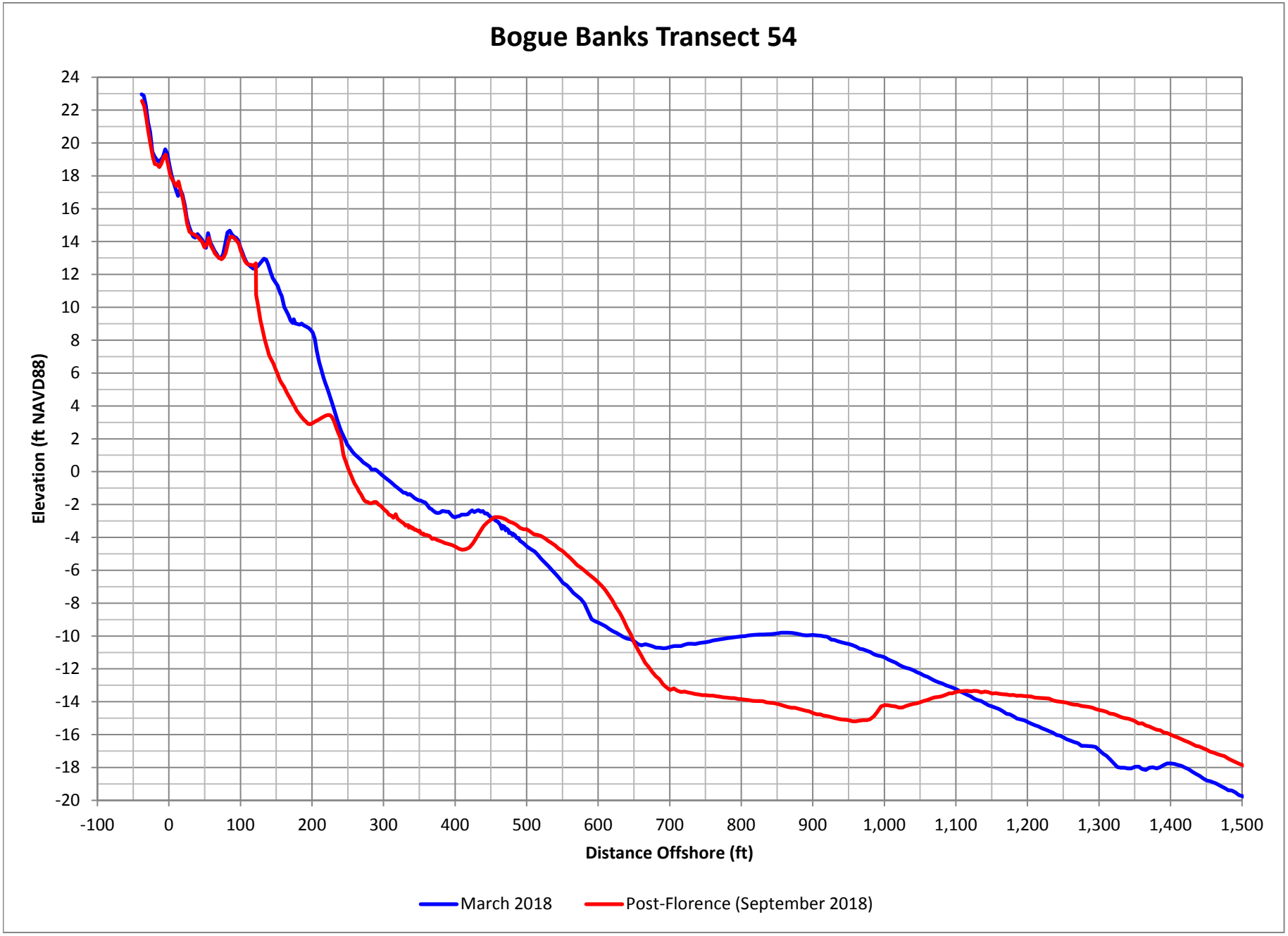


Figure D-108. Bogue Banks Profile Comparison Plot

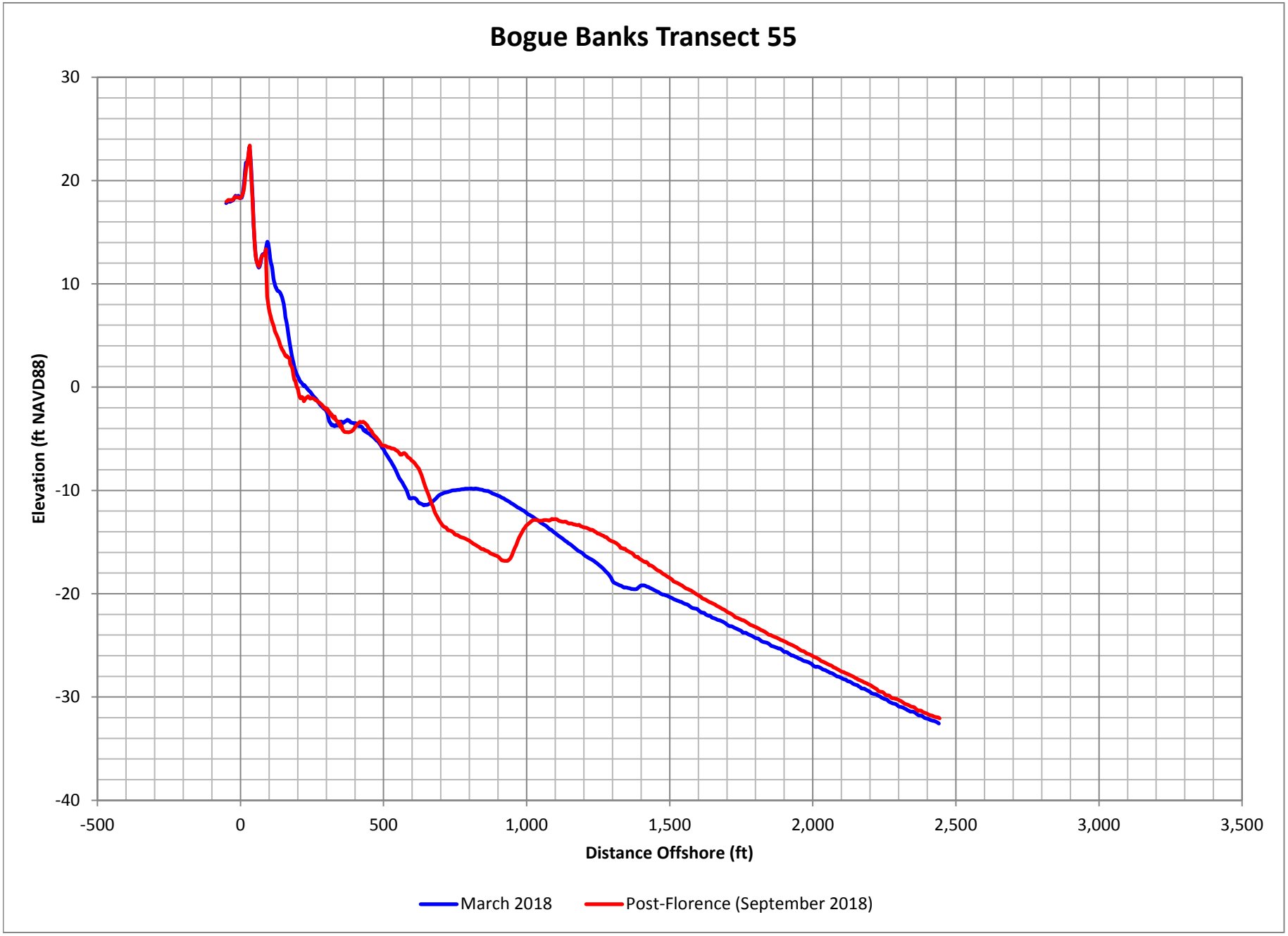


Figure D-109. Bogue Banks Profile Comparison Plot

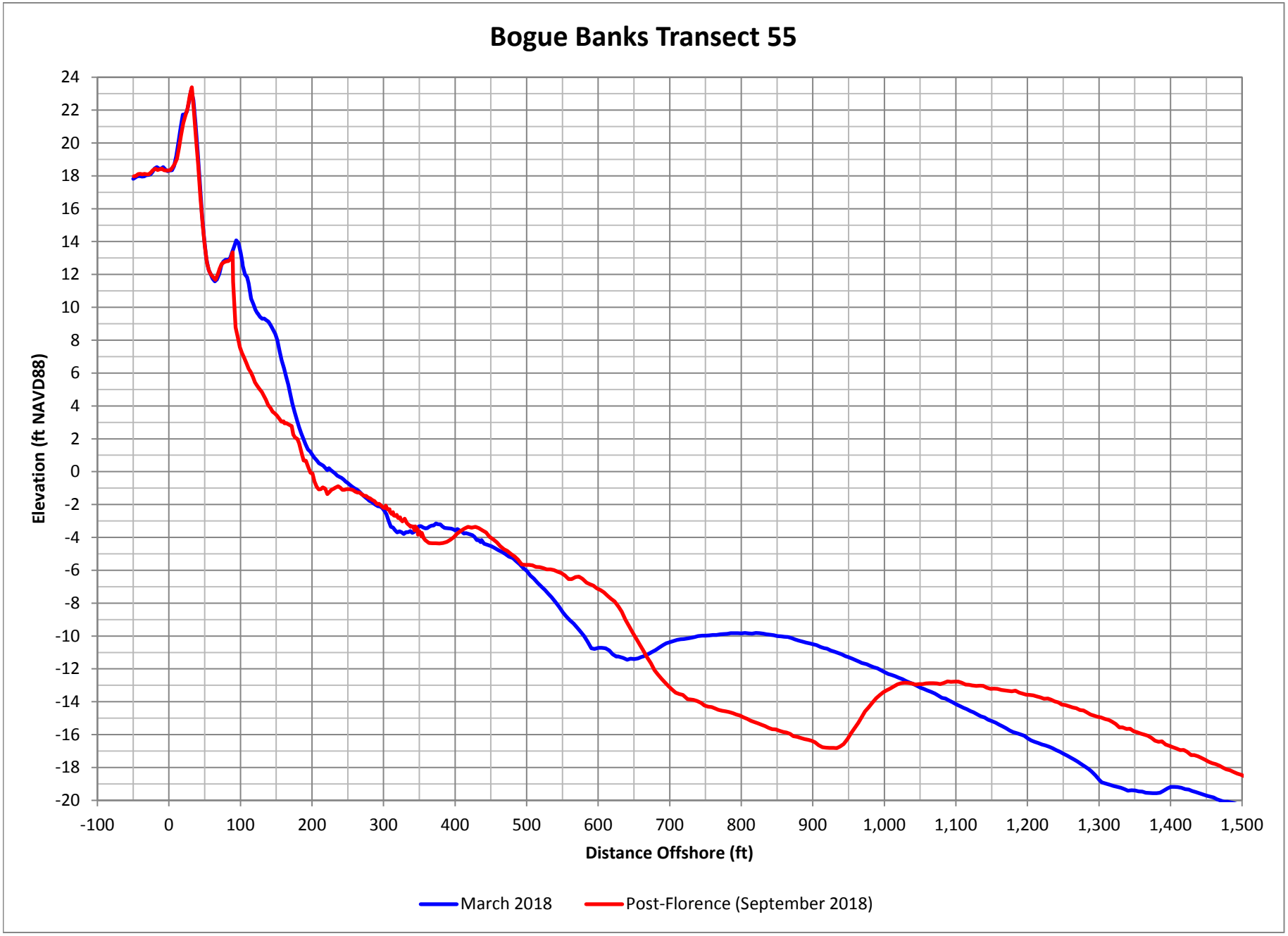


Figure D-110. Bogue Banks Profile Comparison Plot

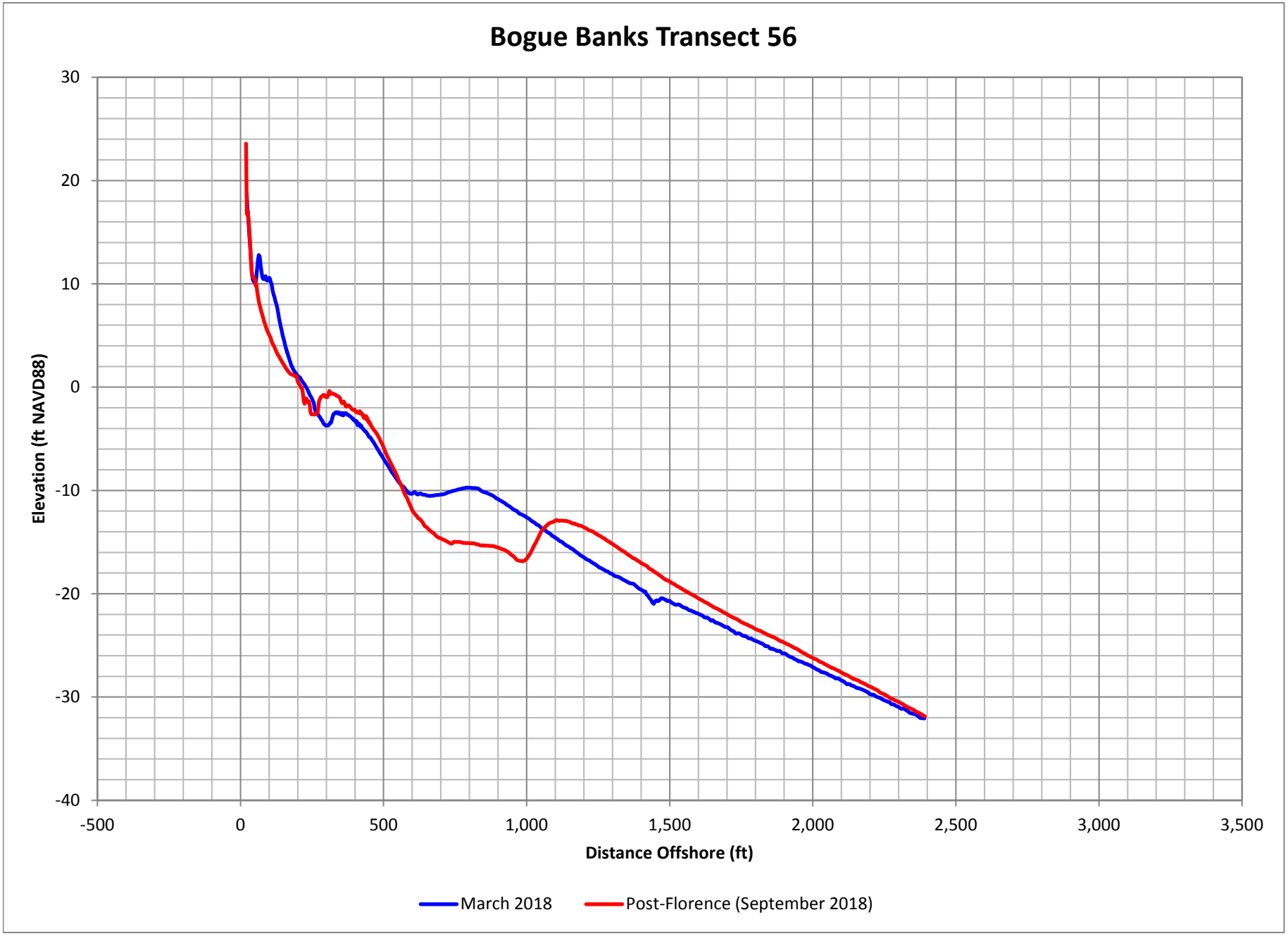


Figure D-111. Bogue Banks Profile Comparison Plot

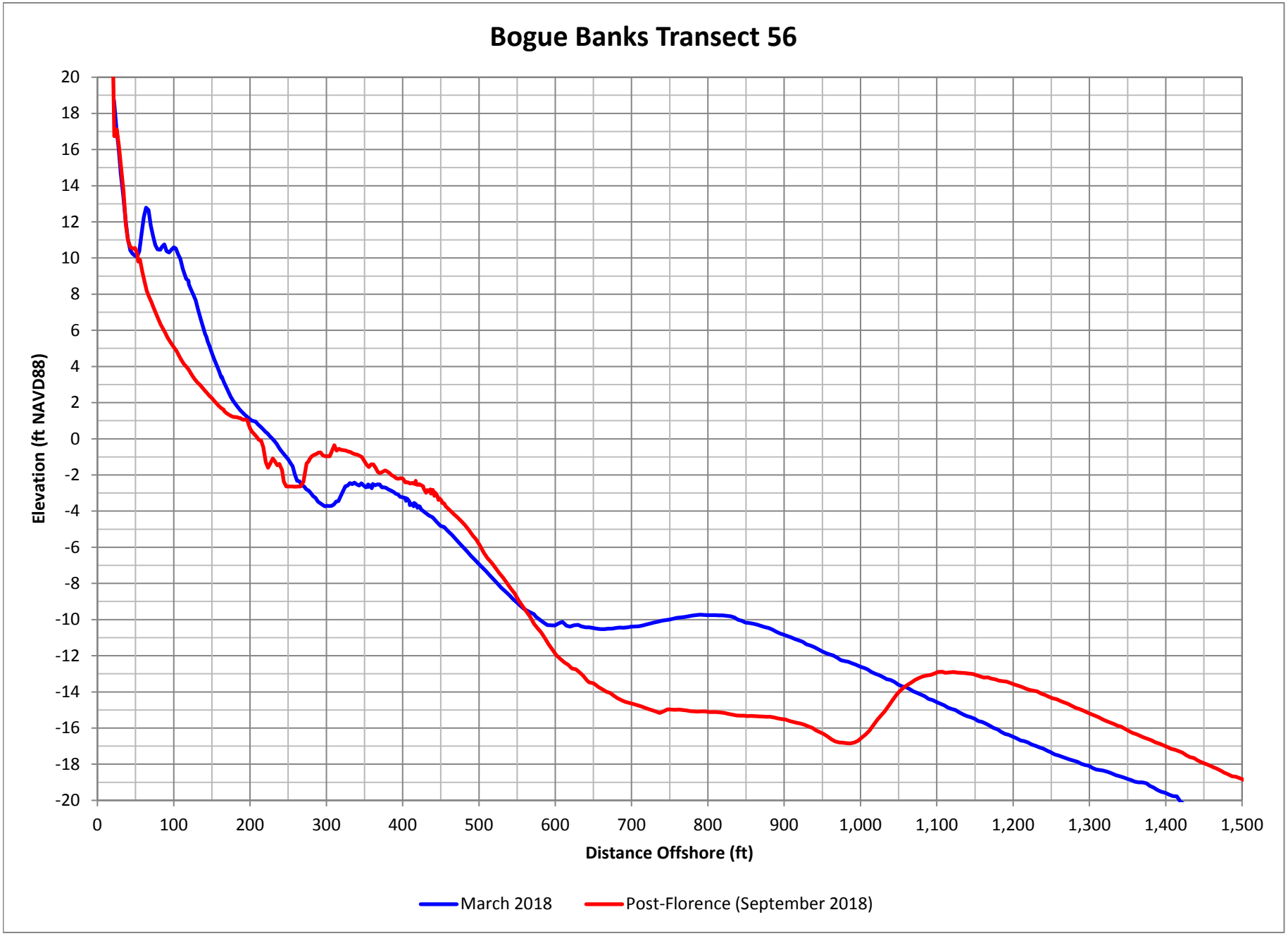


Figure D-112. Bogue Banks Profile Comparison Plot

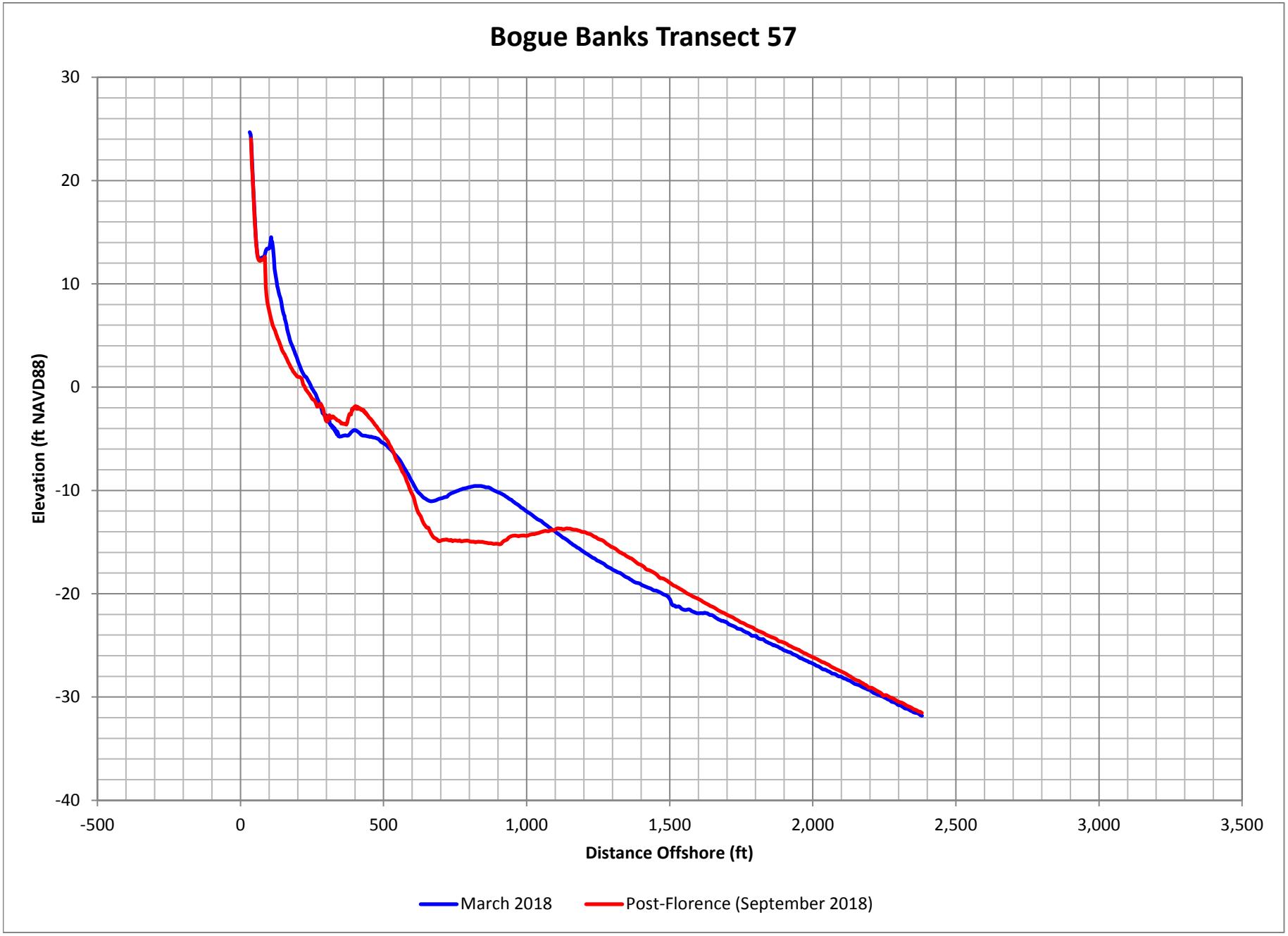


Figure D-113. Bogue Banks Profile Comparison Plot

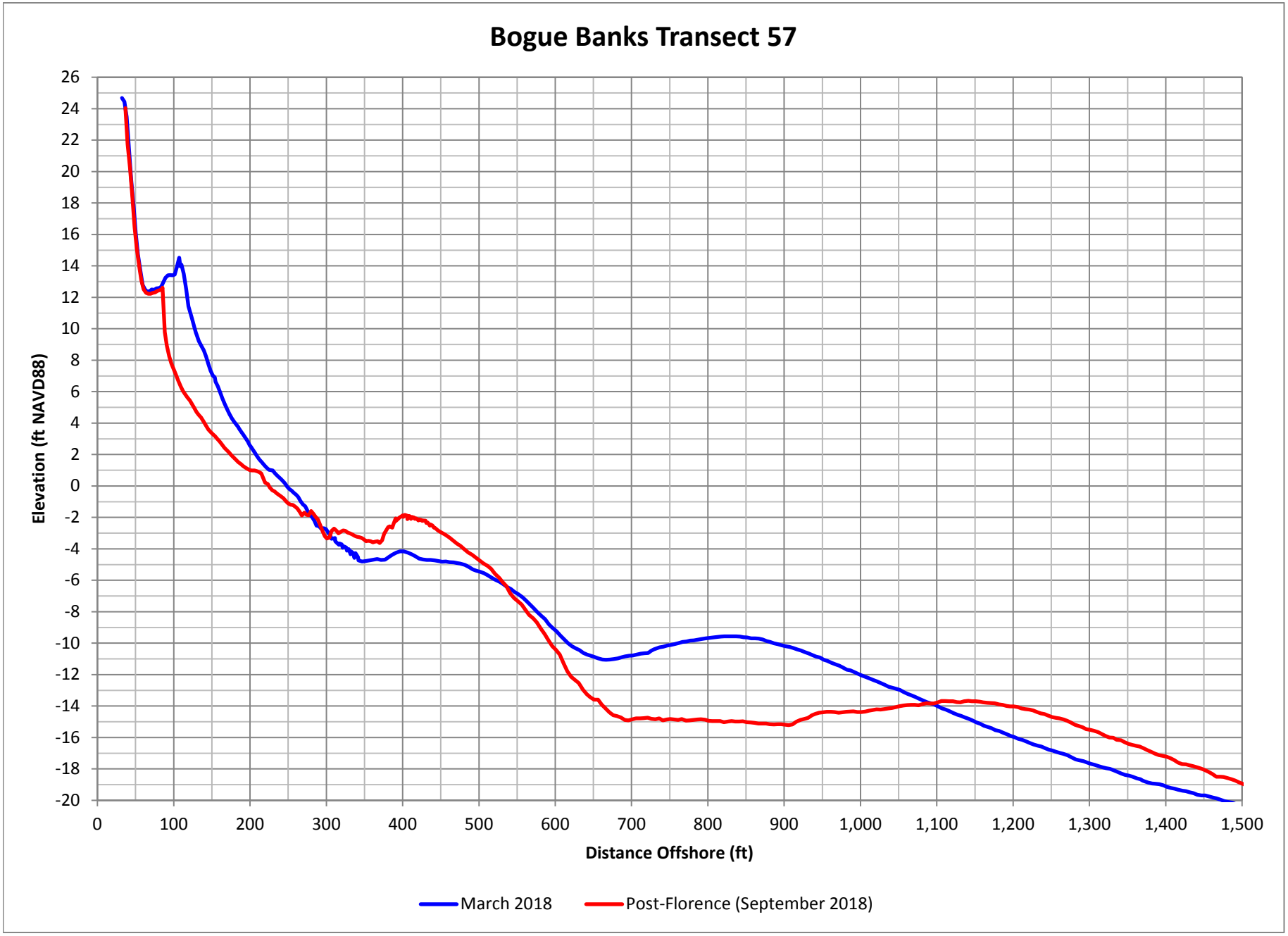


Figure D-114. Bogue Banks Profile Comparison Plot

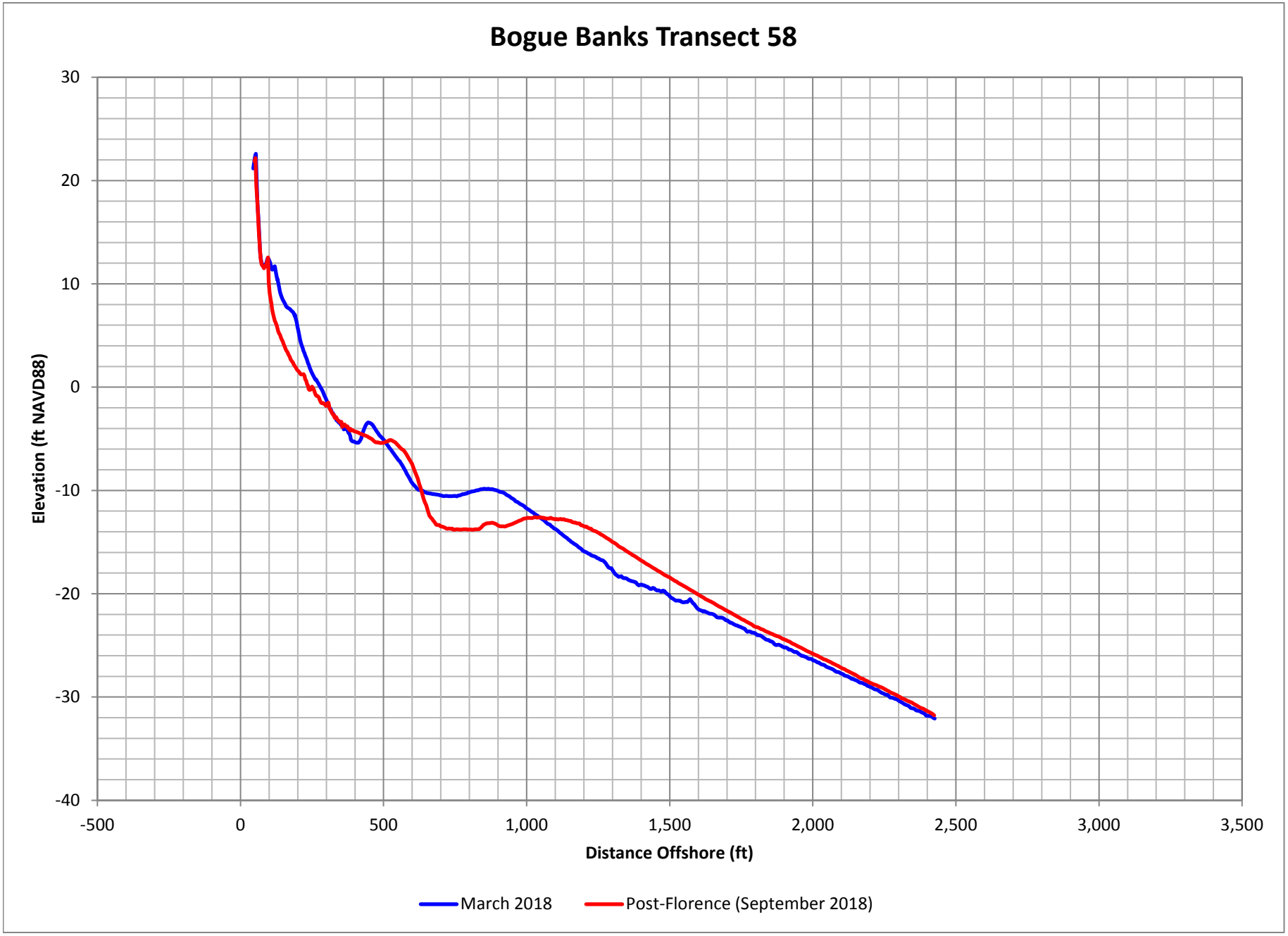


Figure D-115. Bogue Banks Profile Comparison Plot

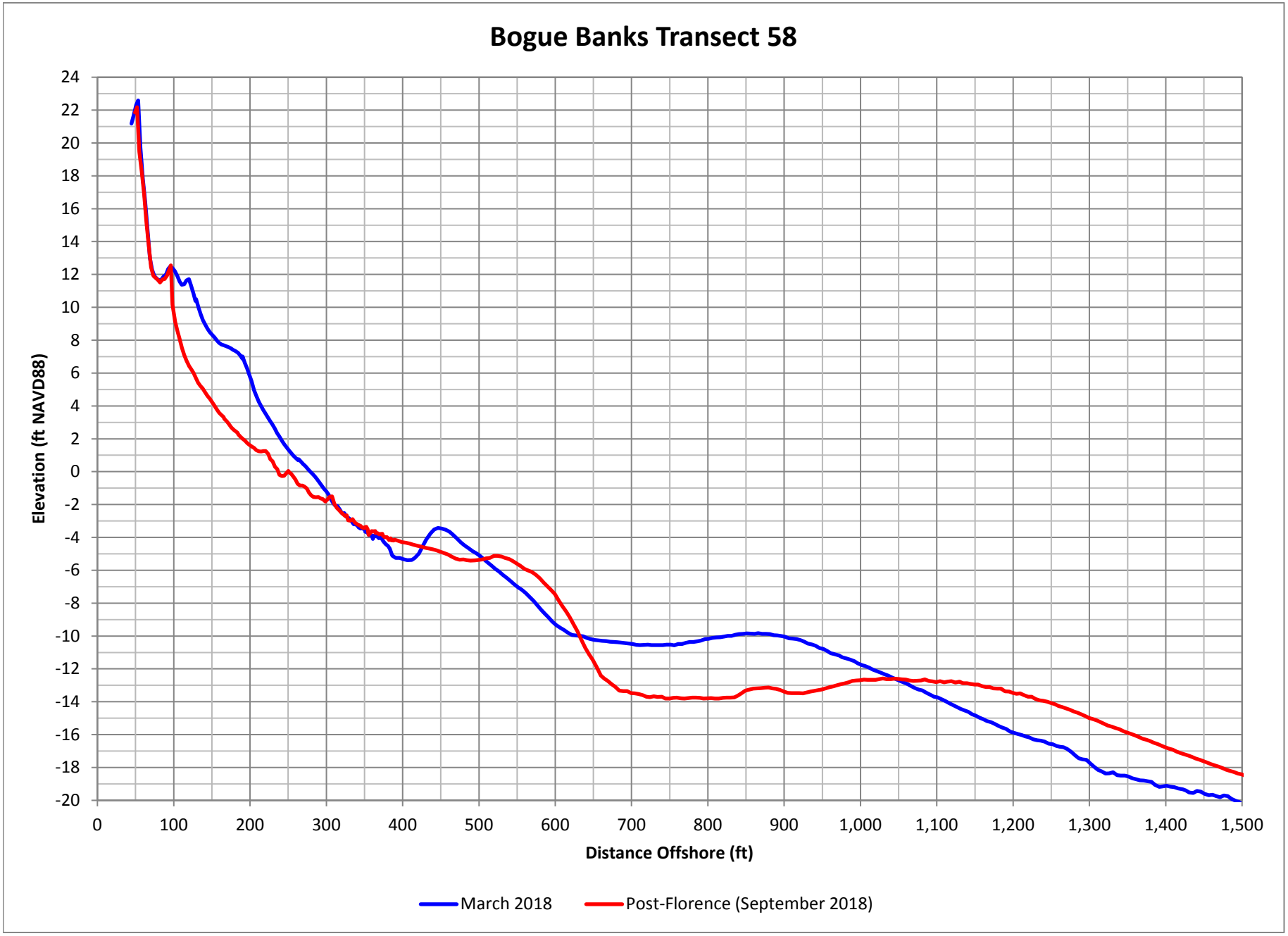


Figure D-116. Bogue Banks Profile Comparison Plot

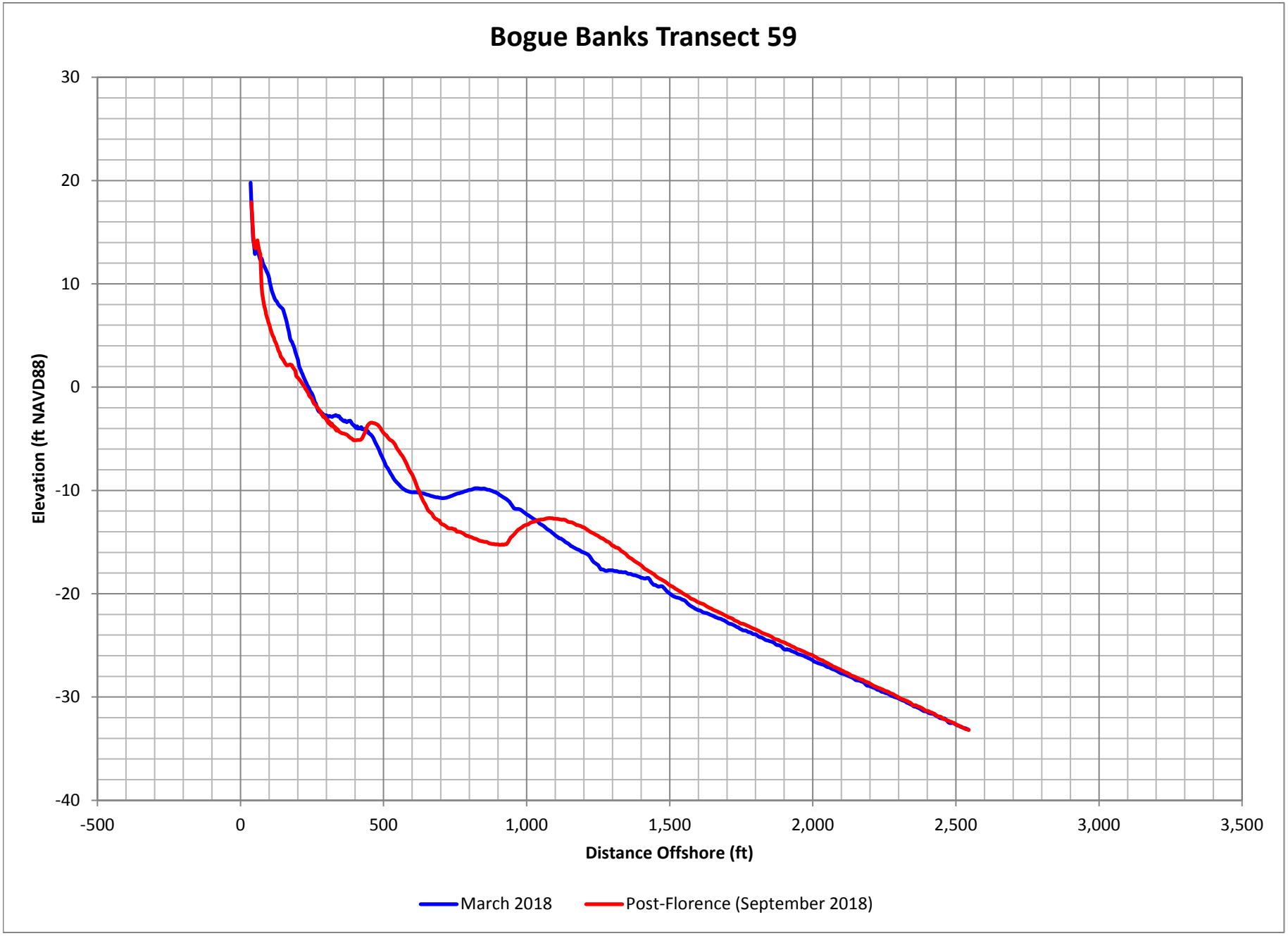


Figure D-117. Bogue Banks Profile Comparison Plot

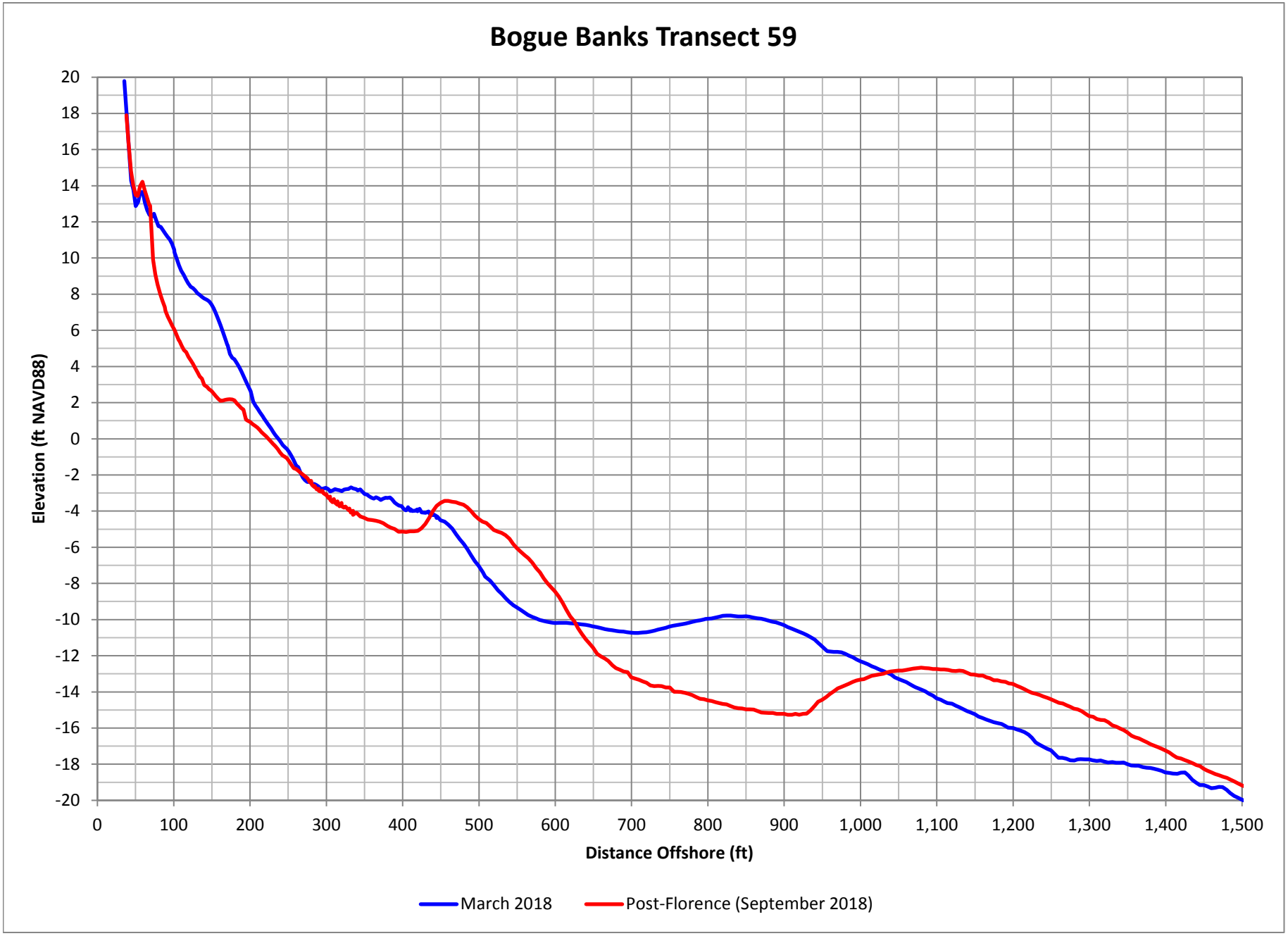


Figure D-118. Bogue Banks Profile Comparison Plot

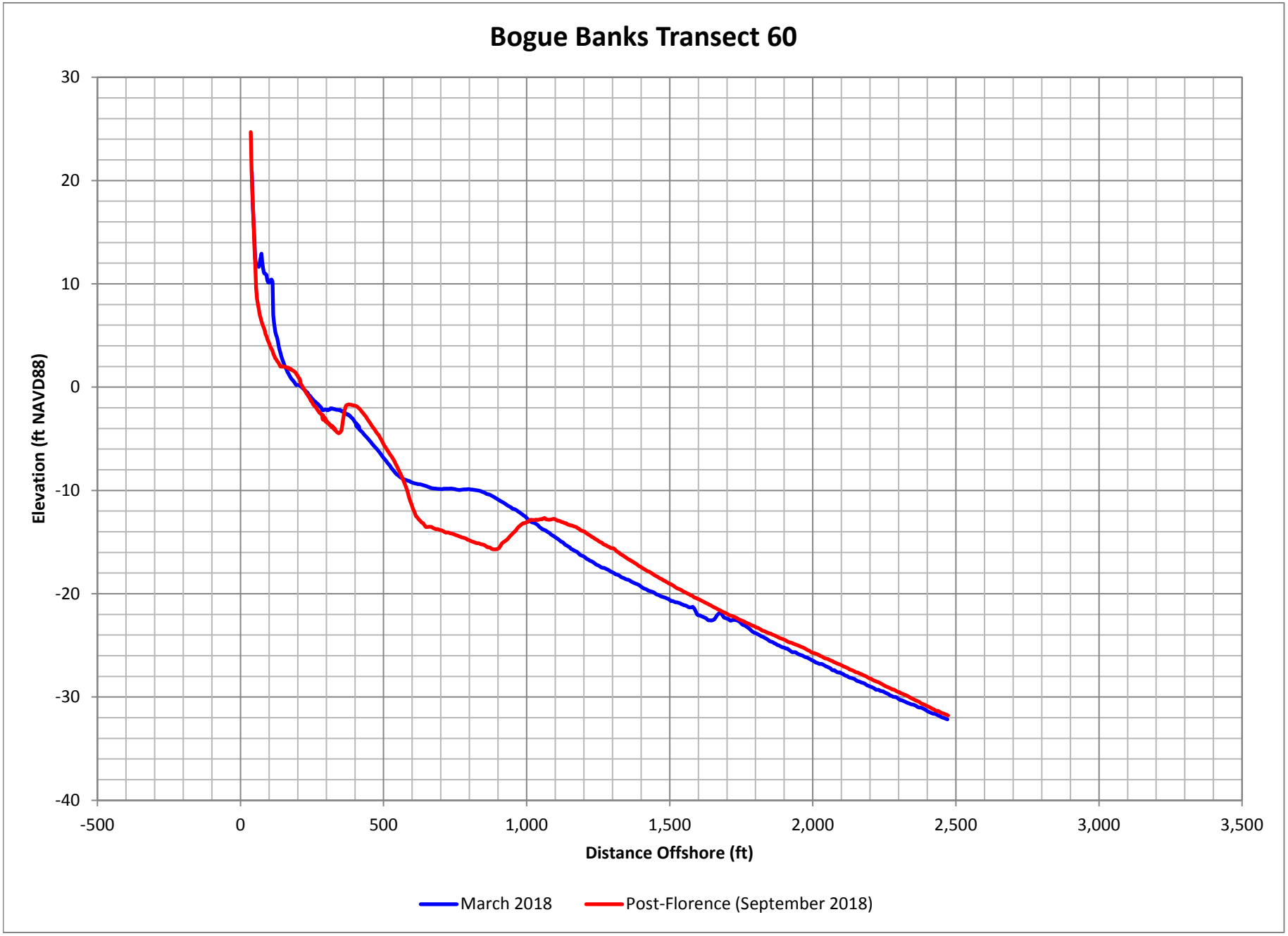


Figure D-119. Bogue Banks Profile Comparison Plot

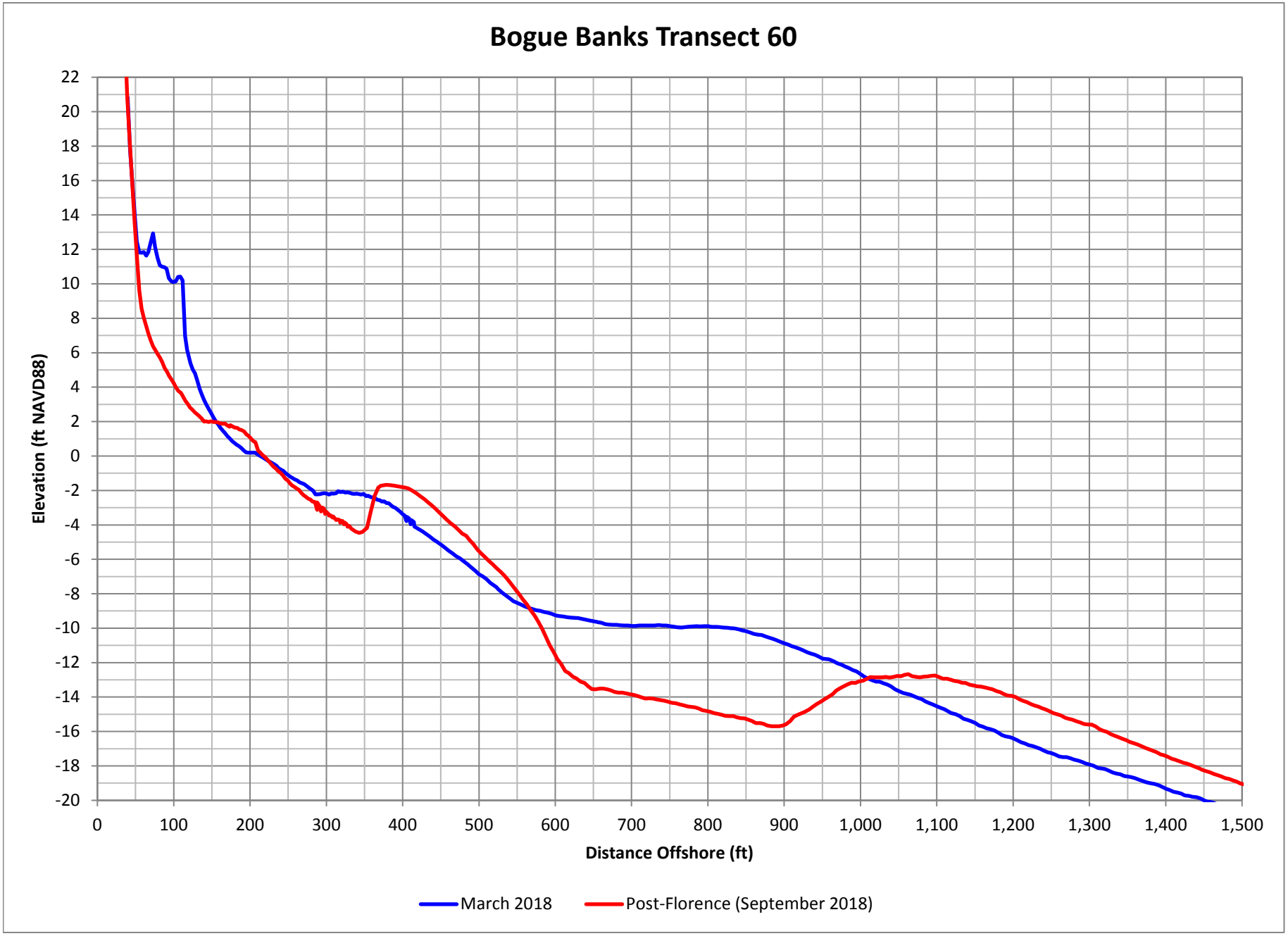


Figure D-120. Bogue Banks Profile Comparison Plot

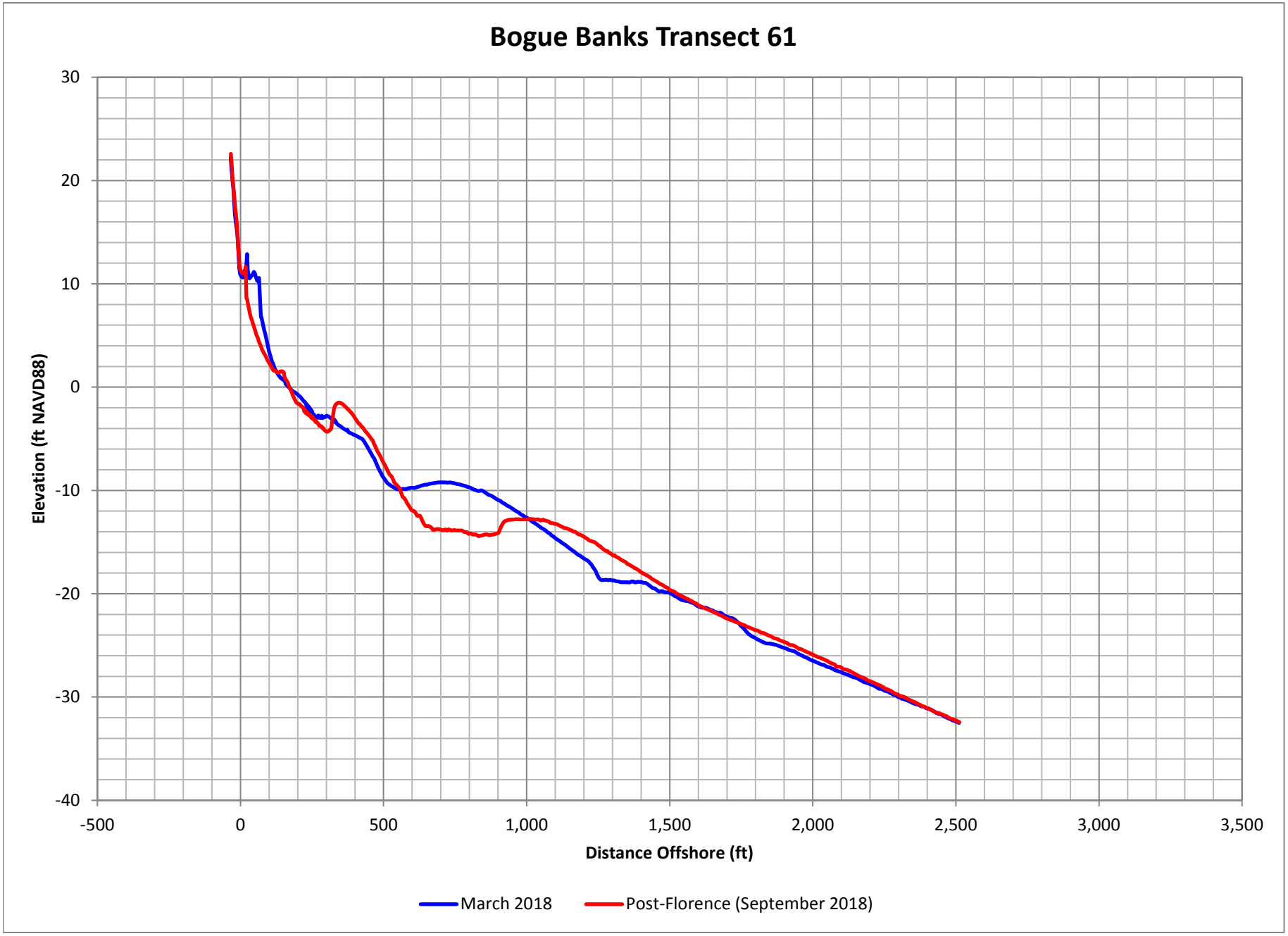


Figure D-121. Bogue Banks Profile Comparison Plot

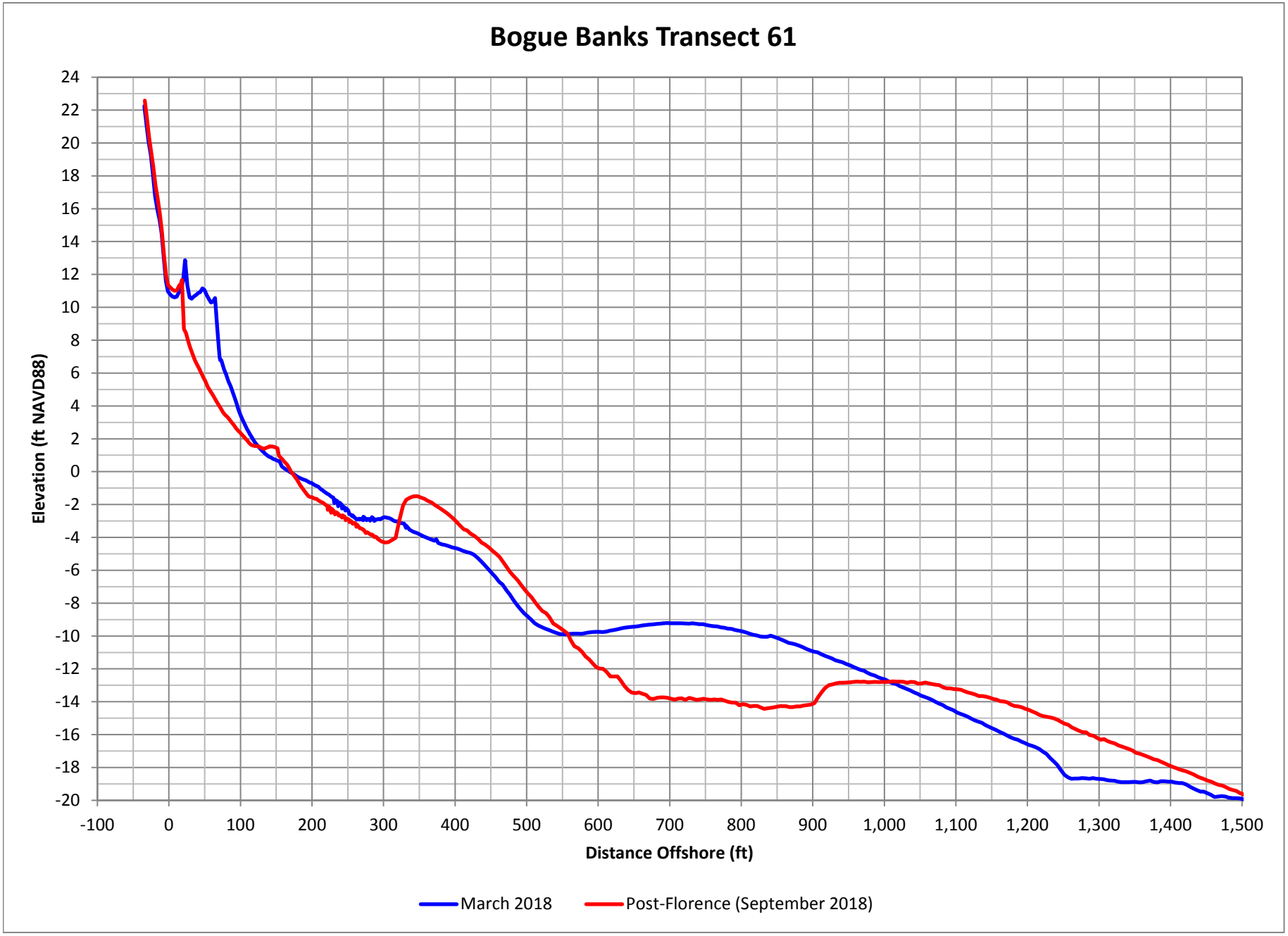


Figure D-122. Bogue Banks Profile Comparison Plot

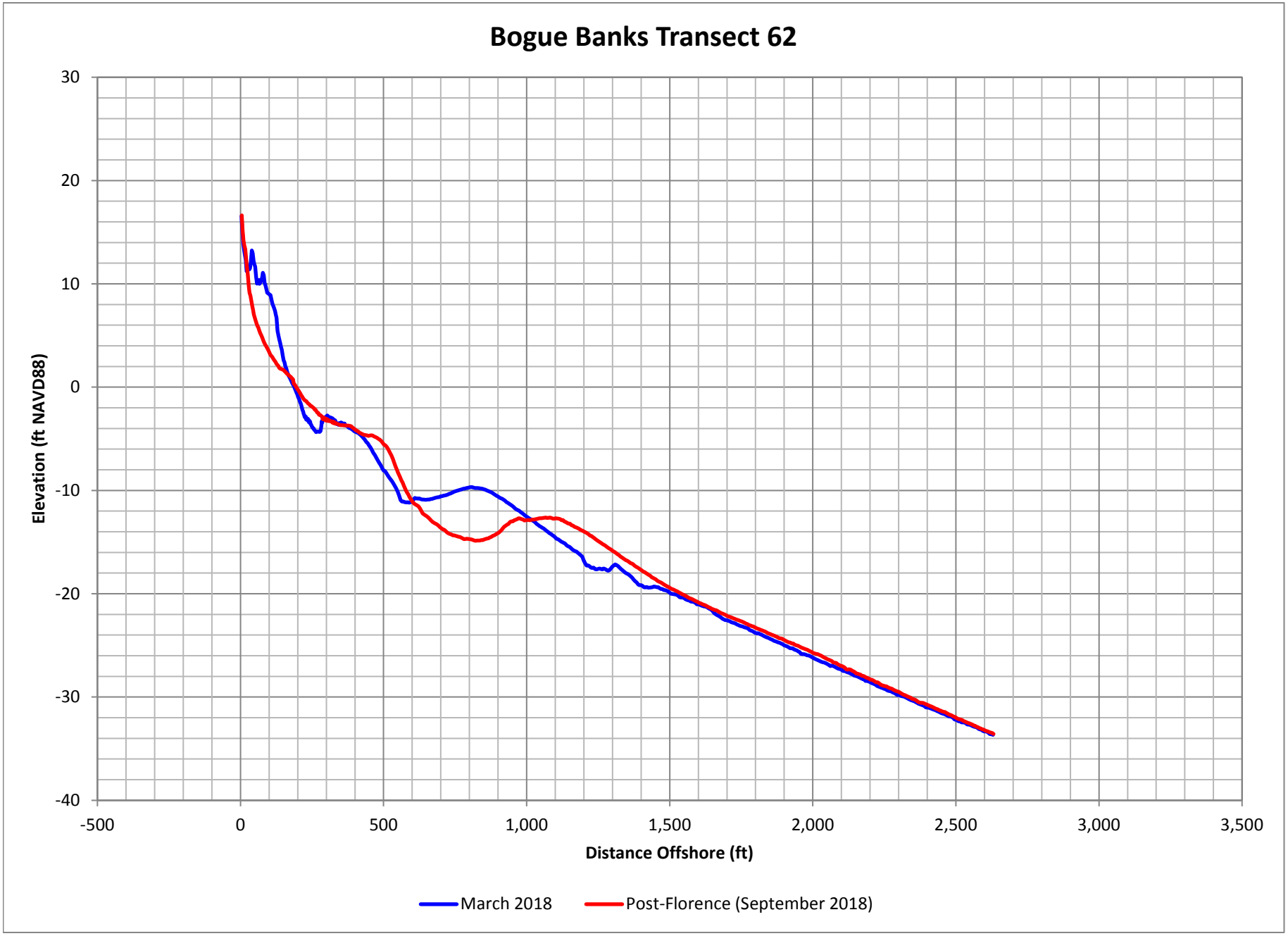


Figure D-123. Bogue Banks Profile Comparison Plot

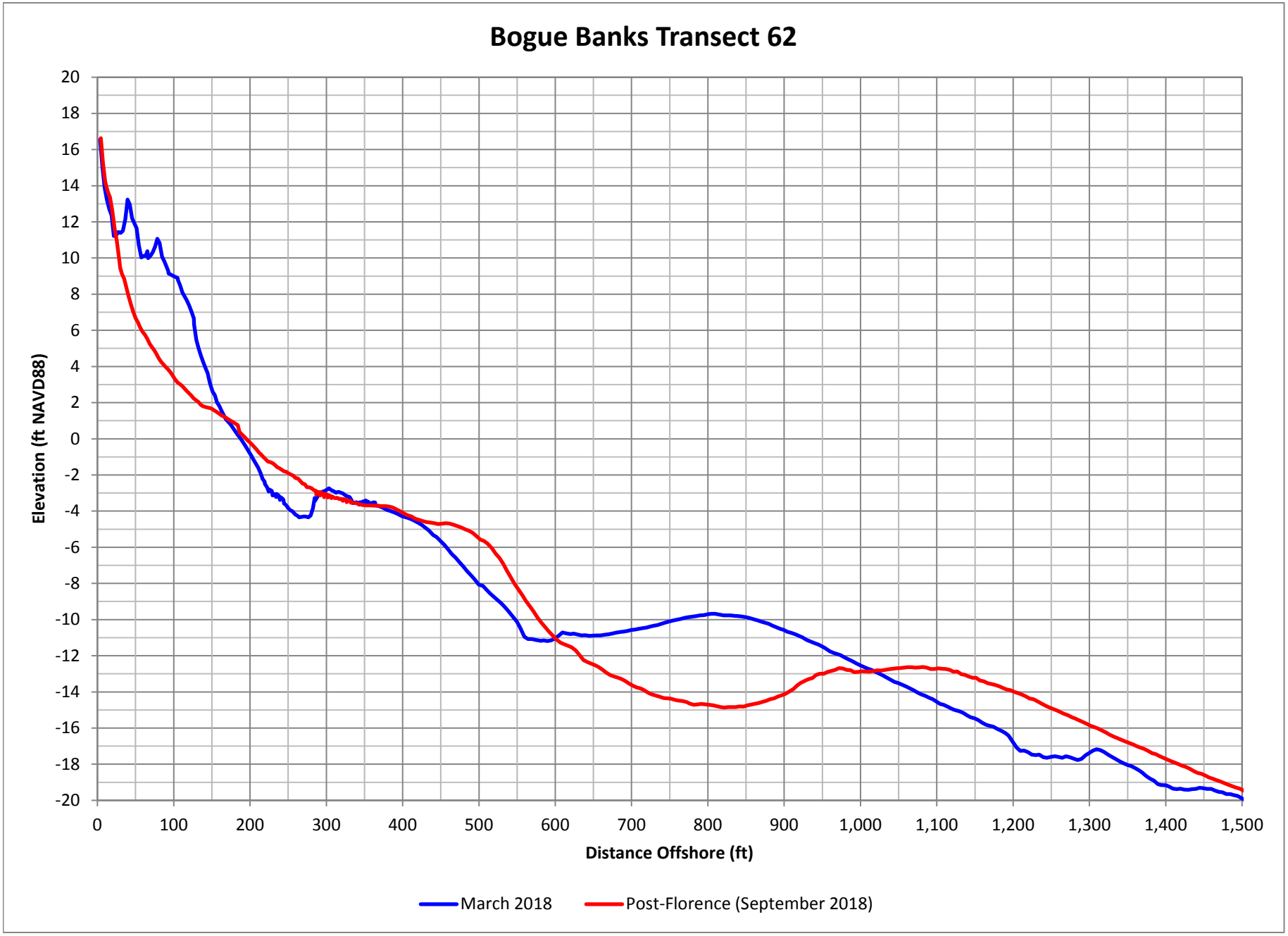


Figure D-124. Bogue Banks Profile Comparison Plot

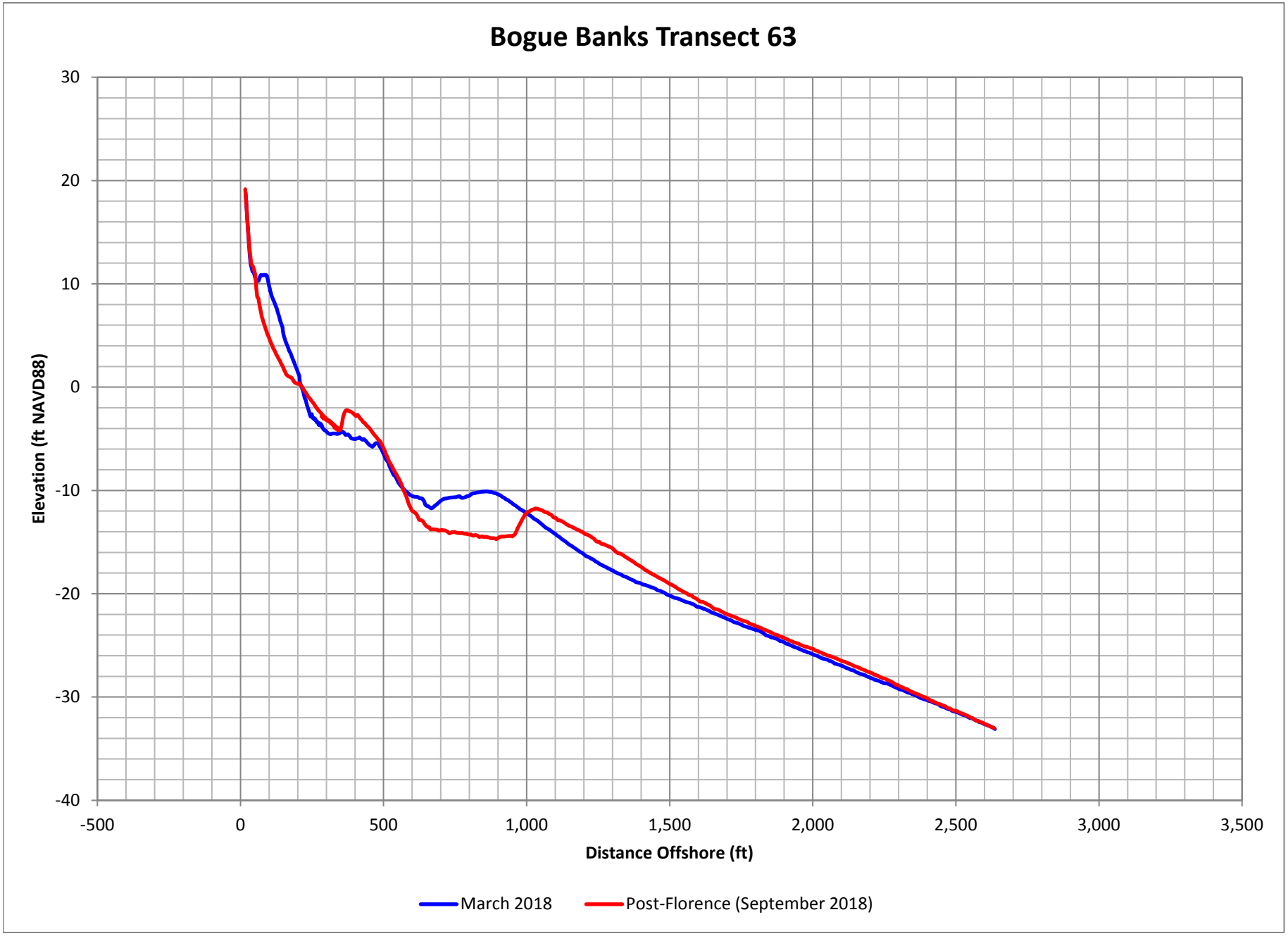


Figure D-125. Bogue Banks Profile Comparison Plot

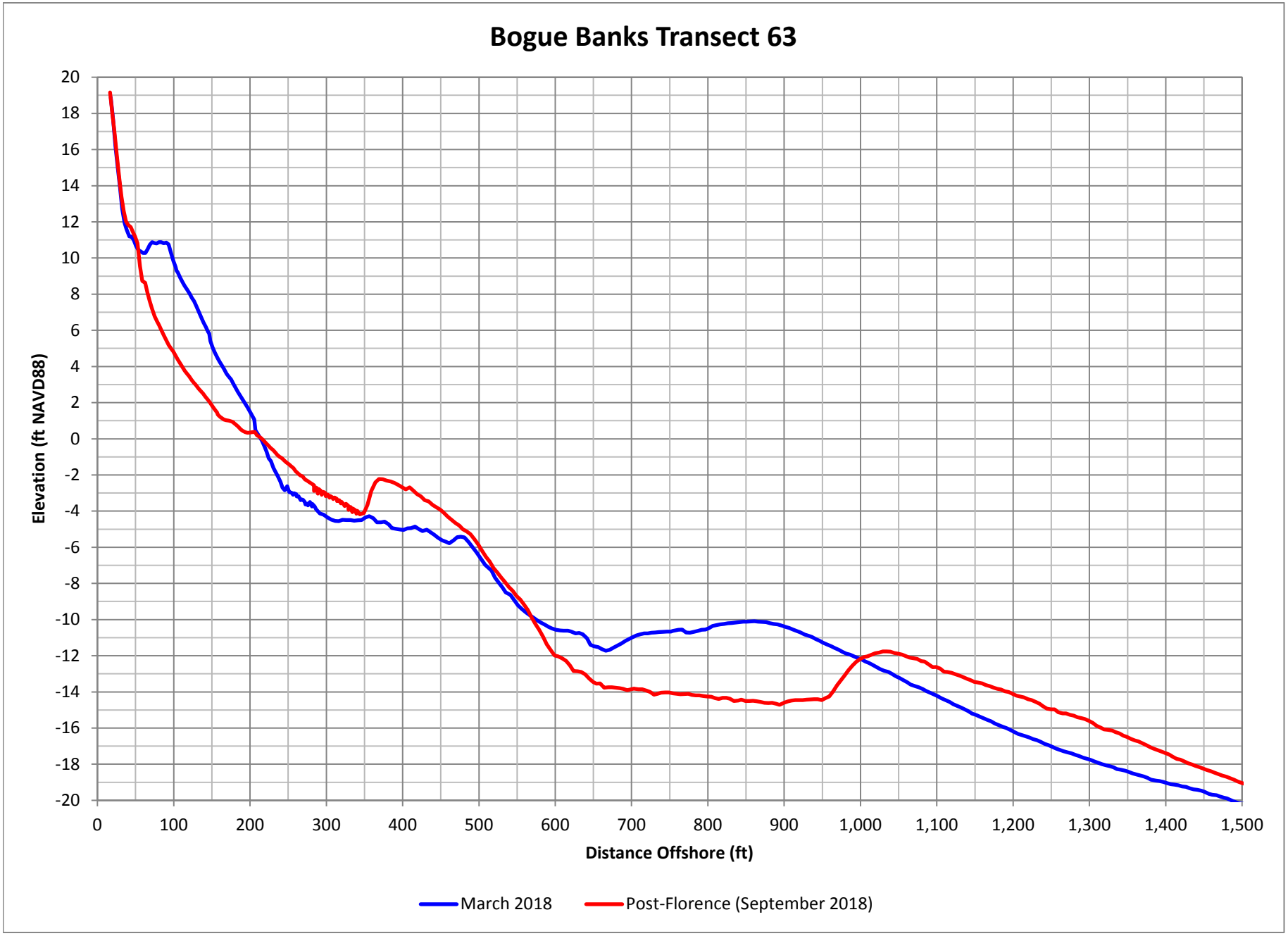


Figure D-126. Bogue Banks Profile Comparison Plot

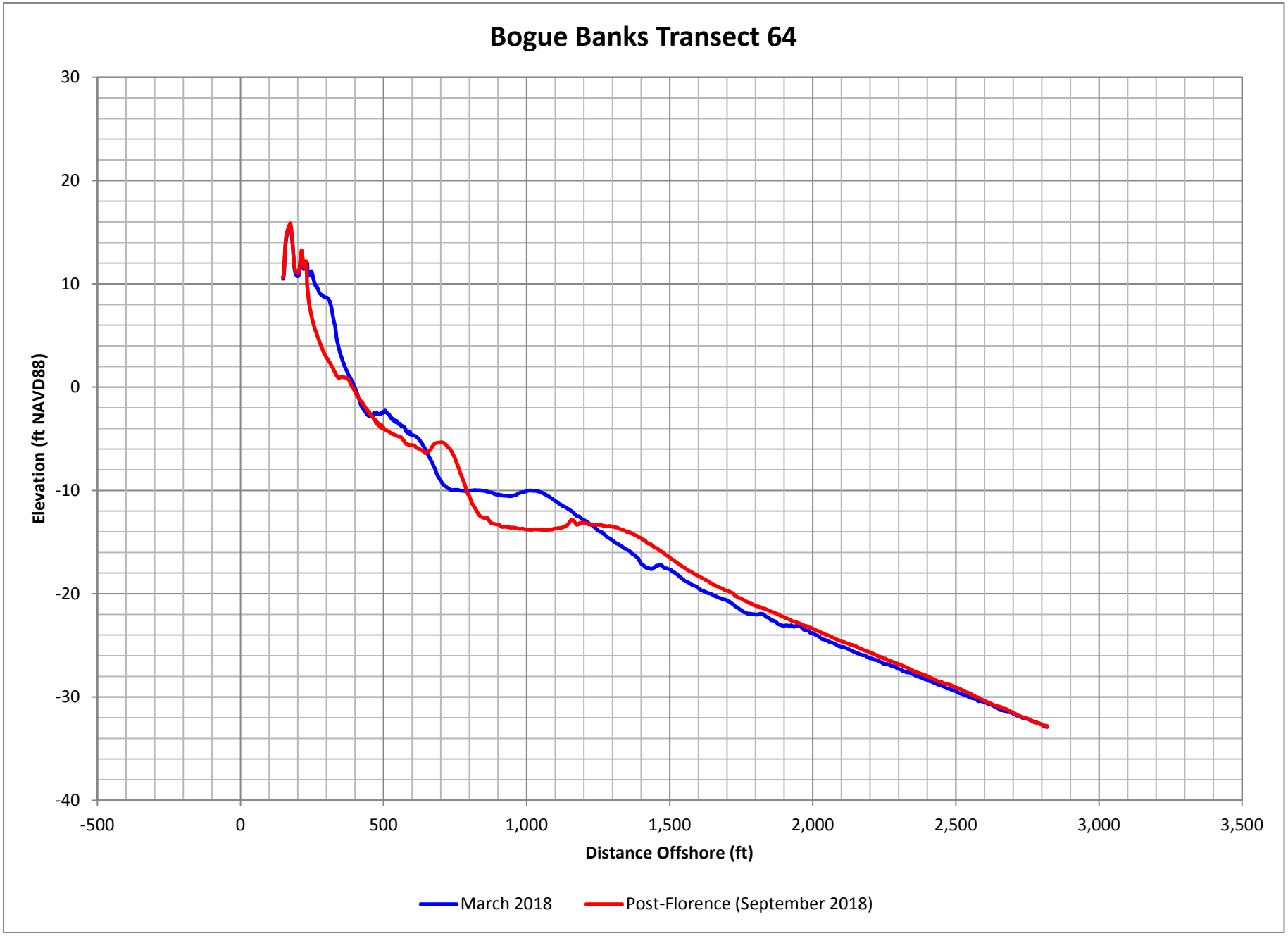


Figure D-127. Bogue Banks Profile Comparison Plot

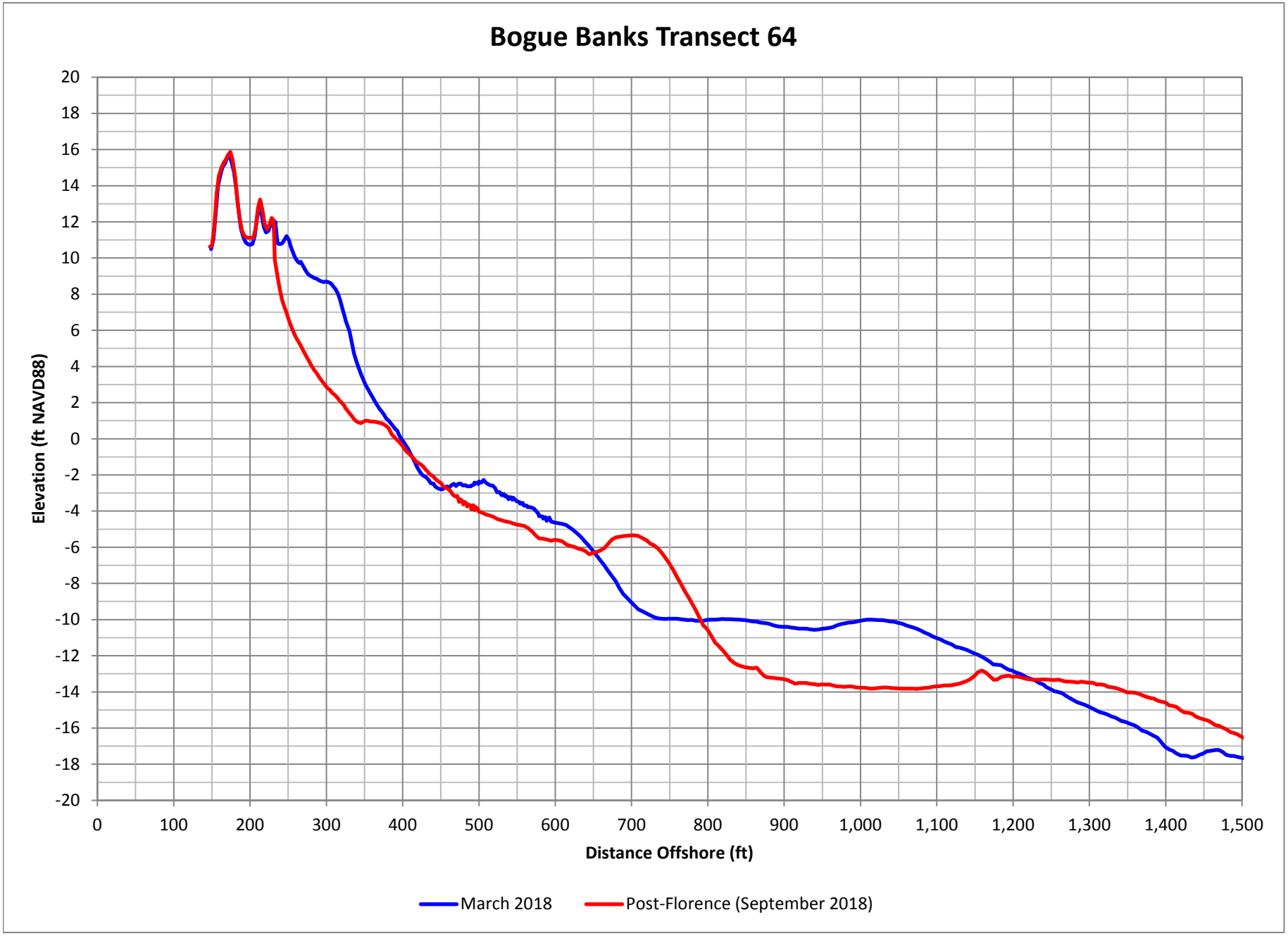


Figure D-128. Bogue Banks Profile Comparison Plot

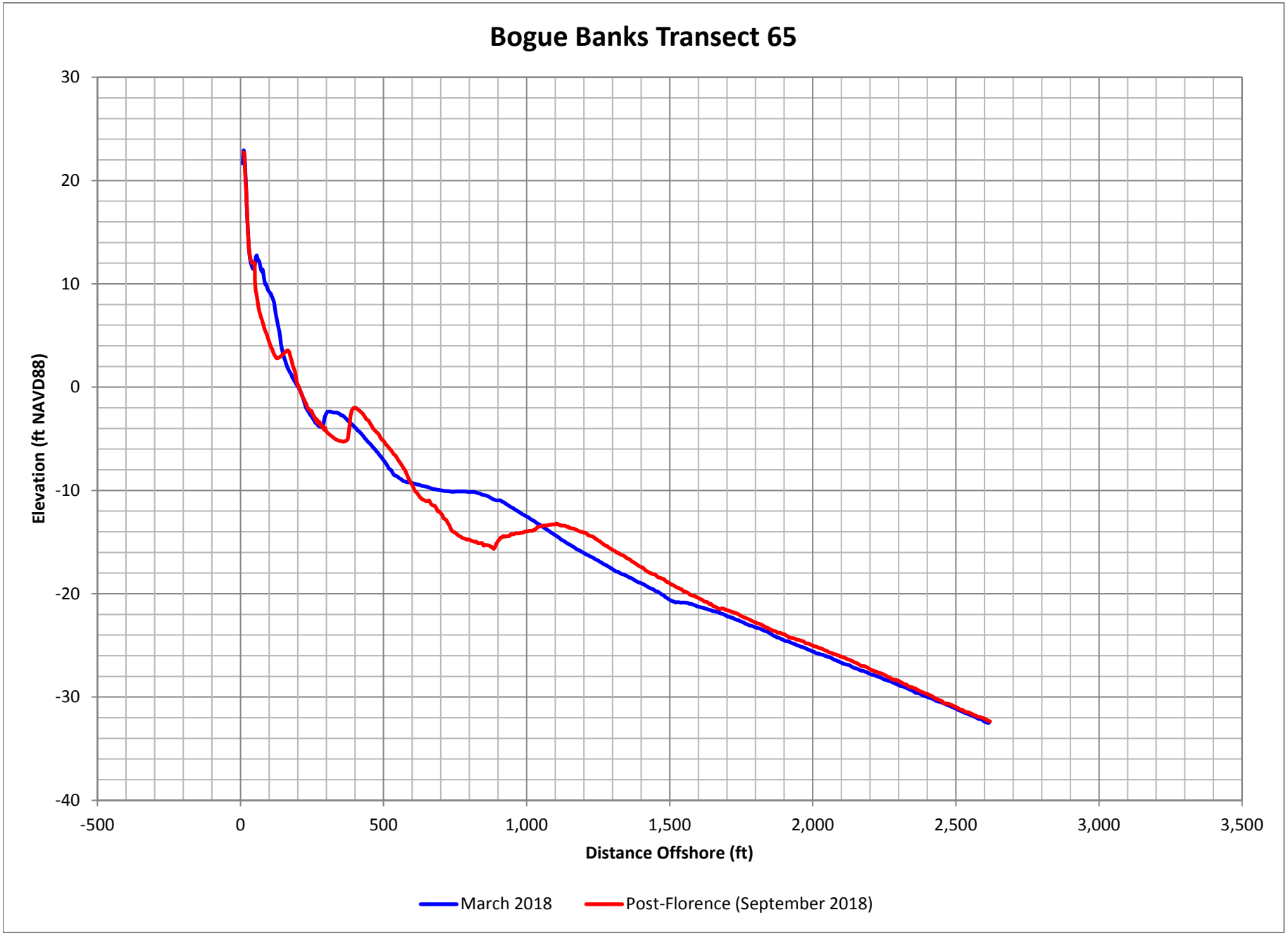


Figure D-129. Bogue Banks Profile Comparison Plot

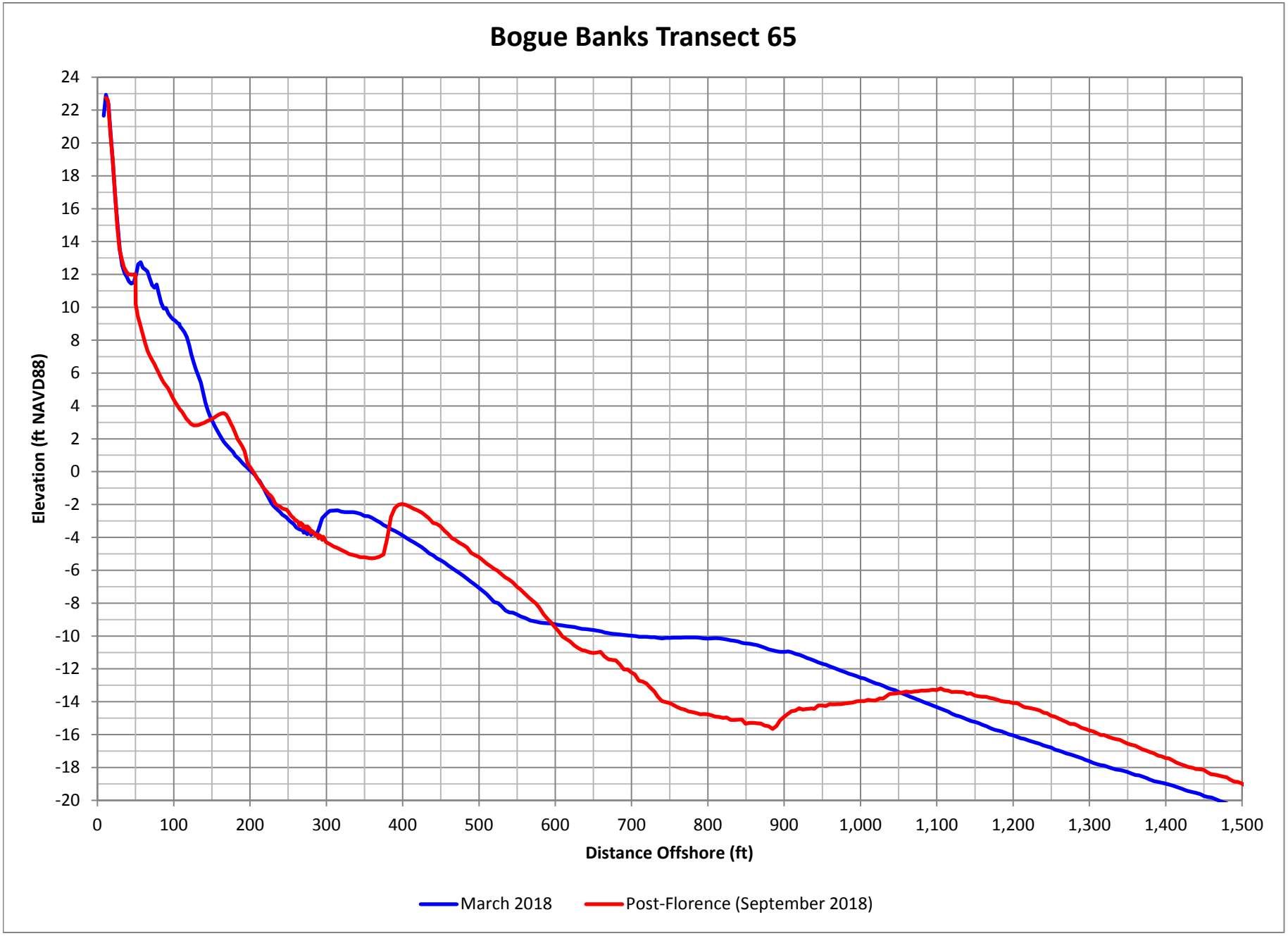


Figure D-130. Bogue Banks Profile Comparison Plot

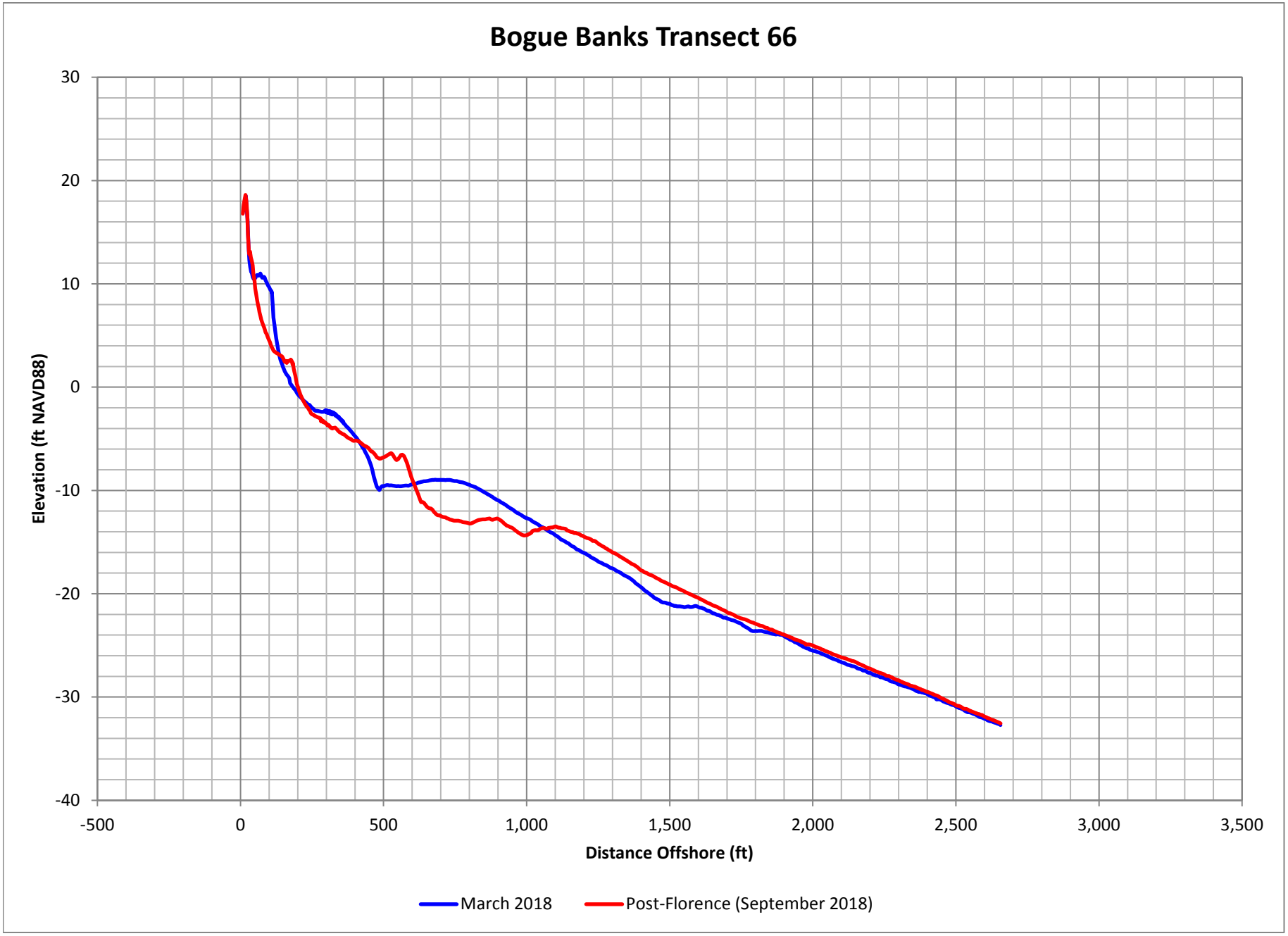


Figure D-131. Bogue Banks Profile Comparison Plot

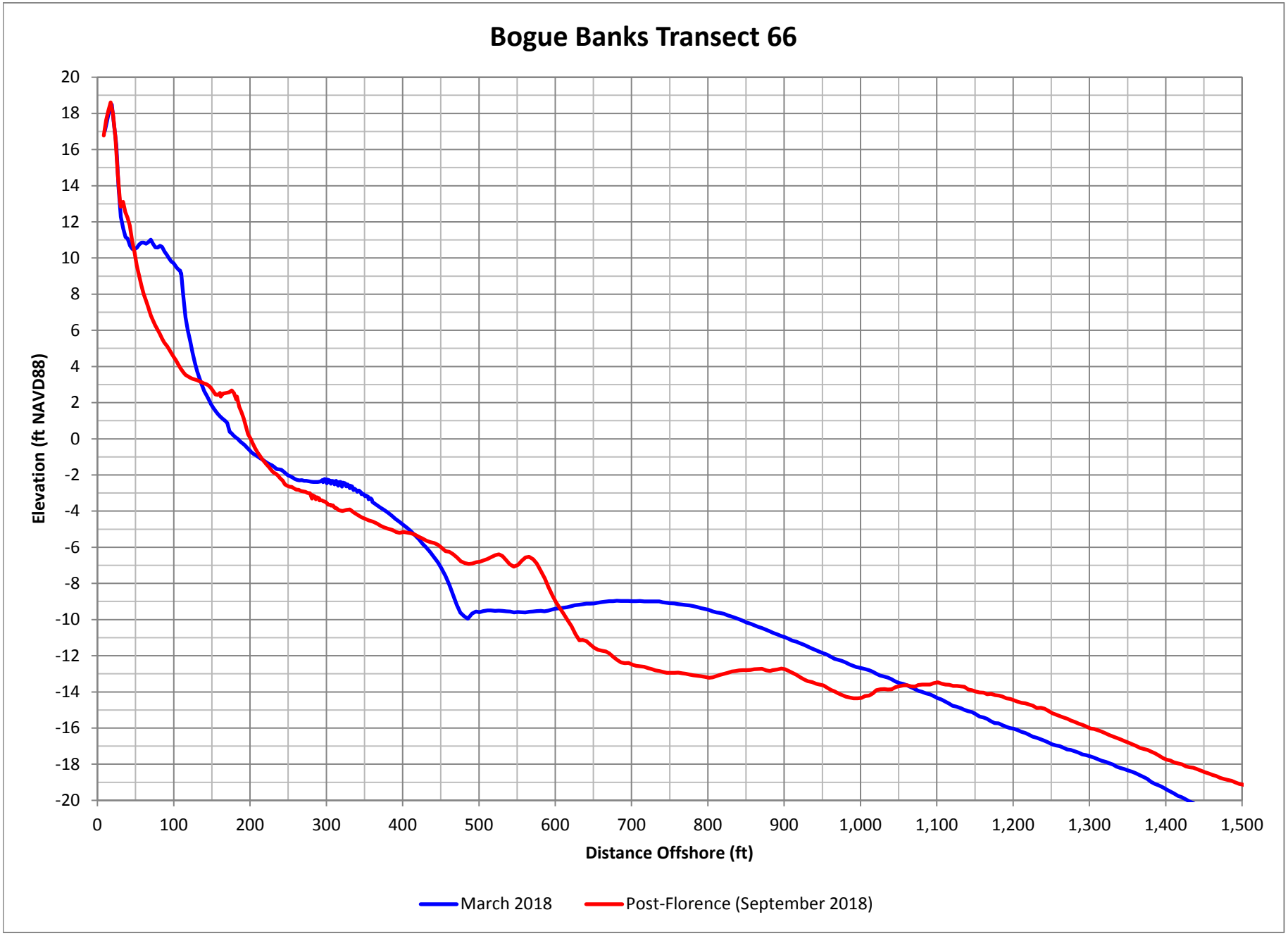


Figure D-132. Bogue Banks Profile Comparison Plot

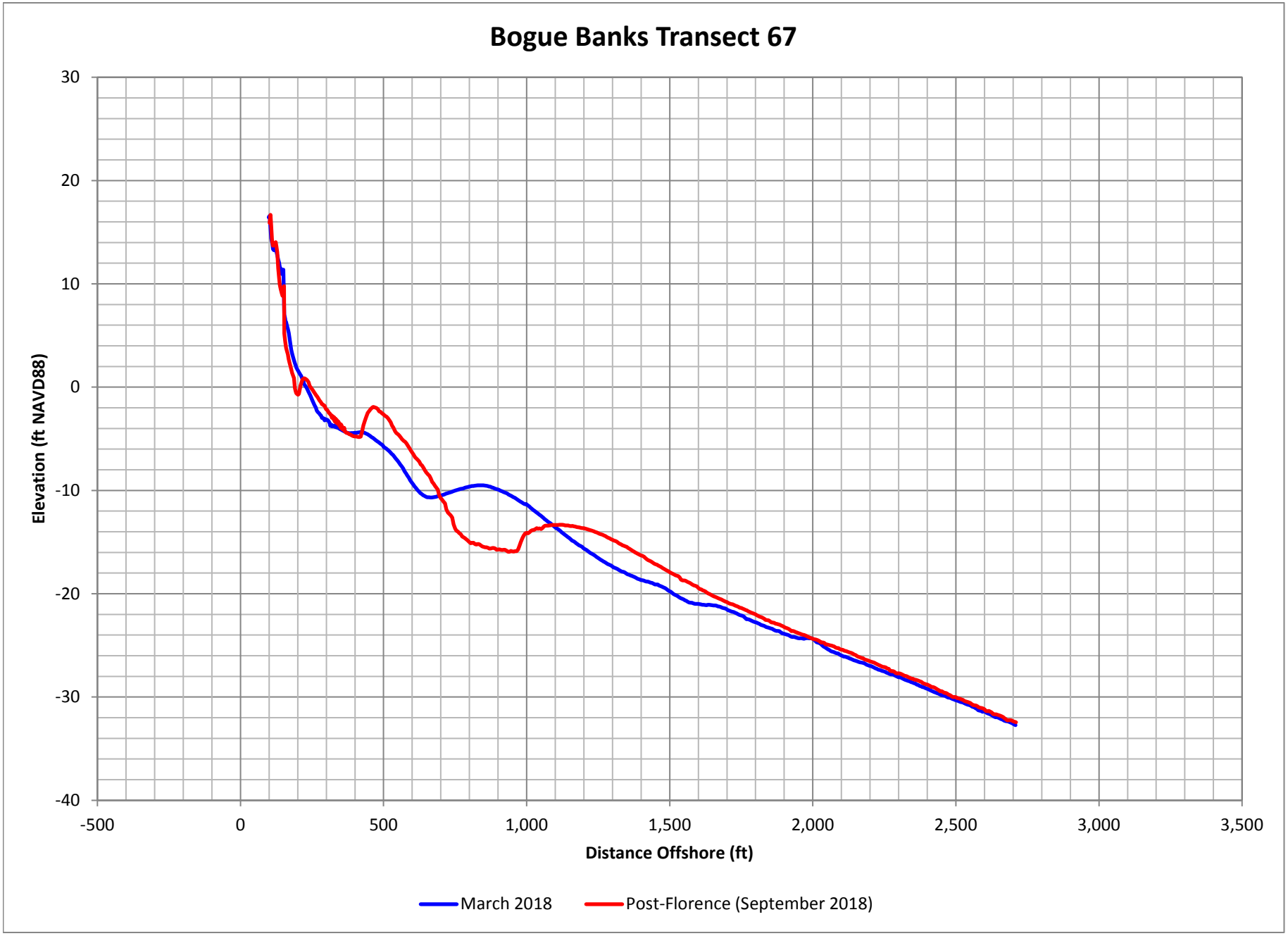


Figure D-133. Bogue Banks Profile Comparison Plot

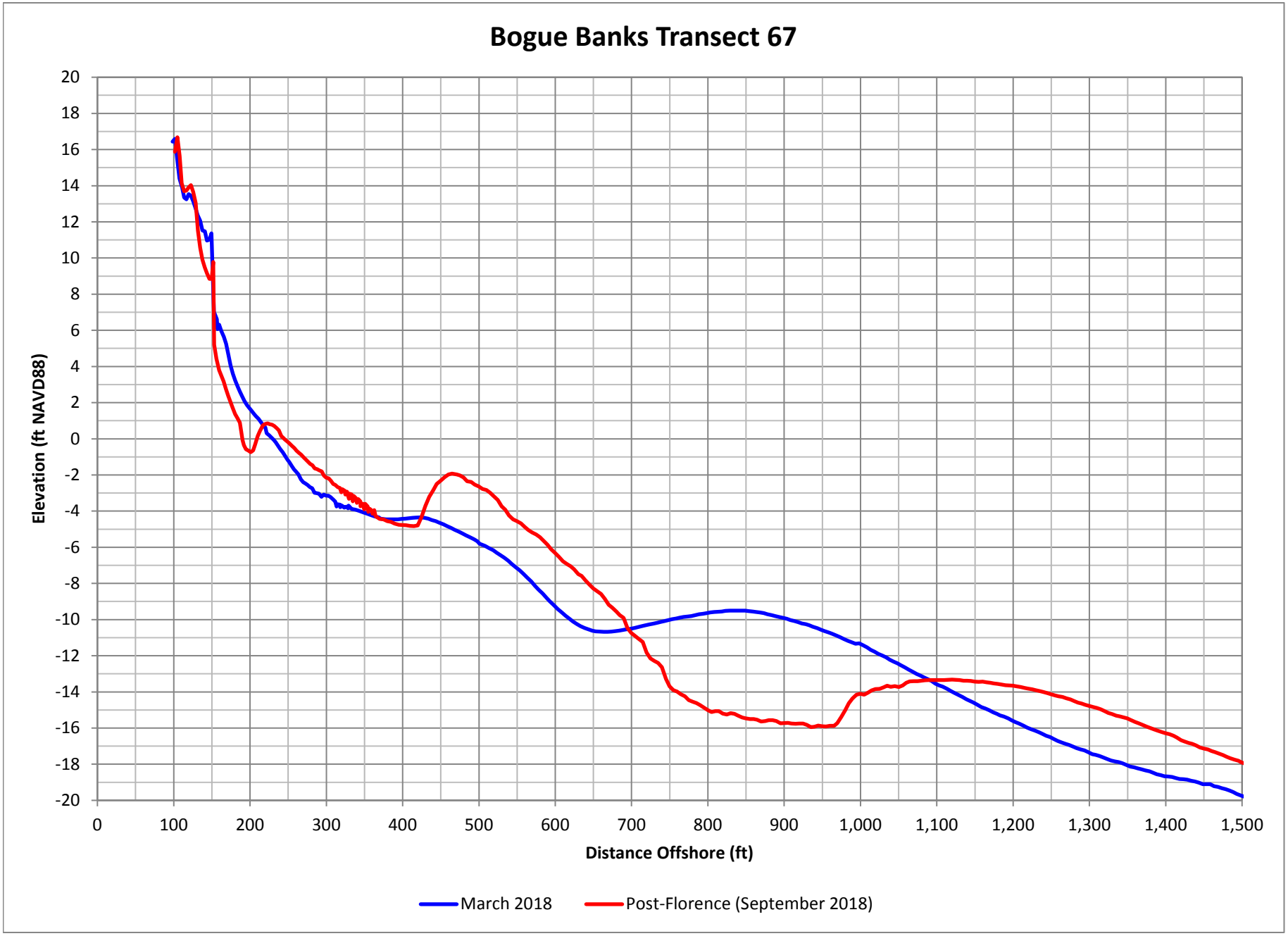


Figure D-134. Bogue Banks Profile Comparison Plot

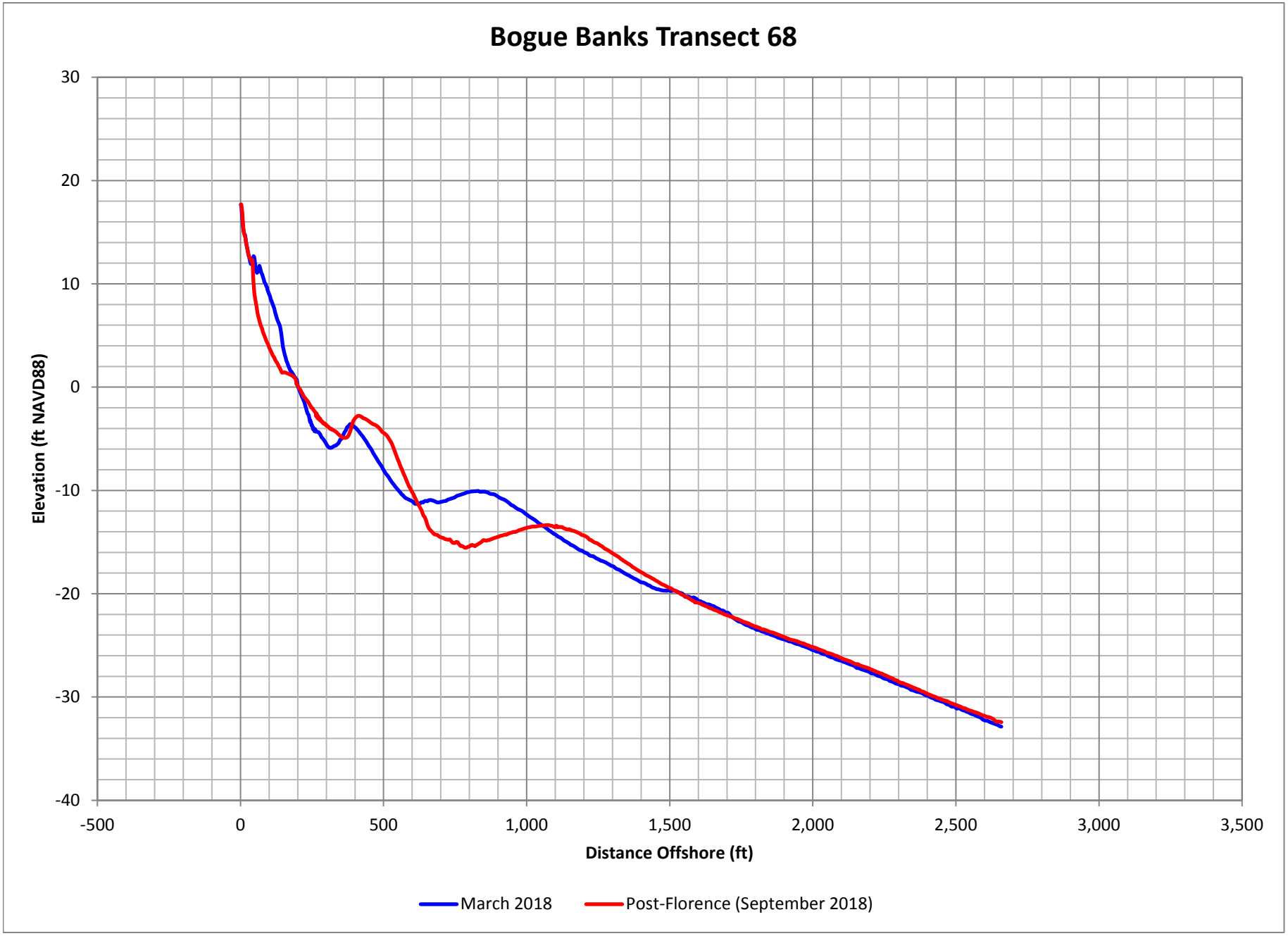


Figure D-135. Bogue Banks Profile Comparison Plot

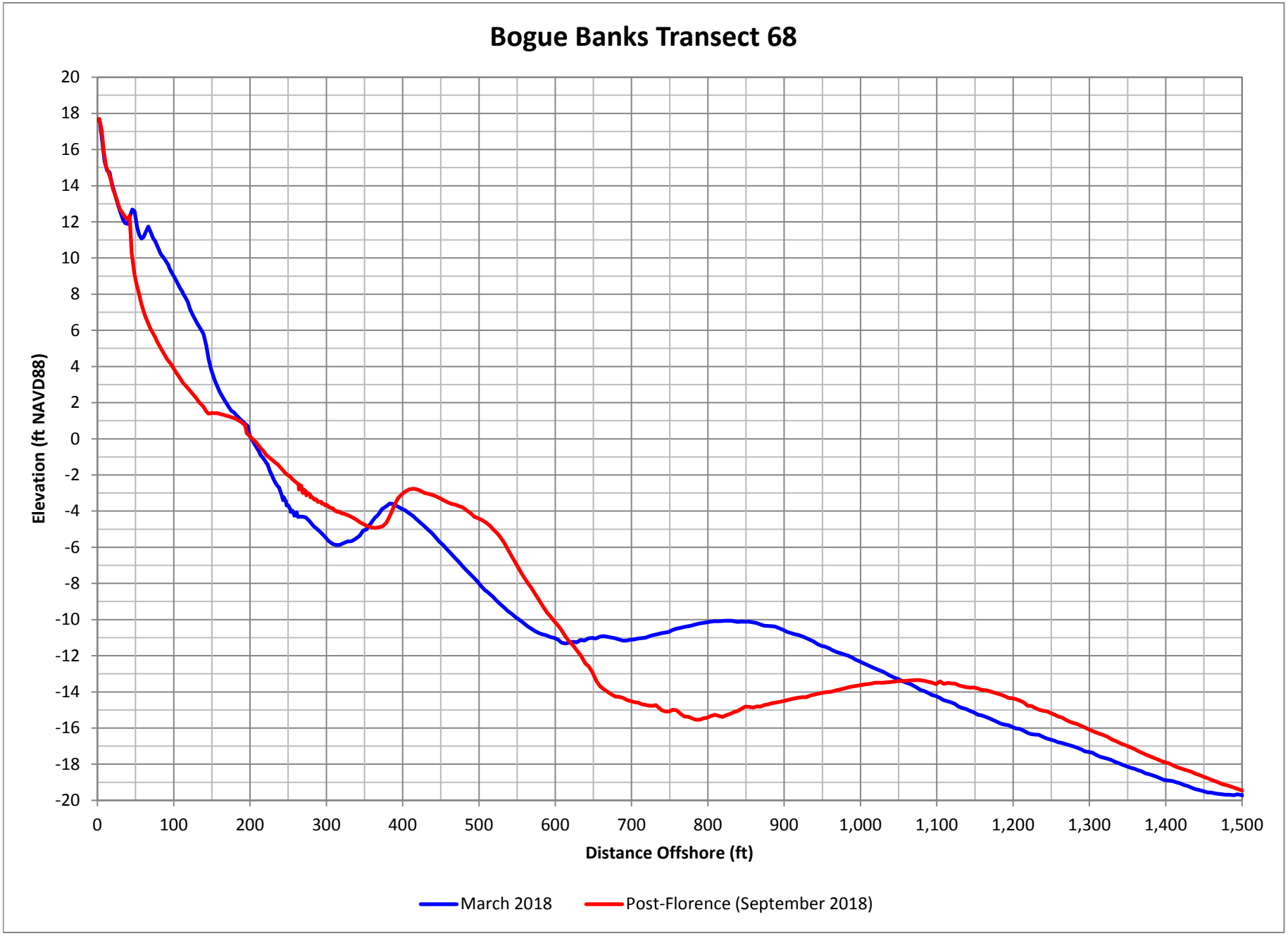


Figure D-136. Bogue Banks Profile Comparison Plot

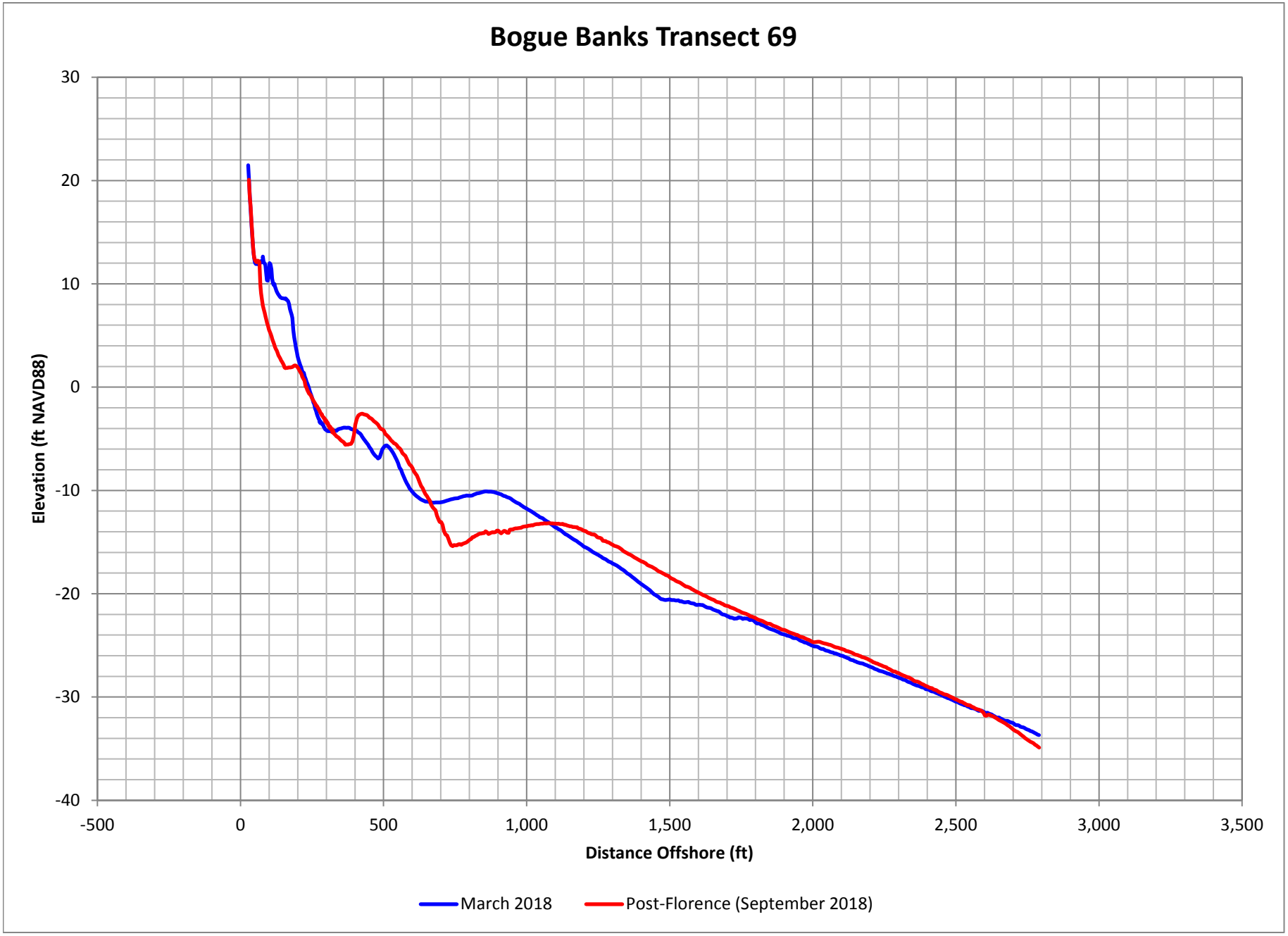


Figure D-137. Bogue Banks Profile Comparison Plot

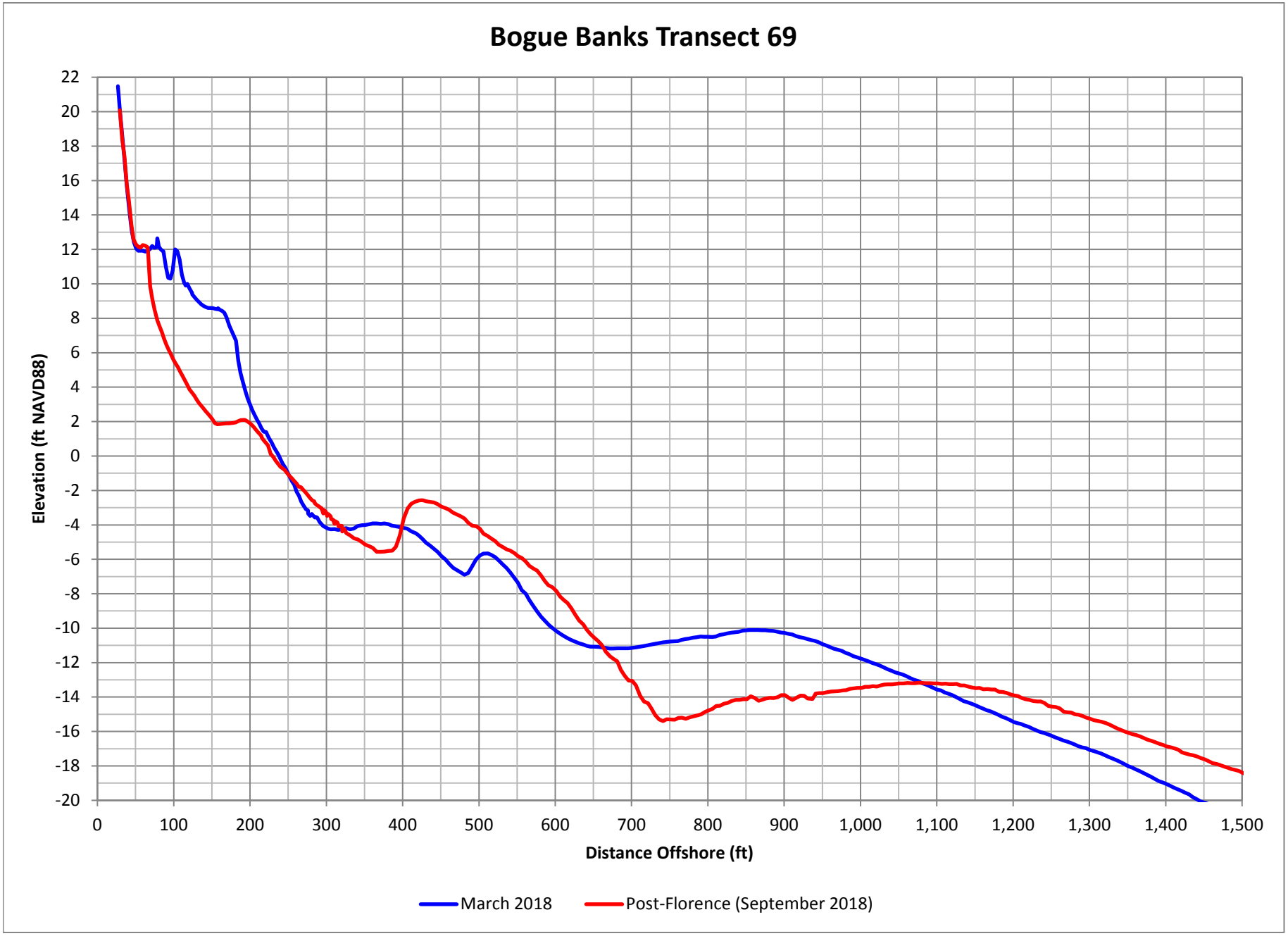


Figure D-138. Bogue Banks Profile Comparison Plot

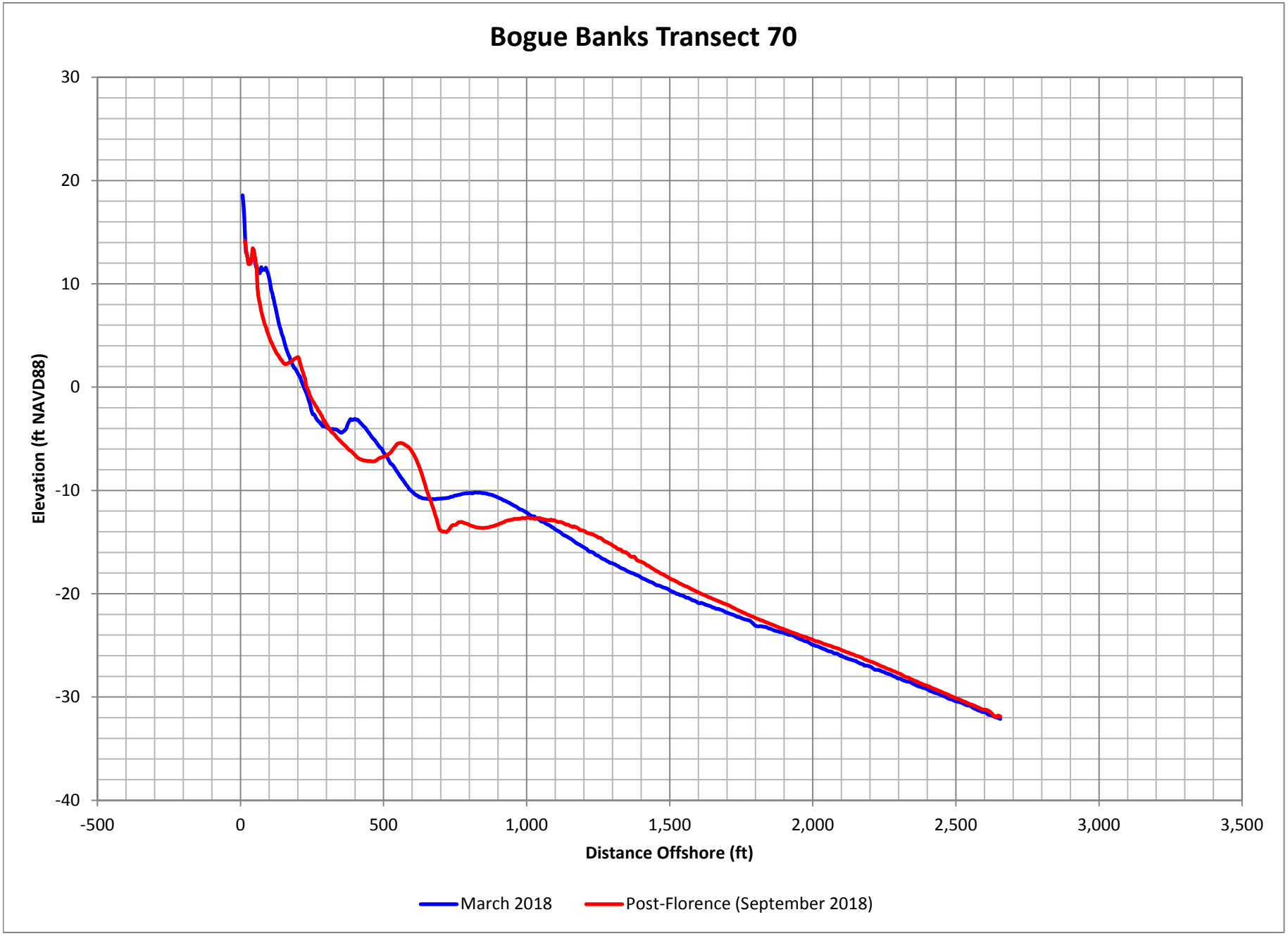


Figure D-139. Bogue Banks Profile Comparison Plot

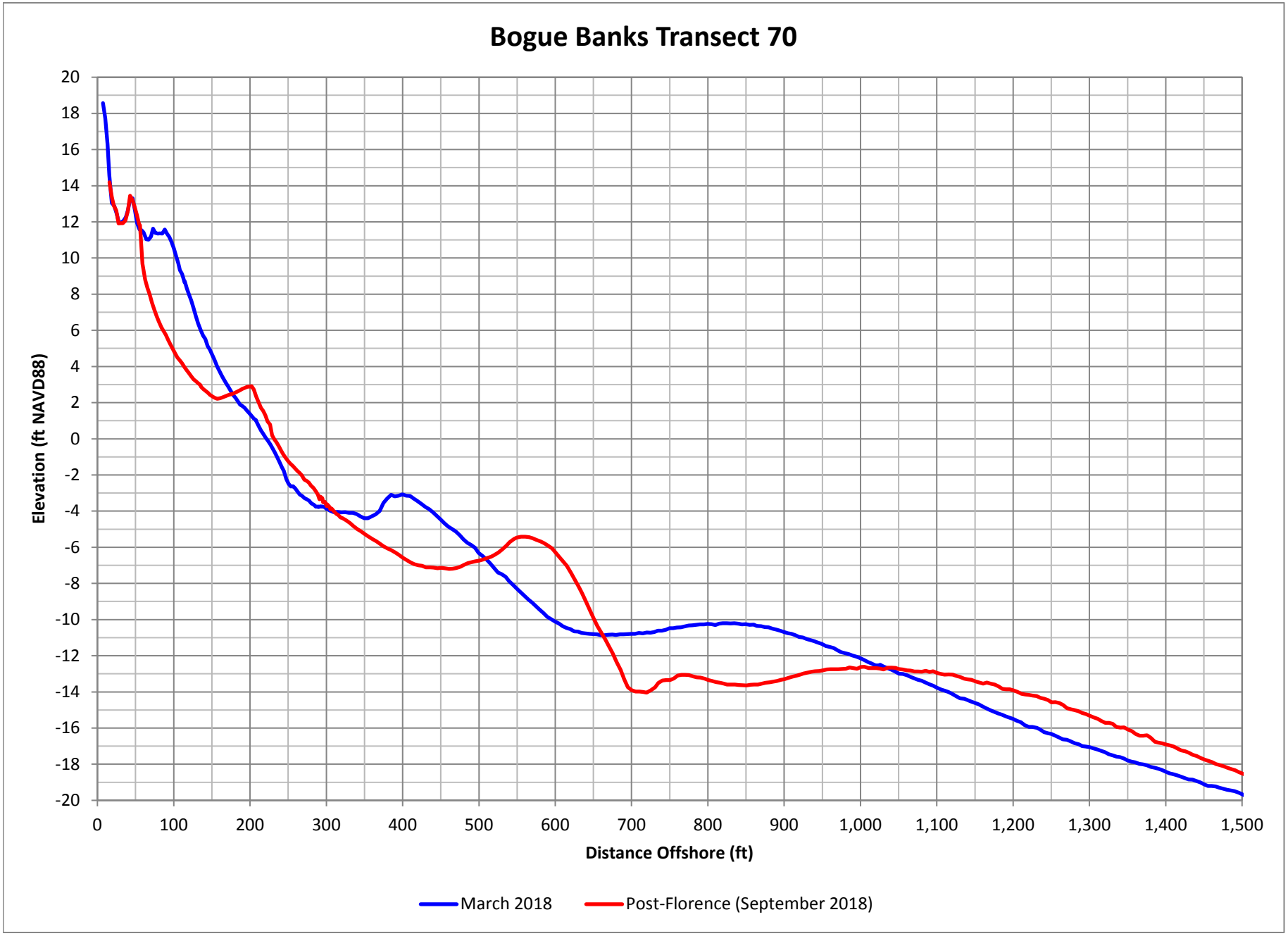


Figure D-140. Bogue Banks Profile Comparison Plot

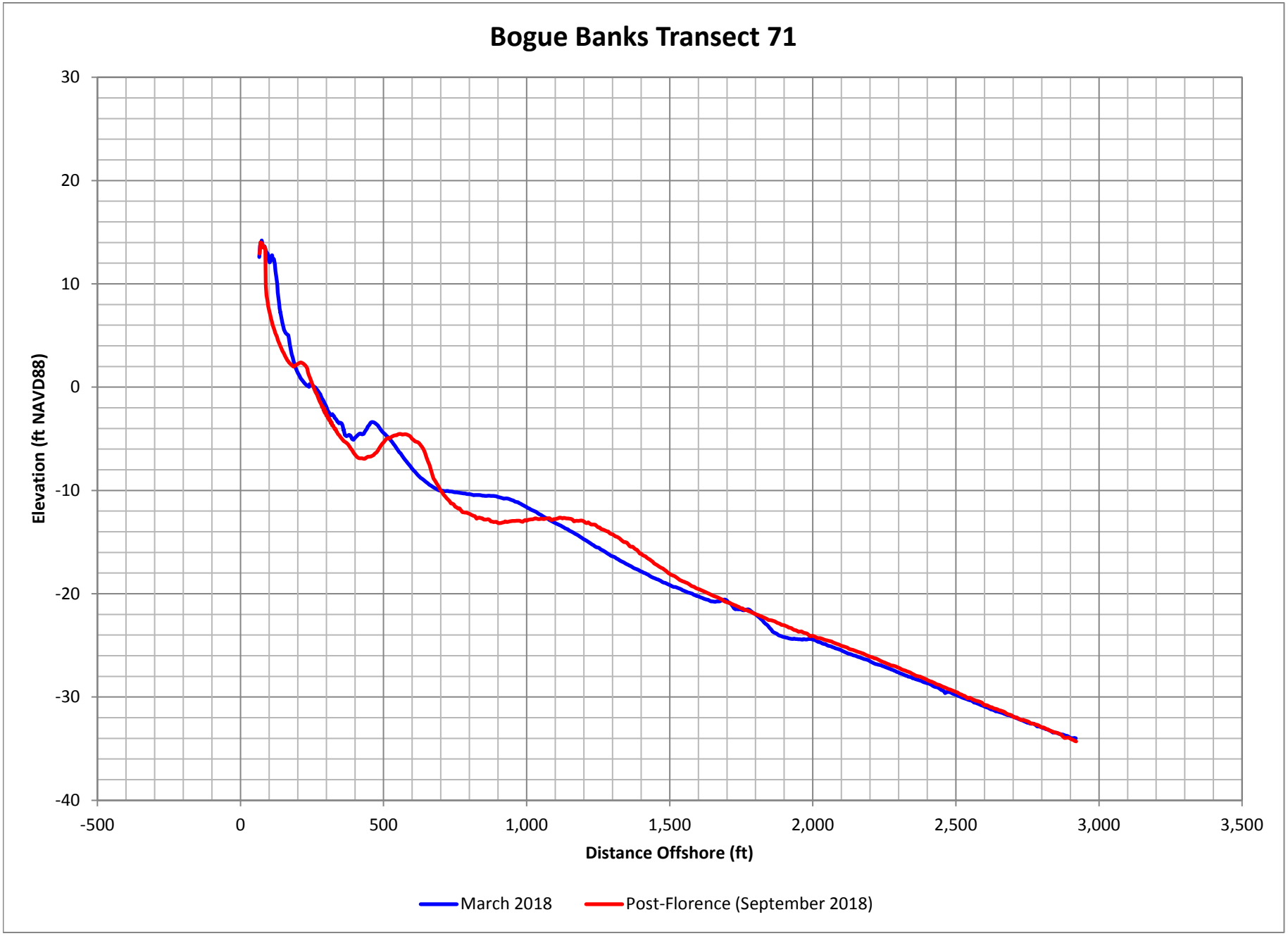


Figure D-141. Bogue Banks Profile Comparison Plot

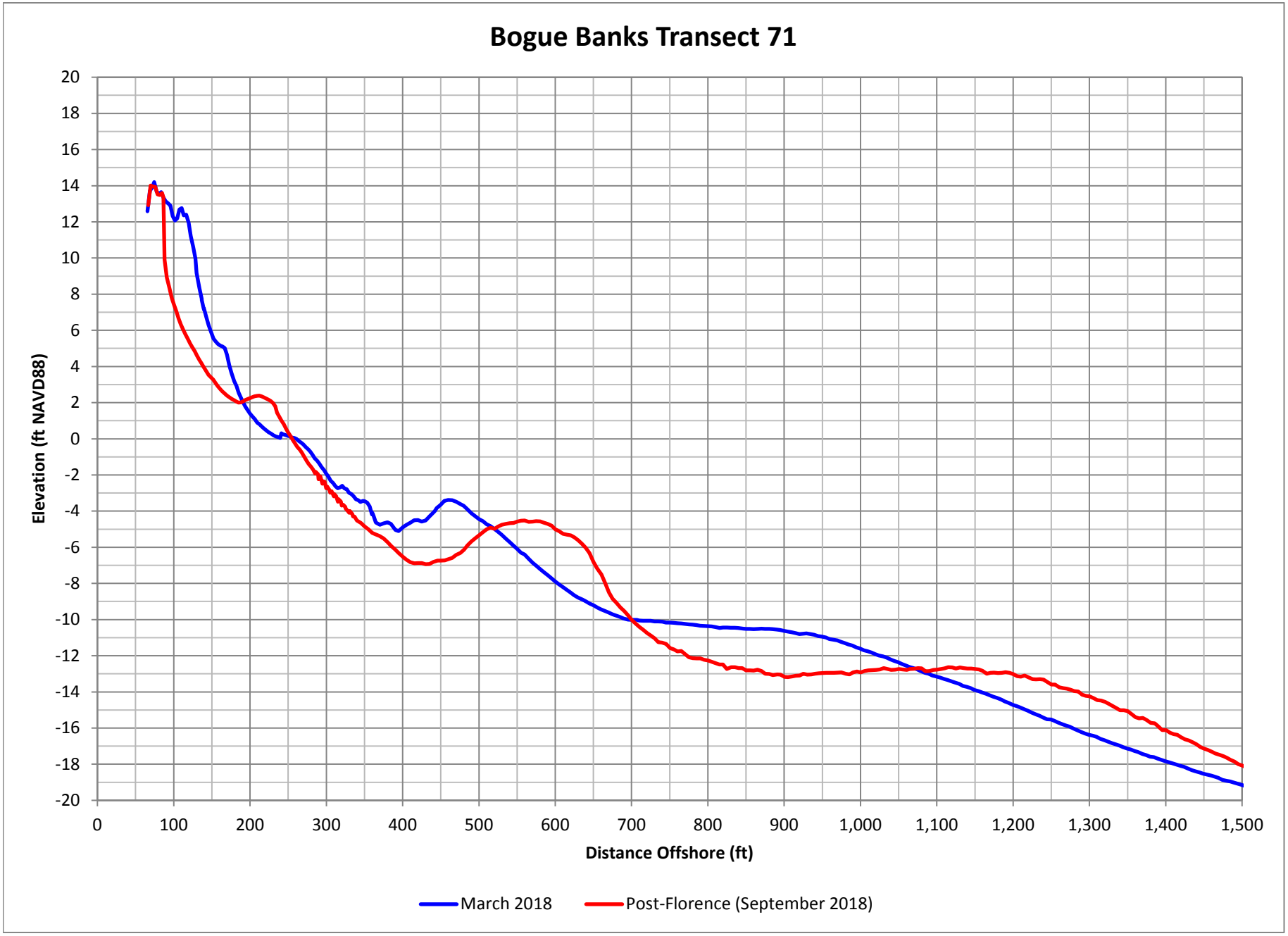


Figure D-142. Bogue Banks Profile Comparison Plot

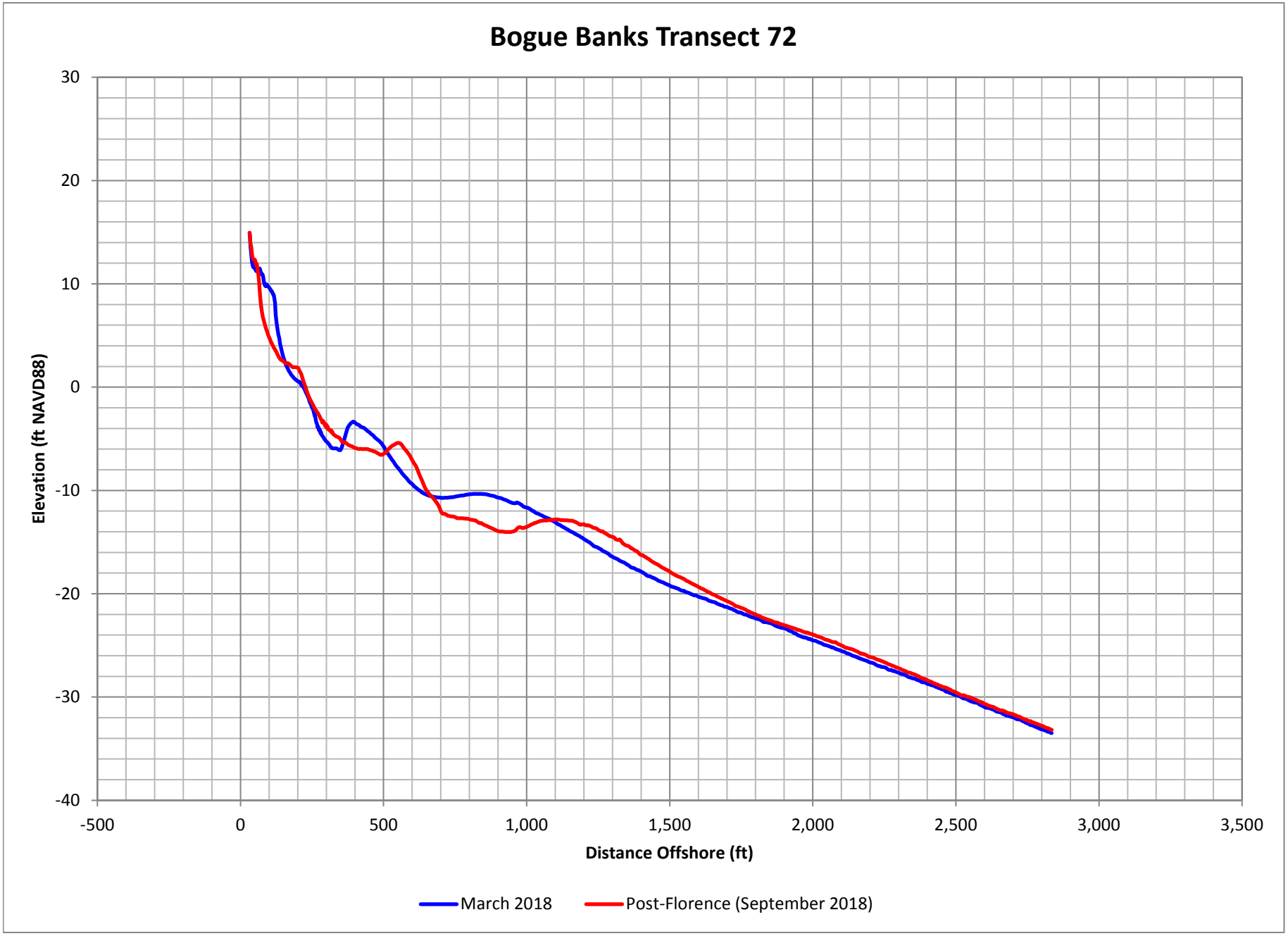


Figure D-143. Bogue Banks Profile Comparison Plot

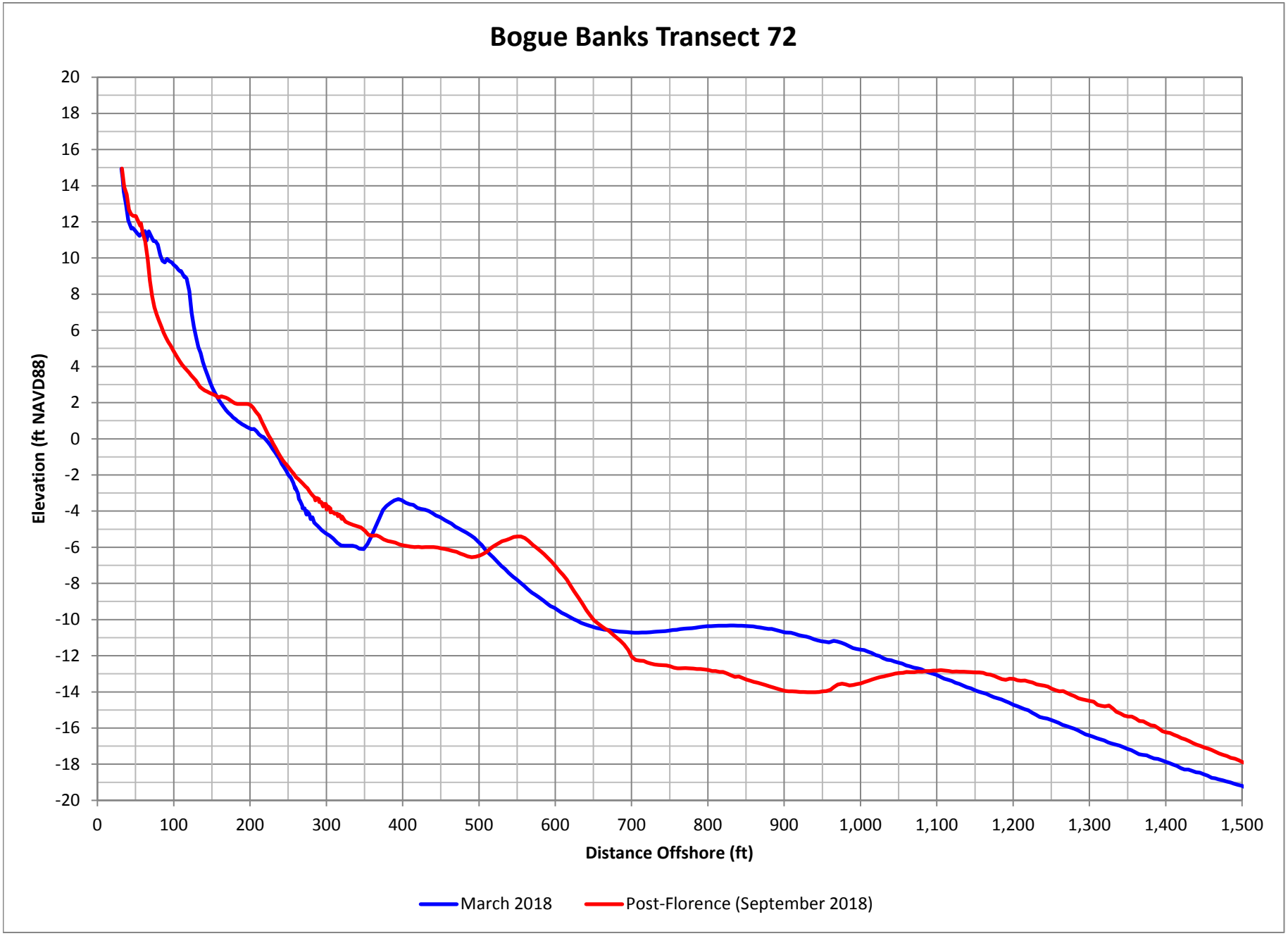


Figure D-144. Bogue Banks Profile Comparison Plot

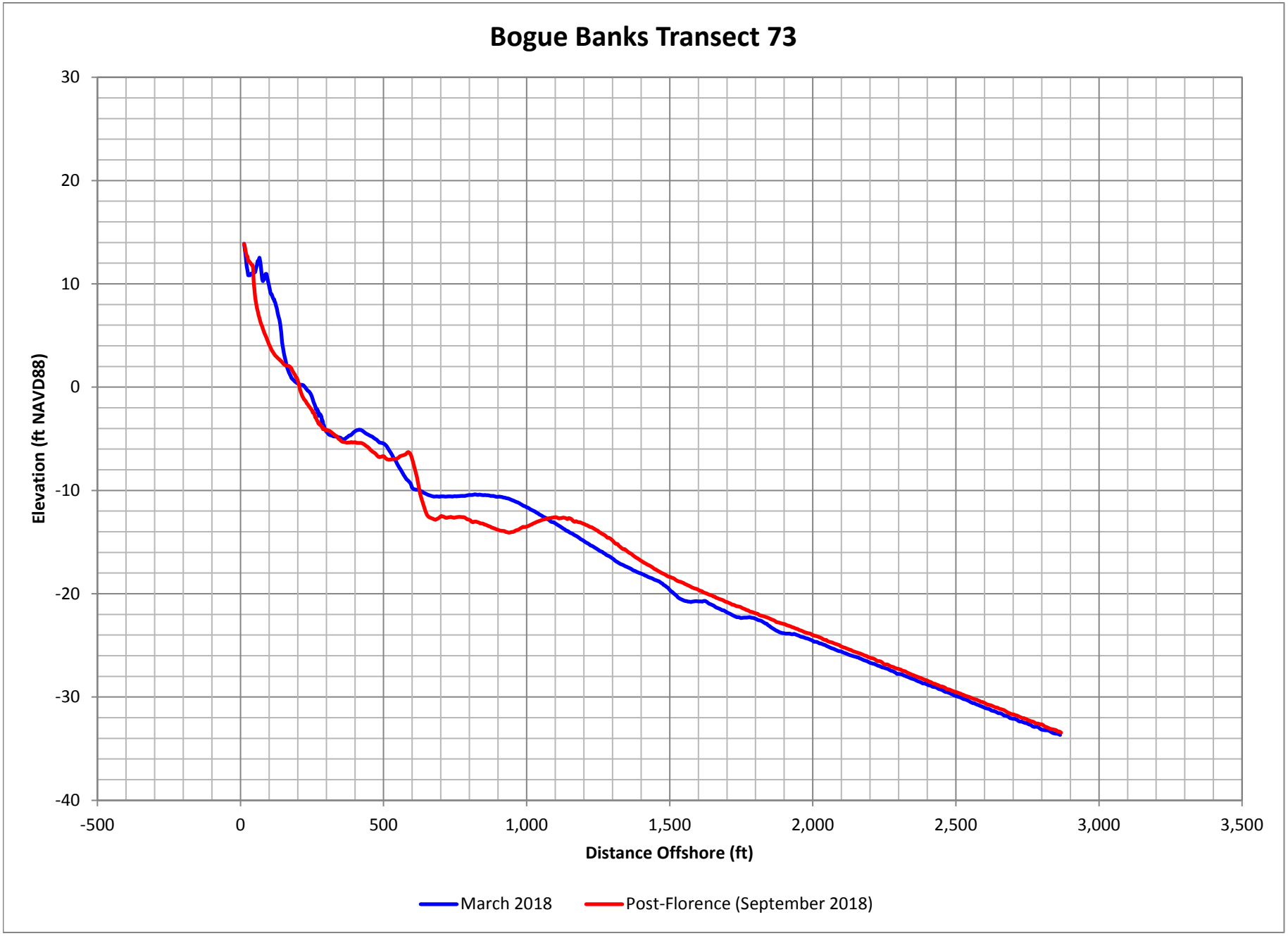


Figure D-145. Bogue Banks Profile Comparison Plot

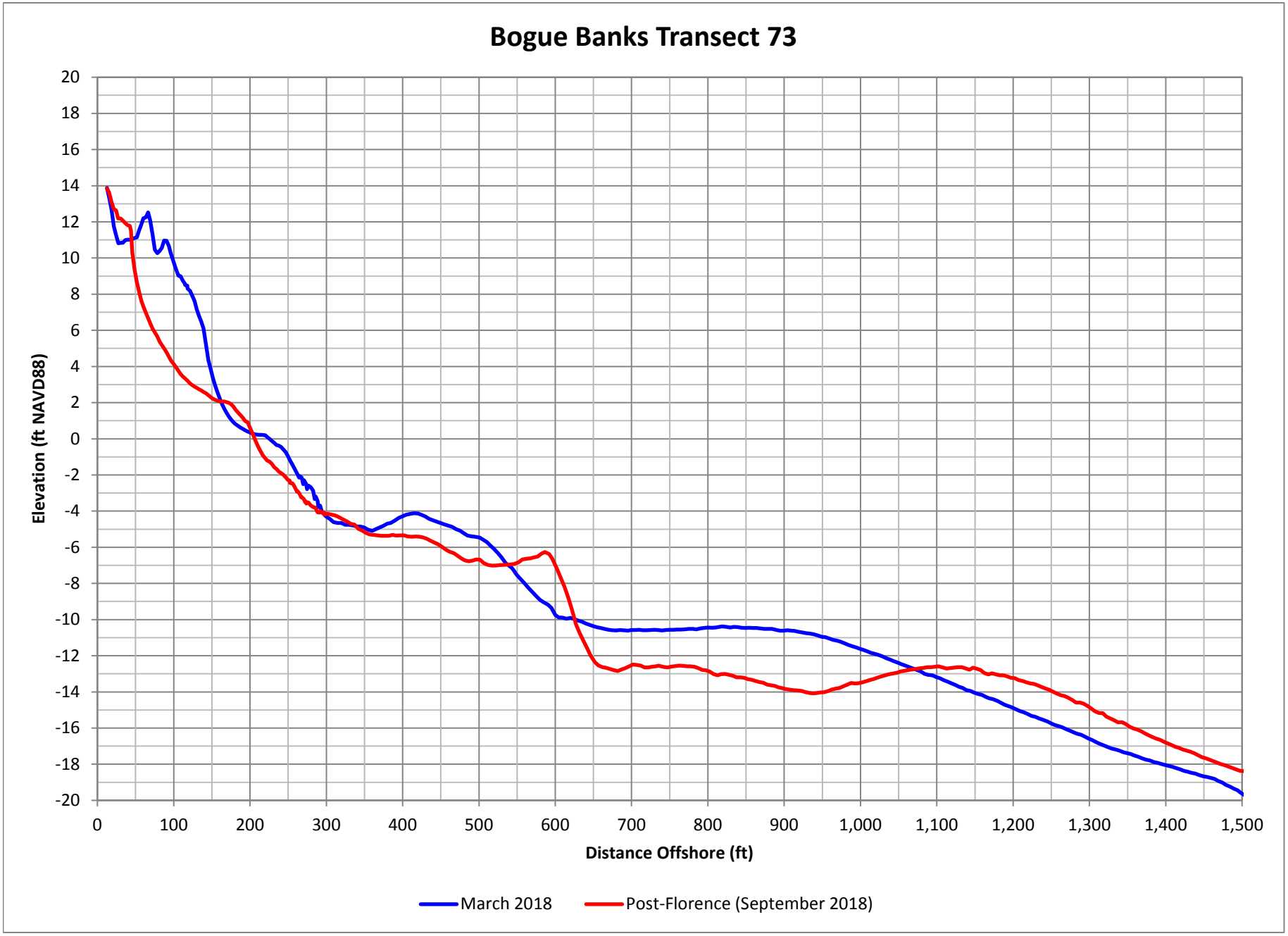


Figure D-146. Bogue Banks Profile Comparison Plot

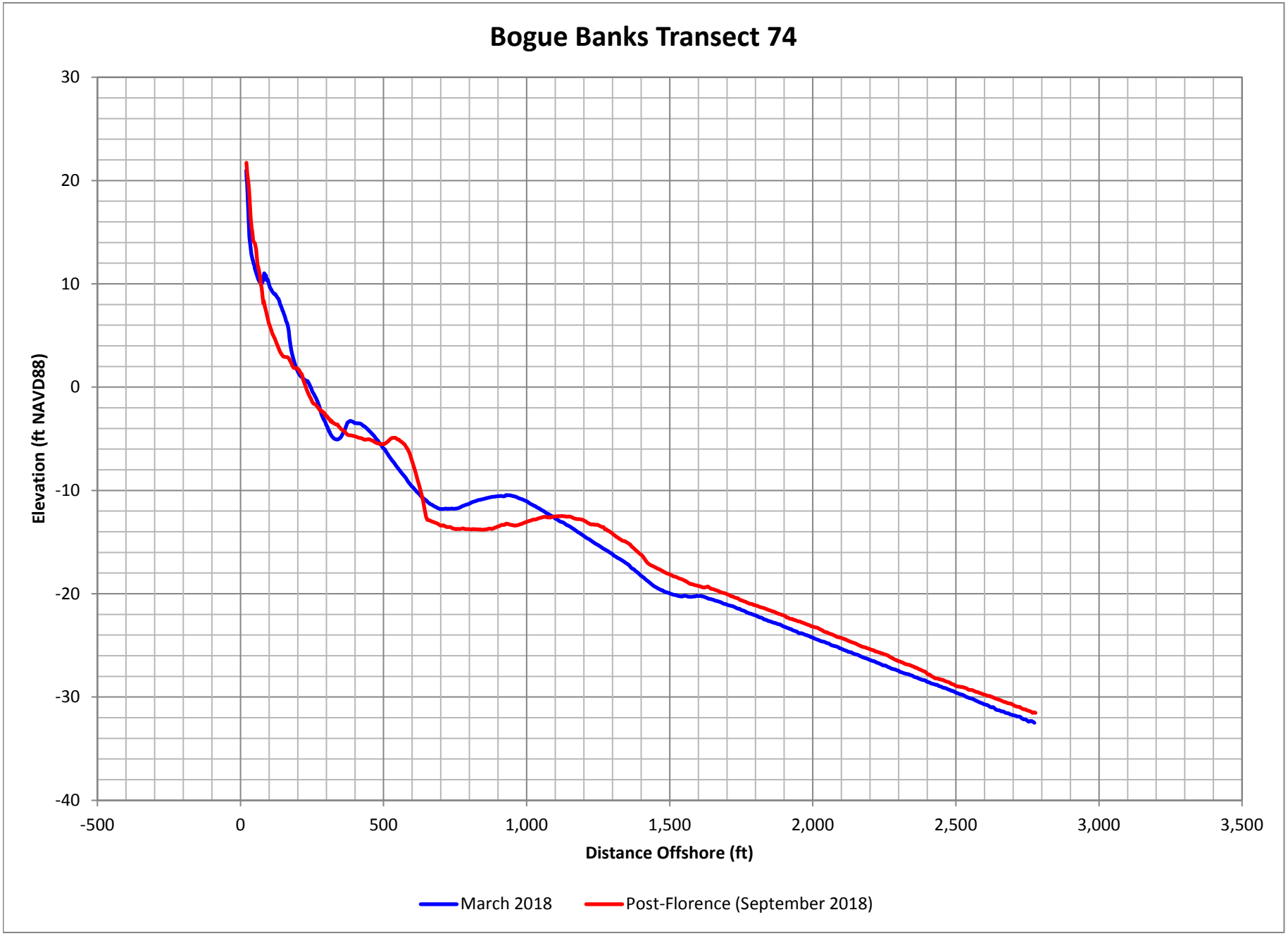


Figure D-147. Bogue Banks Profile Comparison Plot

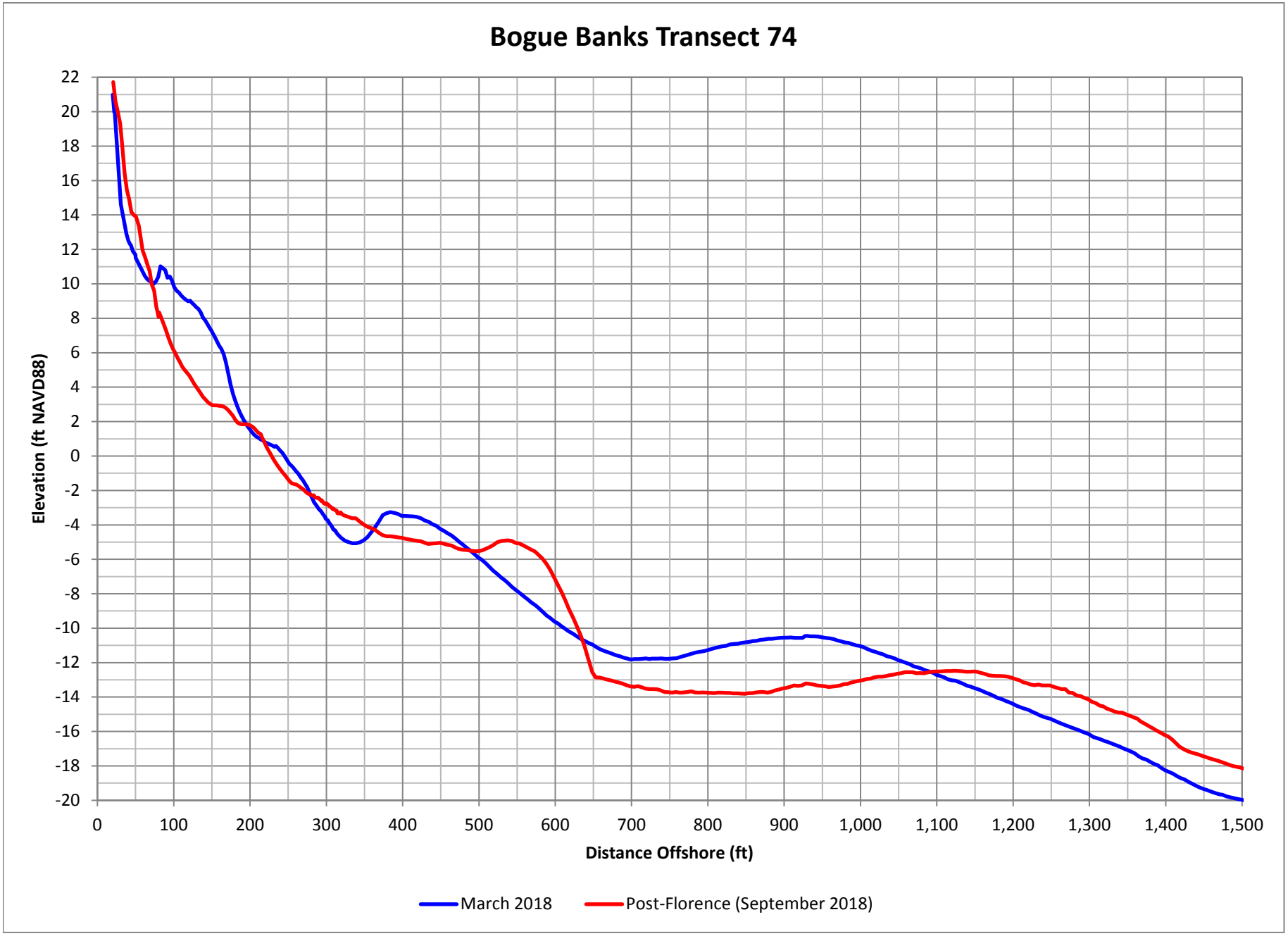


Figure D-148. Bogue Banks Profile Comparison Plot

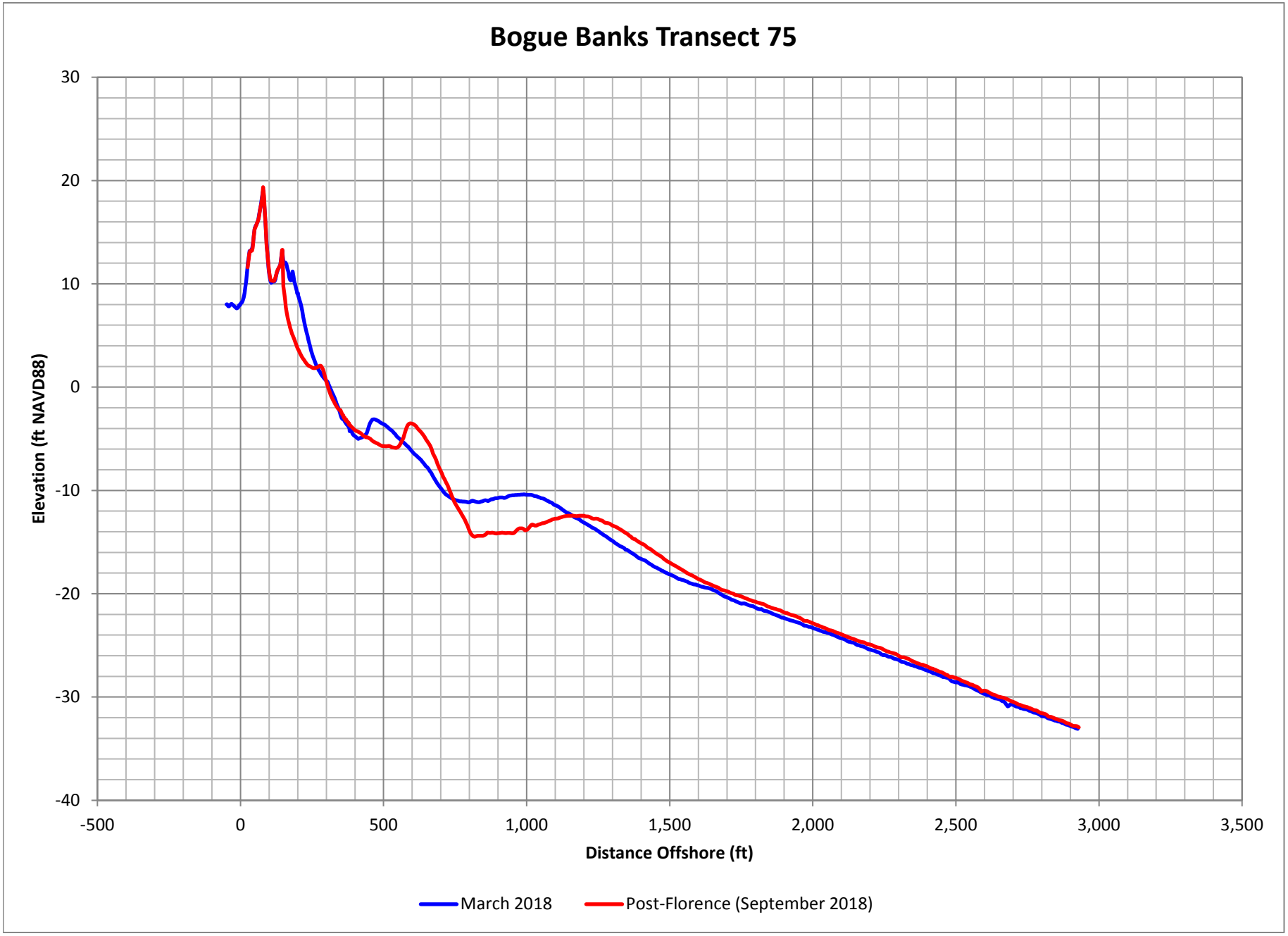


Figure D-149. Bogue Banks Profile Comparison Plot

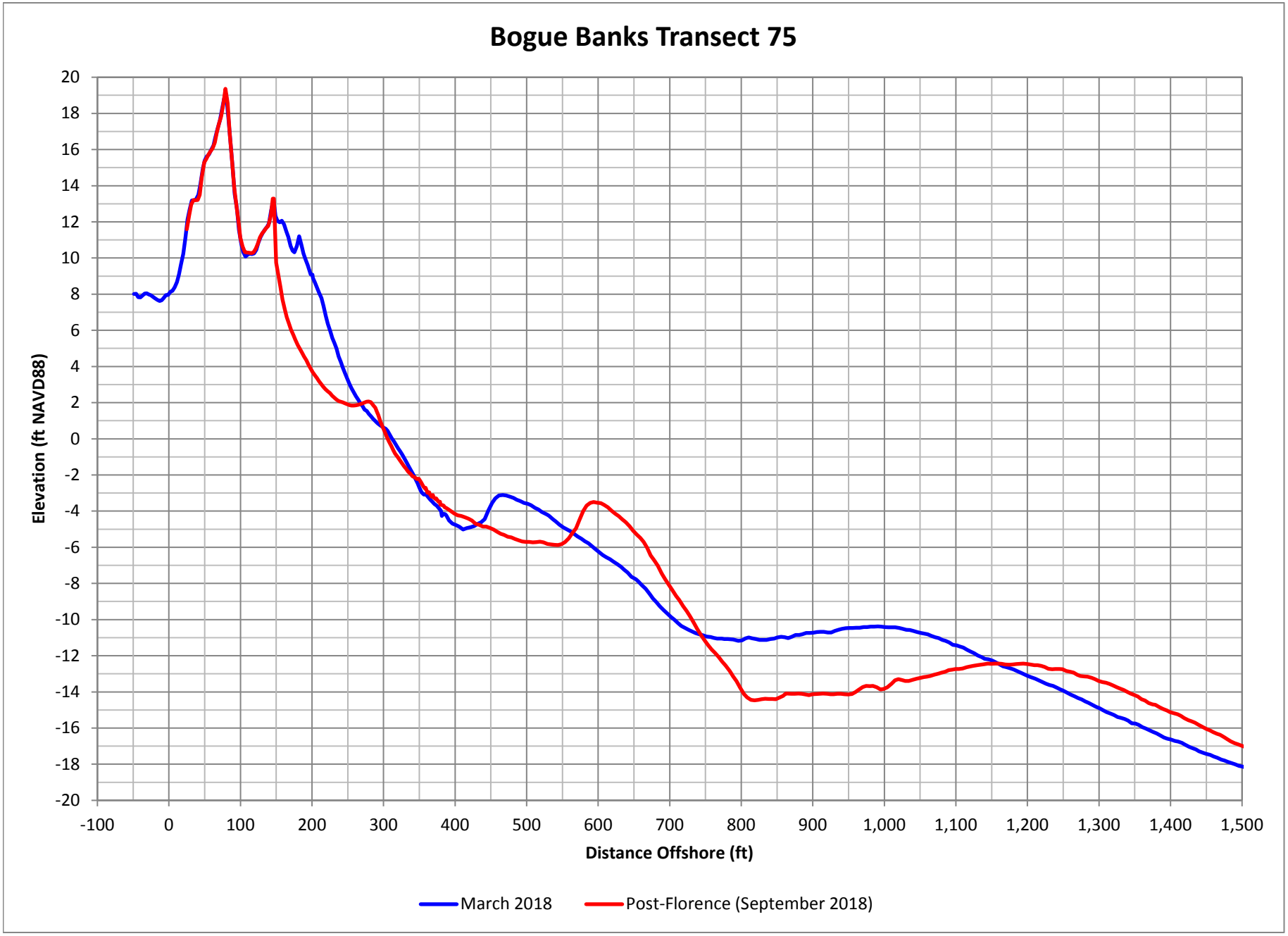


Figure D-150. Bogue Banks Profile Comparison Plot

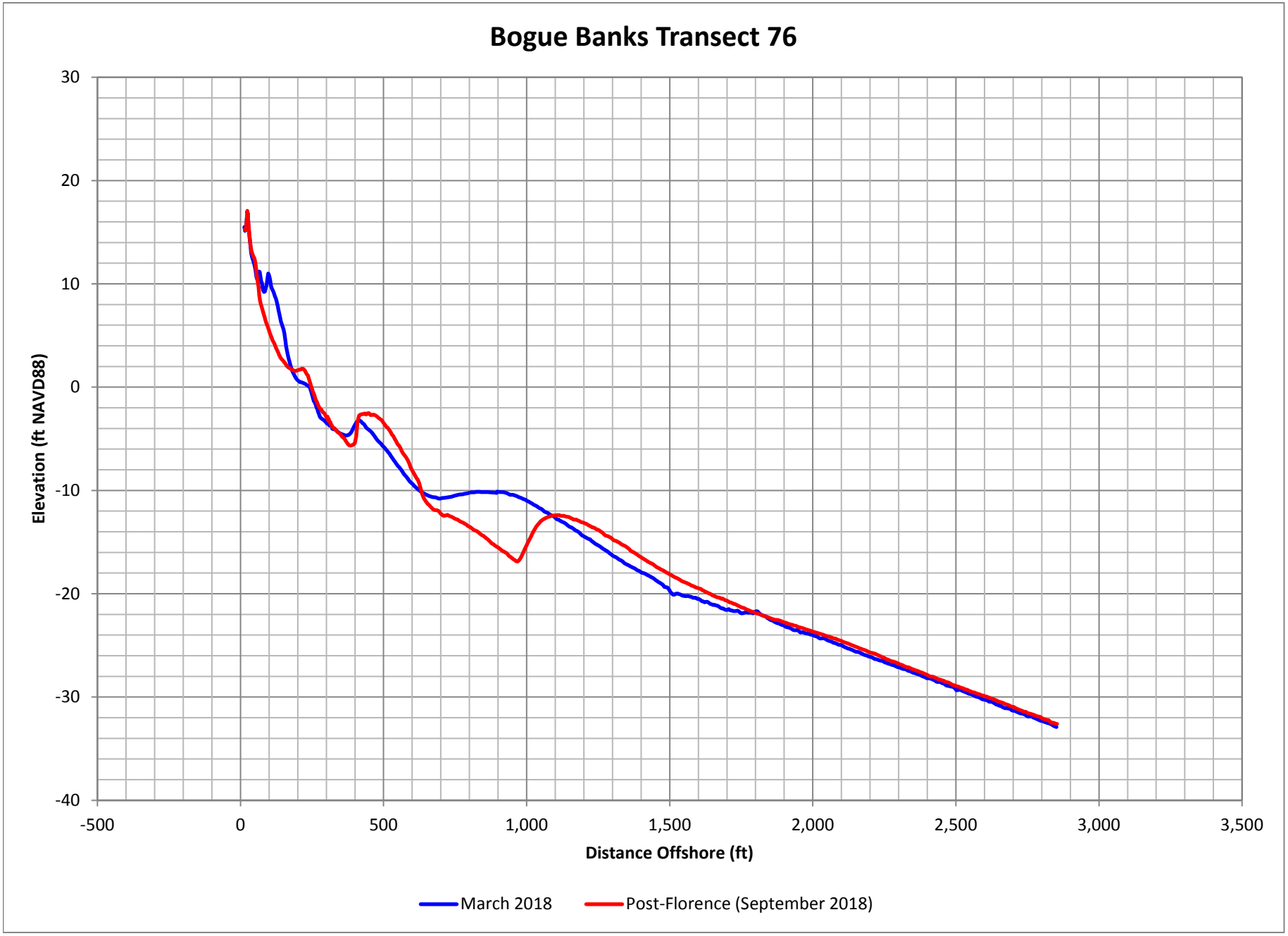


Figure D-151. Bogue Banks Profile Comparison Plot

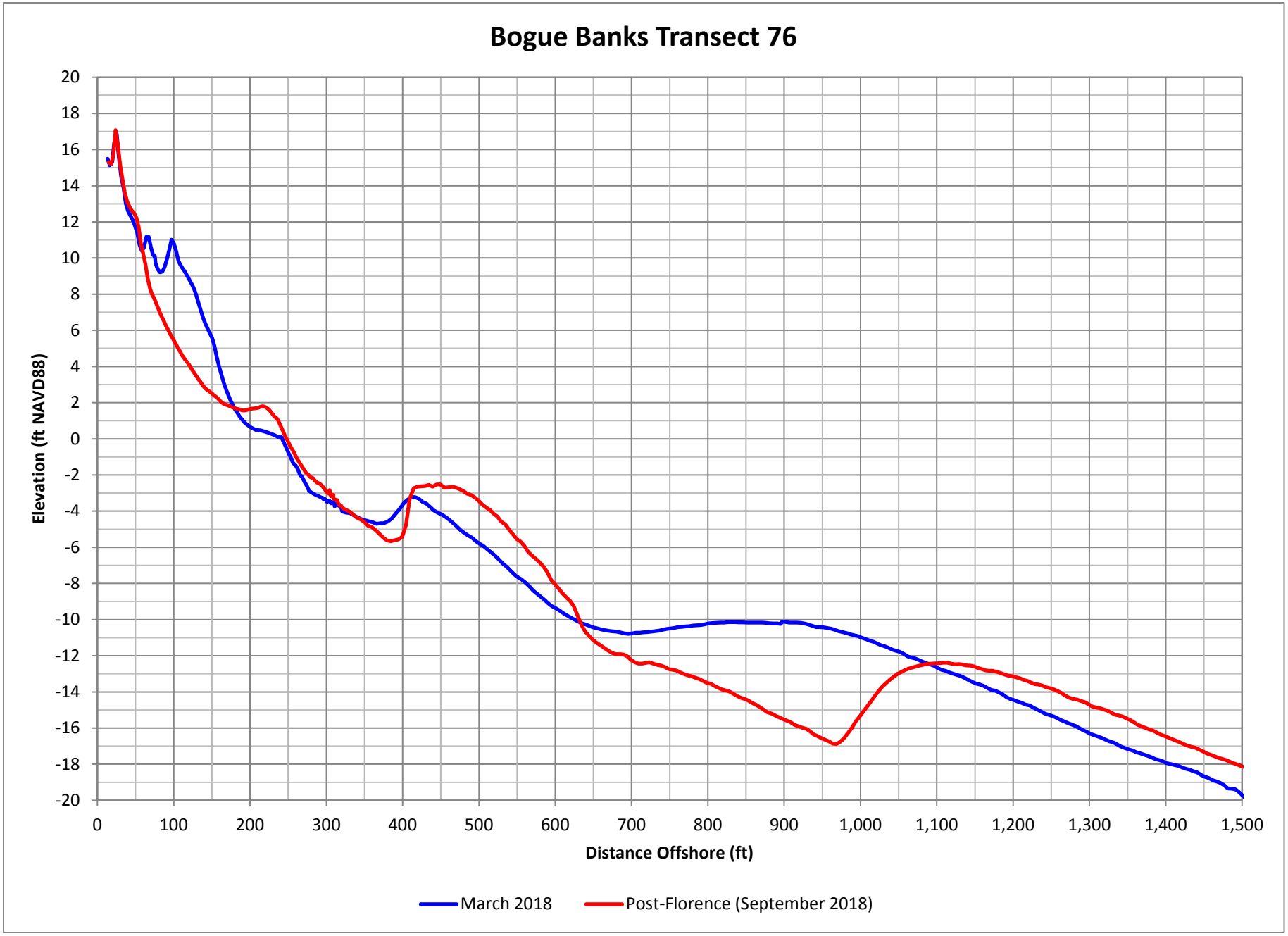


Figure D-152. Bogue Banks Profile Comparison Plot

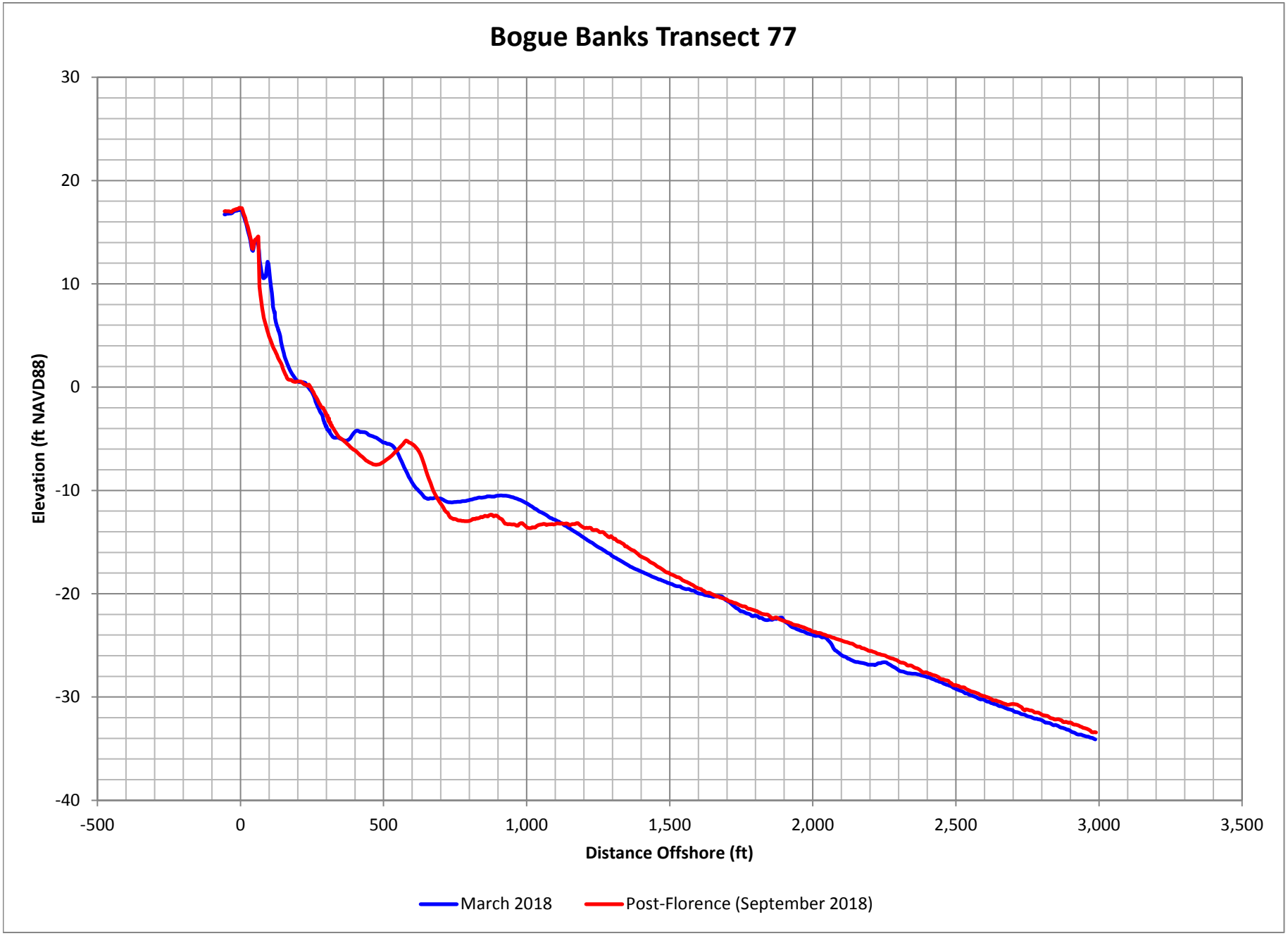


Figure D-153. Bogue Banks Profile Comparison Plot

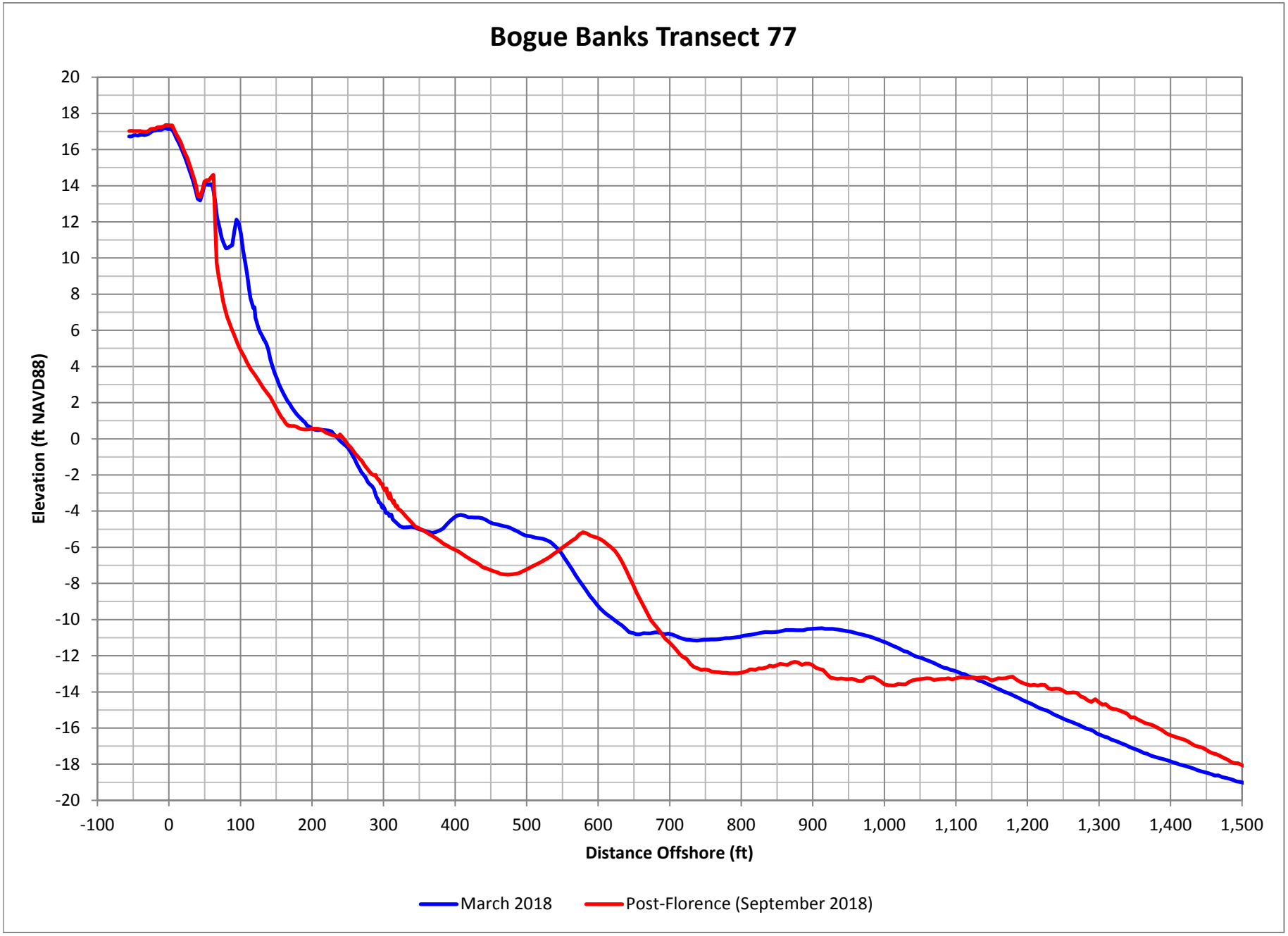


Figure D-154. Bogue Banks Profile Comparison Plot

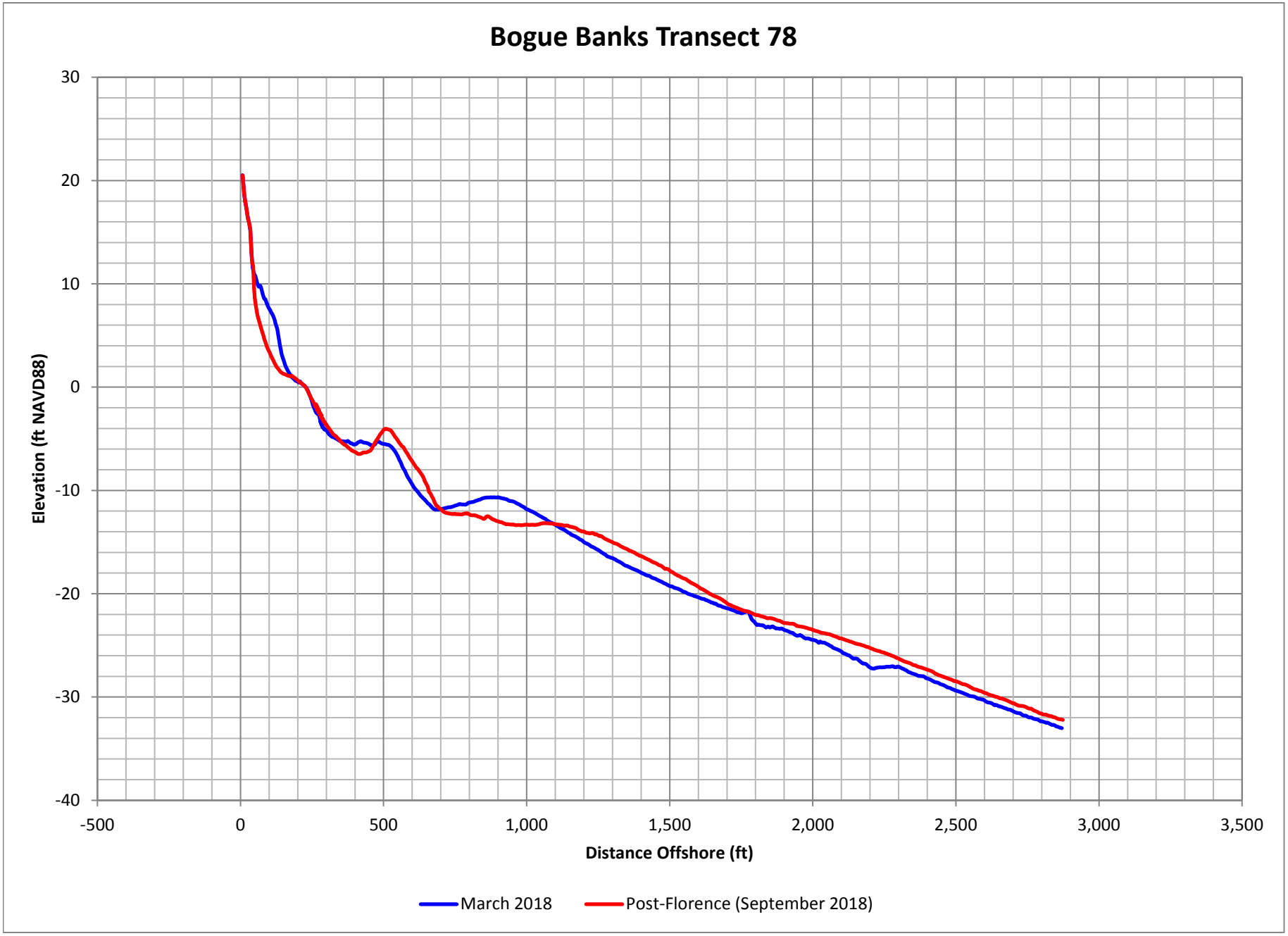


Figure D-155. Bogue Banks Profile Comparison Plot

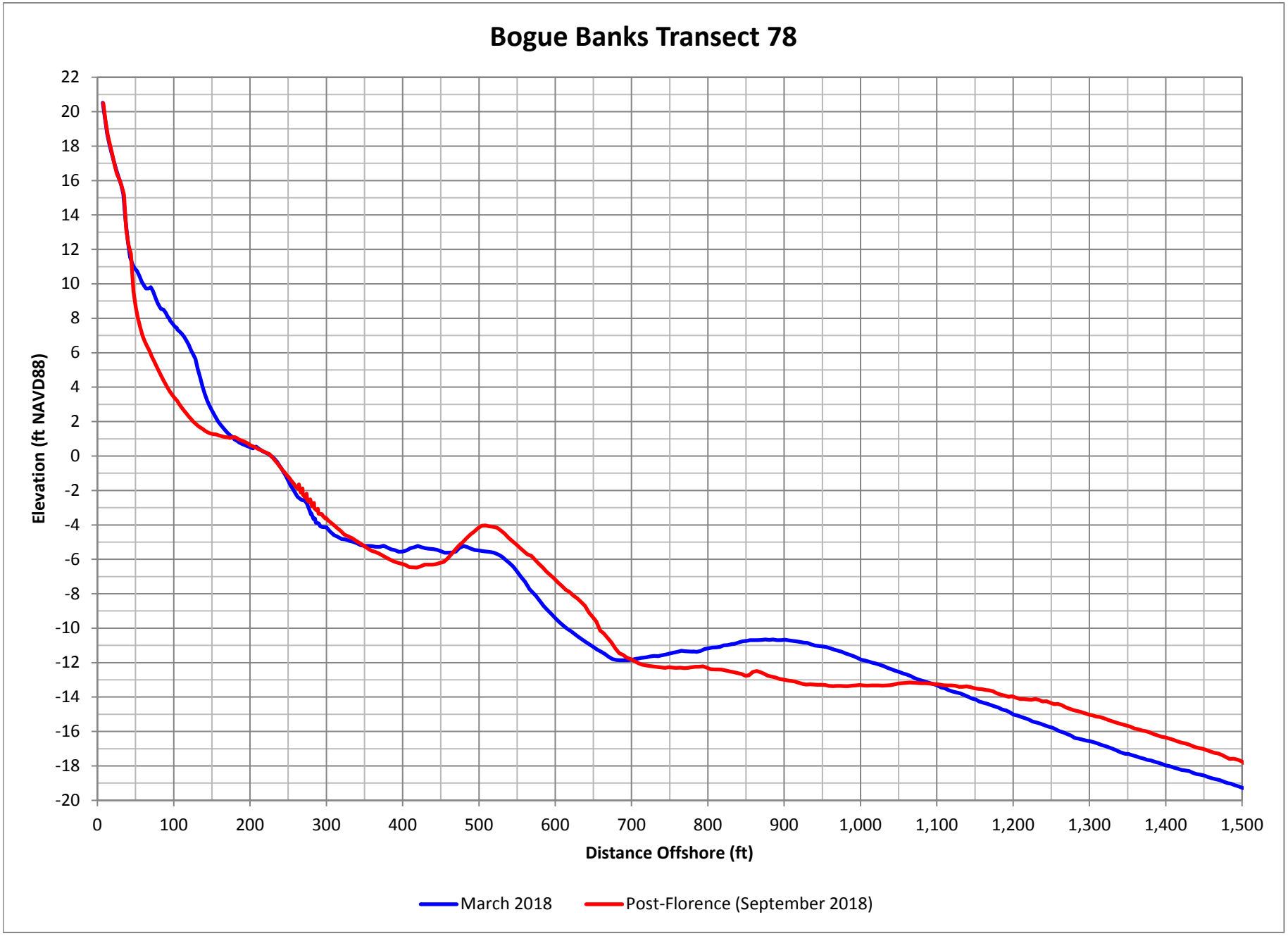


Figure D-156. Bogue Banks Profile Comparison Plot

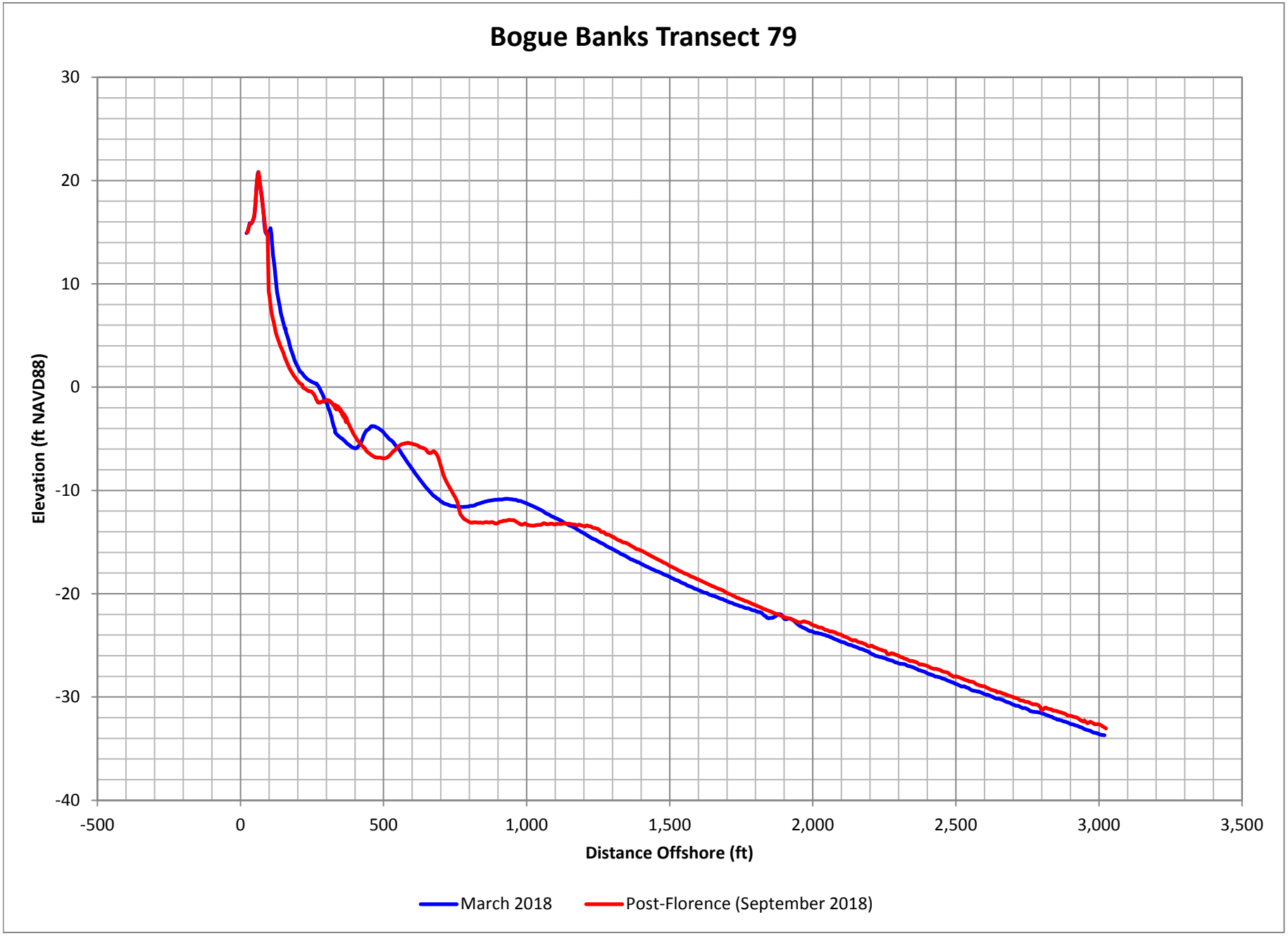


Figure D-157. Bogue Banks Profile Comparison Plot

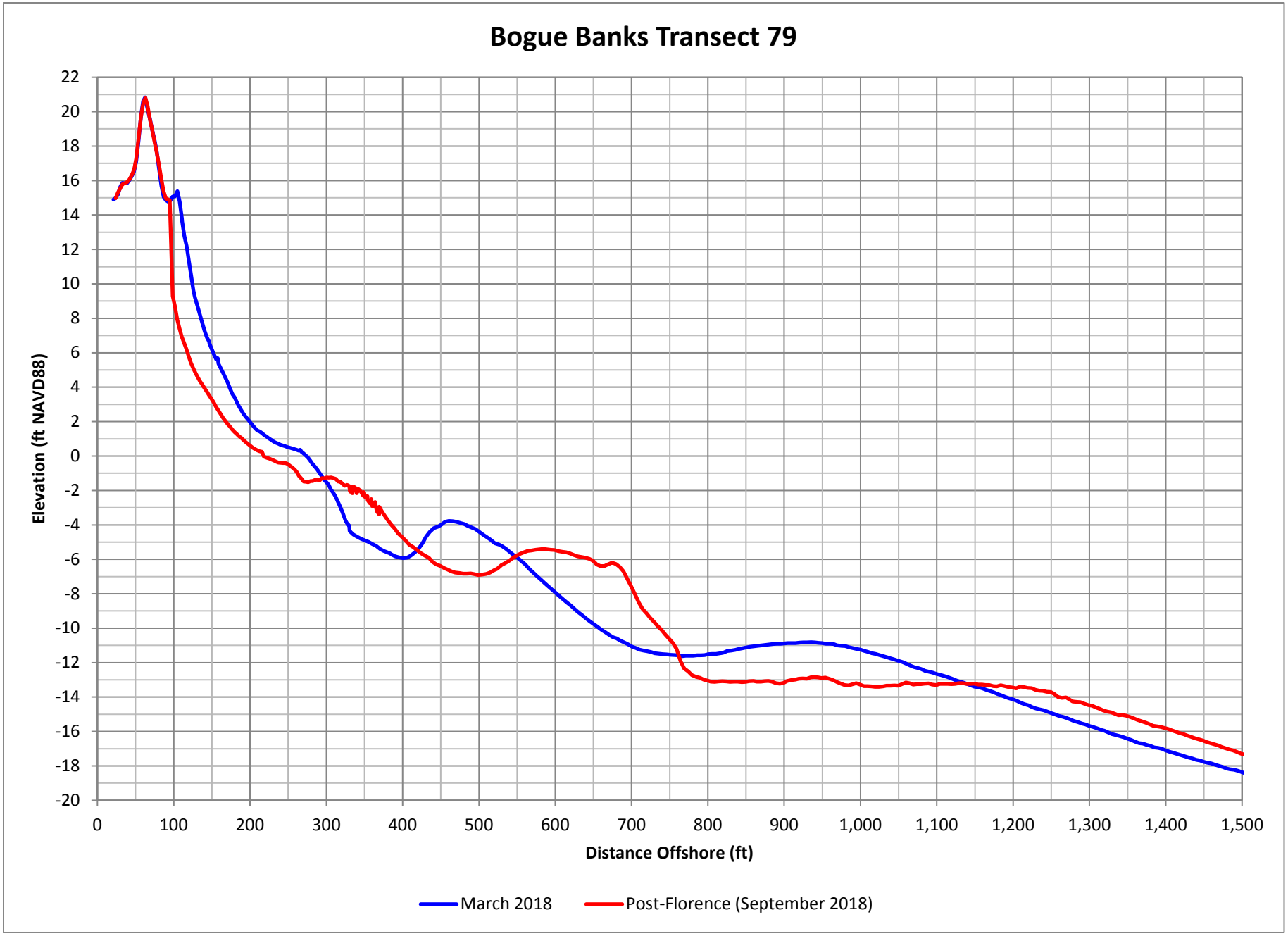


Figure D-158. Bogue Banks Profile Comparison Plot

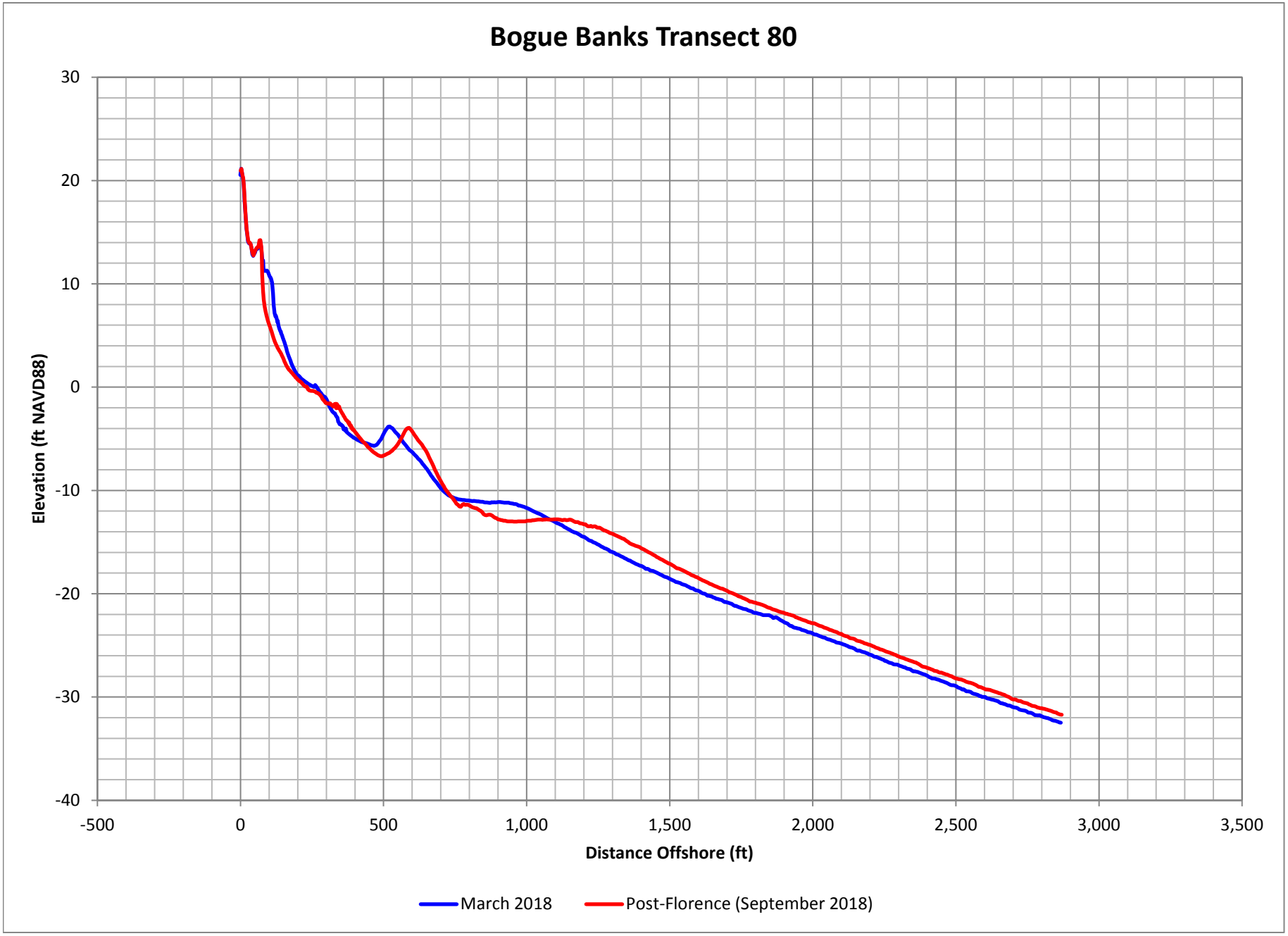


Figure D-159. Bogue Banks Profile Comparison Plot

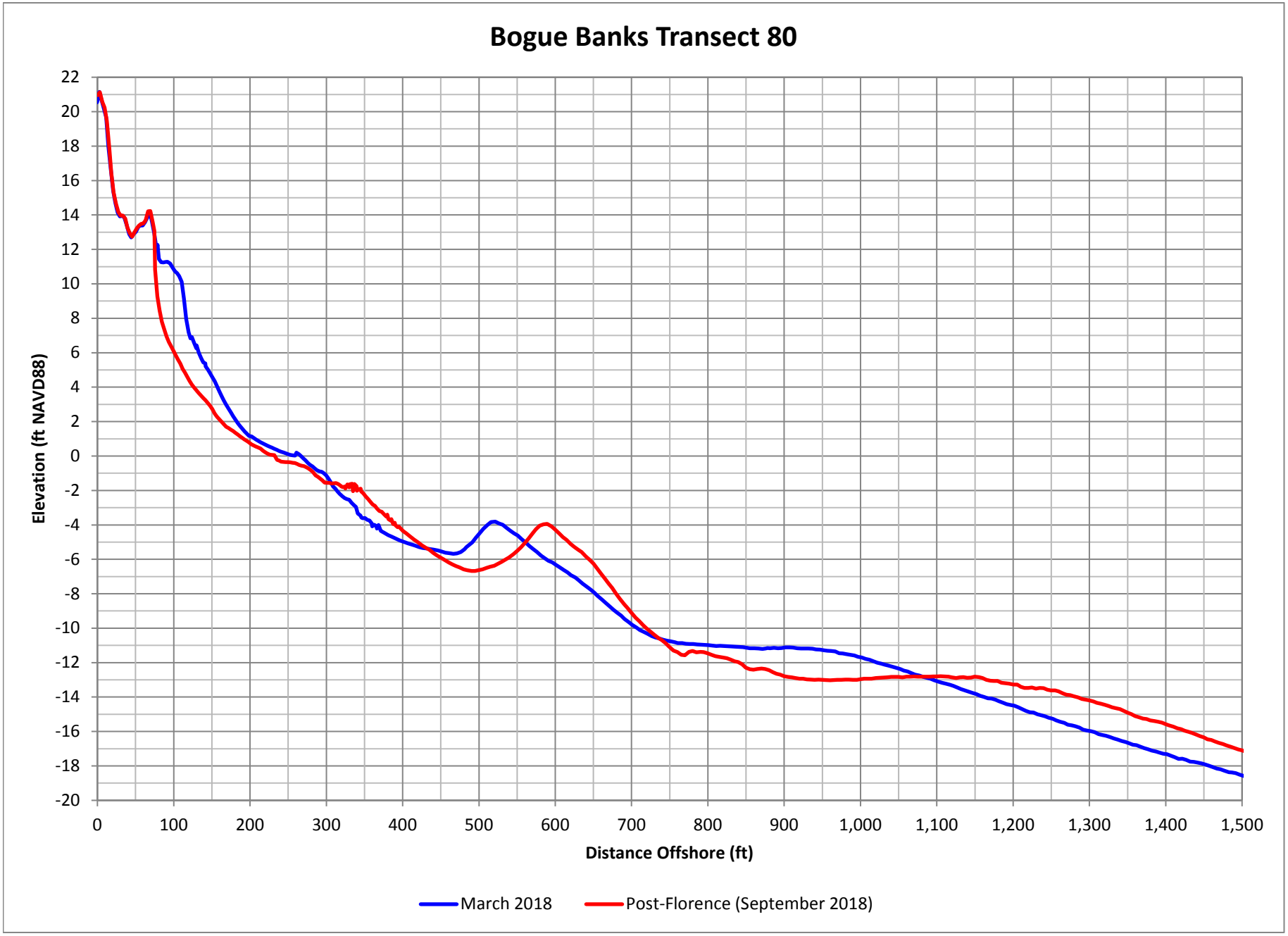


Figure D-160. Bogue Banks Profile Comparison Plot

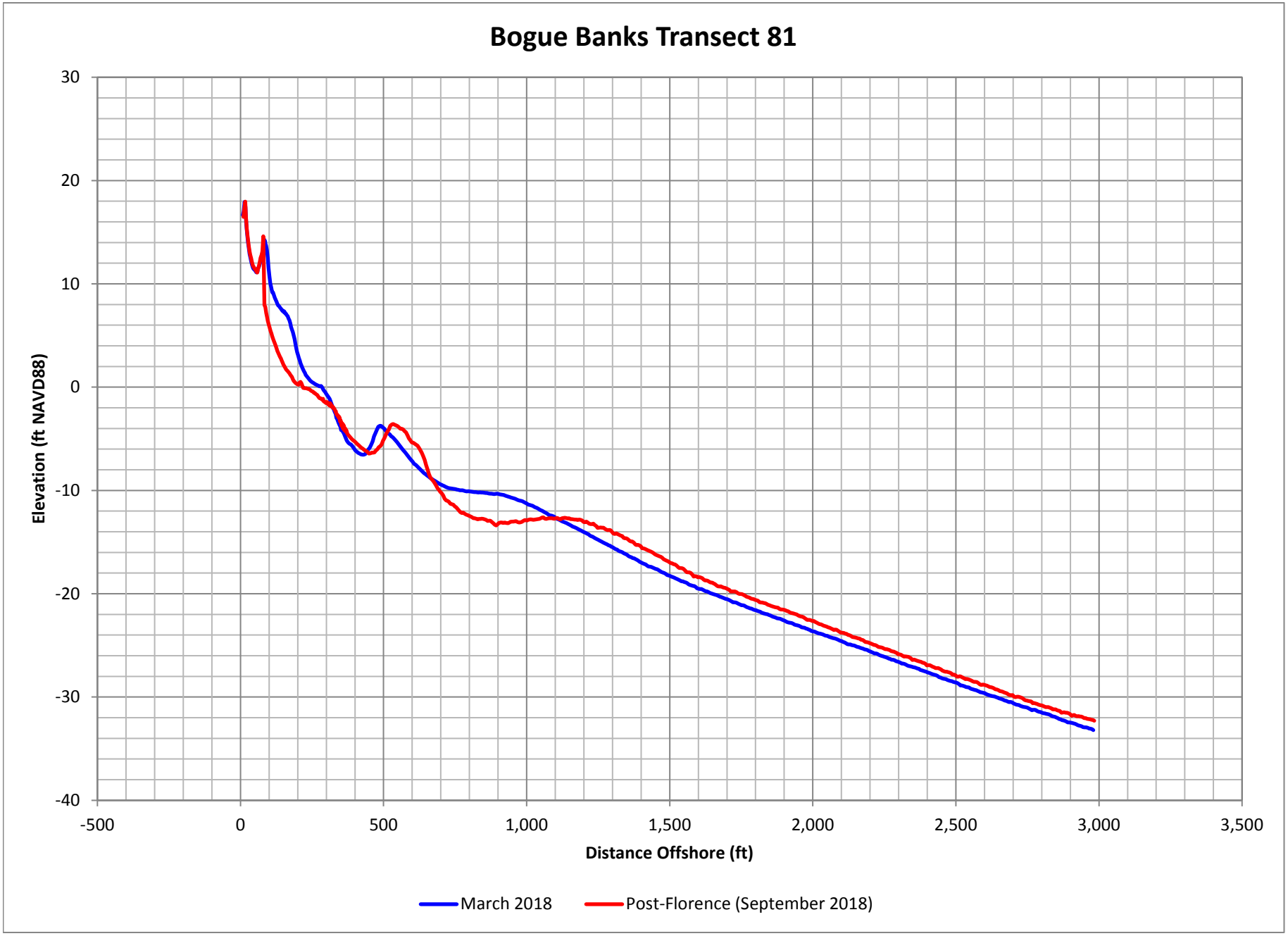


Figure D-161. Bogue Banks Profile Comparison Plot

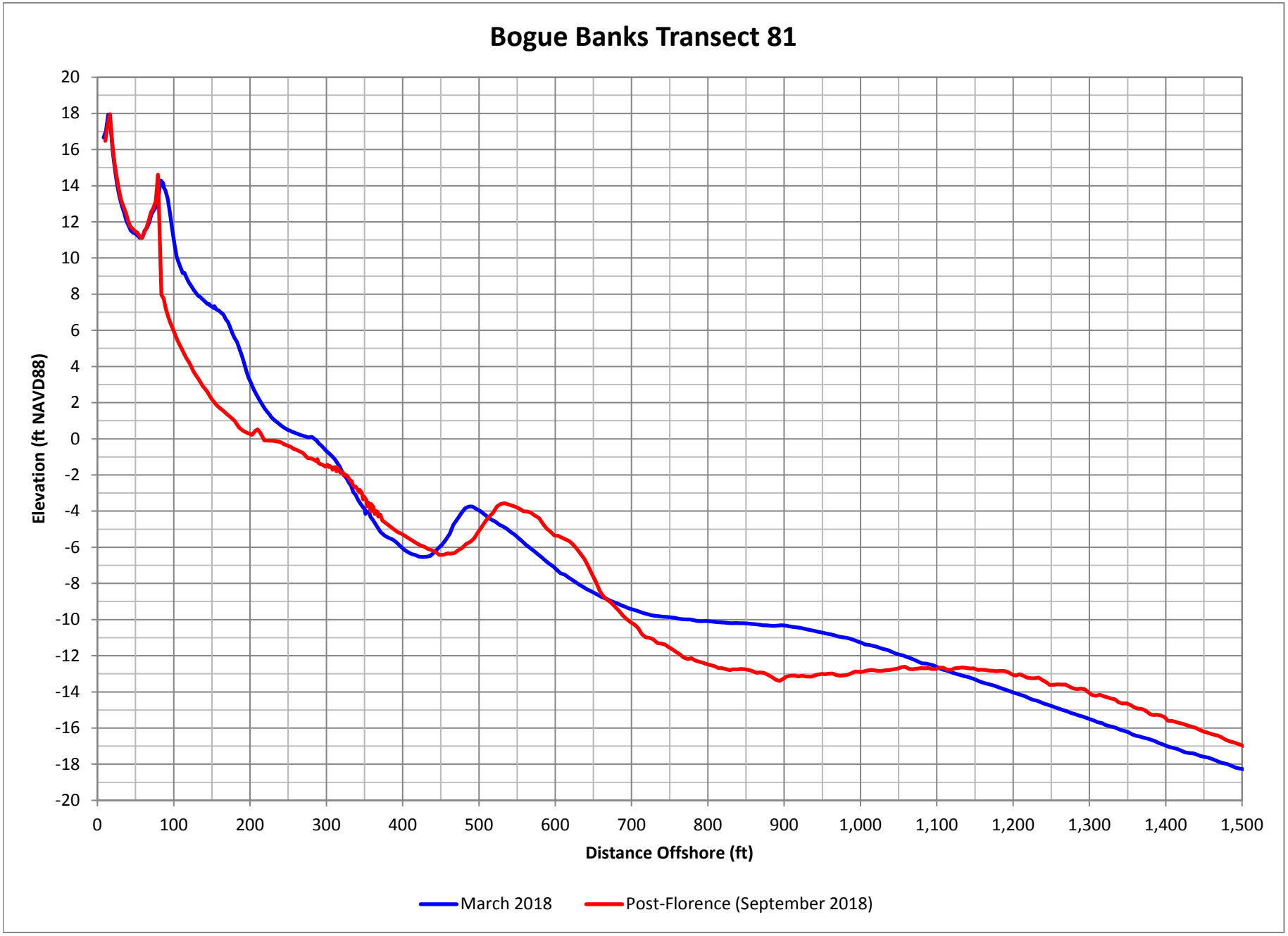


Figure D-162. Bogue Banks Profile Comparison Plot

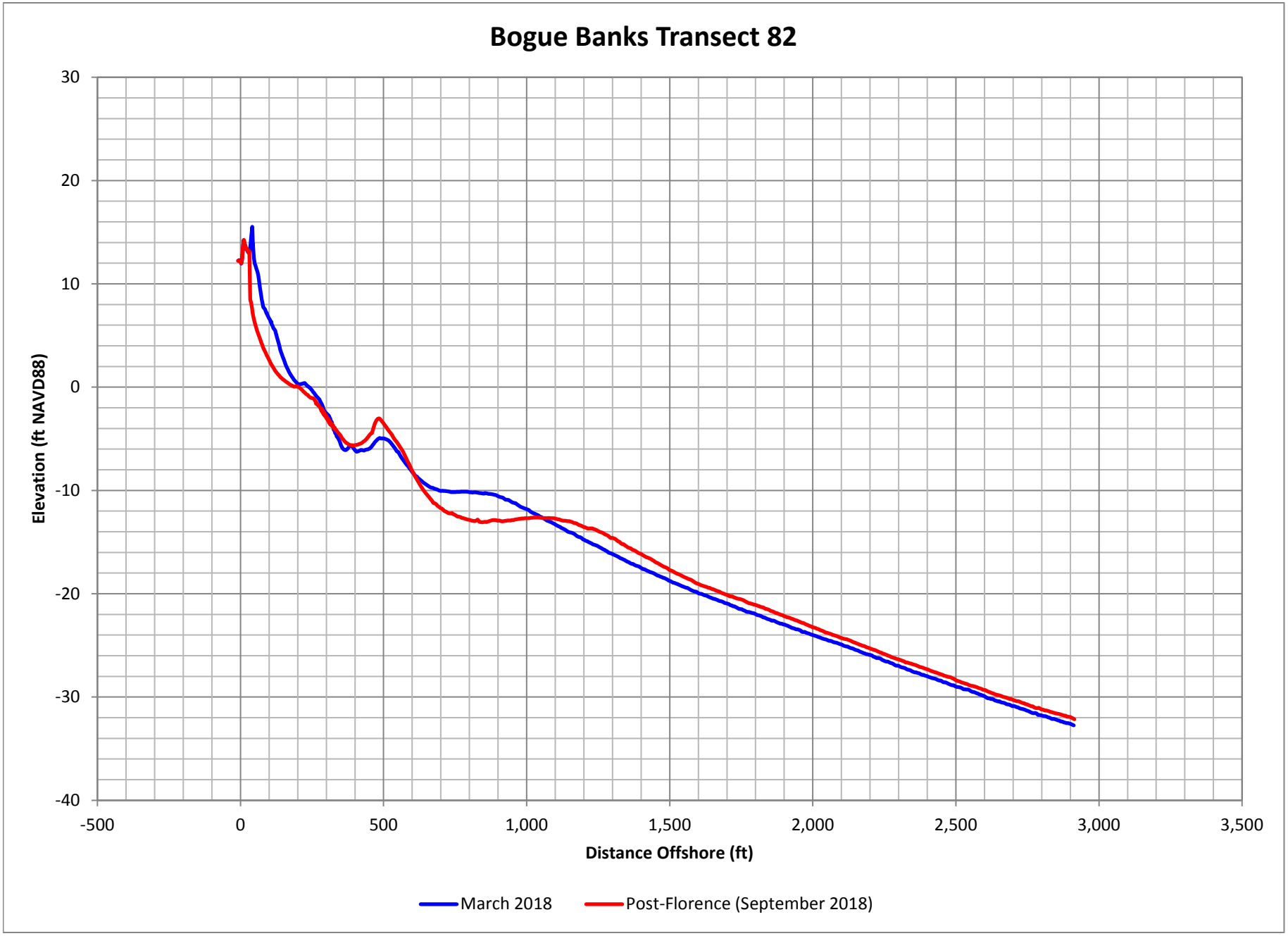


Figure D-163. Bogue Banks Profile Comparison Plot

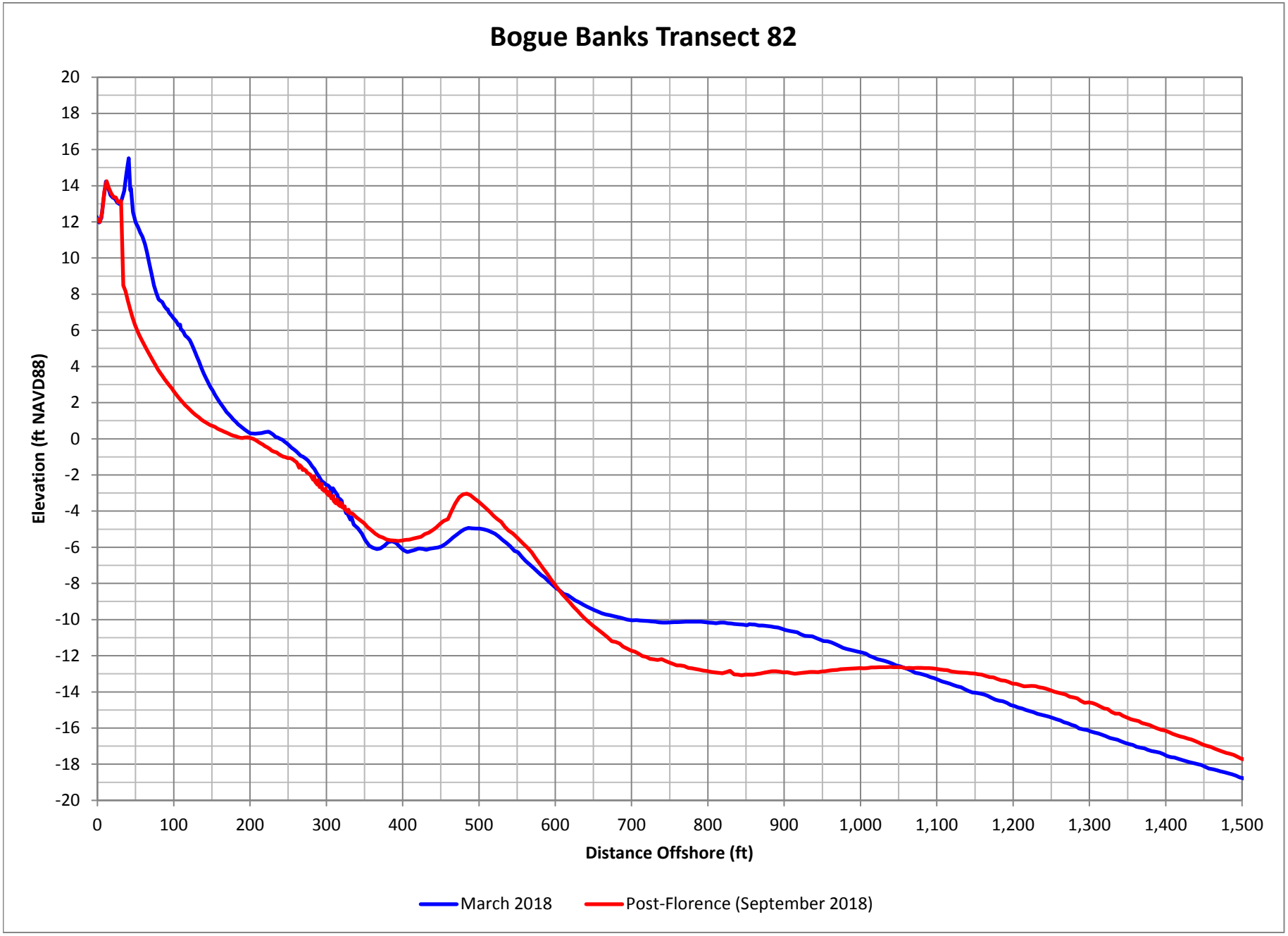


Figure D-164. Bogue Banks Profile Comparison Plot

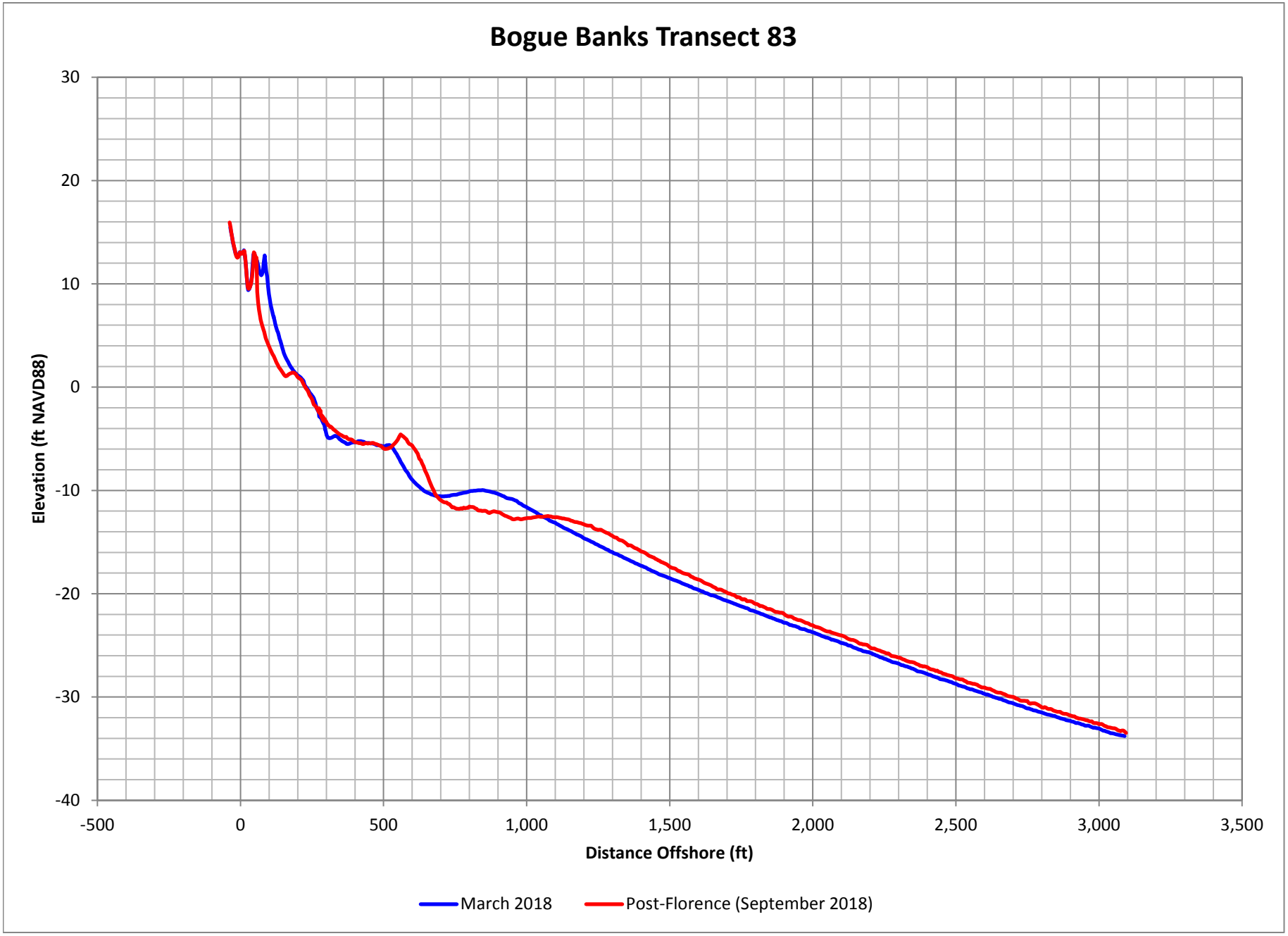


Figure D-165. Bogue Banks Profile Comparison Plot

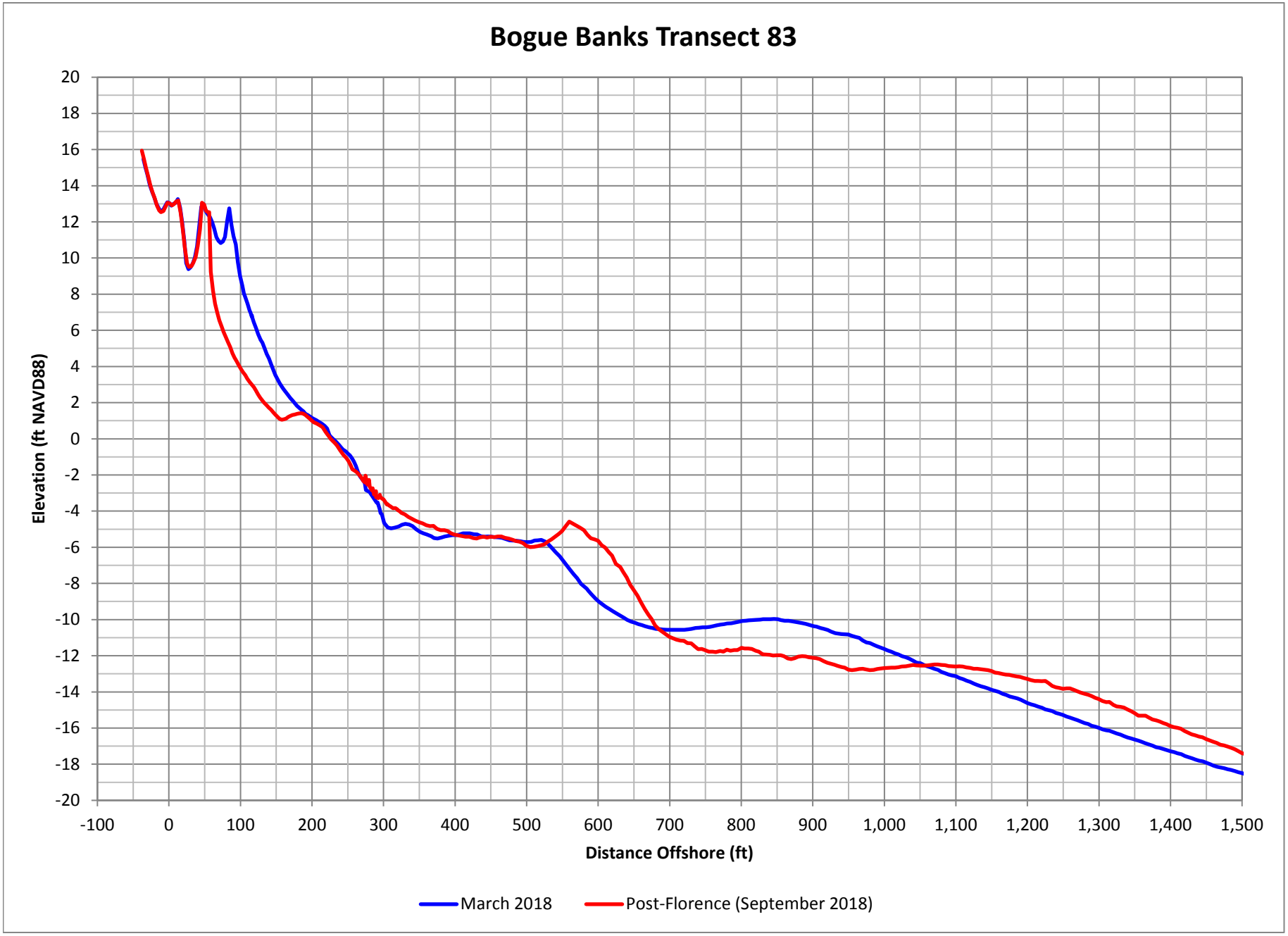


Figure D-166. Bogue Banks Profile Comparison Plot

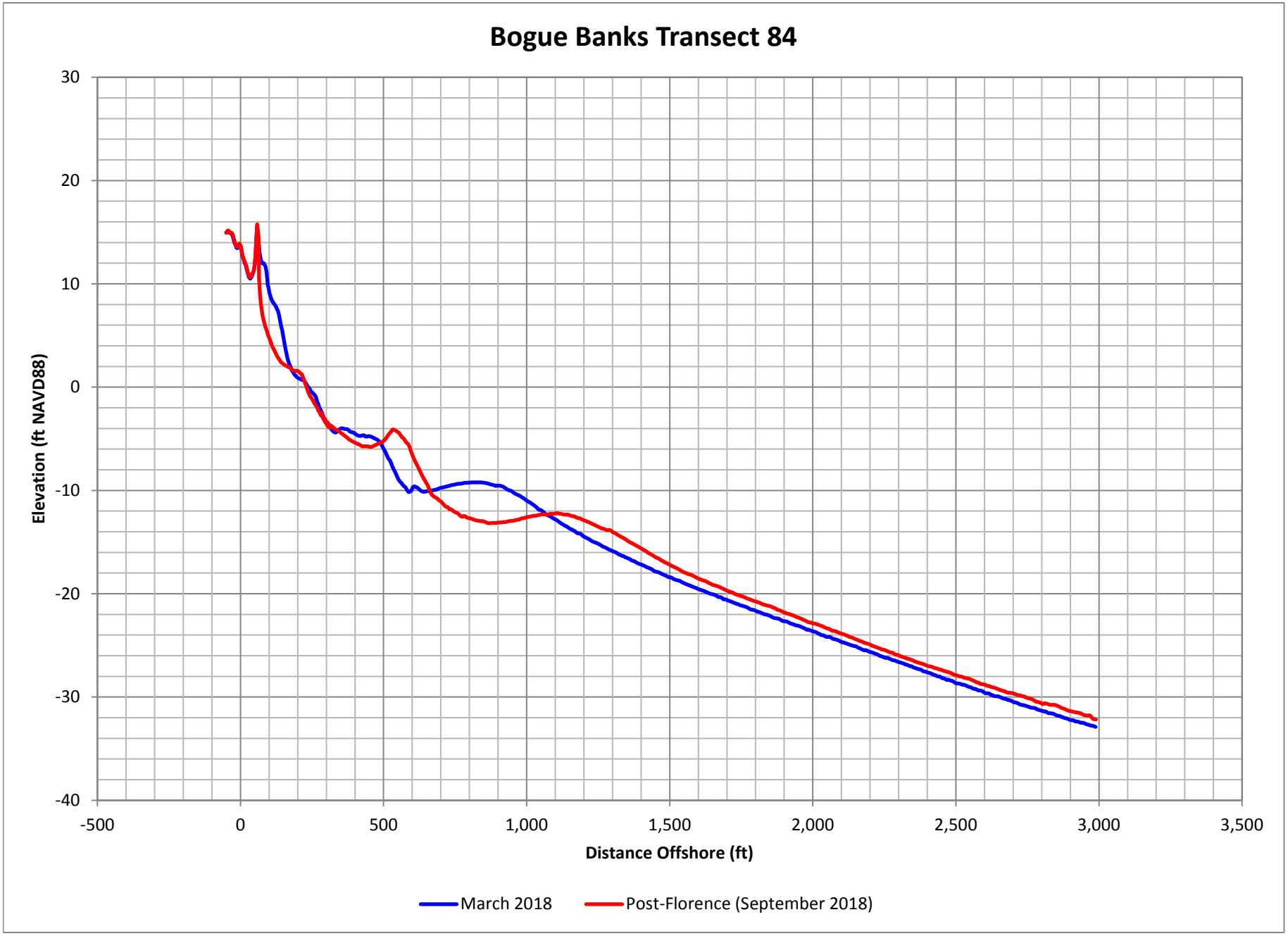


Figure D-167. Bogue Banks Profile Comparison Plot

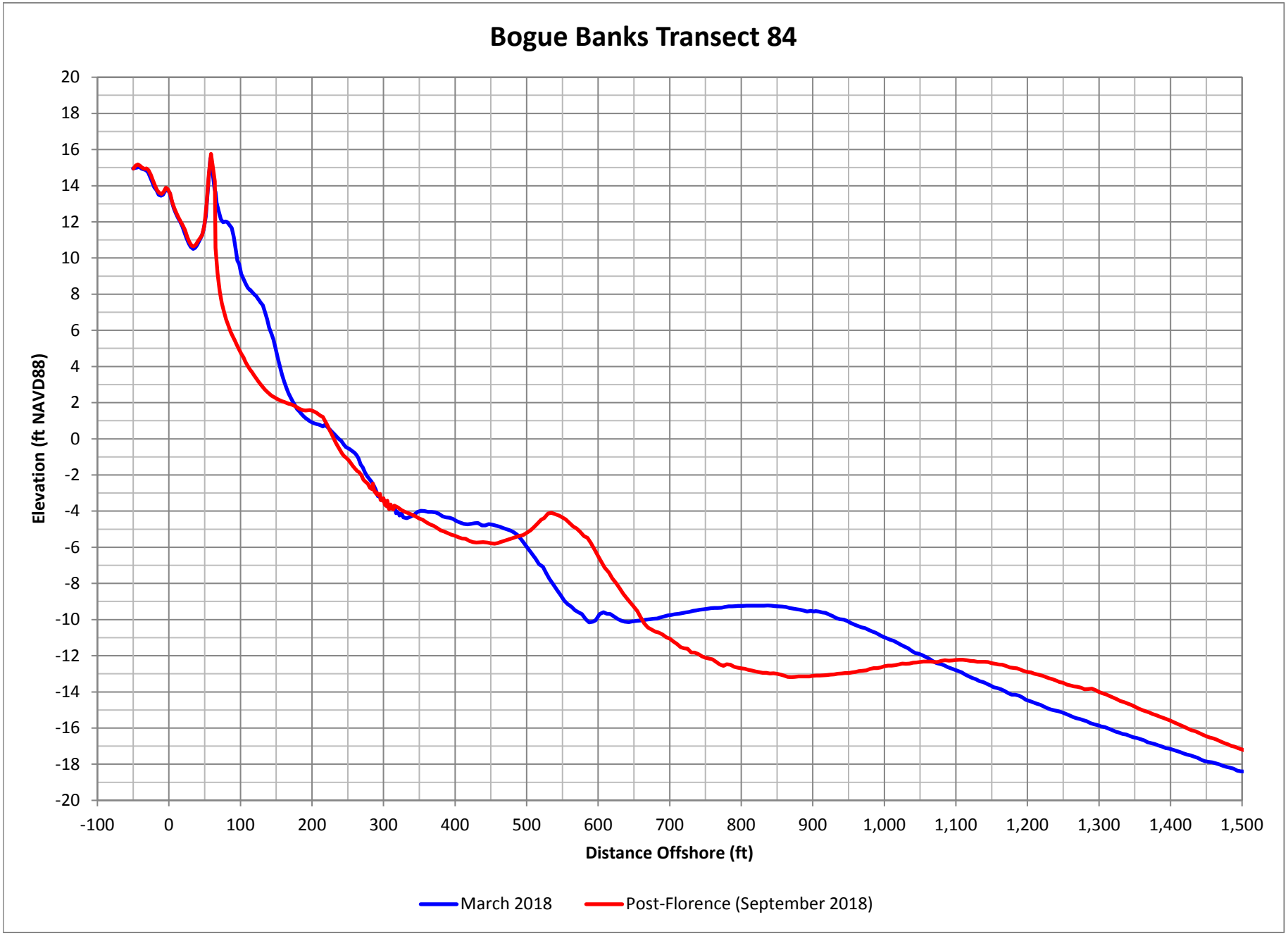


Figure D-168. Bogue Banks Profile Comparison Plot

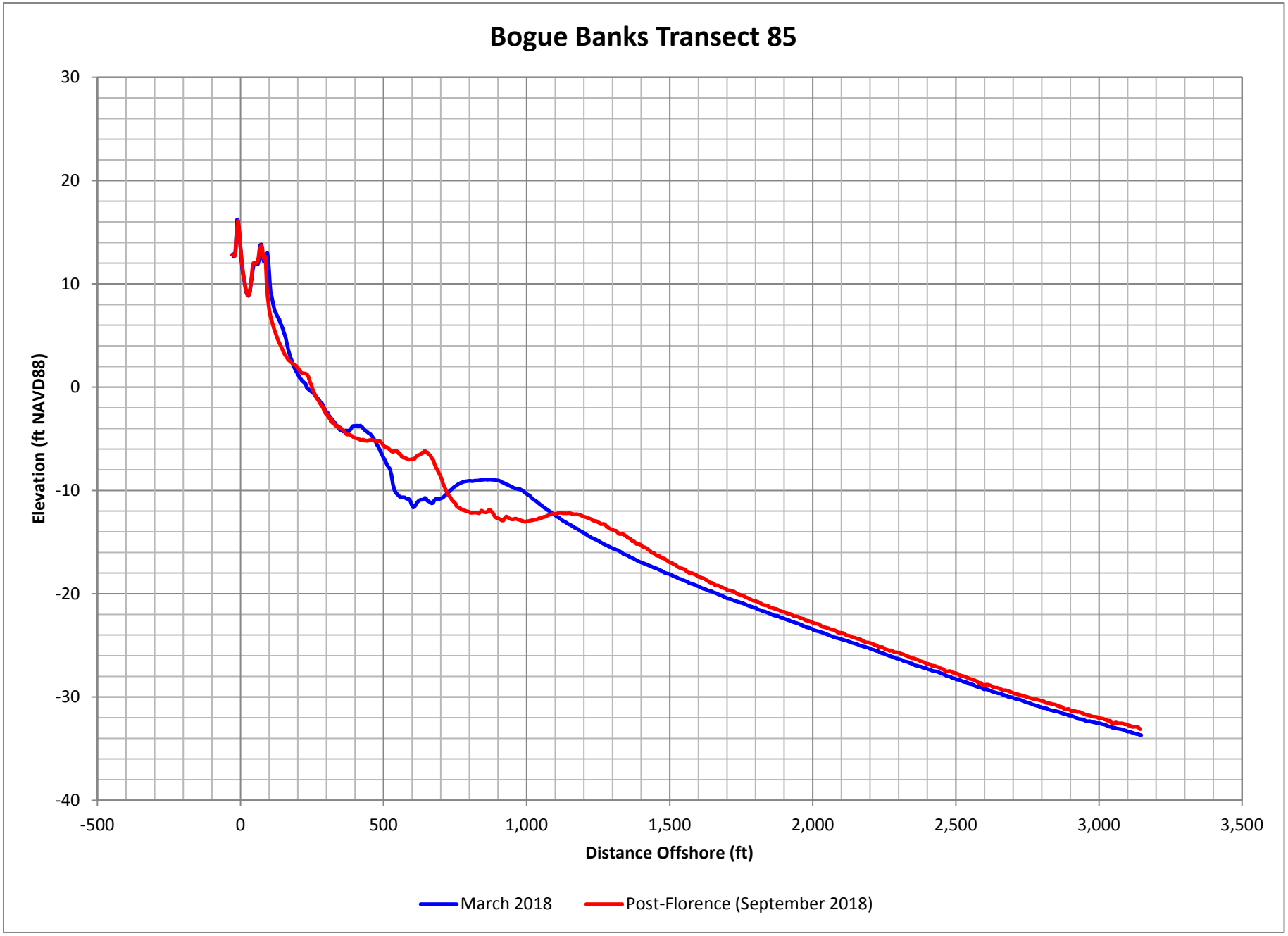


Figure D-169. Bogue Banks Profile Comparison Plot

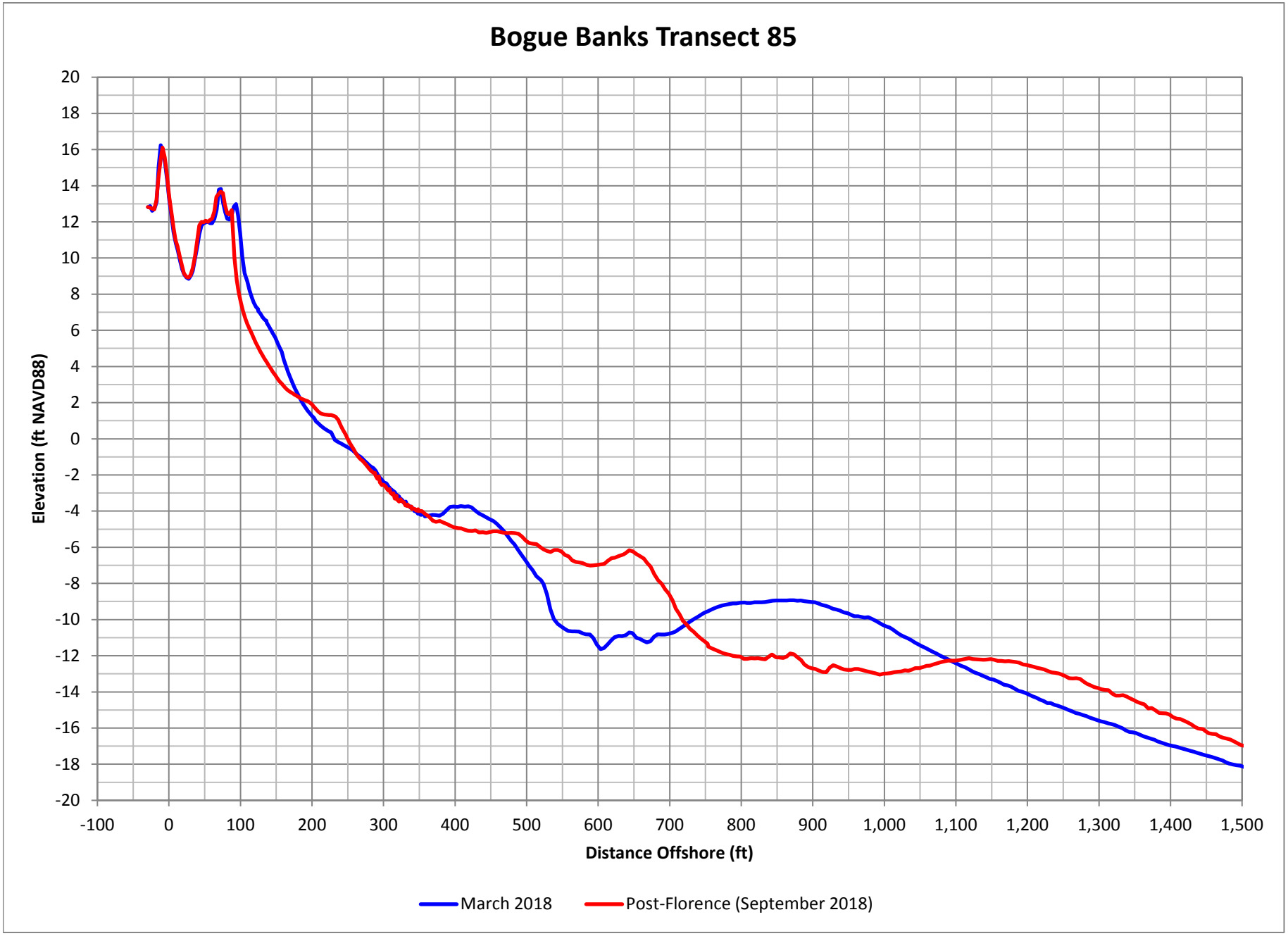


Figure D-170. Bogue Banks Profile Comparison Plot

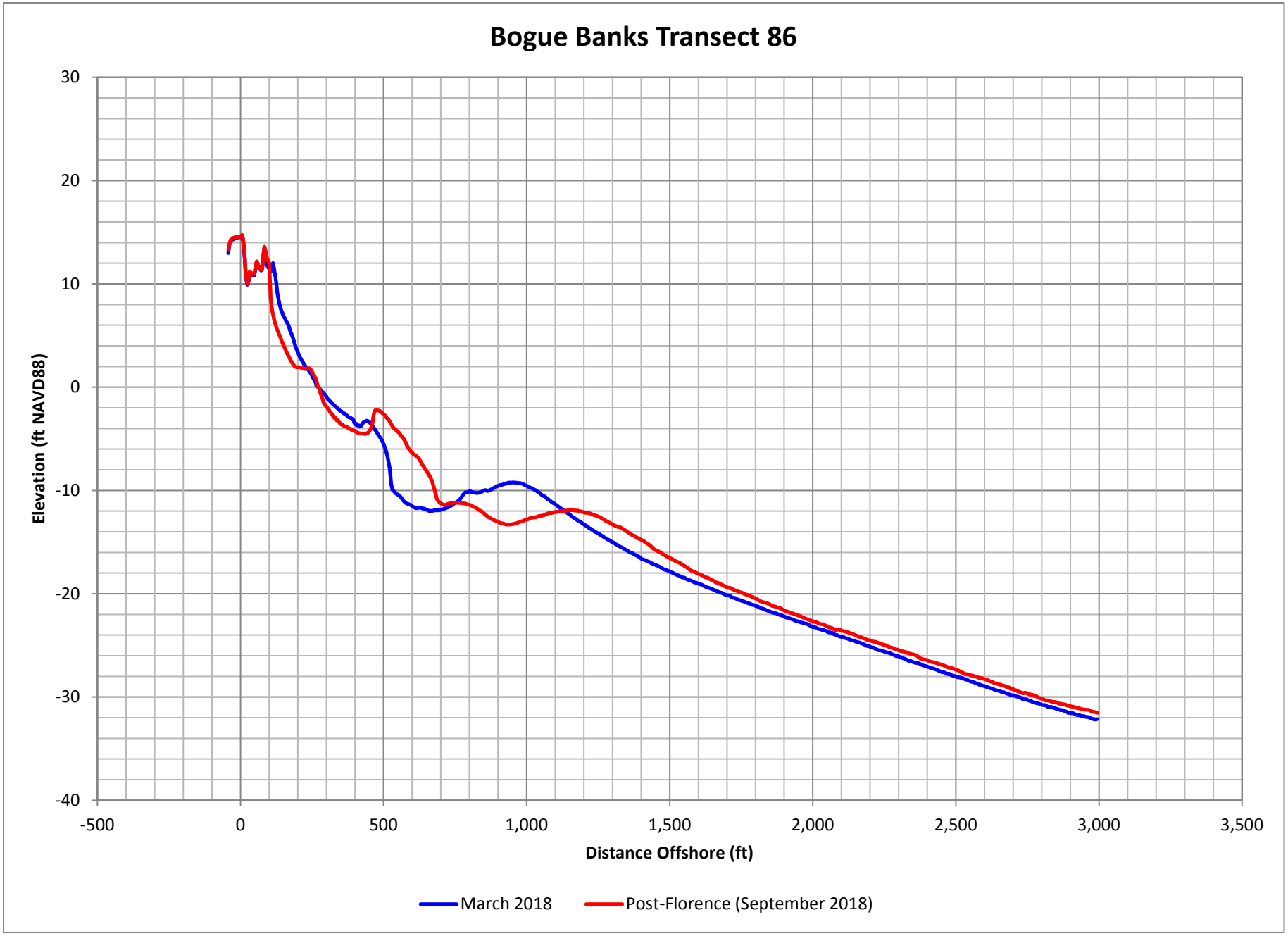
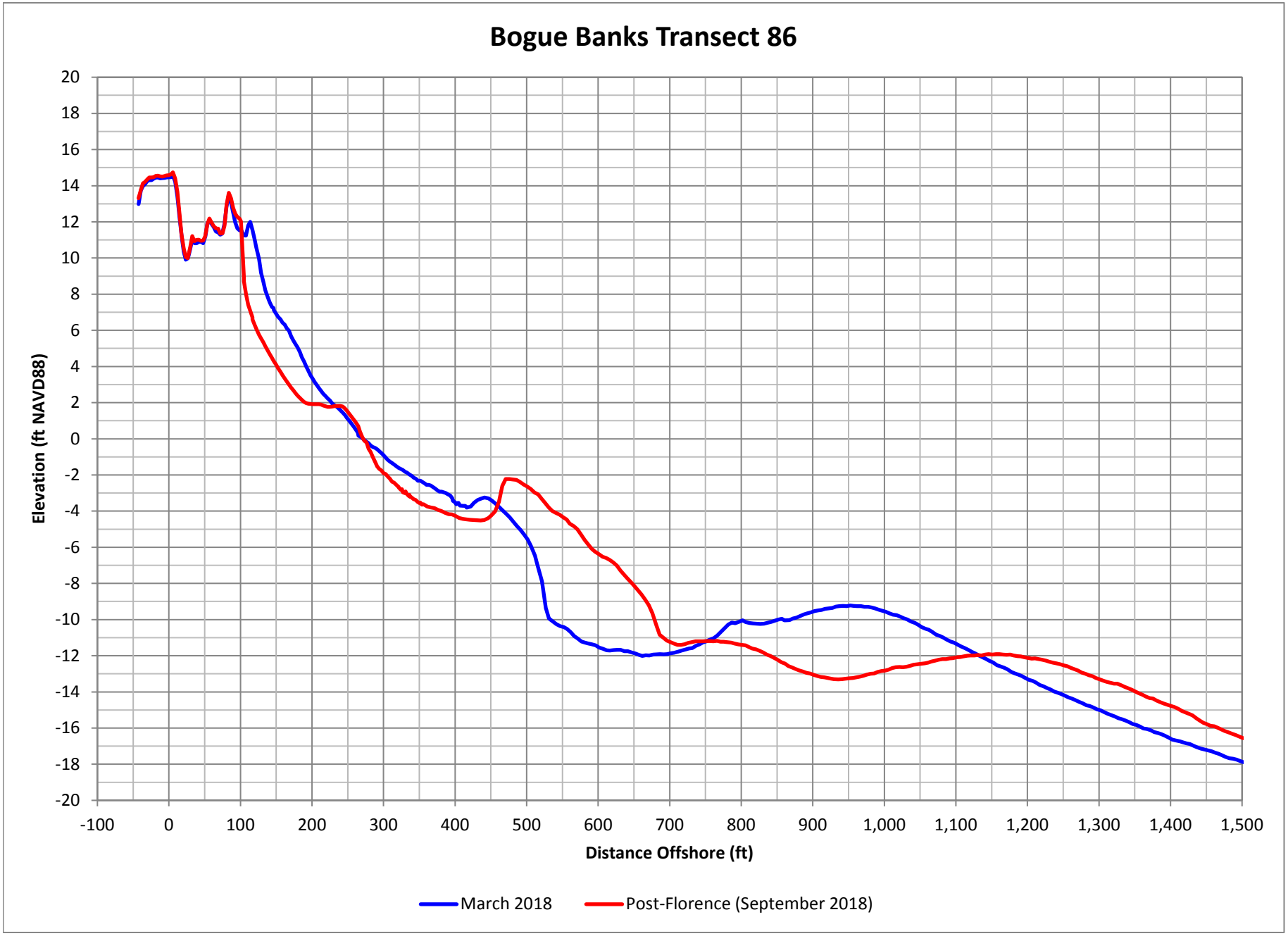


Figure D-171. Bogue Banks Profile Comparison Plot



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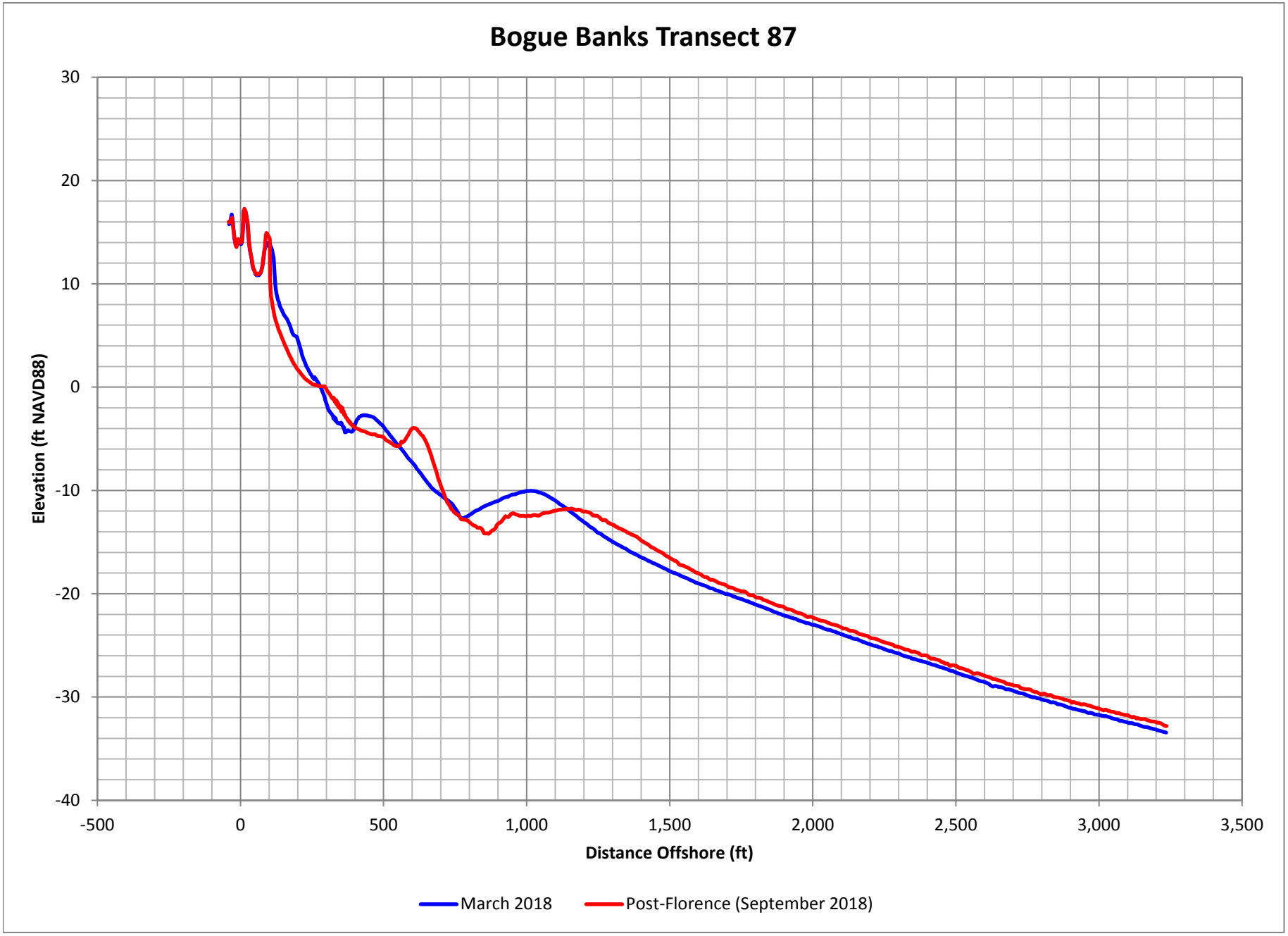

Figure D-173. Bogue Banks Profile Comparison Plot

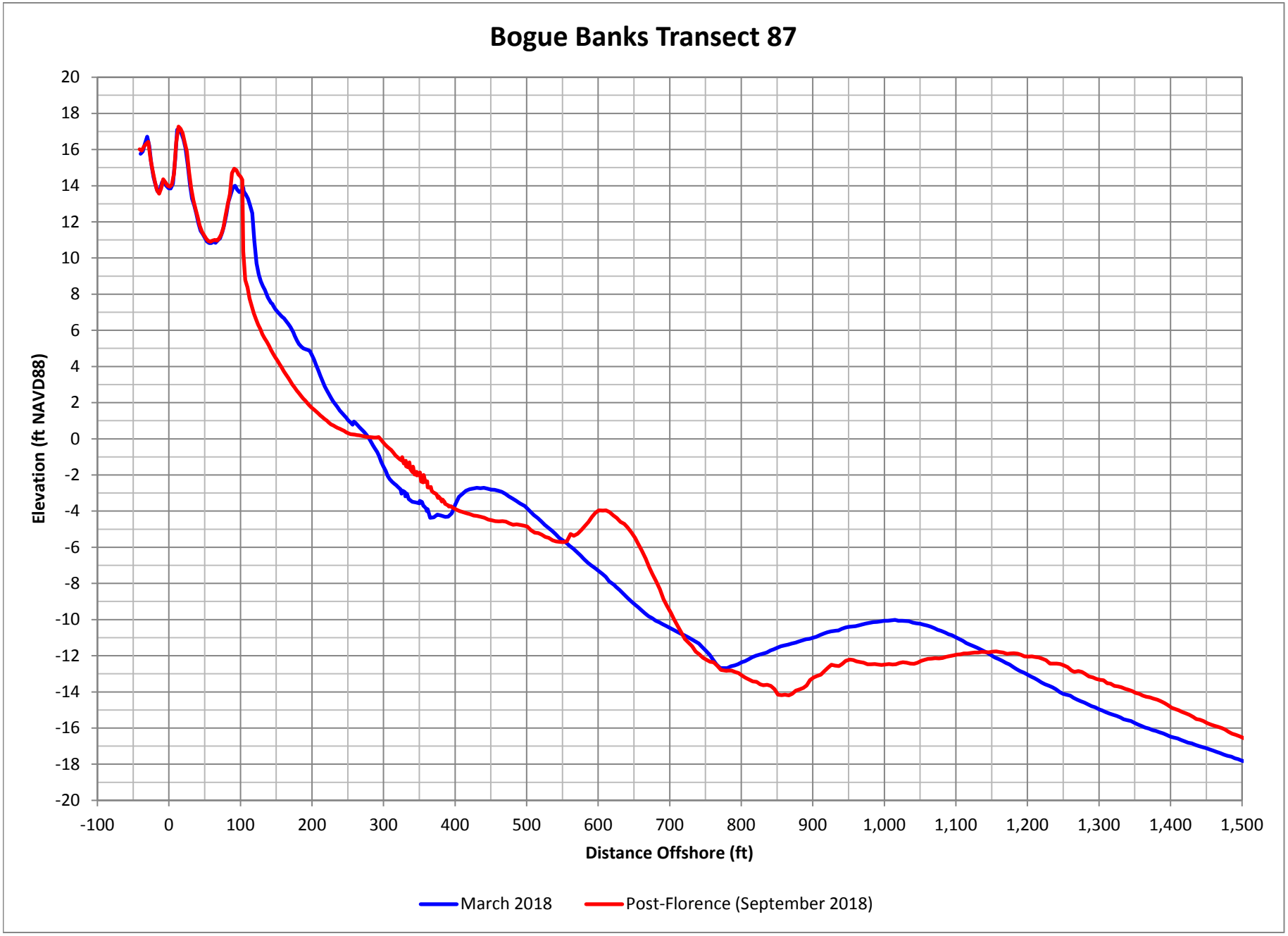

Figure D-174. Bogue Banks Profile Comparison Plot

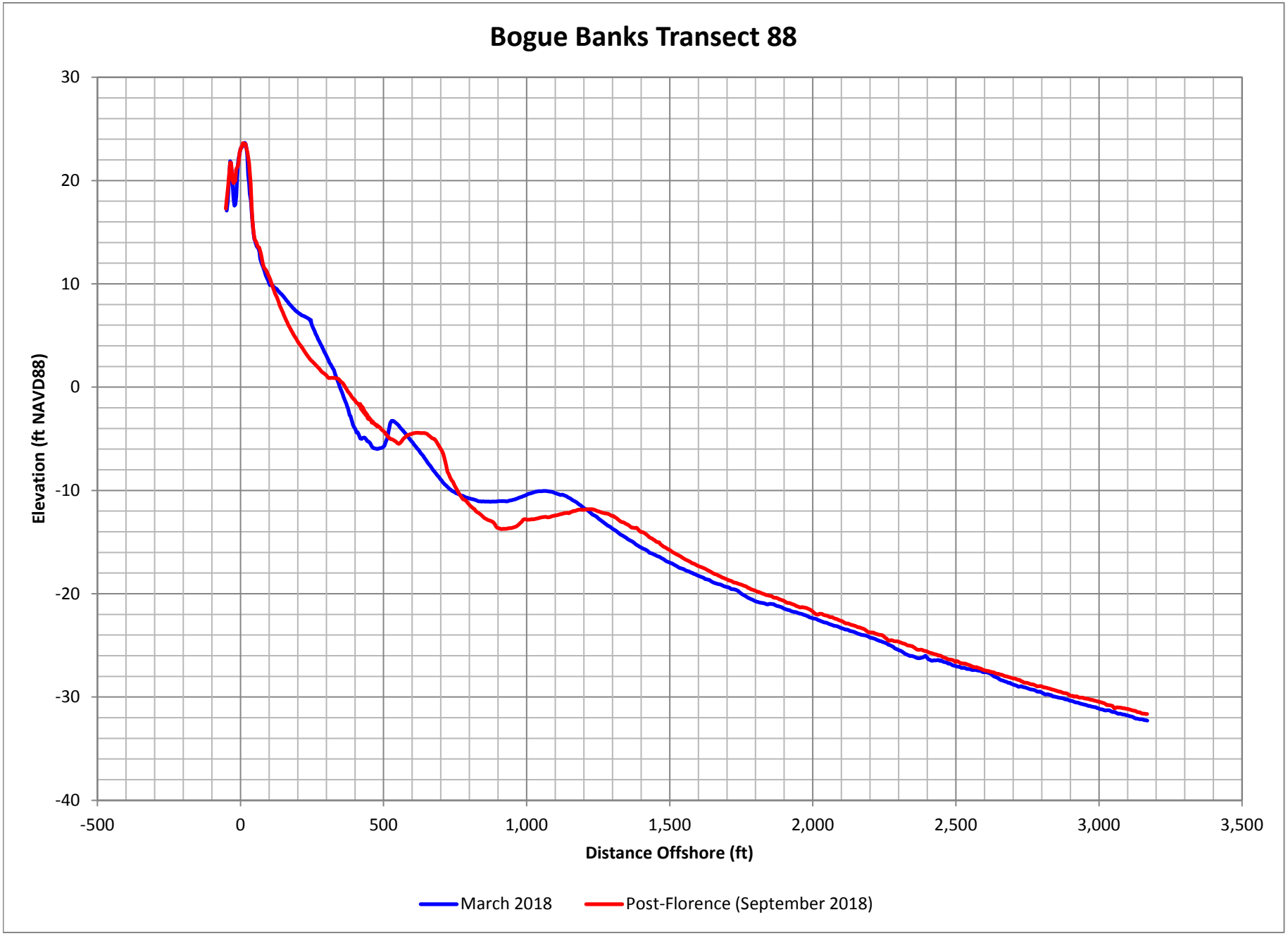

Figure D-175. Bogue Banks Profile Comparison Plot

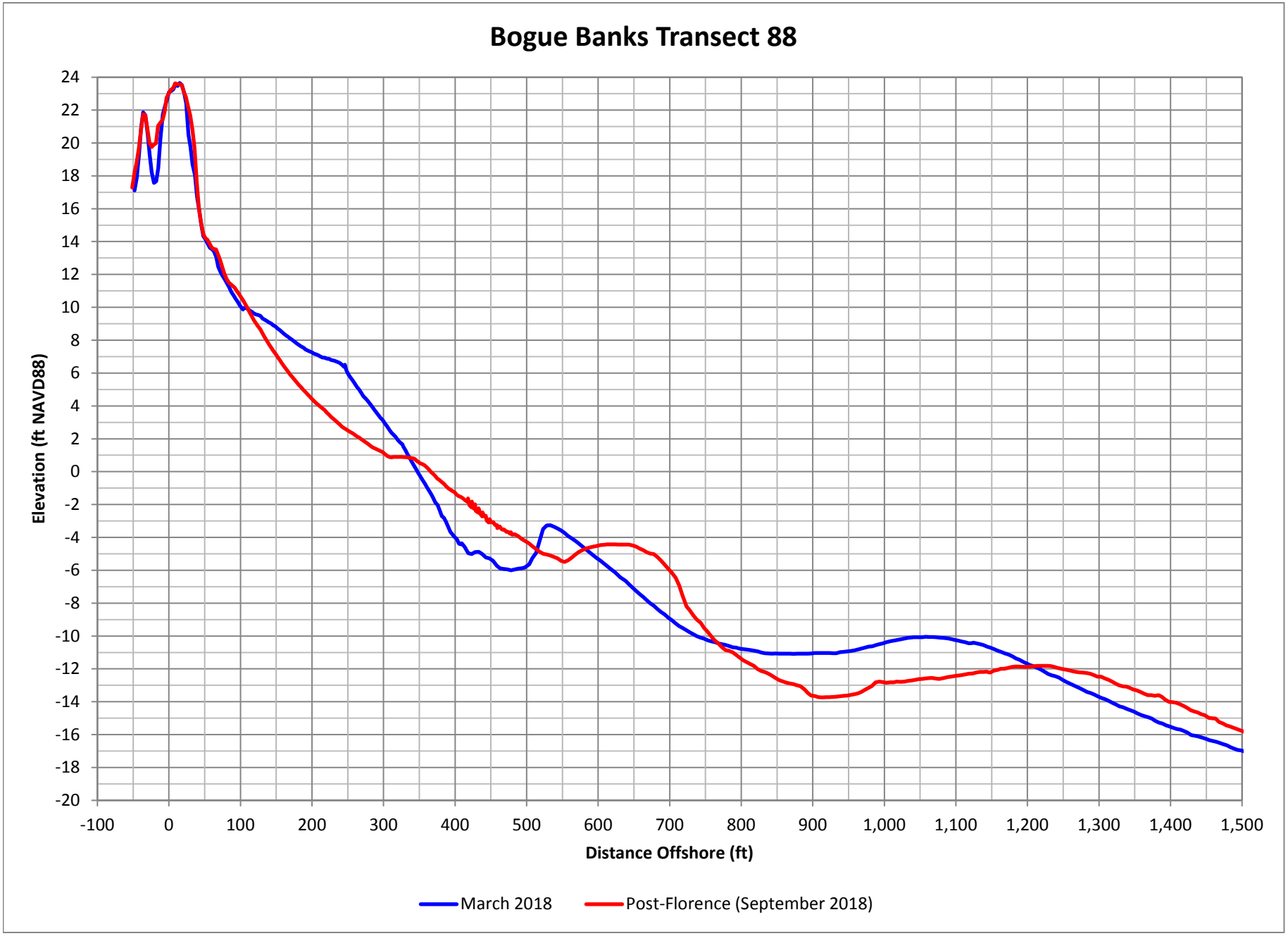

Figure D-176. Bogue Banks Profile Comparison Plot

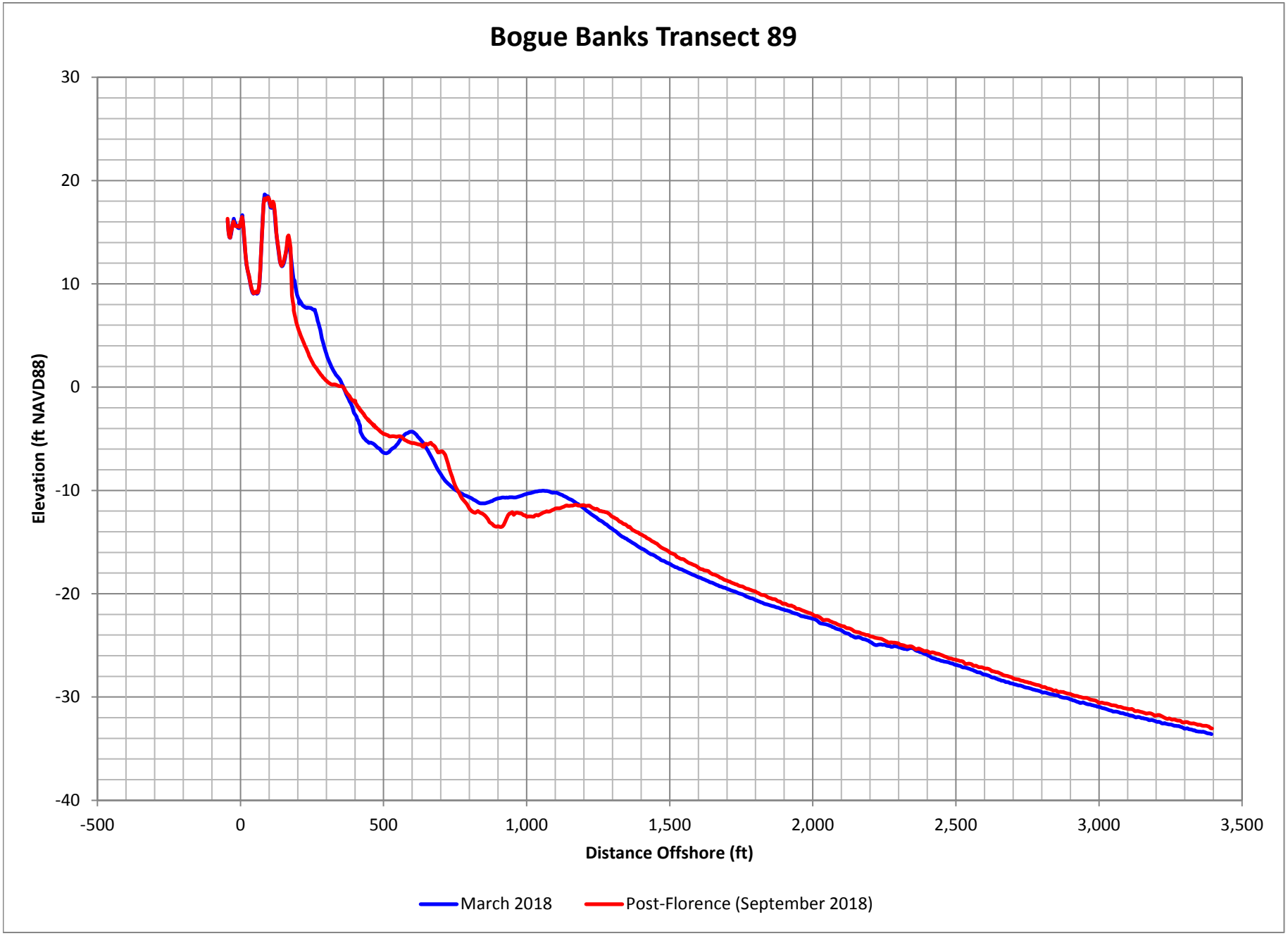

Figure D-177. Bogue Banks Profile Comparison Plot

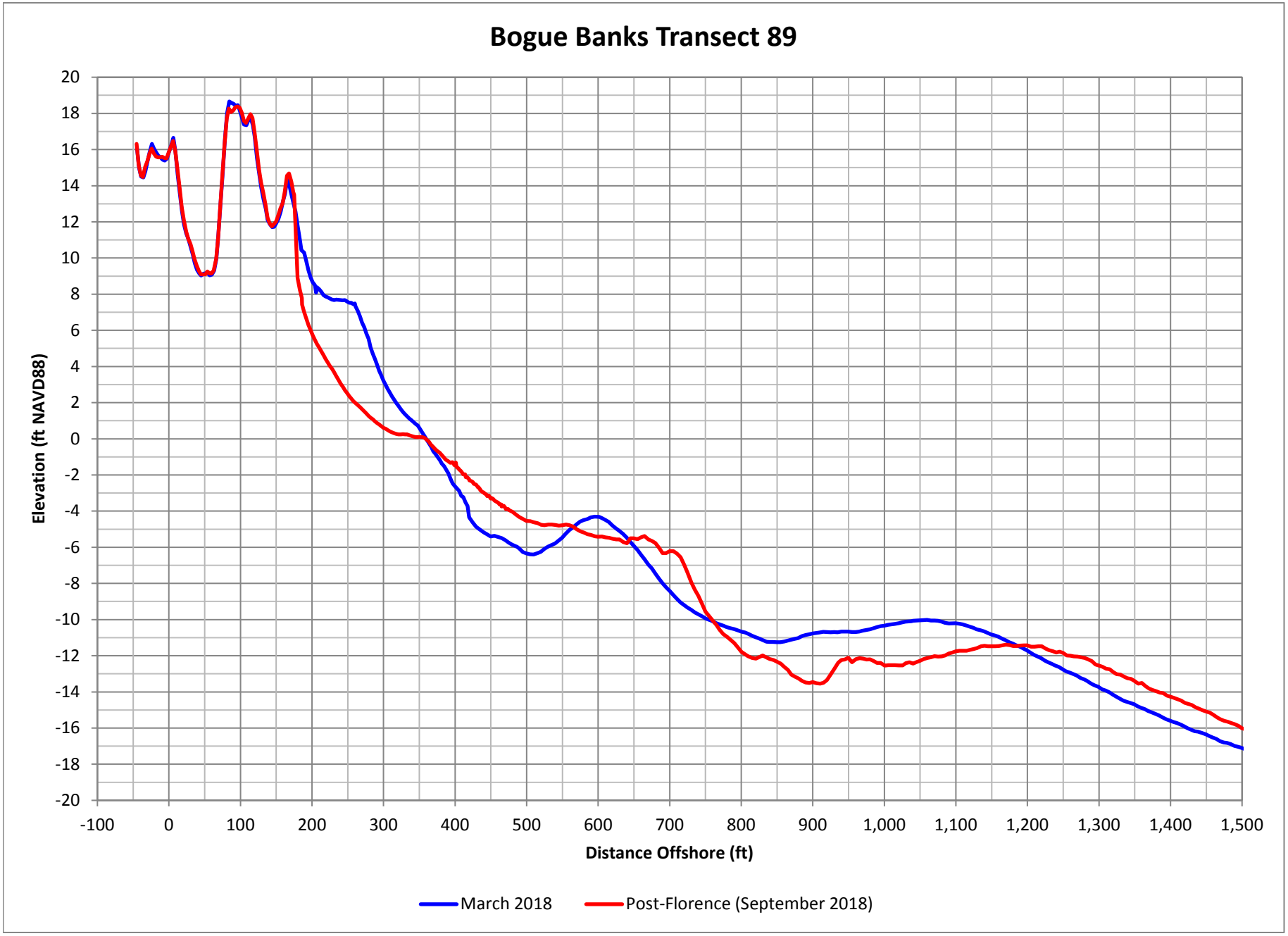

Figure D-178. Bogue Banks Profile Comparison Plot

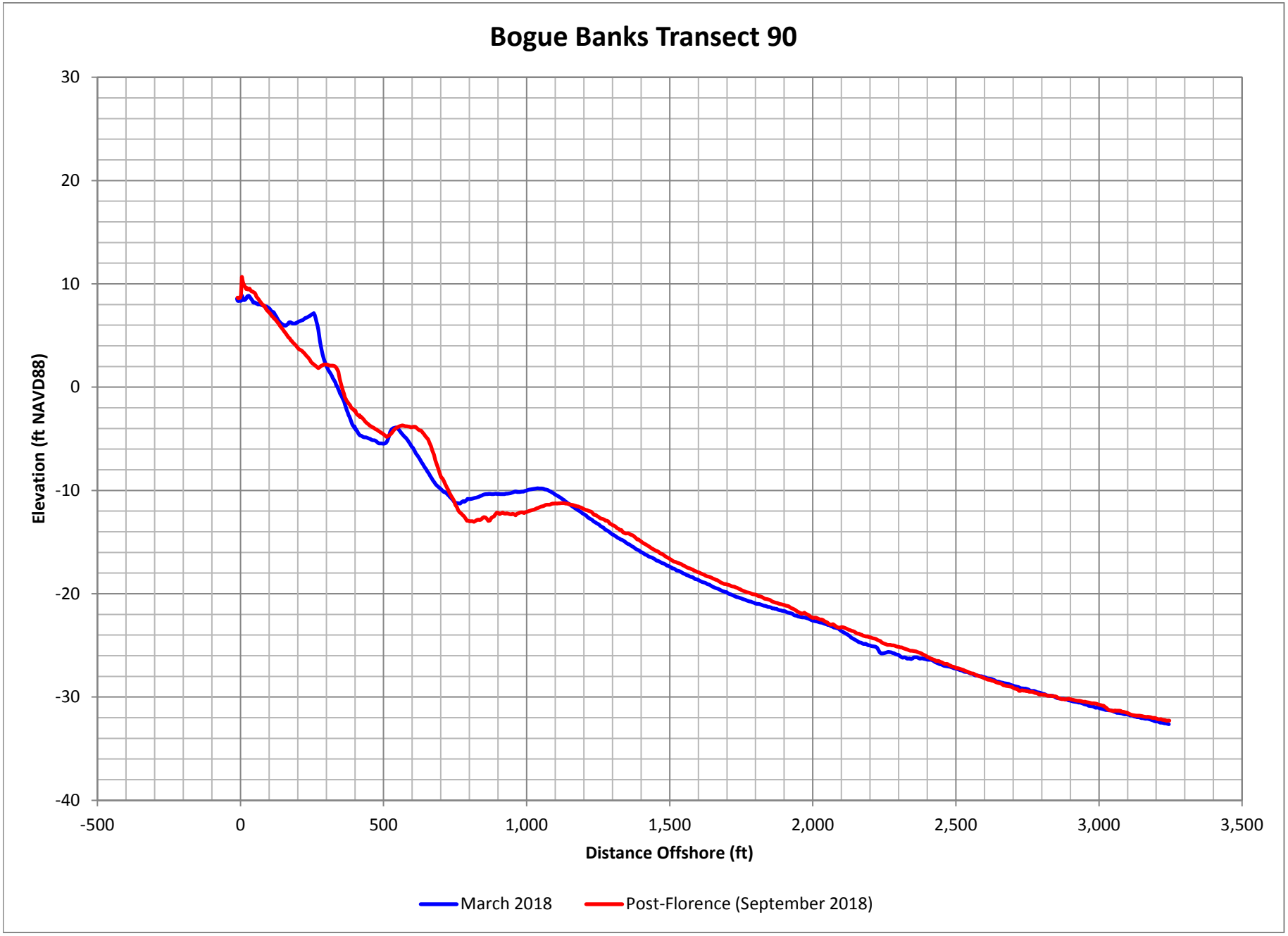

Figure D-179. Bogue Banks Profile Comparison Plot

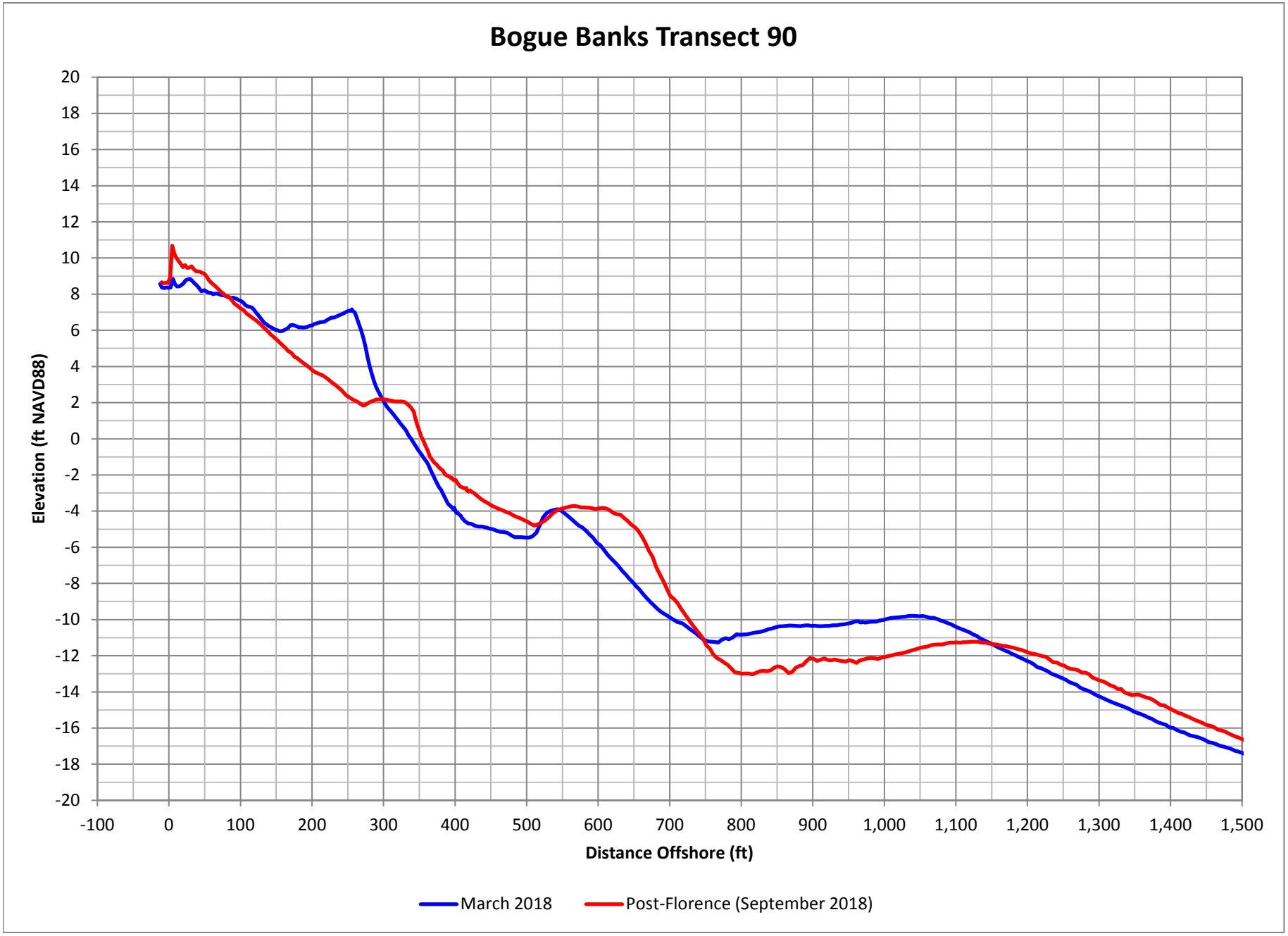

Figure D-180. Bogue Banks Profile Comparison Plot

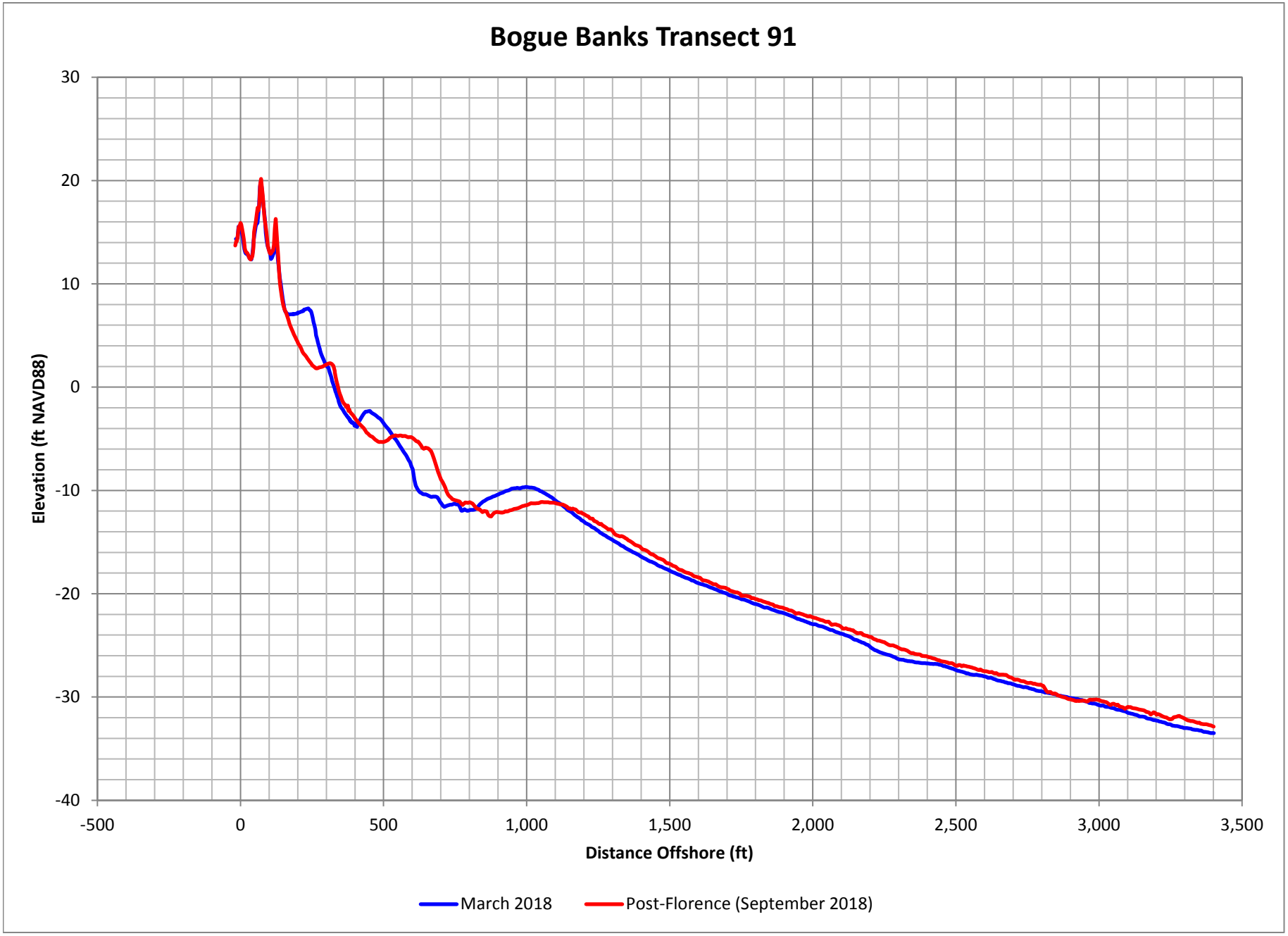

Figure D-181. Bogue Banks Profile Comparison Plot

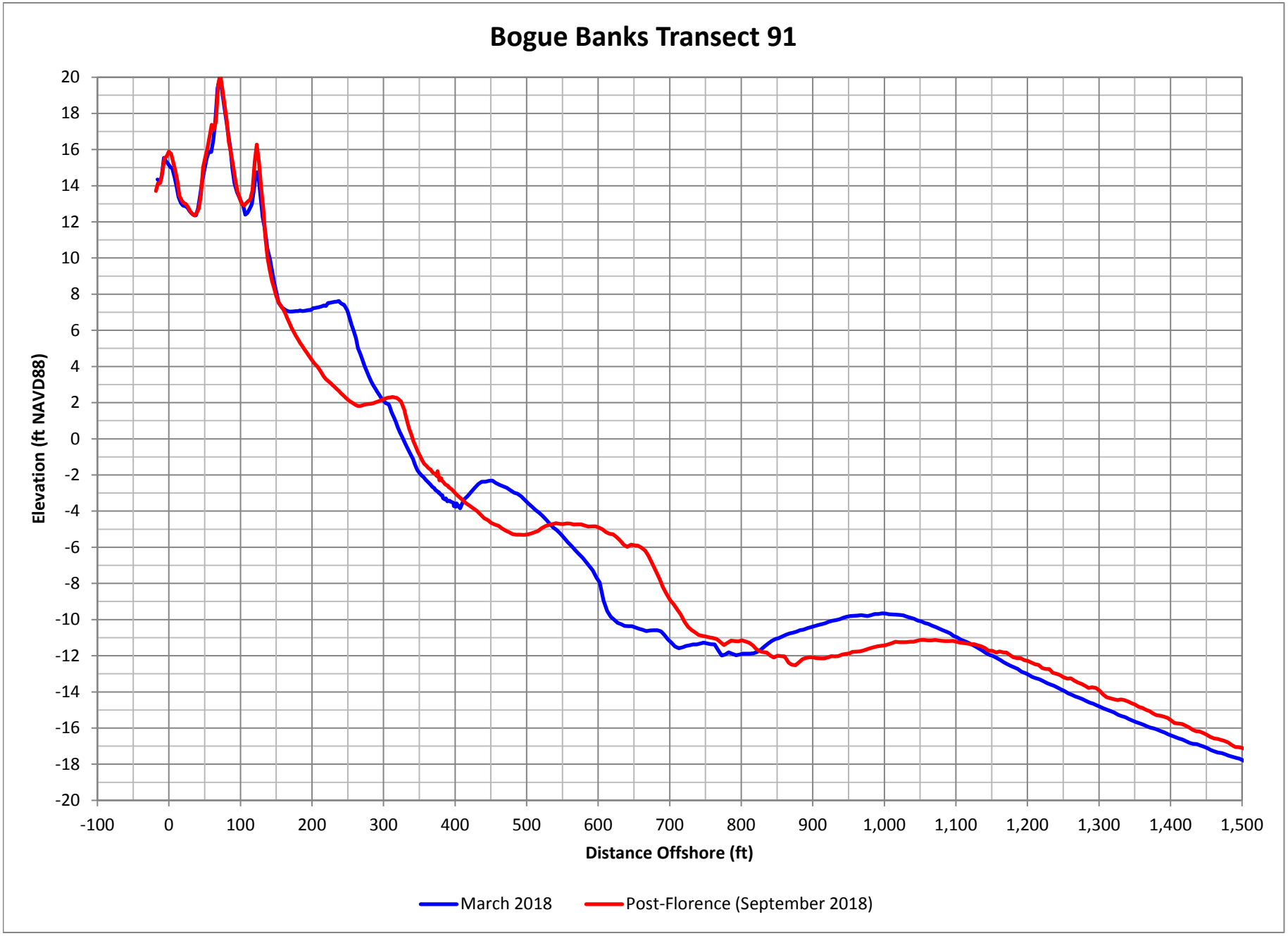

Figure D-182. Bogue Banks Profile Comparison Plot

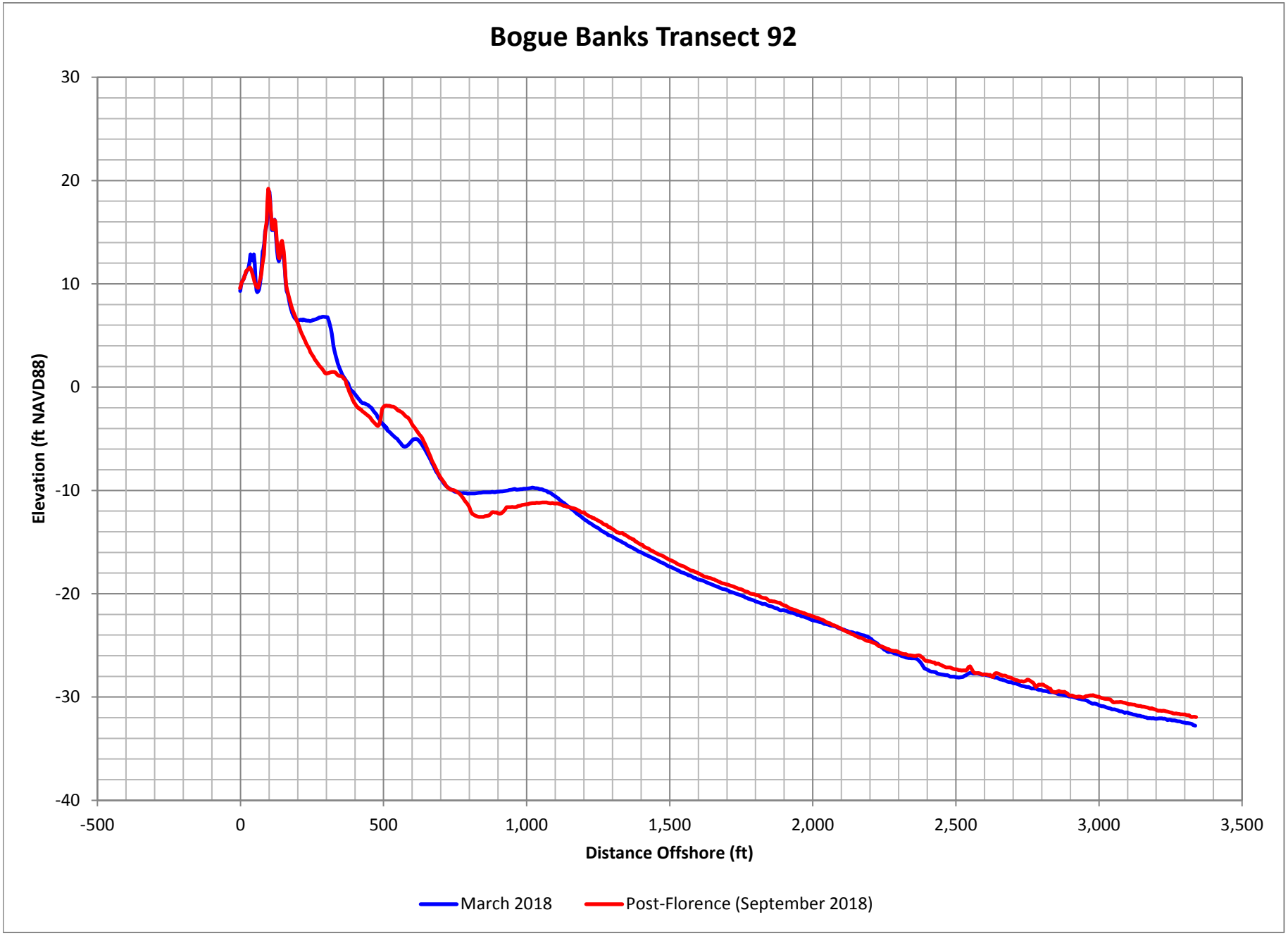

Figure D-183. Bogue Banks Profile Comparison Plot

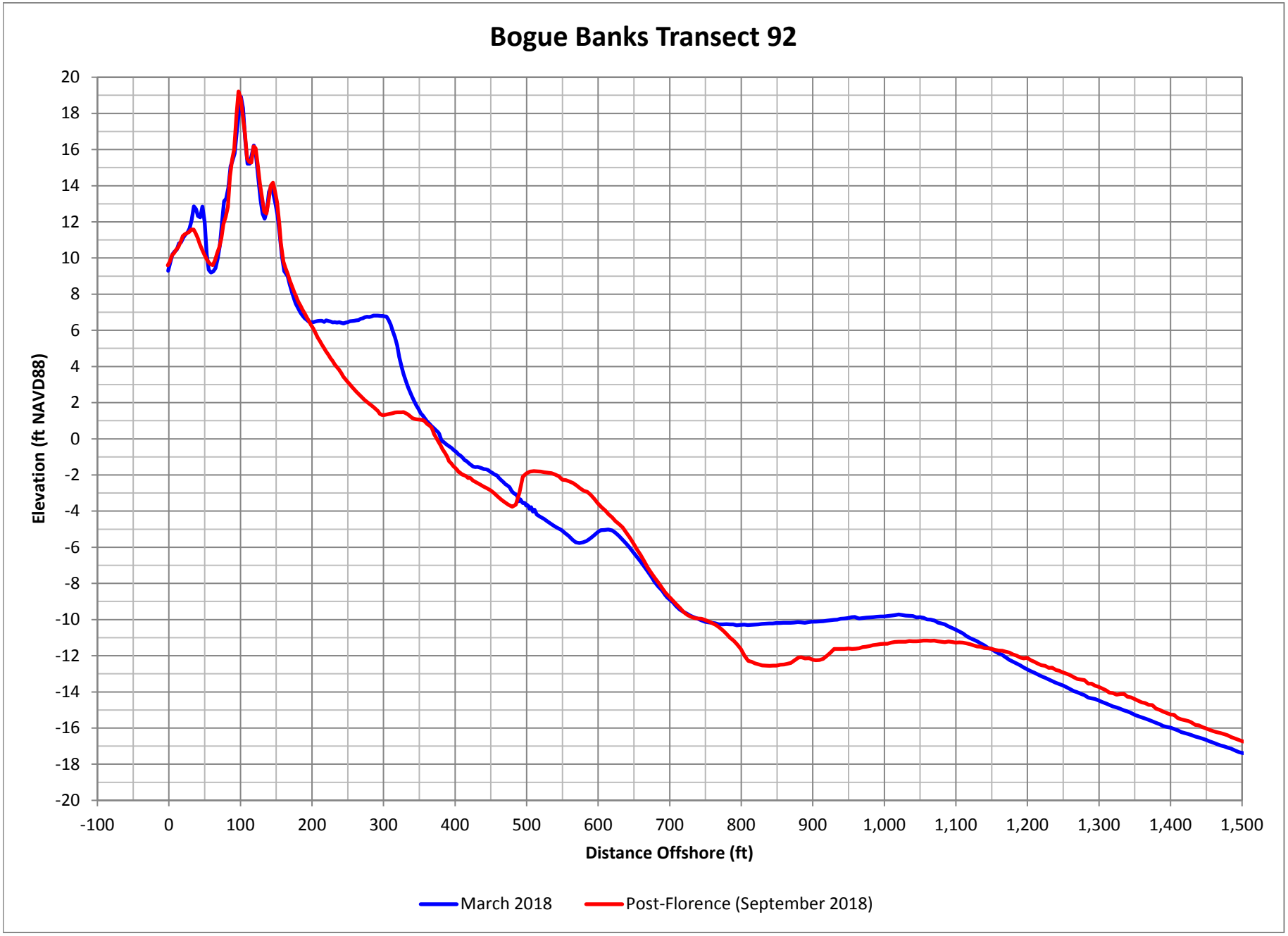

Figure D-184. Bogue Banks Profile Comparison Plot

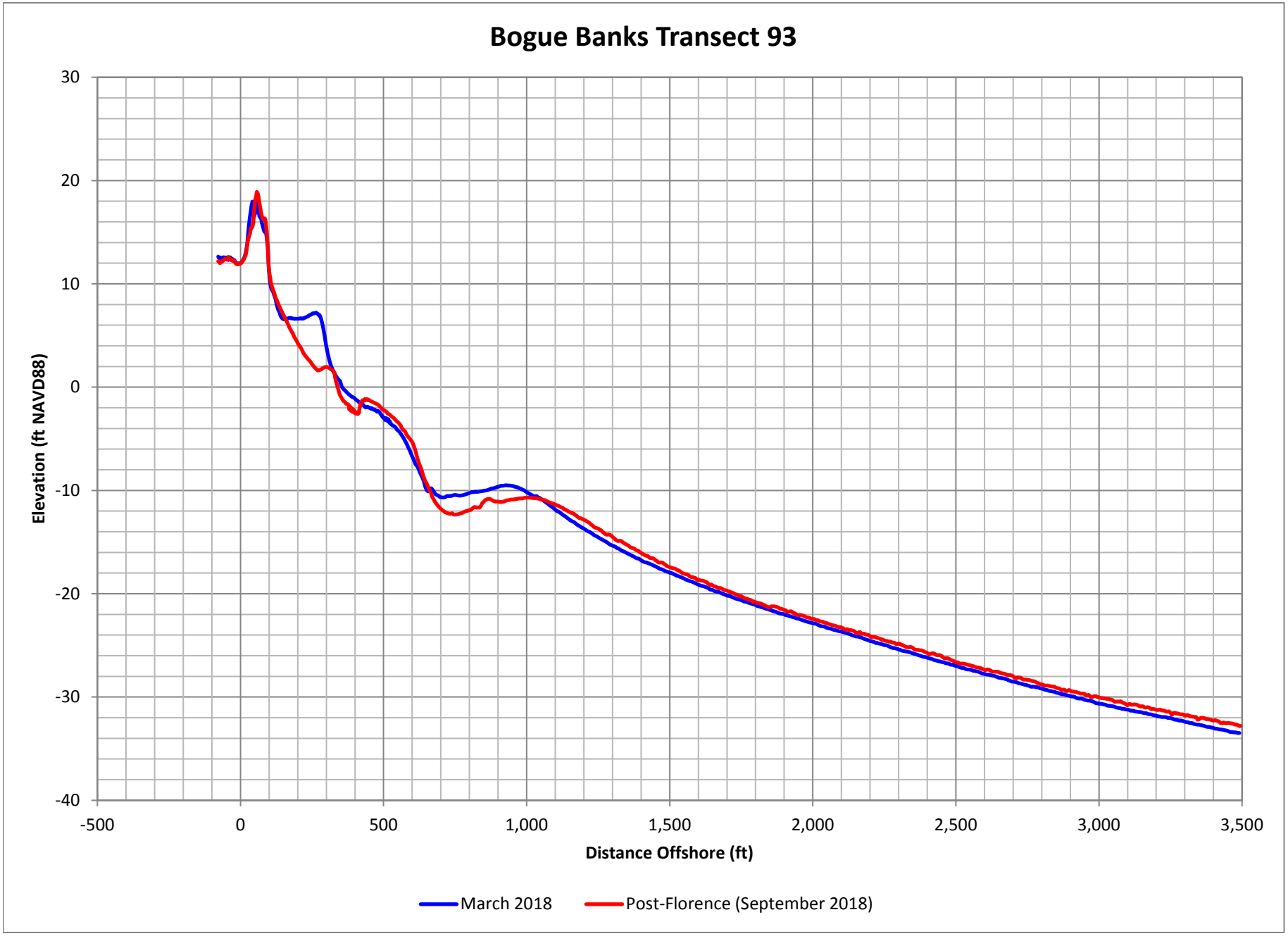

Figure D-185. Bogue Banks Profile Comparison Plot

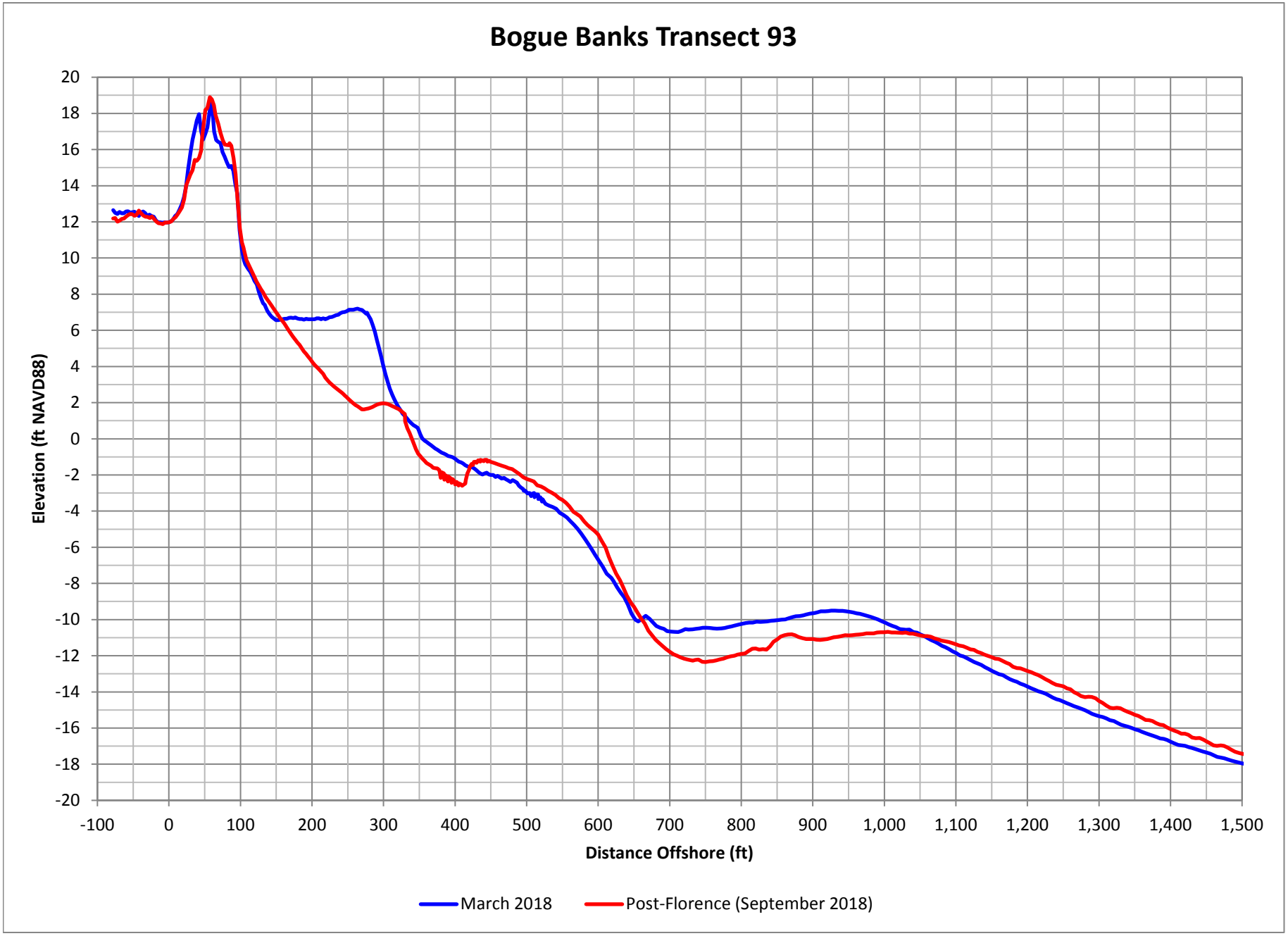

Figure D-186. Bogue Banks Profile Comparison Plot

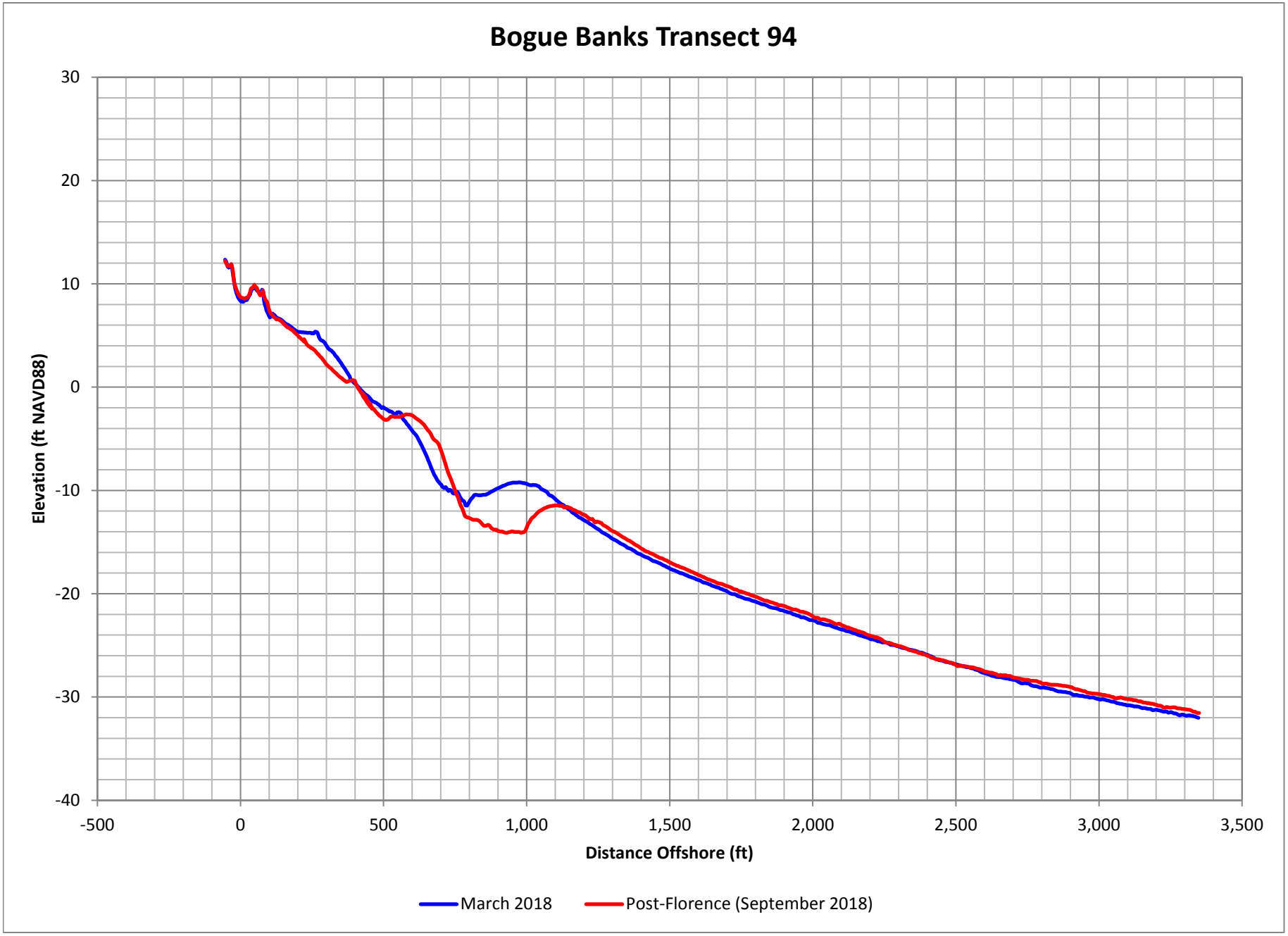

Figure D-187. Bogue Banks Profile Comparison Plot

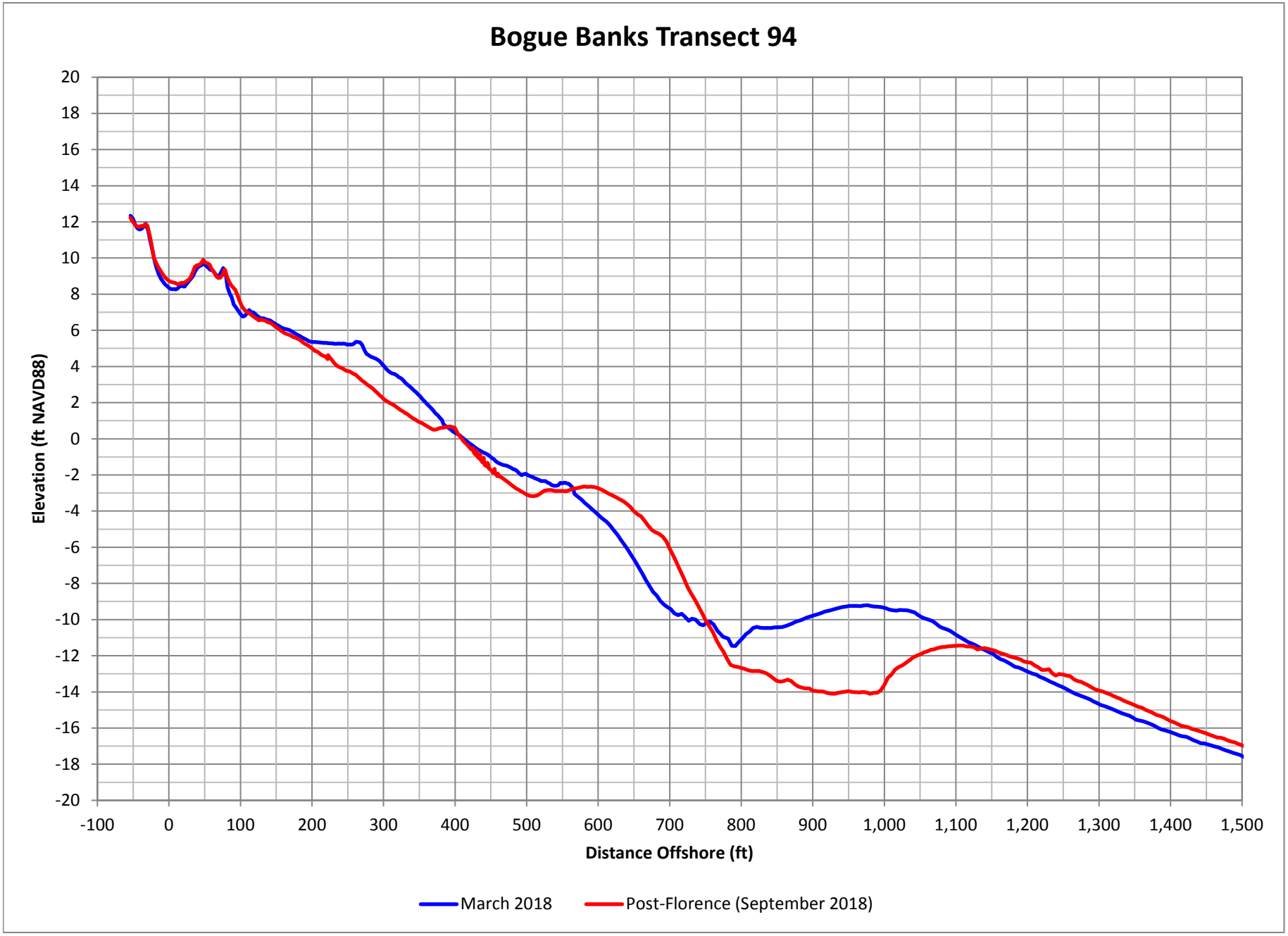

Figure D-188. Bogue Banks Profile Comparison Plot

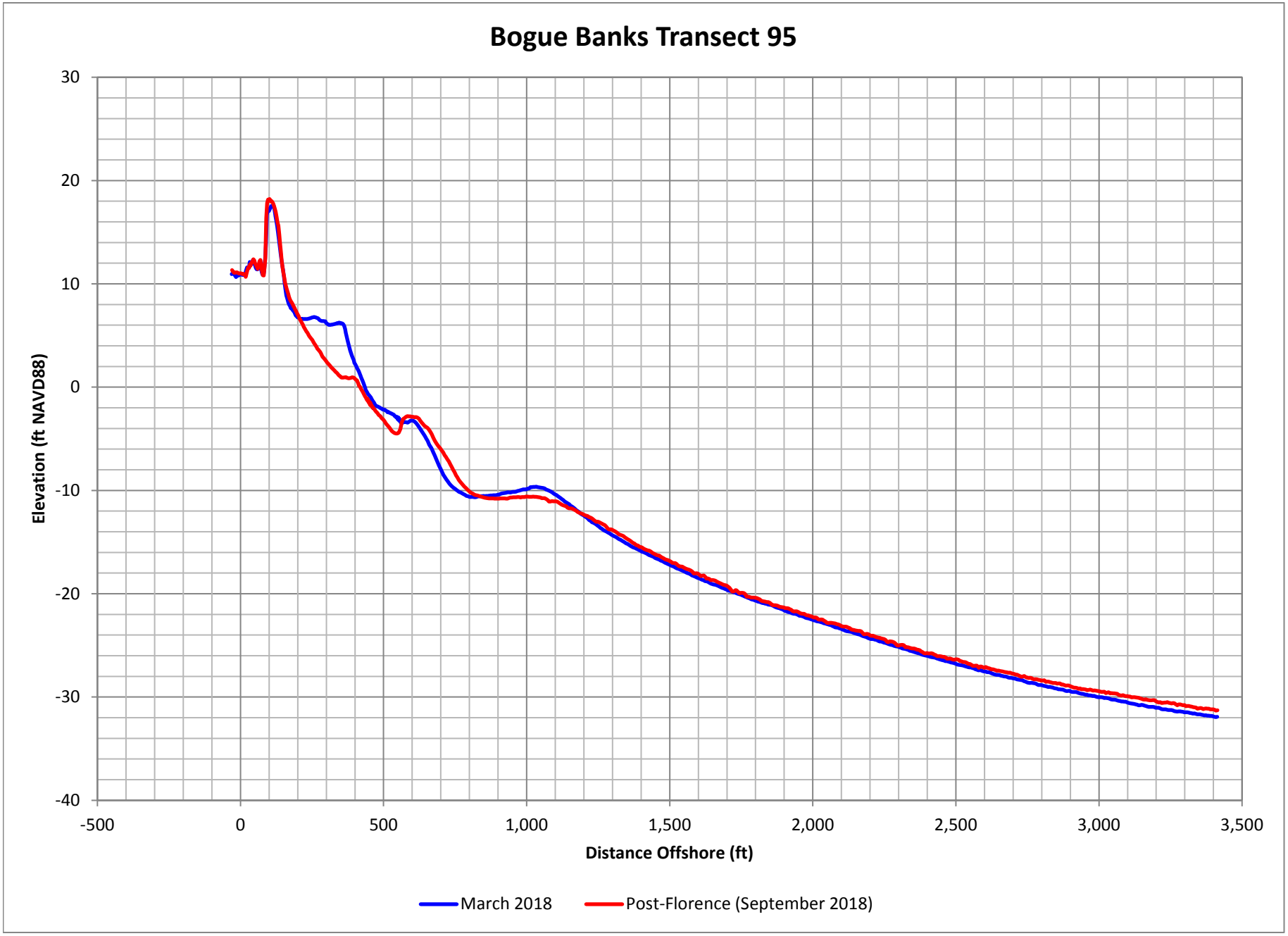

Figure D-189. Bogue Banks Profile Comparison Plot

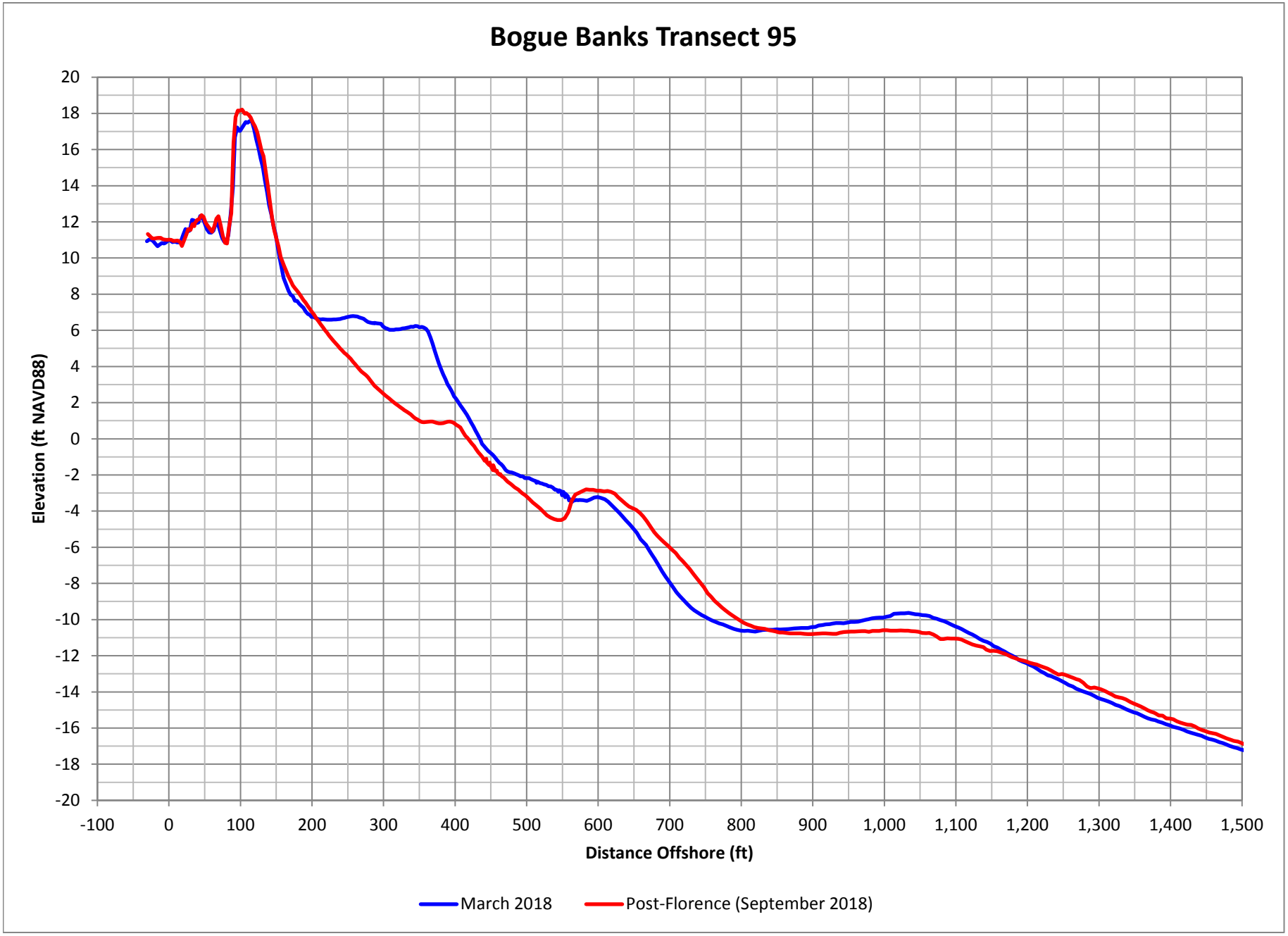

Figure D-190. Bogue Banks Profile Comparison Plot

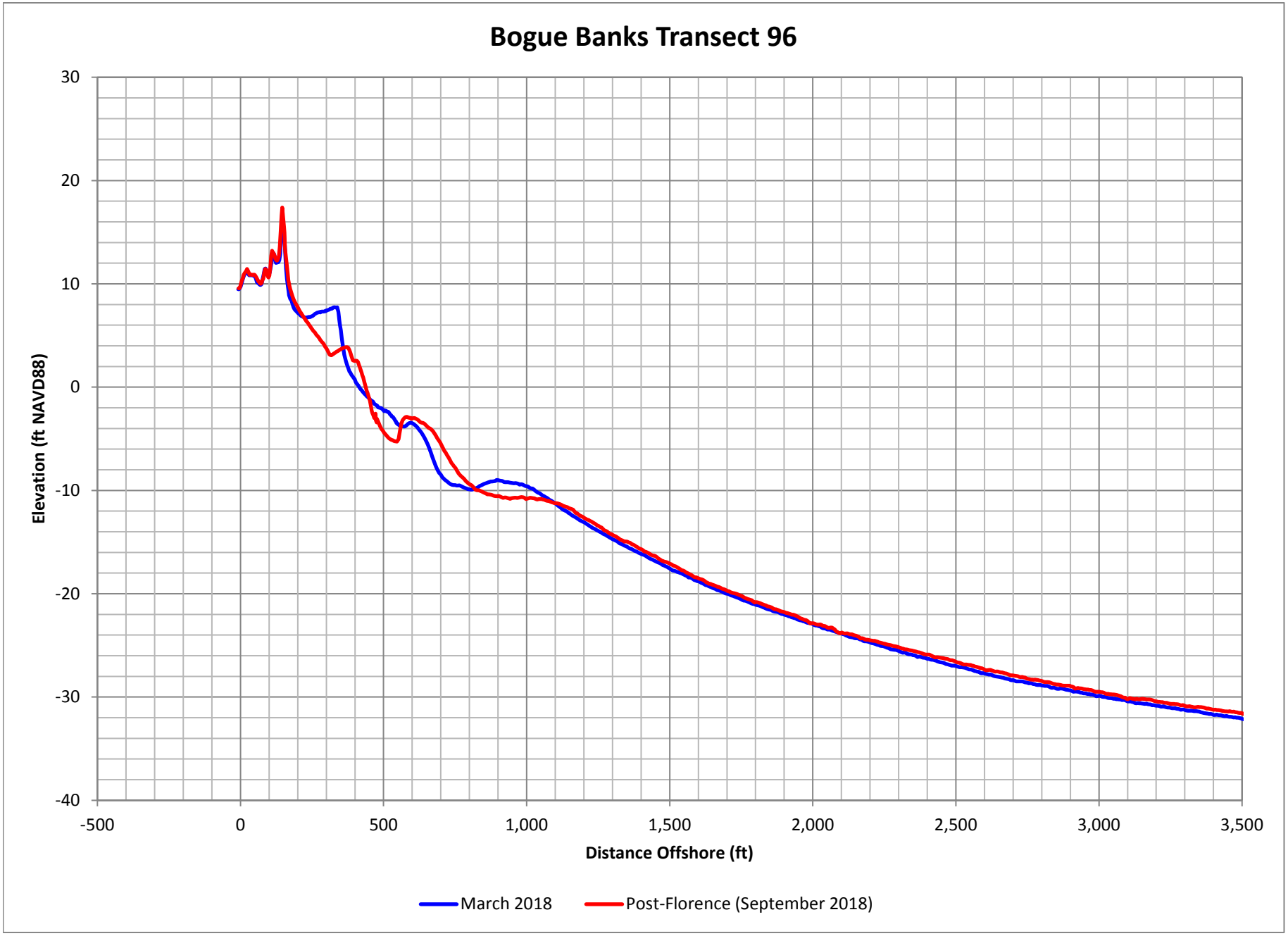

Figure D-191. Bogue Banks Profile Comparison Plot

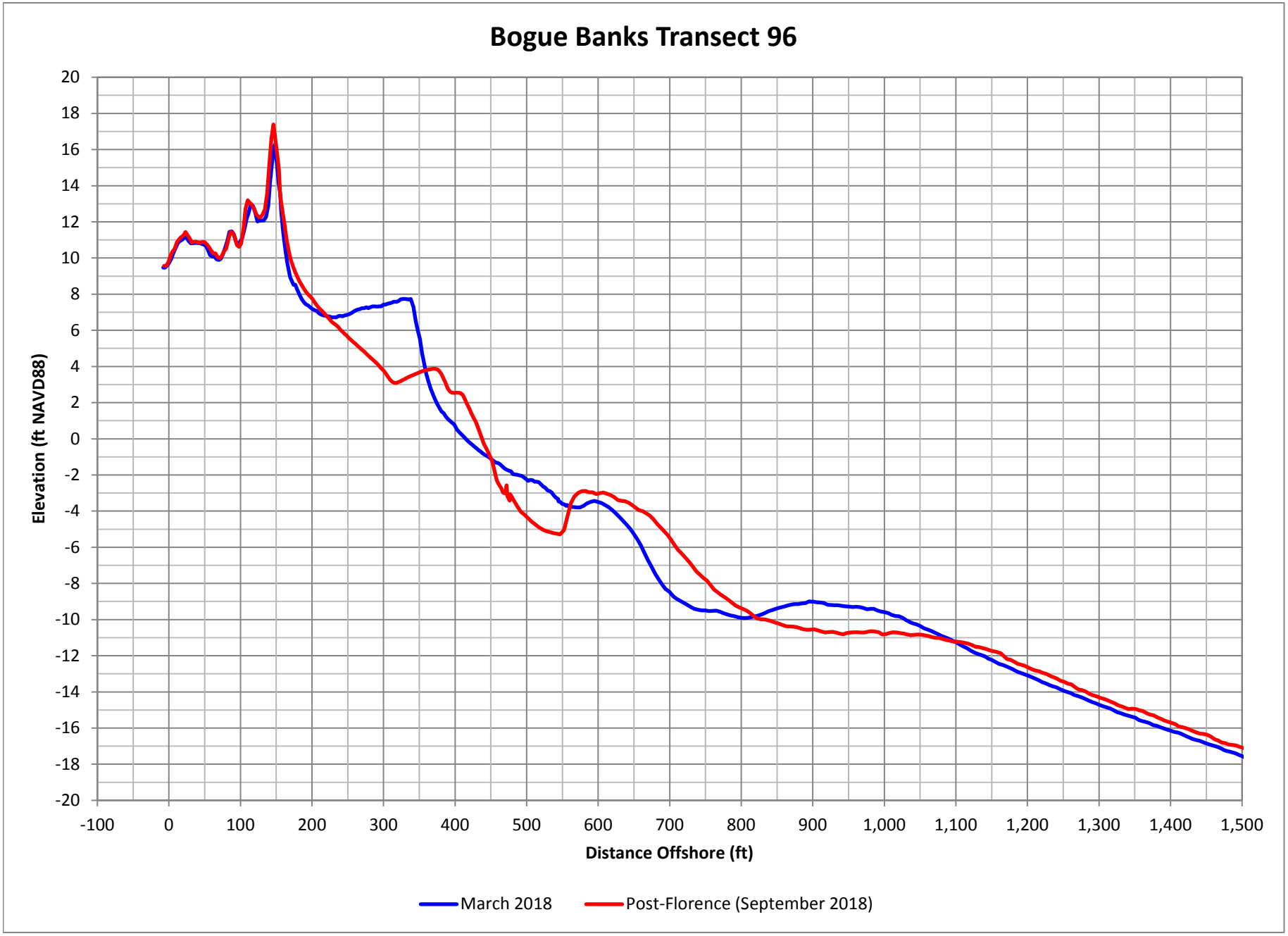

Figure D-192. Bogue Banks Profile Comparison Plot

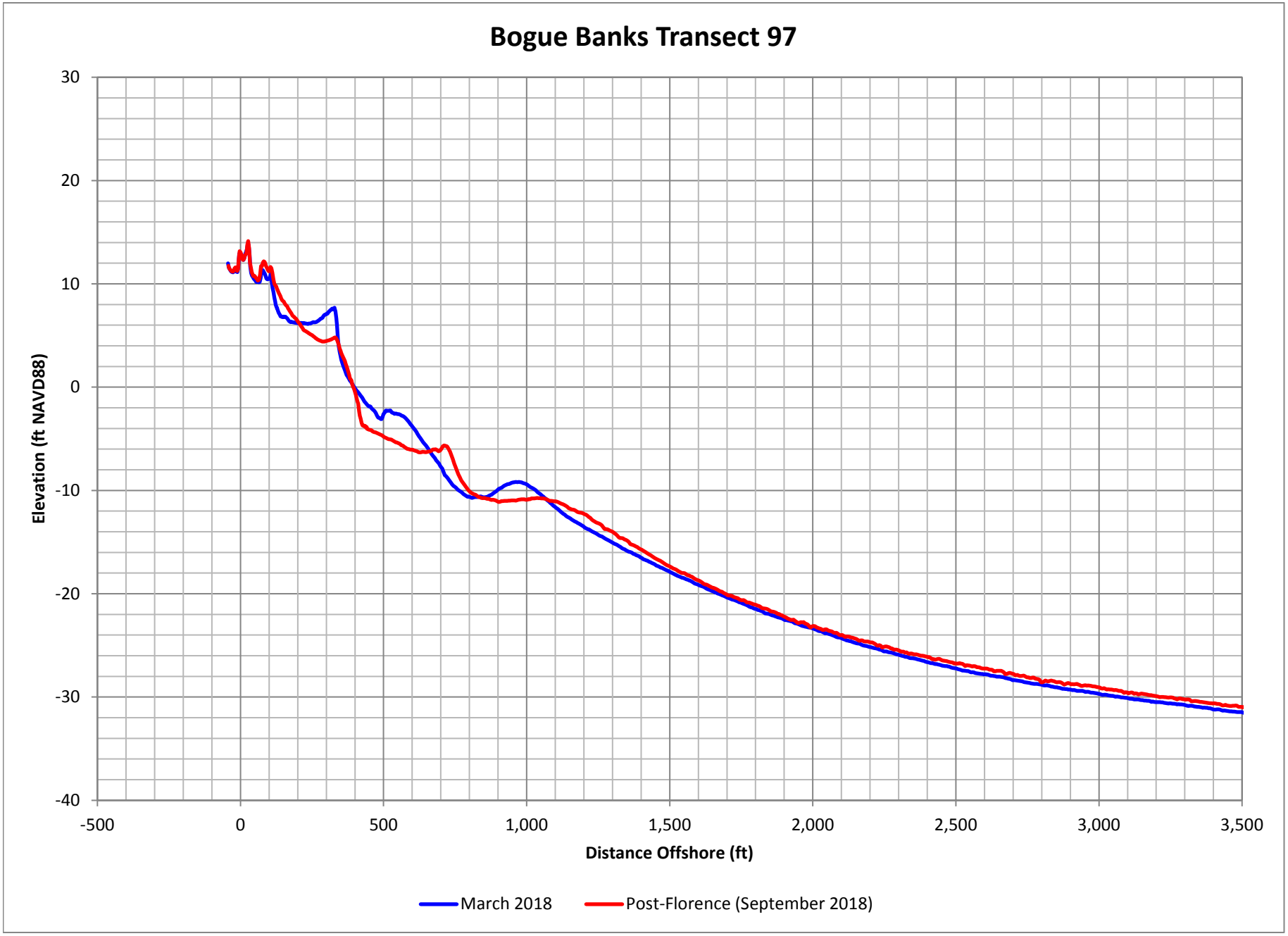

Figure D-193. Bogue Banks Profile Comparison Plot

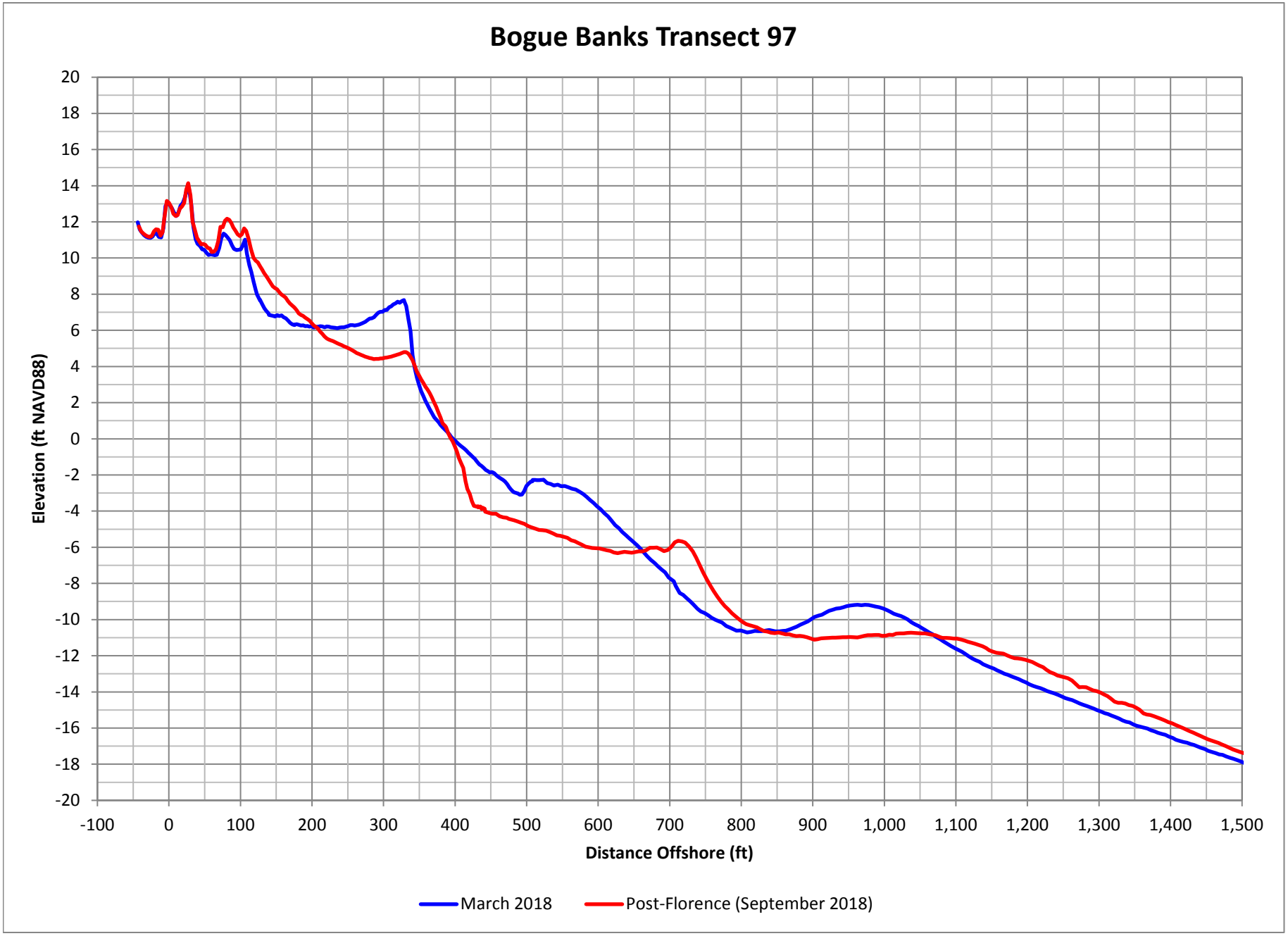

Figure D-194. Bogue Banks Profile Comparison Plot

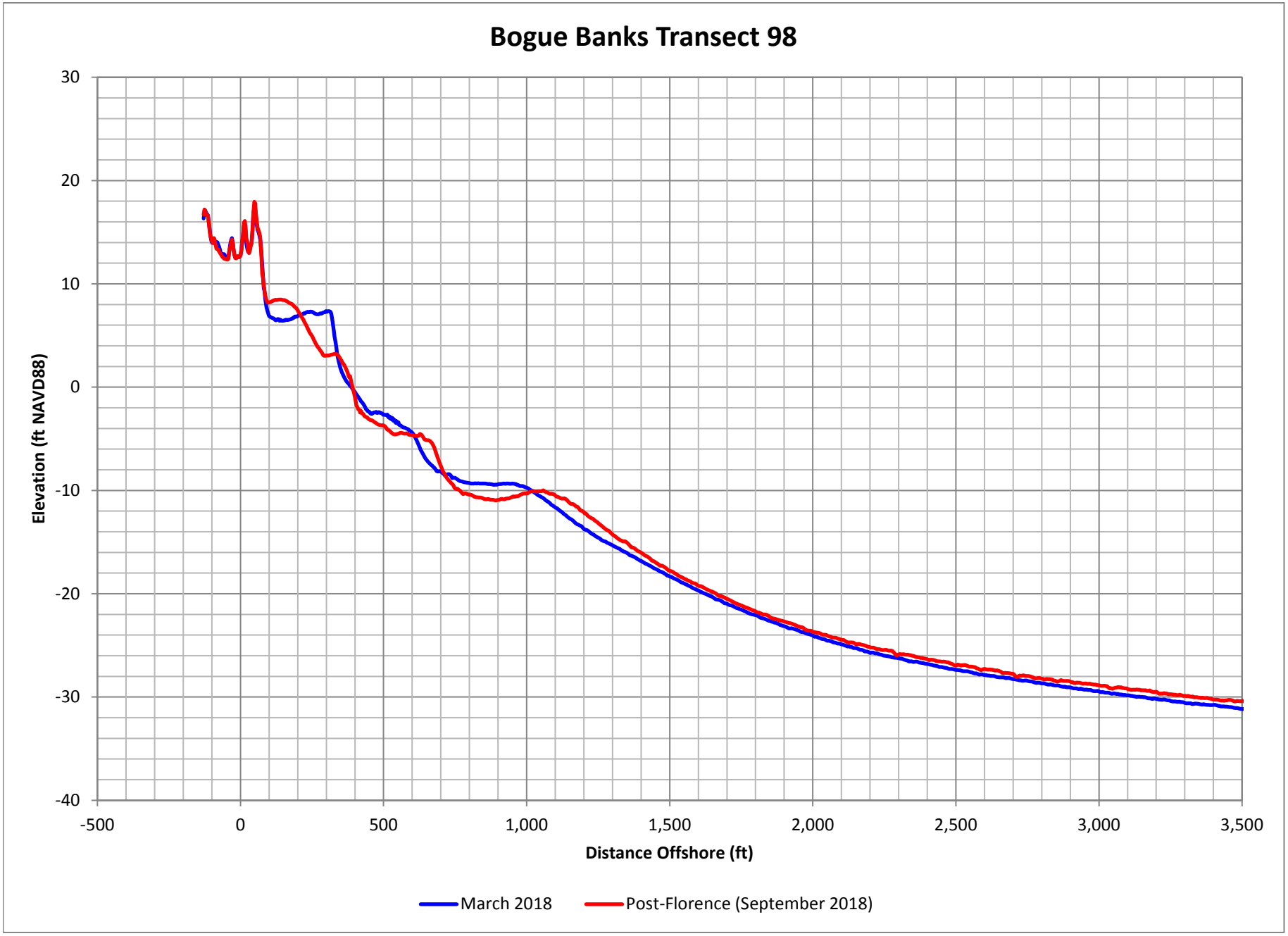

Figure D-195. Bogue Banks Profile Comparison Plot

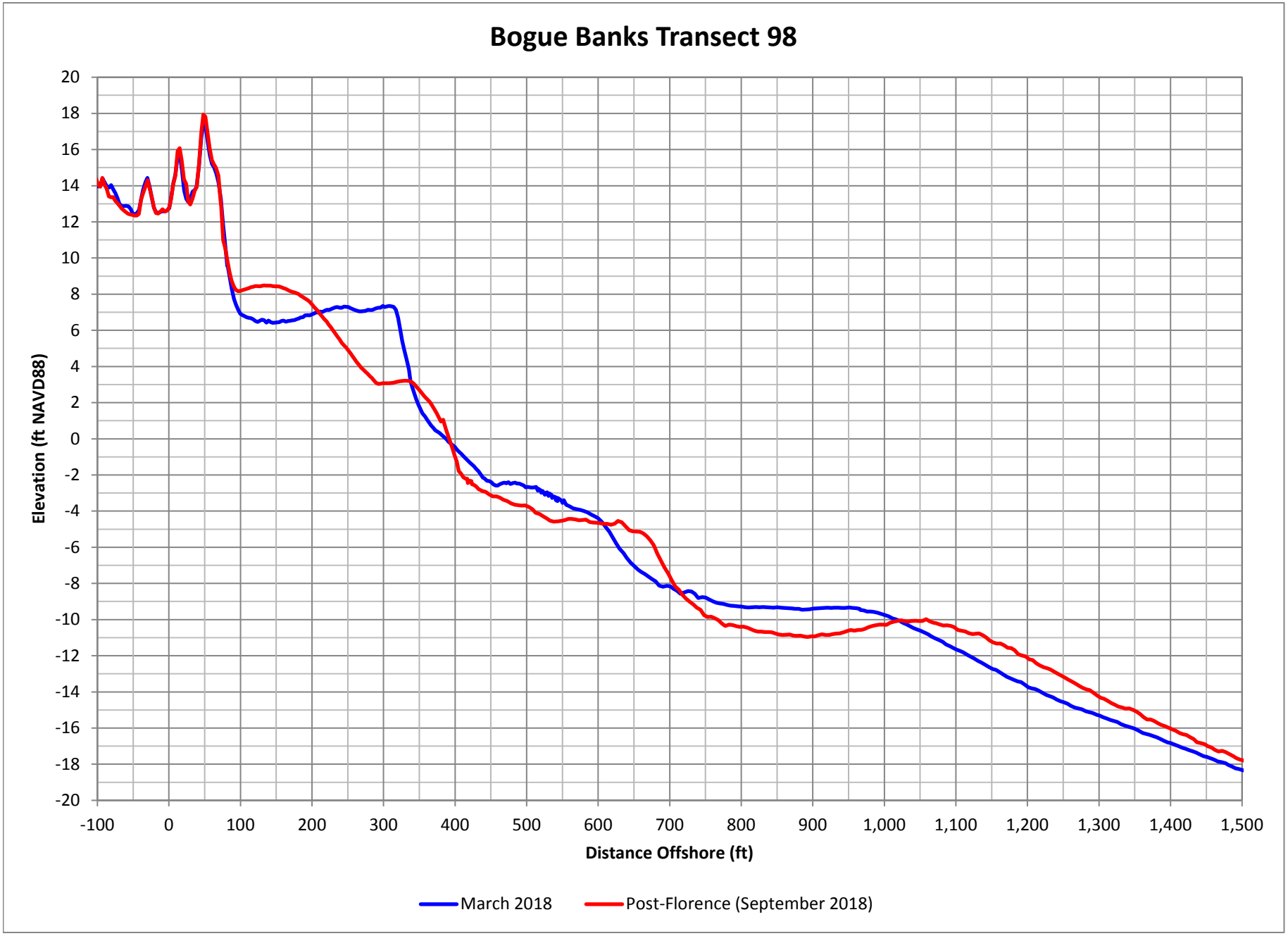

Figure D-196. Bogue Banks Profile Comparison Plot

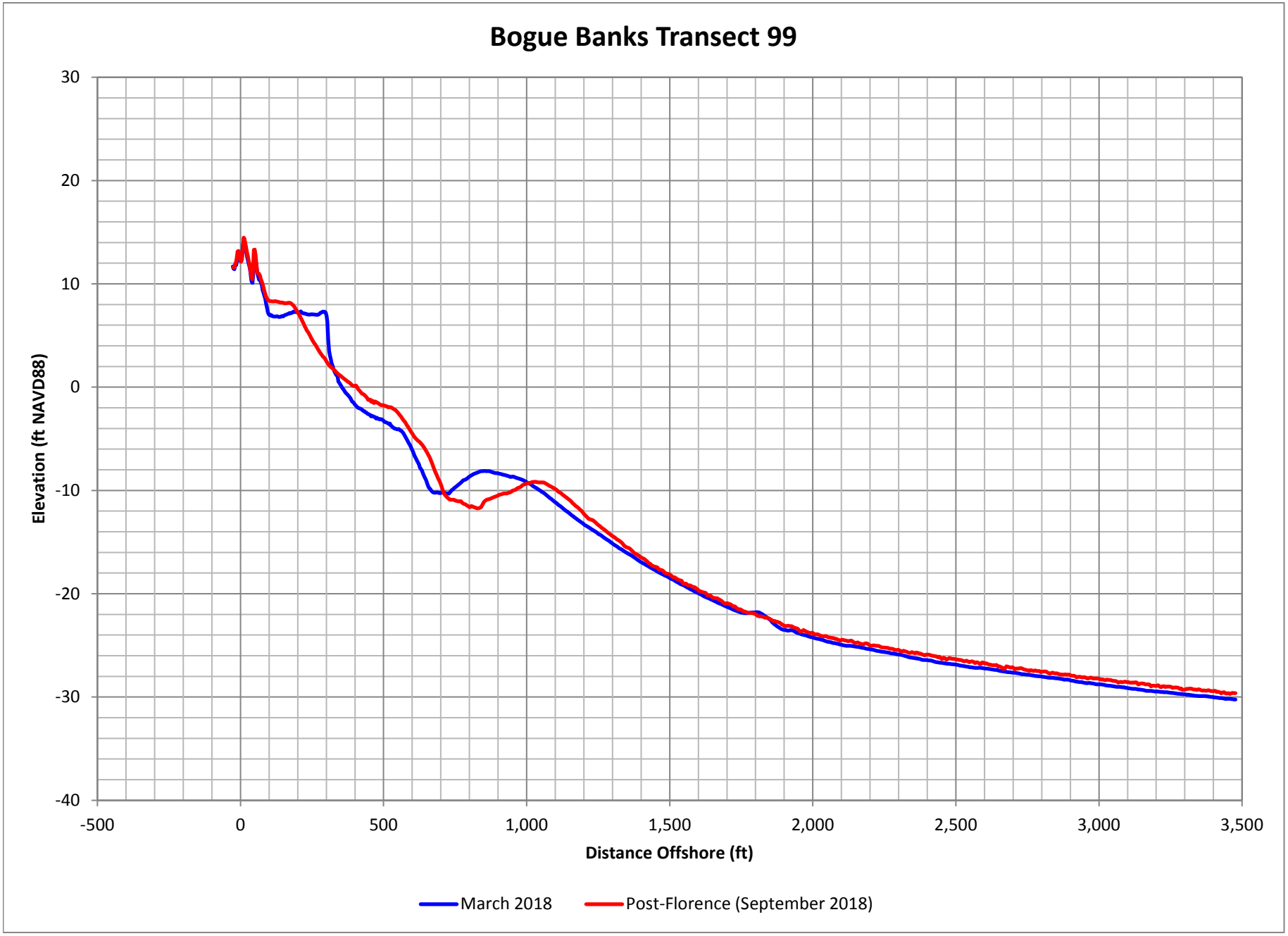

Figure D-197. Bogue Banks Profile Comparison Plot

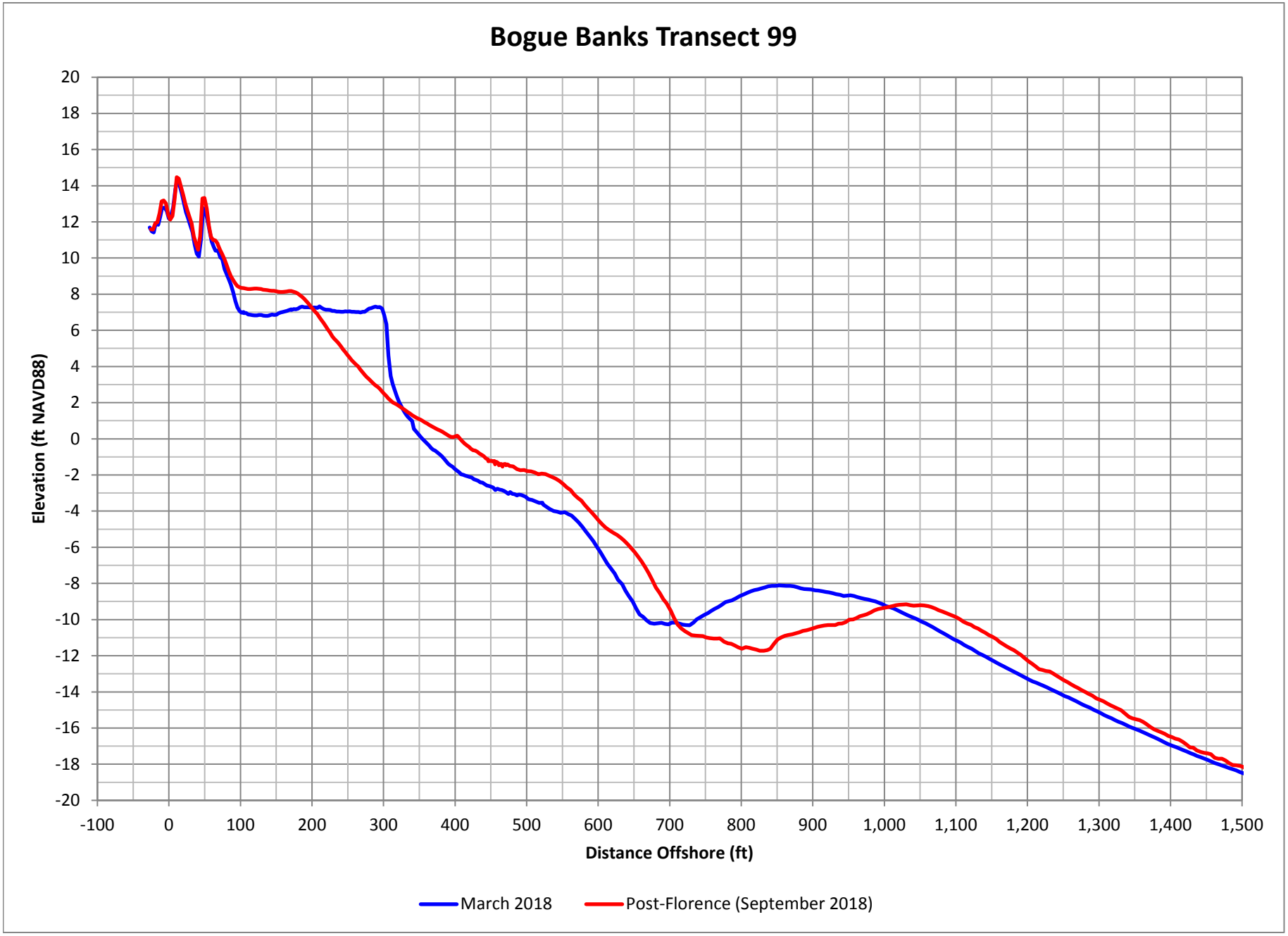

Figure D-198. Bogue Banks Profile Comparison Plot

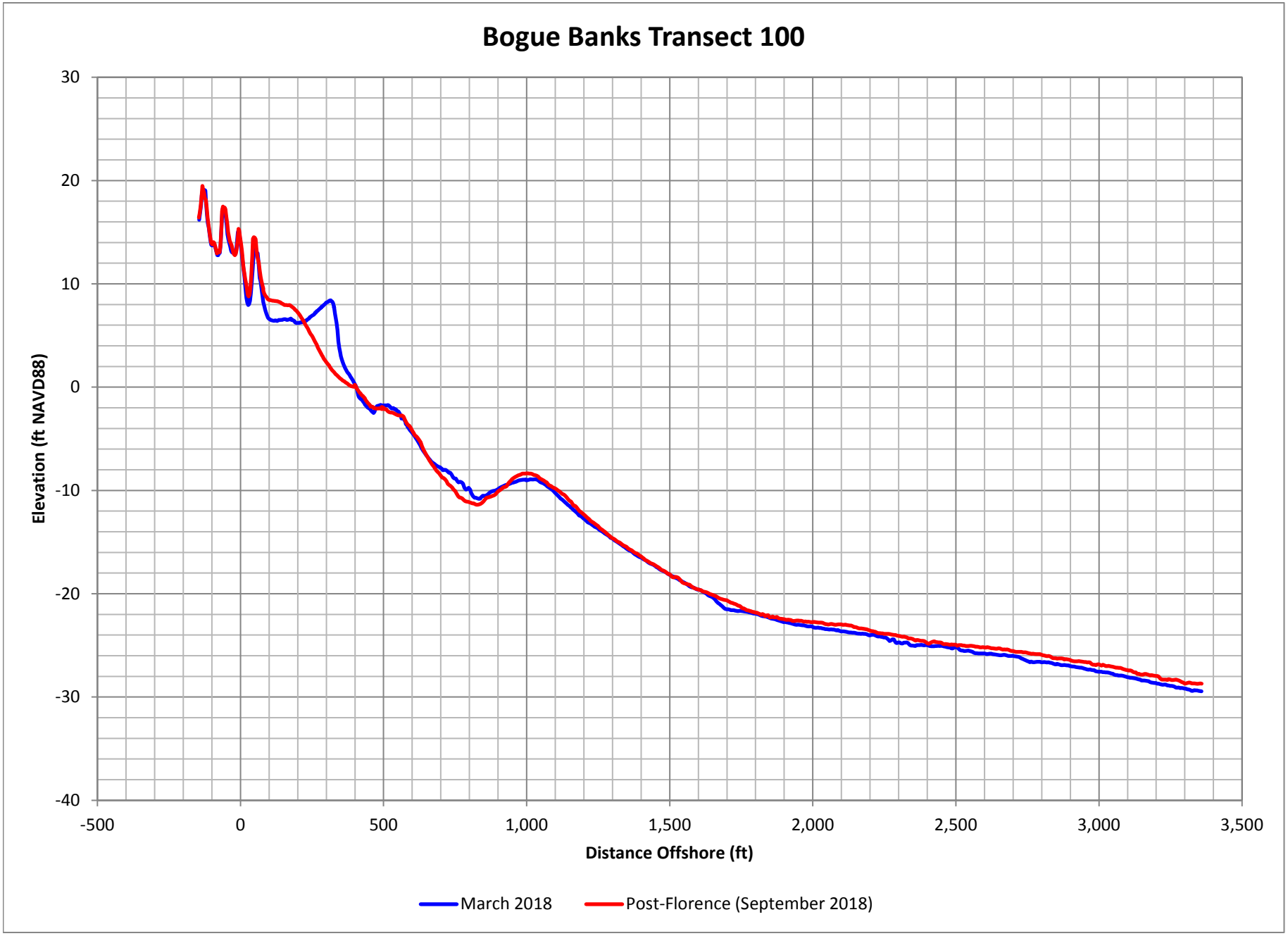

Figure D-199. Bogue Banks Profile Comparison Plot

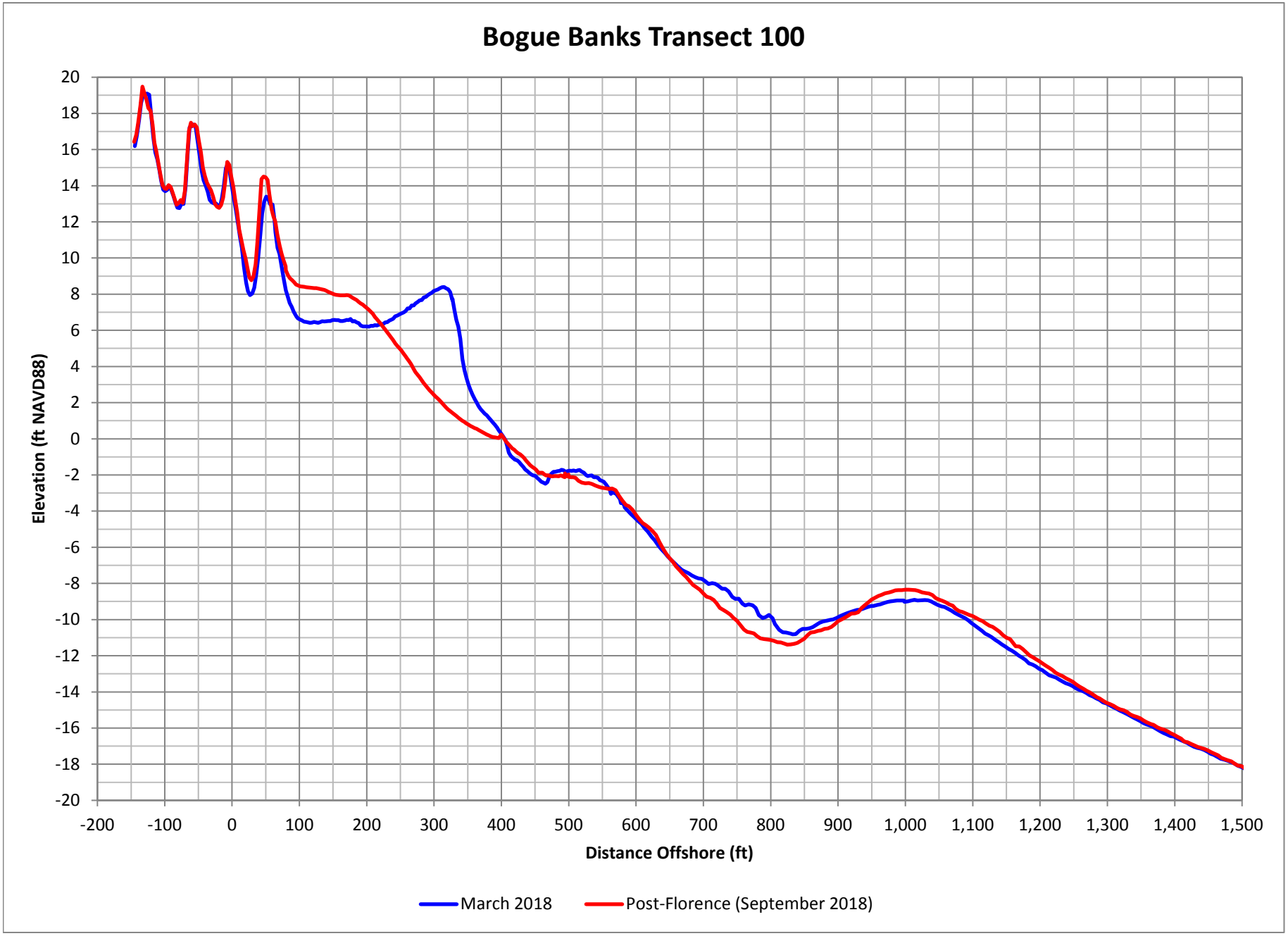

Figure D-200. Bogue Banks Profile Comparison Plot

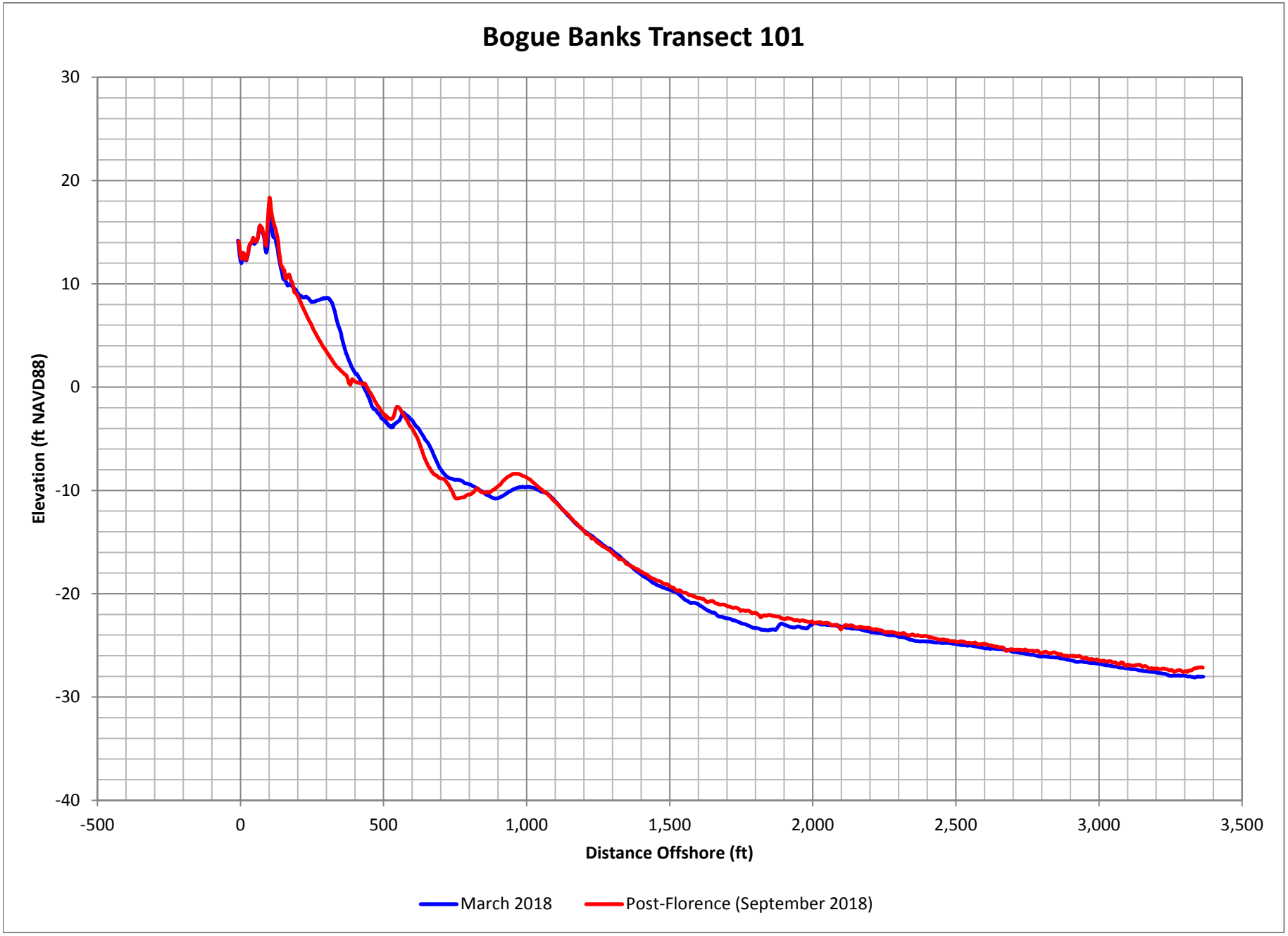

Figure D-201. Bogue Banks Profile Comparison Plot

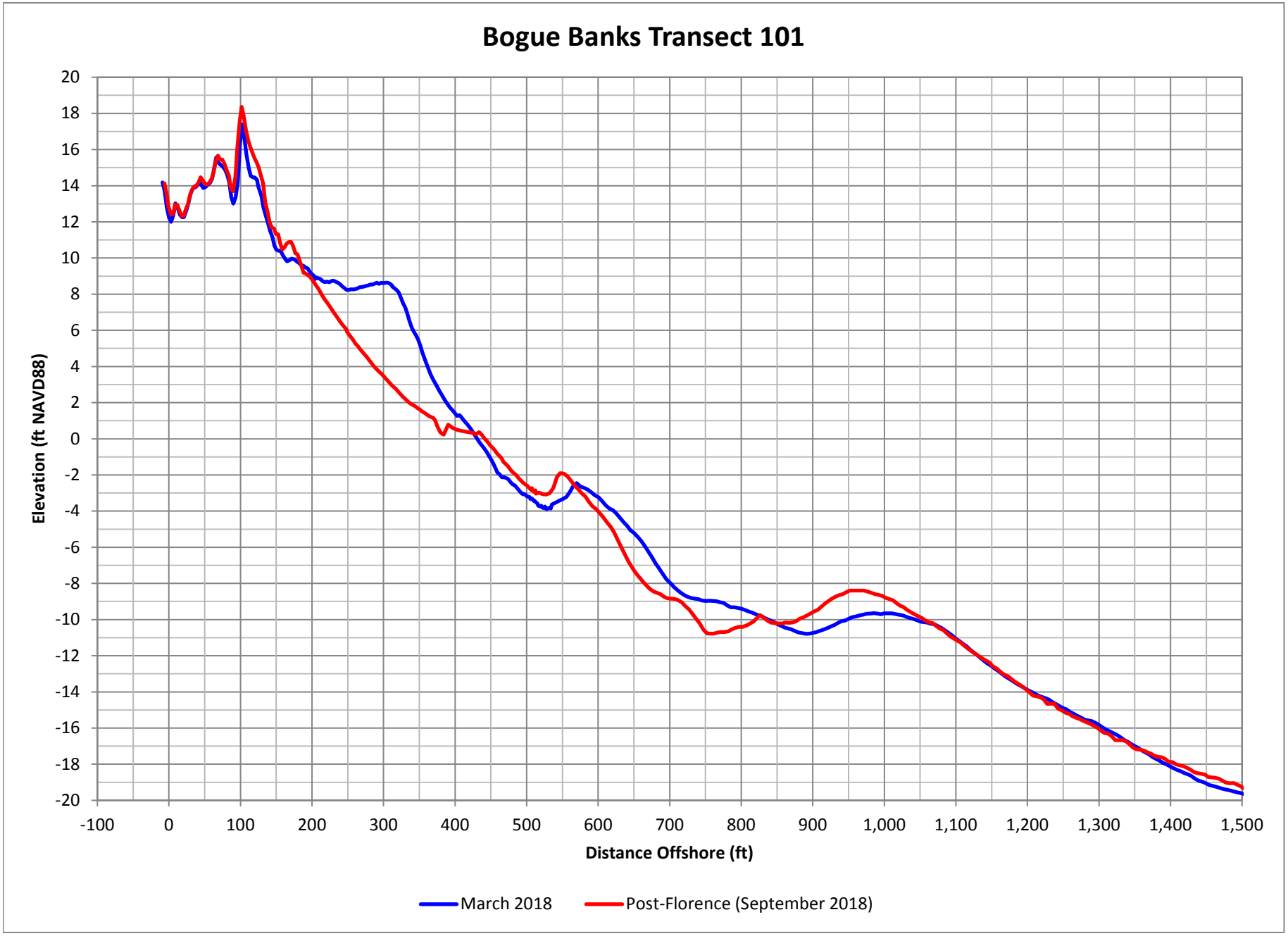

Figure D-202. Bogue Banks Profile Comparison Plot

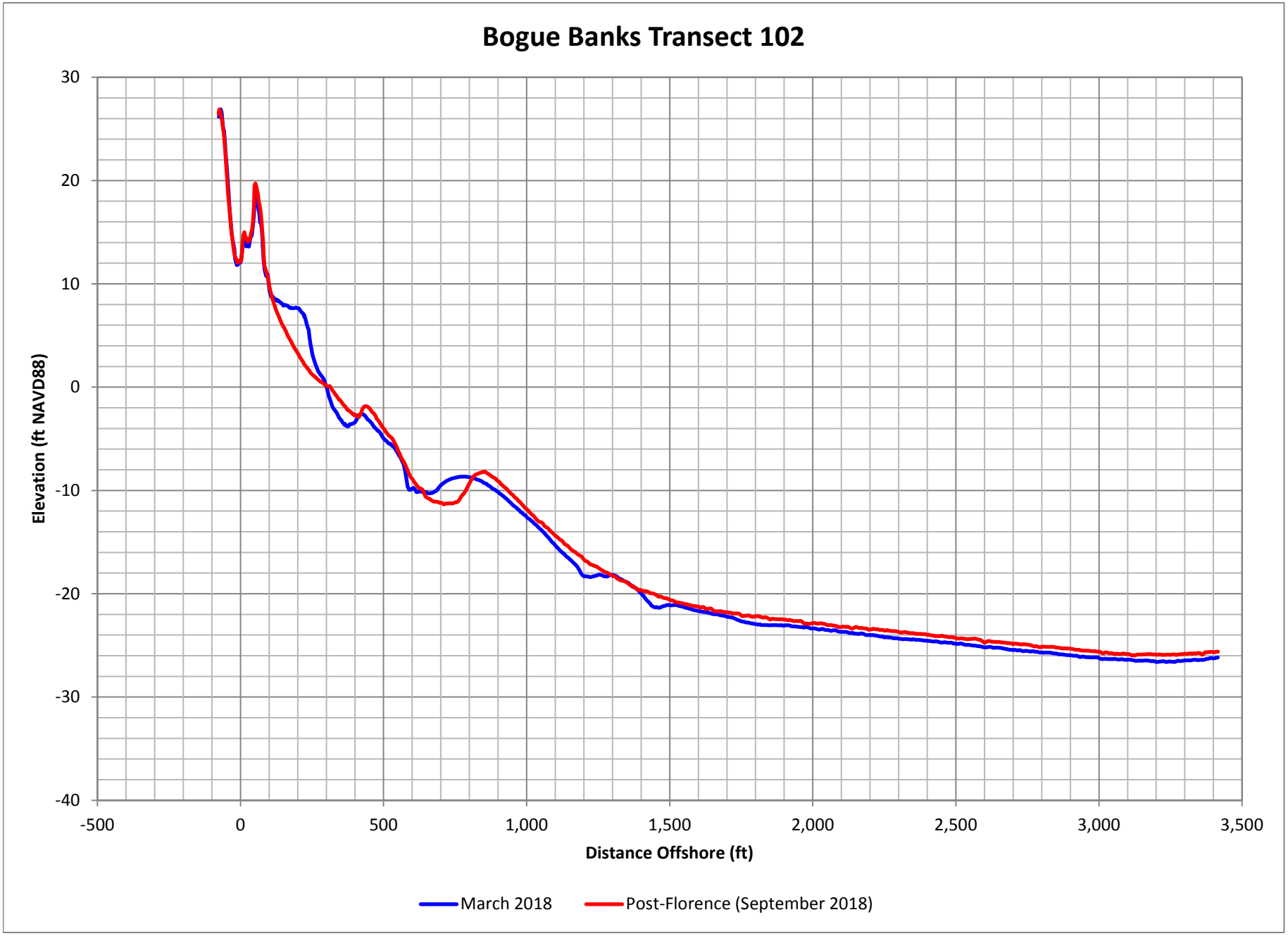

Figure D-203. Bogue Banks Profile Comparison Plot

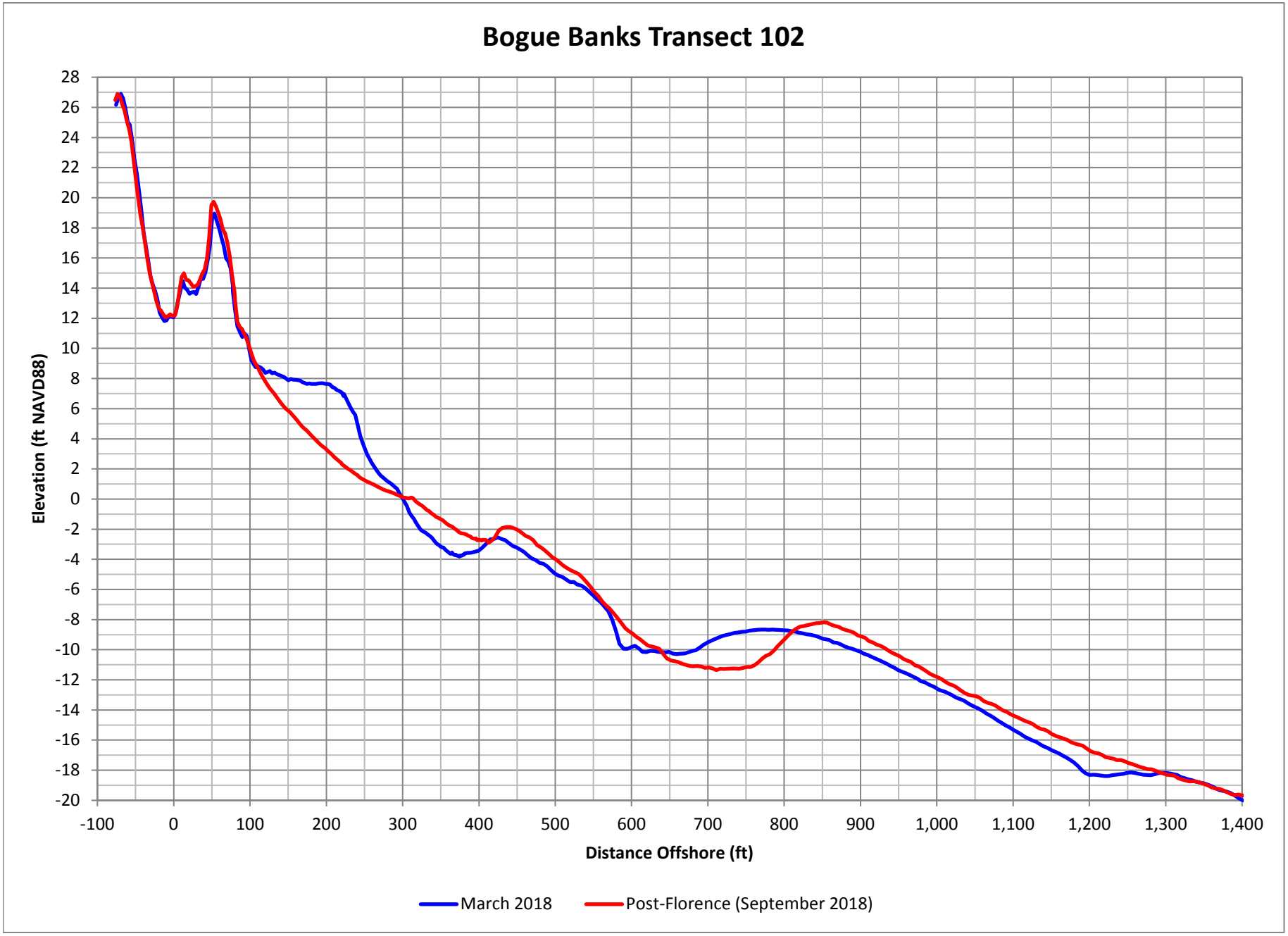

Figure D-204. Bogue Banks Profile Comparison Plot

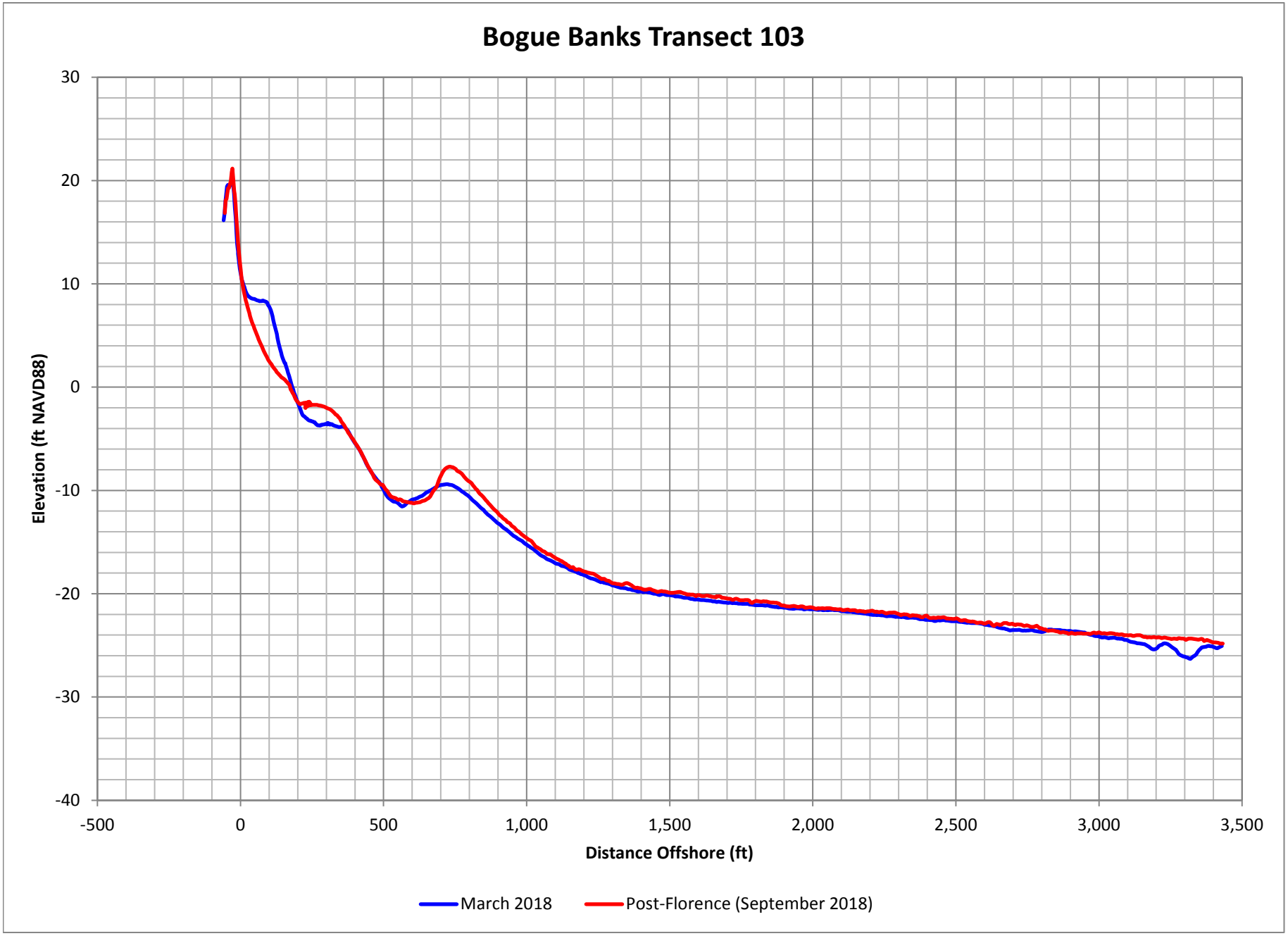

Figure D-205. Bogue Banks Profile Comparison Plot

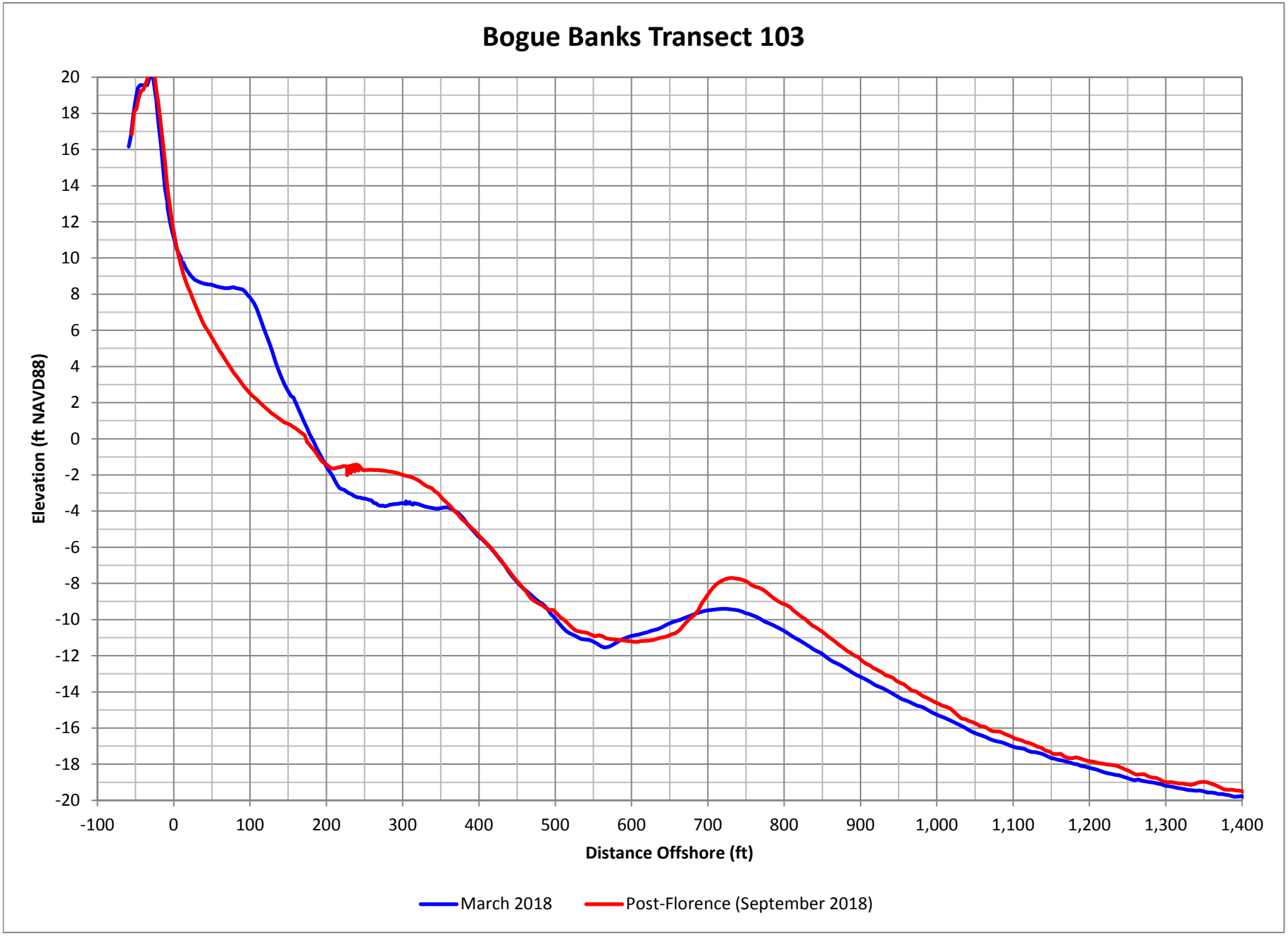

Figure D-206. Bogue Banks Profile Comparison Plot

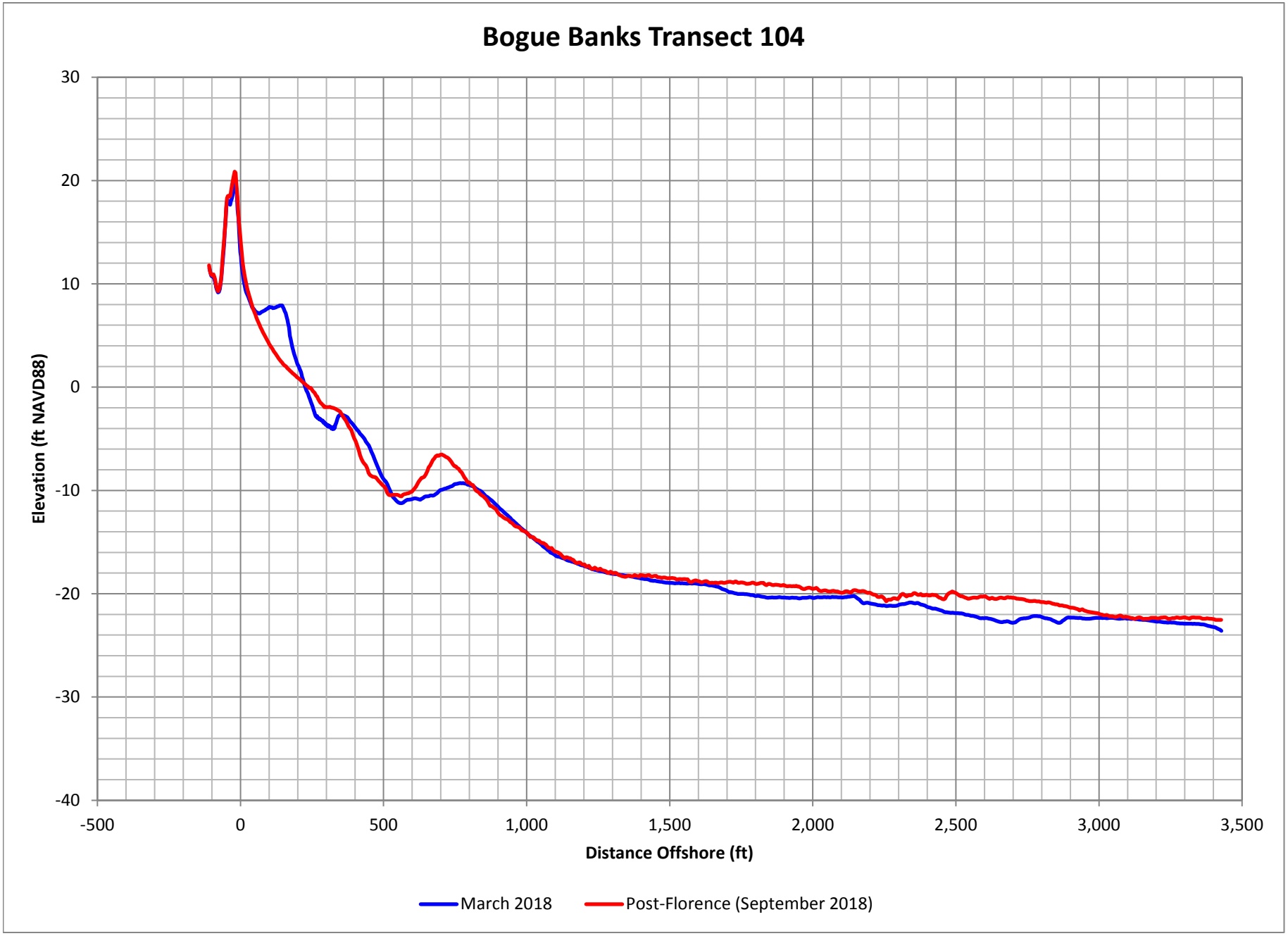

Figure D-207. Bogue Banks Profile Comparison Plot

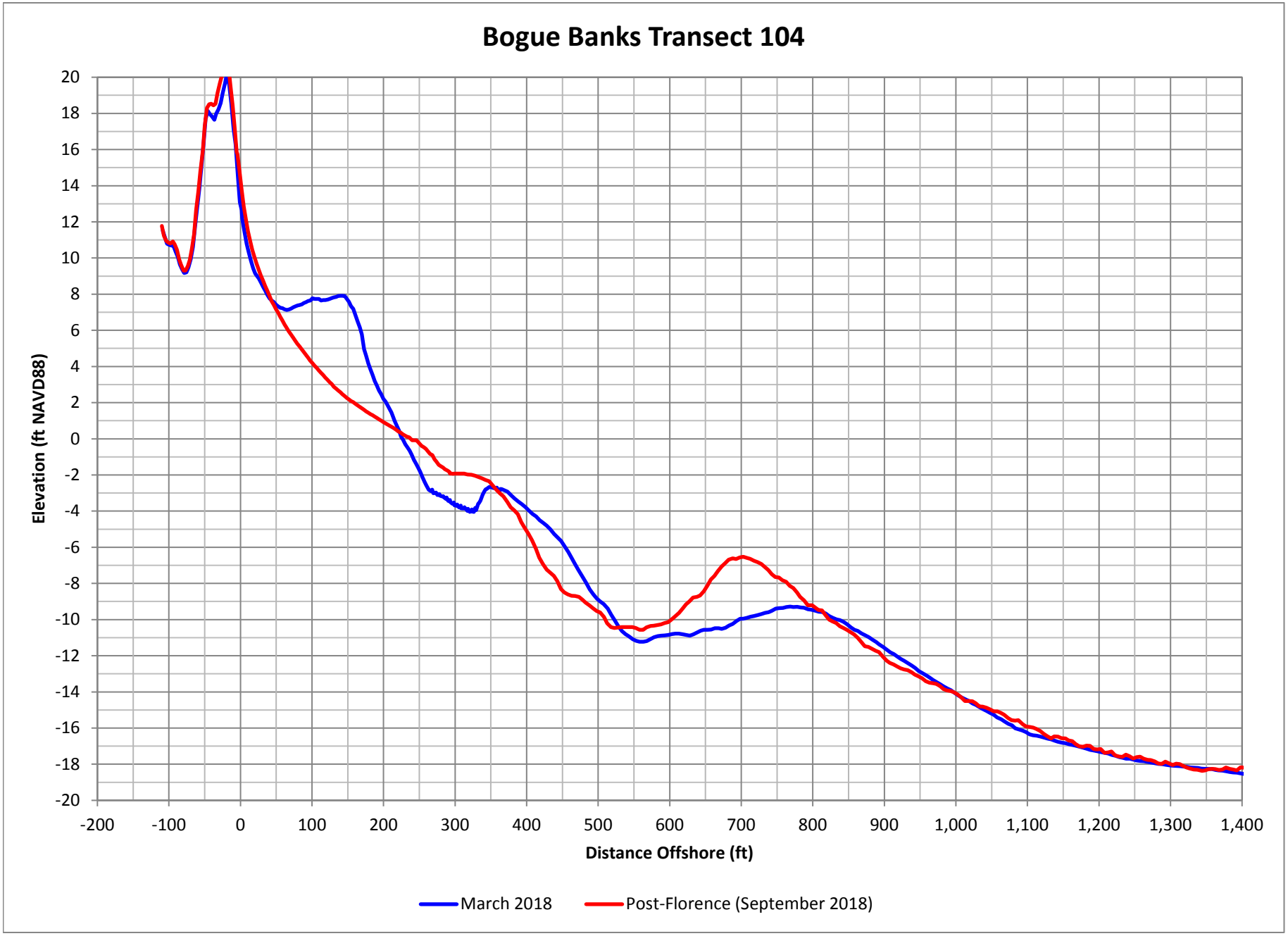

Figure D-208. Bogue Banks Profile Comparison Plot

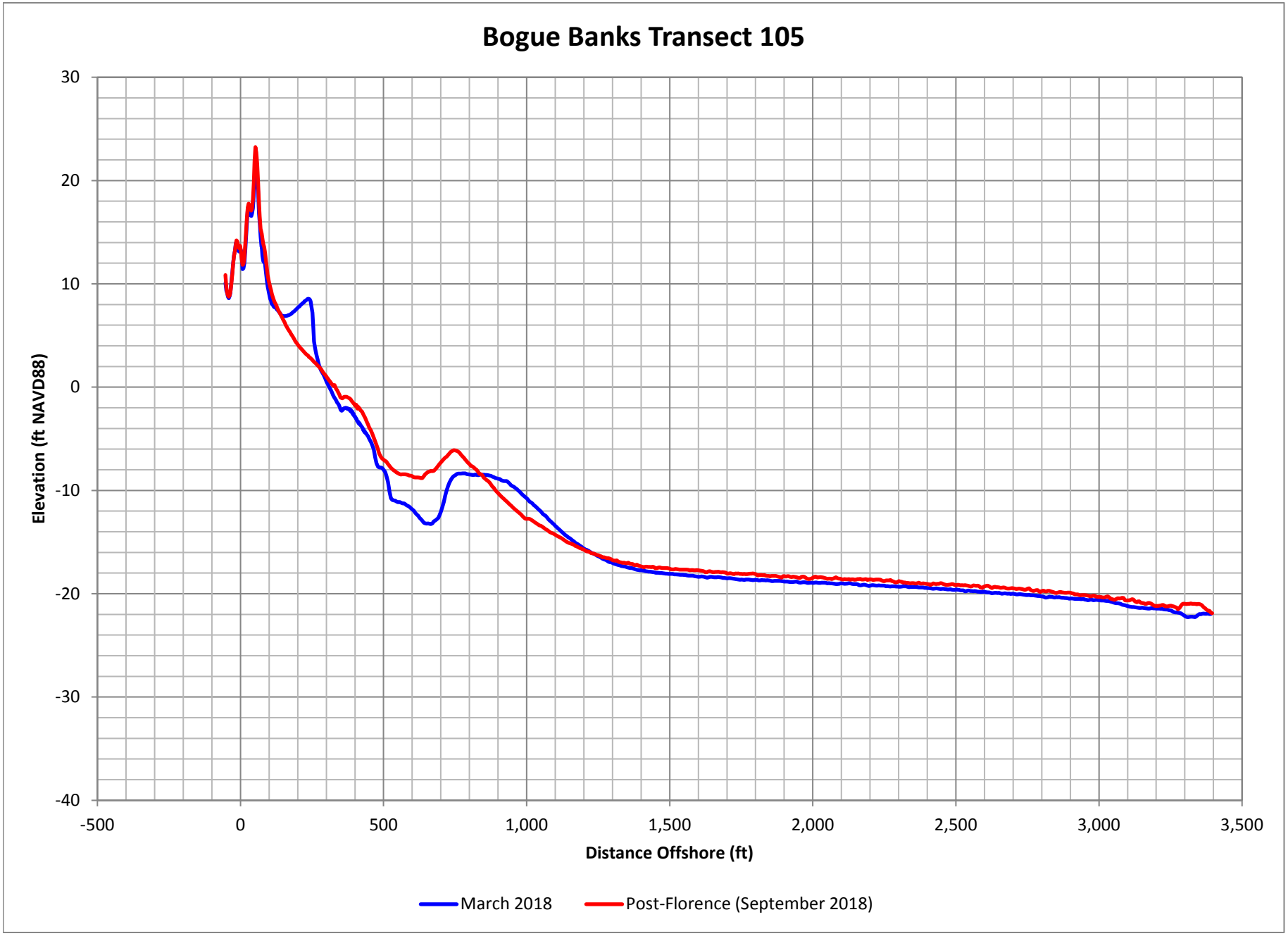

Figure D-209. Bogue Banks Profile Comparison Plot

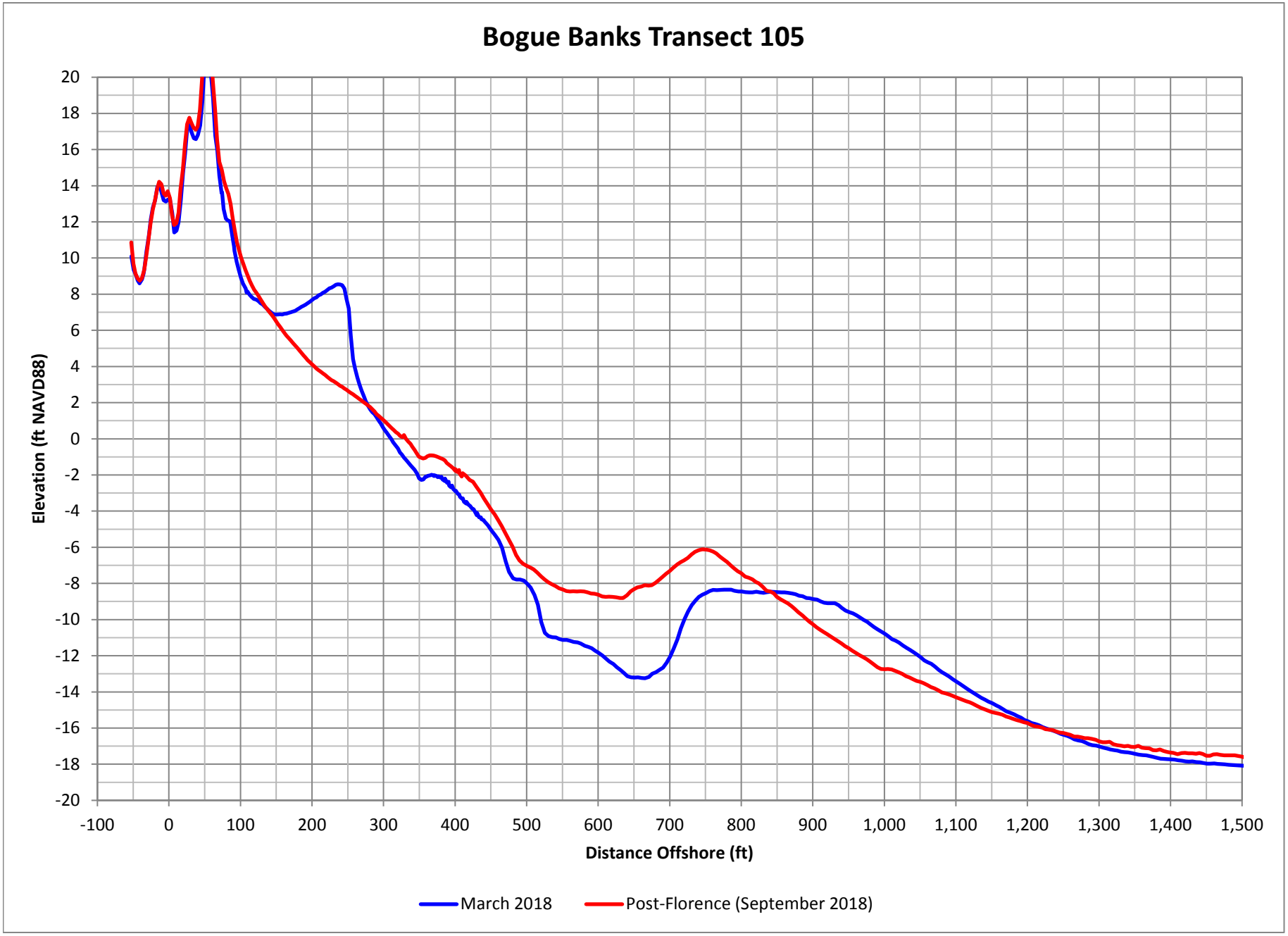

Figure D-210. Bogue Banks Profile Comparison Plot

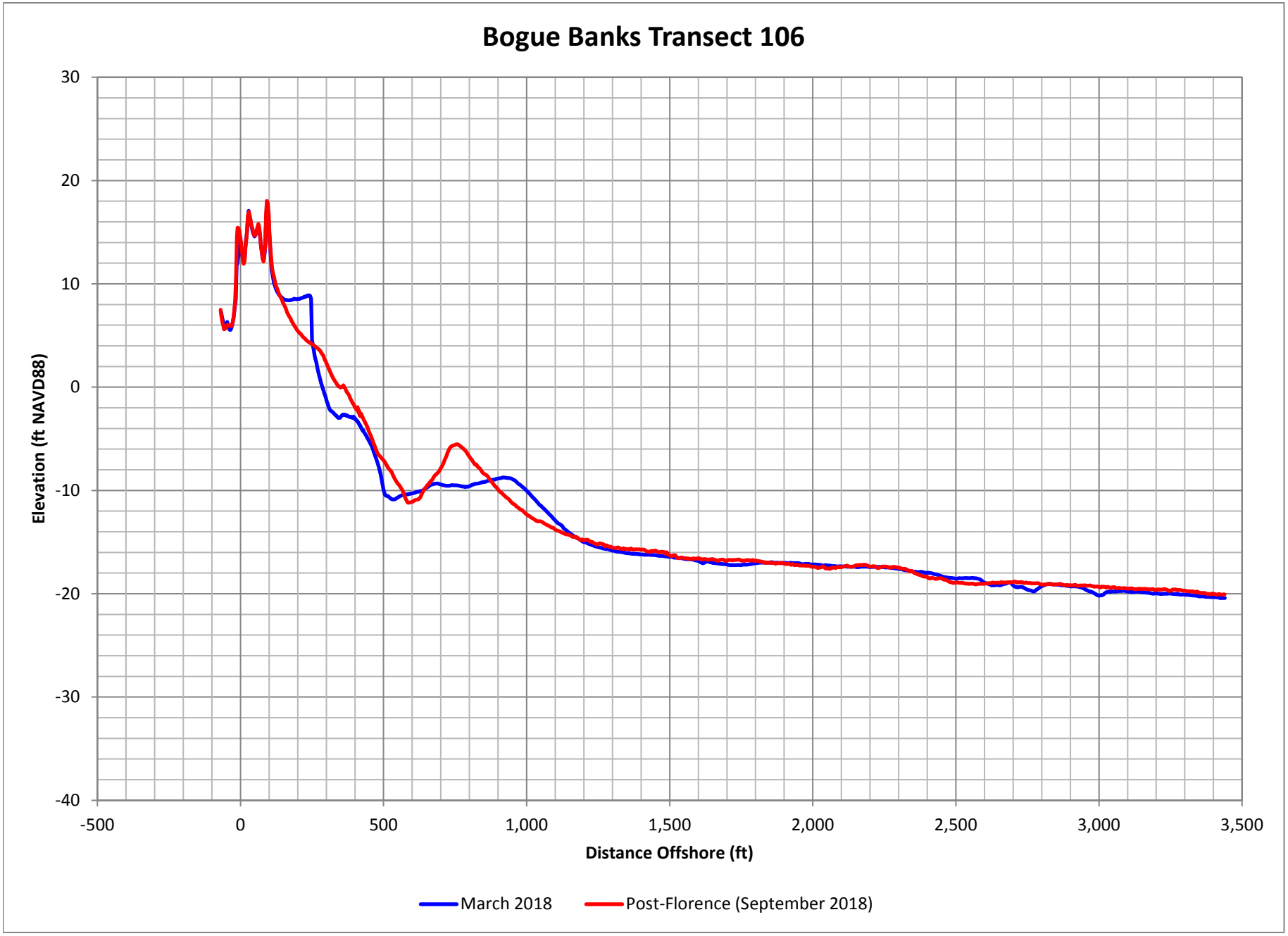

Figure D-211. Bogue Banks Profile Comparison Plot

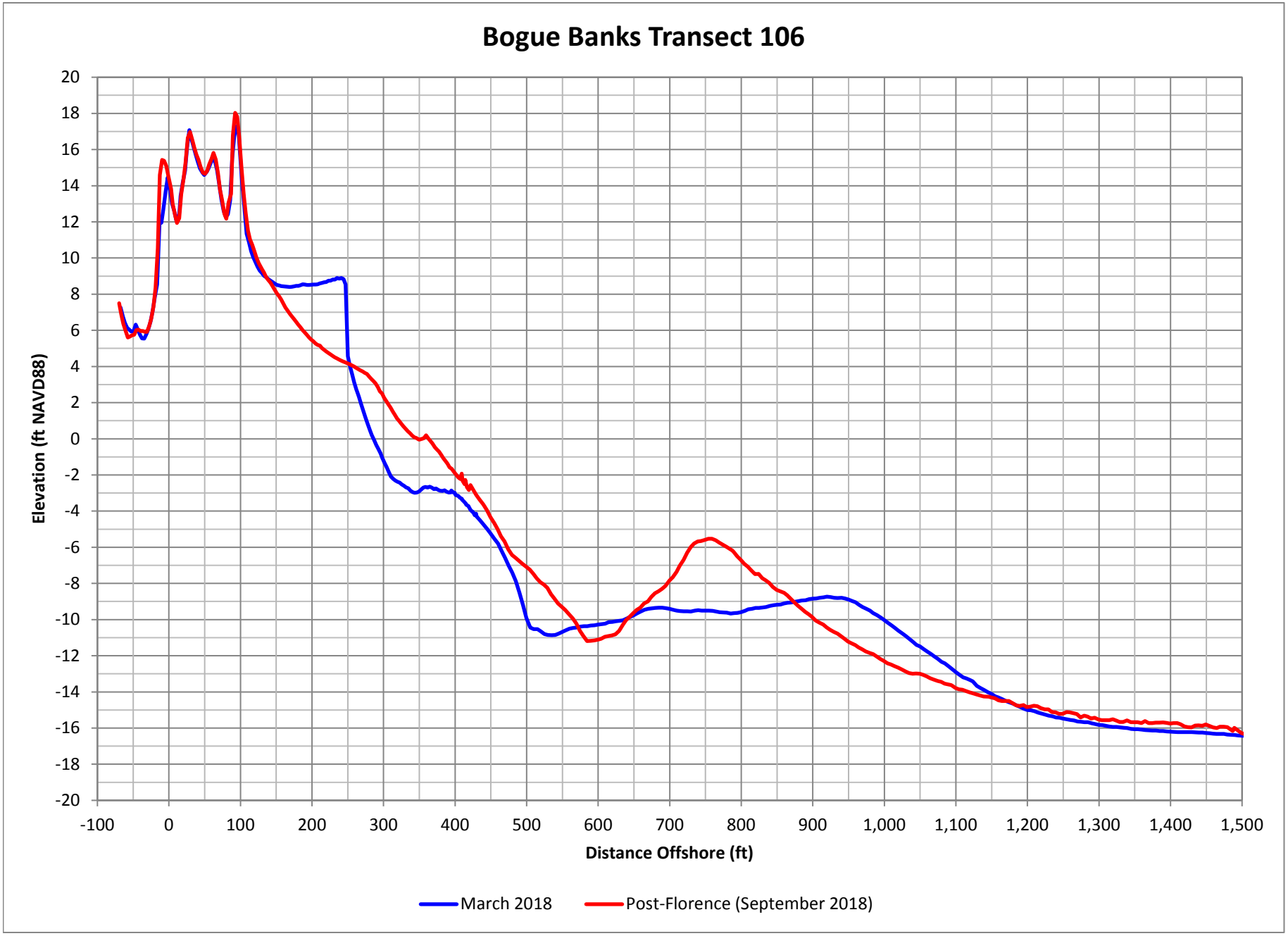

Figure D-212. Bogue Banks Profile Comparison Plot

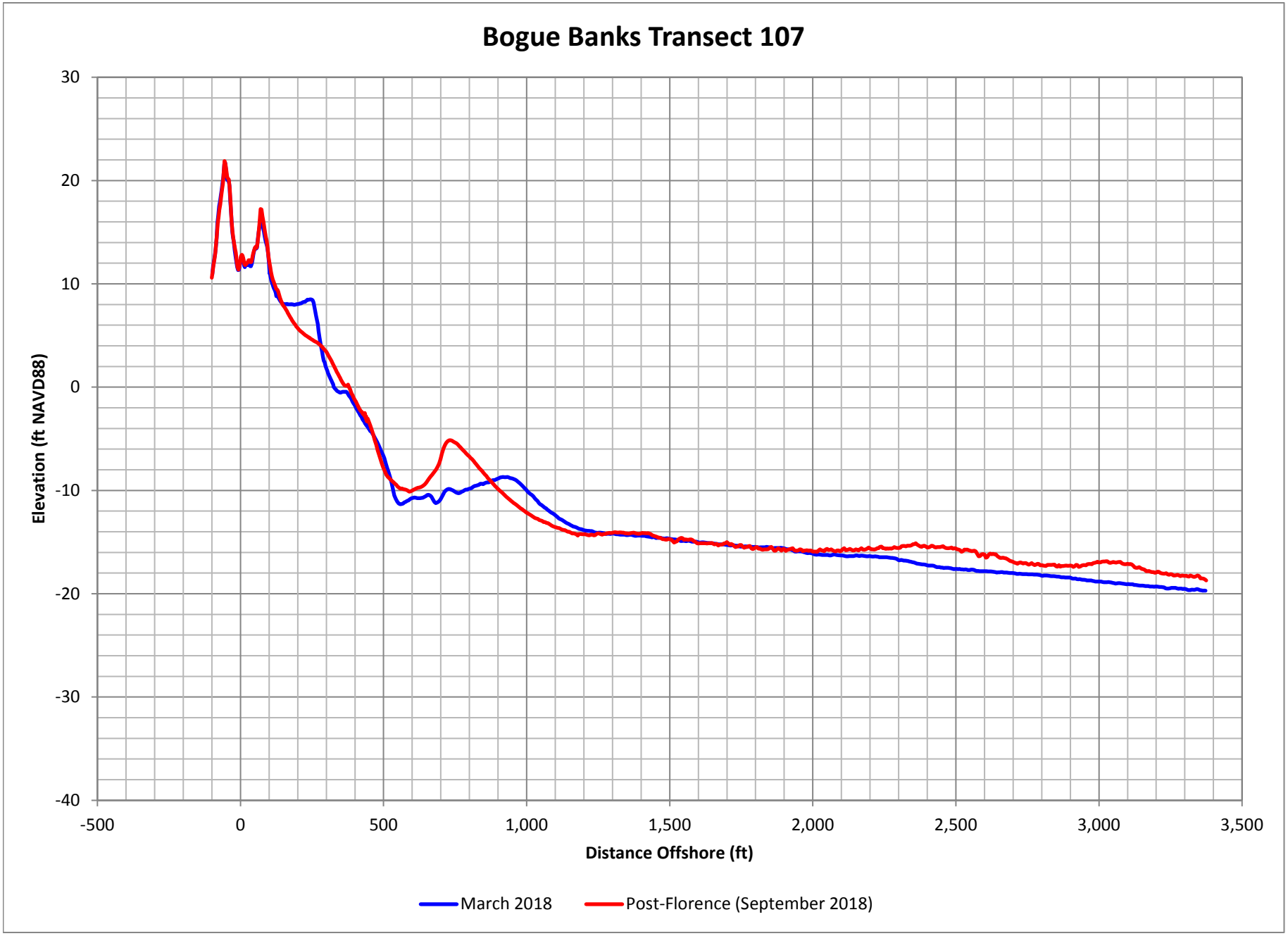

Figure D-213. Bogue Banks Profile Comparison Plot

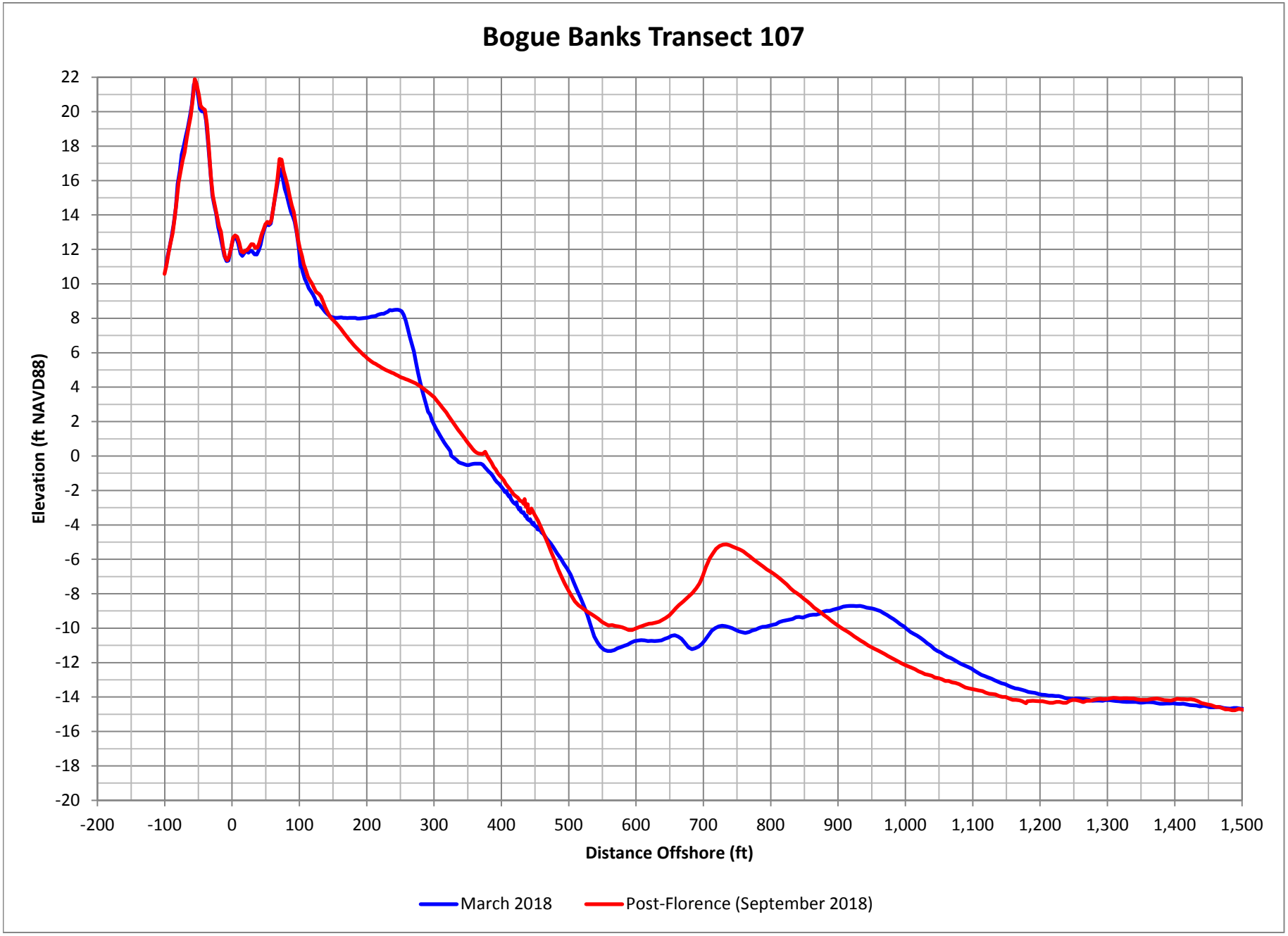

Figure D-214. Bogue Banks Profile Comparison Plot

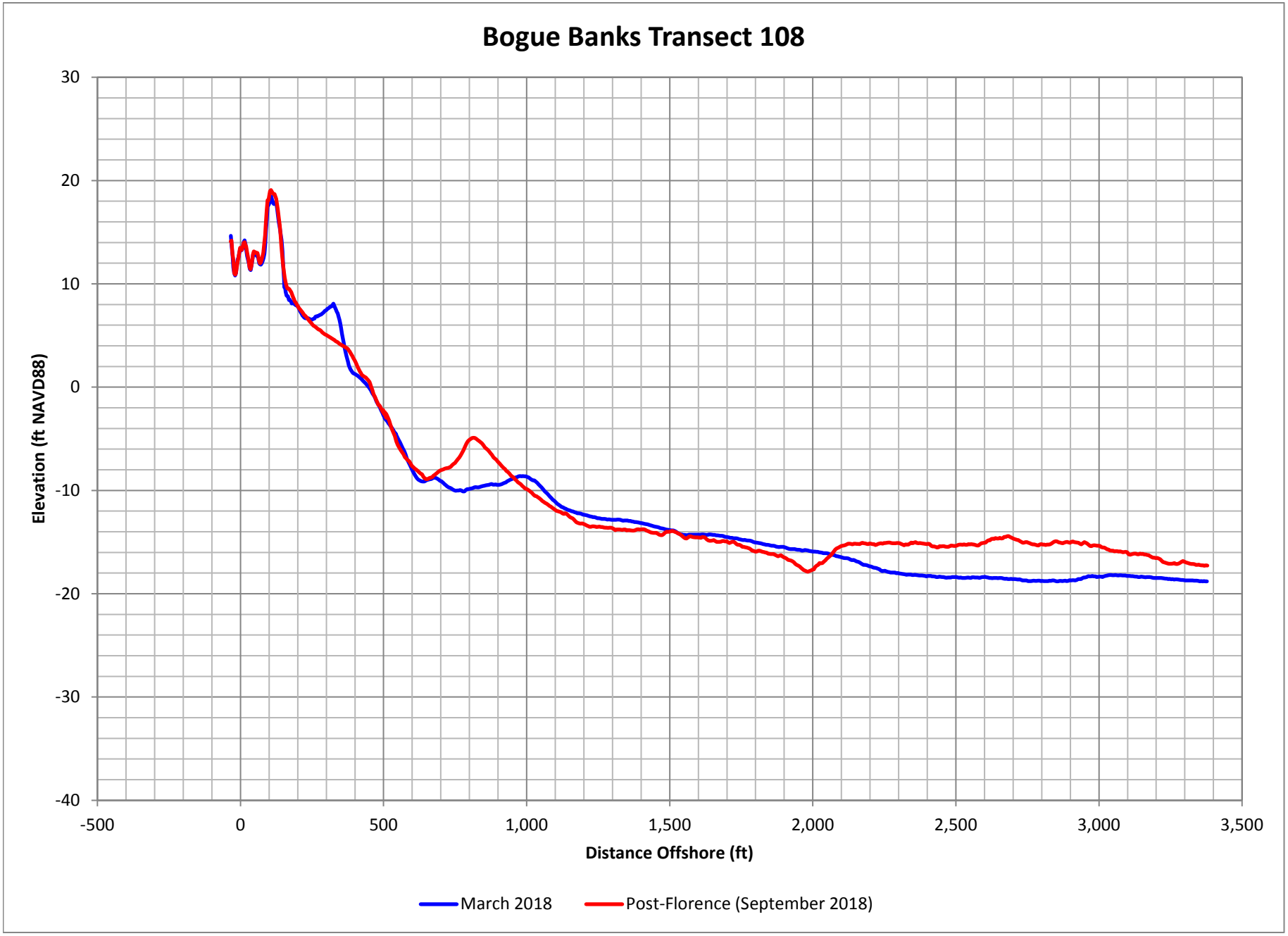

Figure D-215. Bogue Banks Profile Comparison Plot

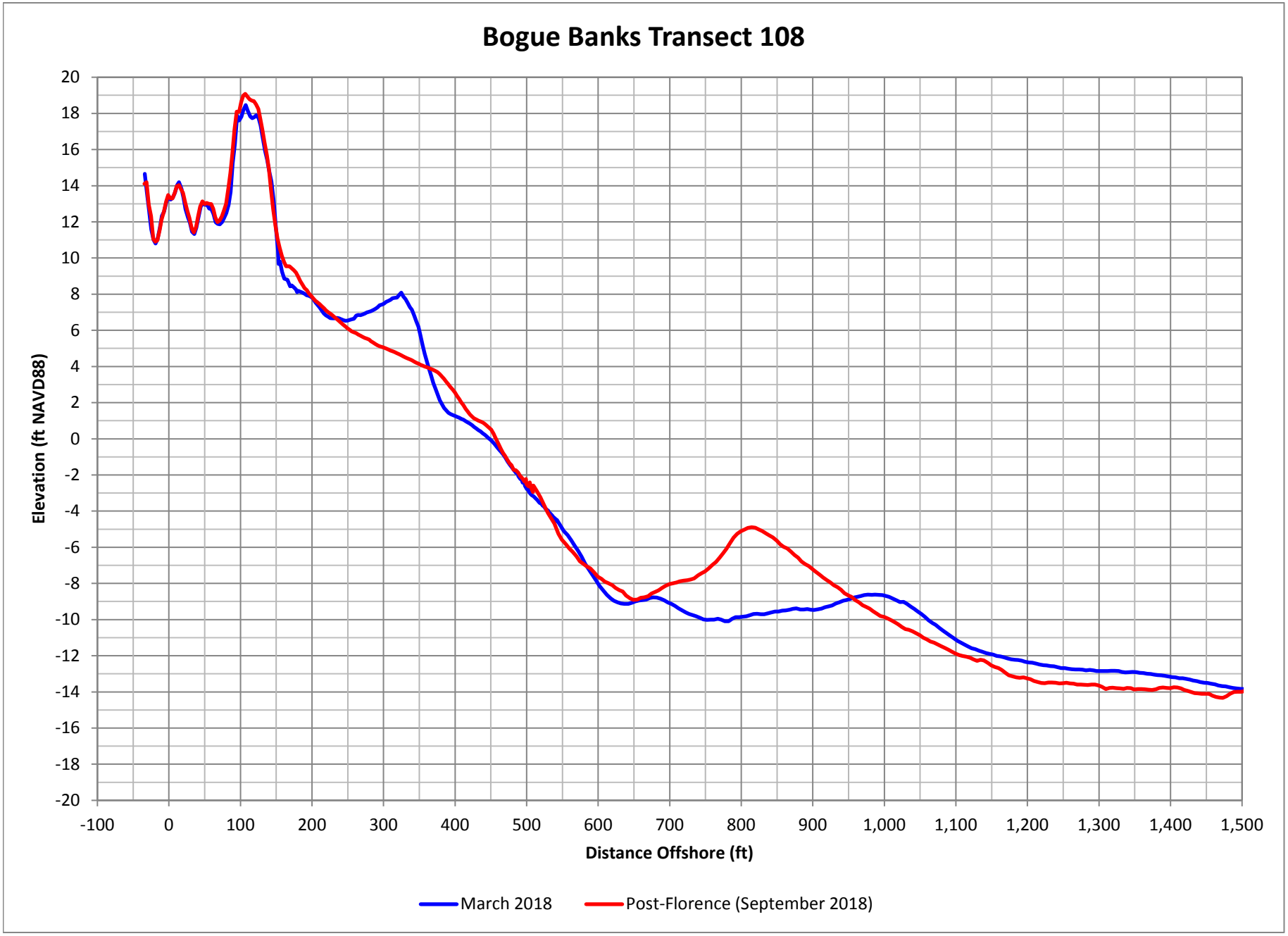

Figure D-216. Bogue Banks Profile Comparison Plot

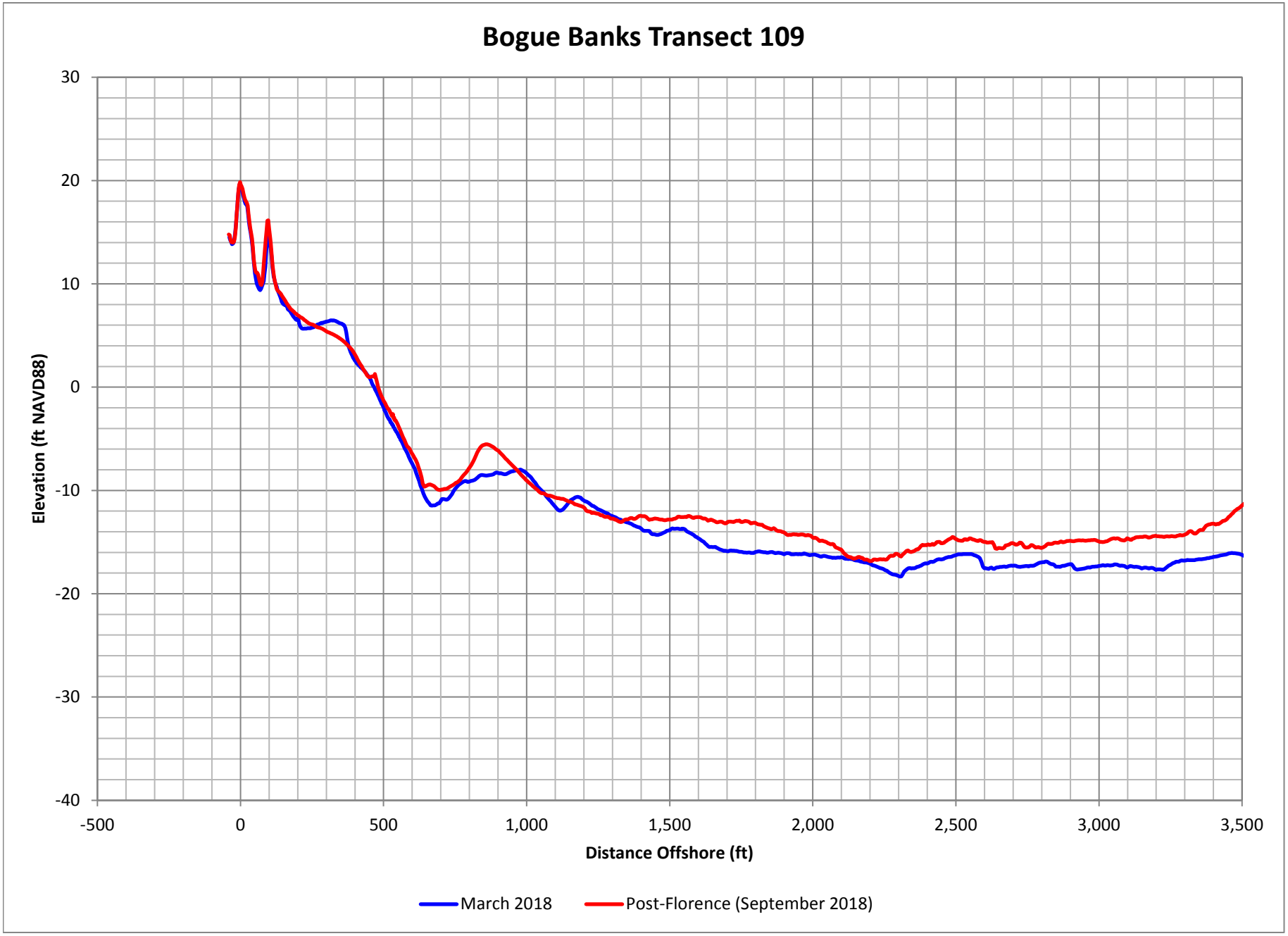

Figure D-217. Bogue Banks Profile Comparison Plot

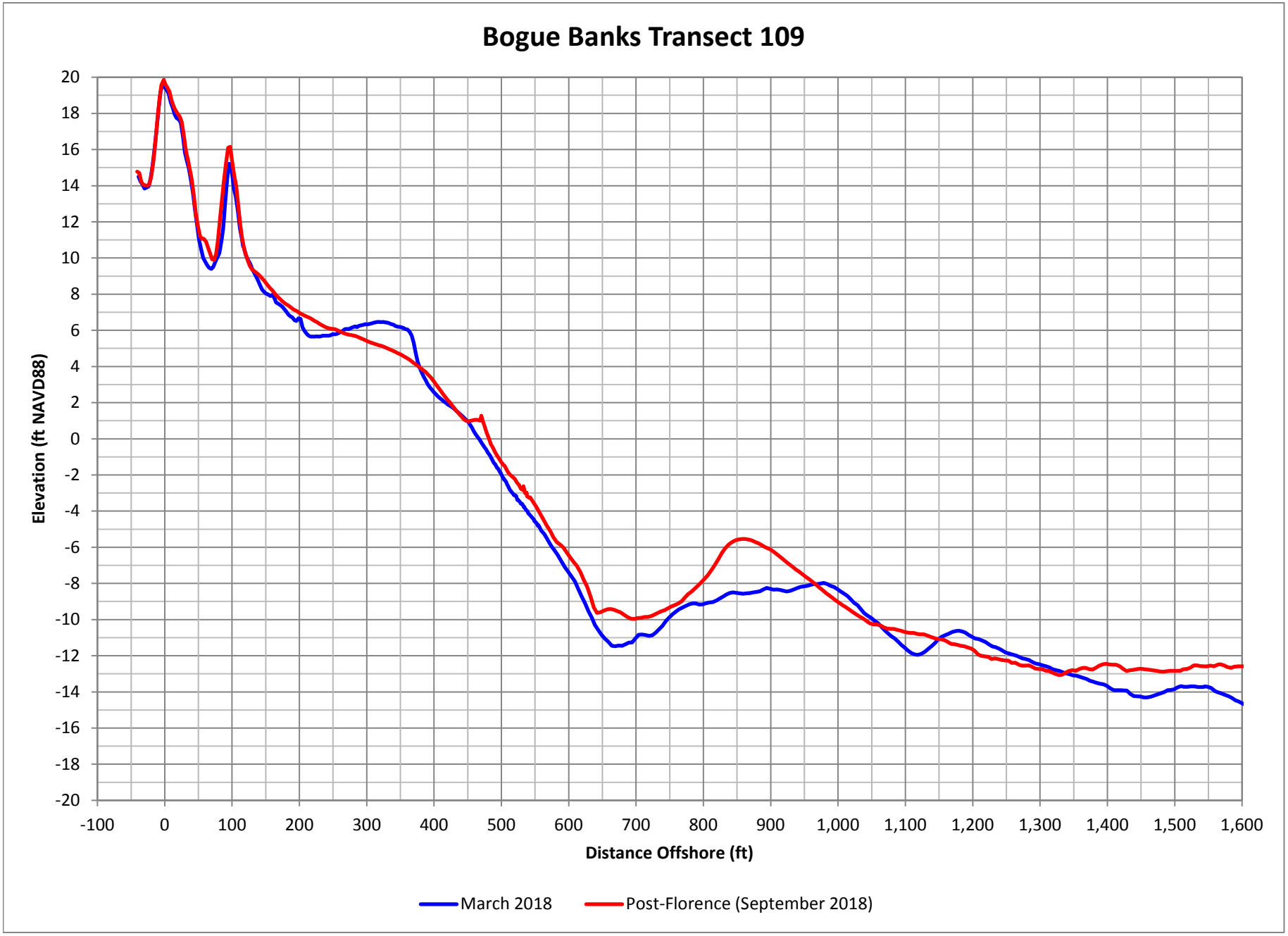

Figure D-218. Bogue Banks Profile Comparison Plot

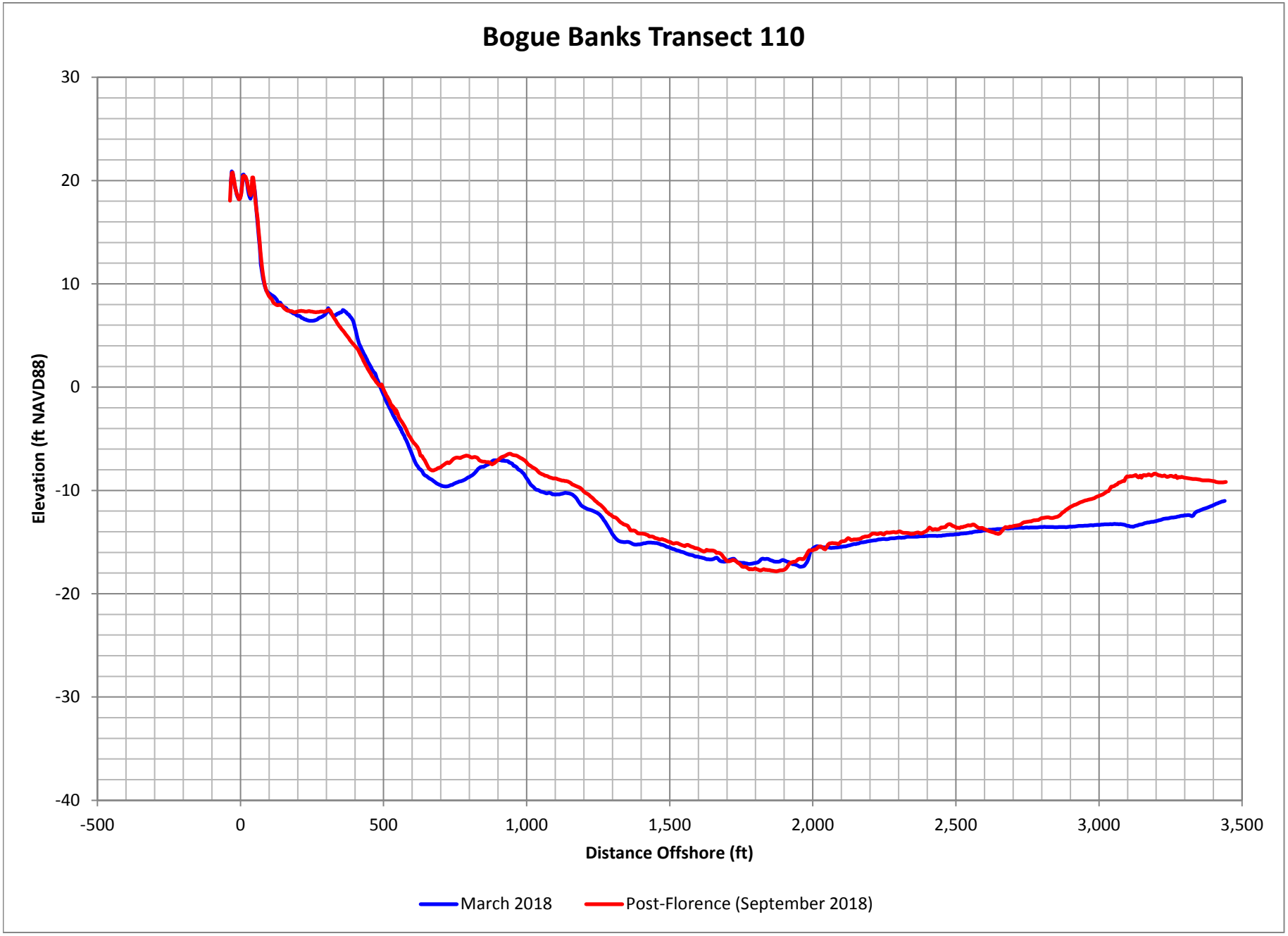

Figure D-219. Bogue Banks Profile Comparison Plot

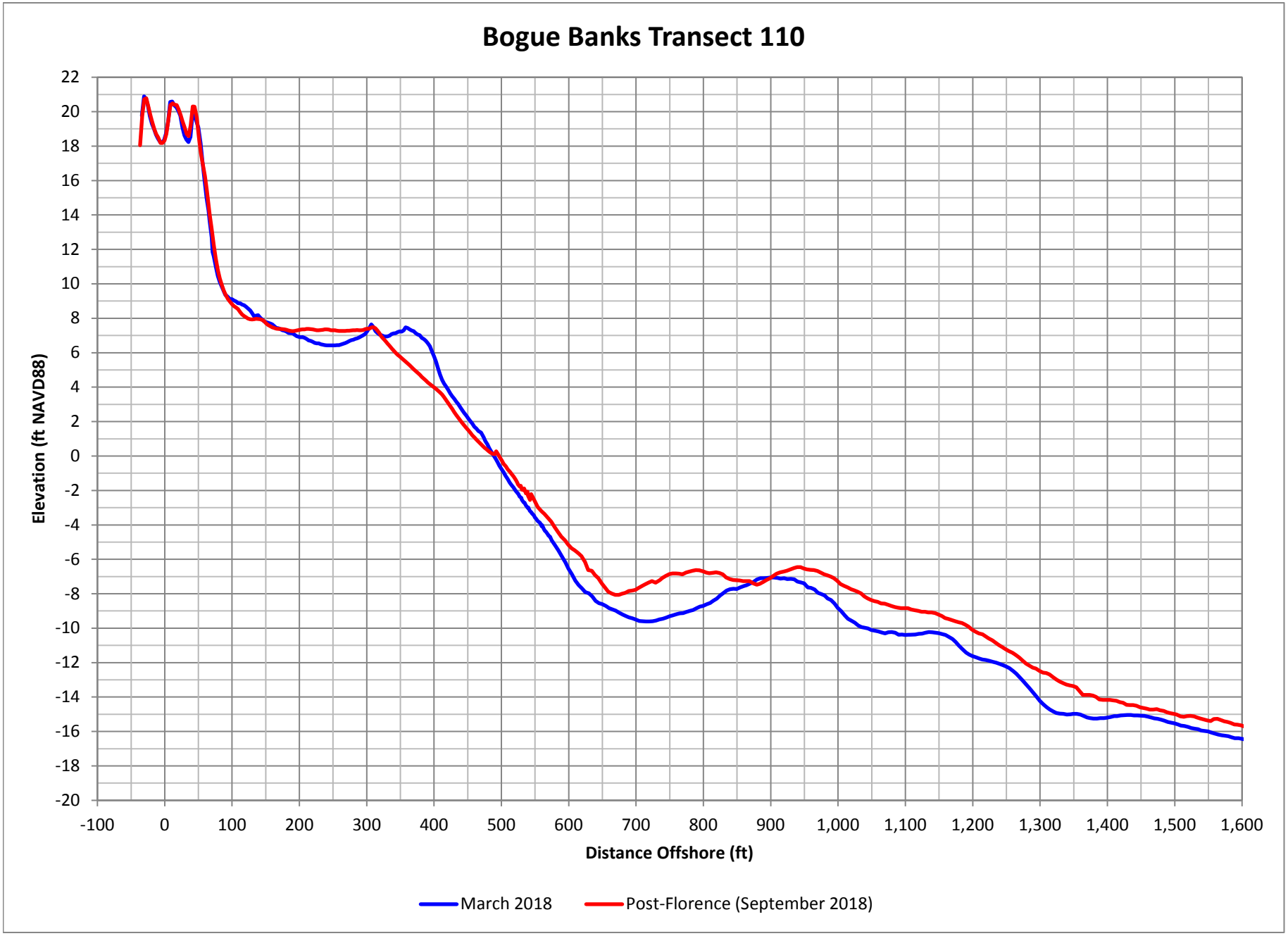

Figure D-220. Bogue Banks Profile Comparison Plot

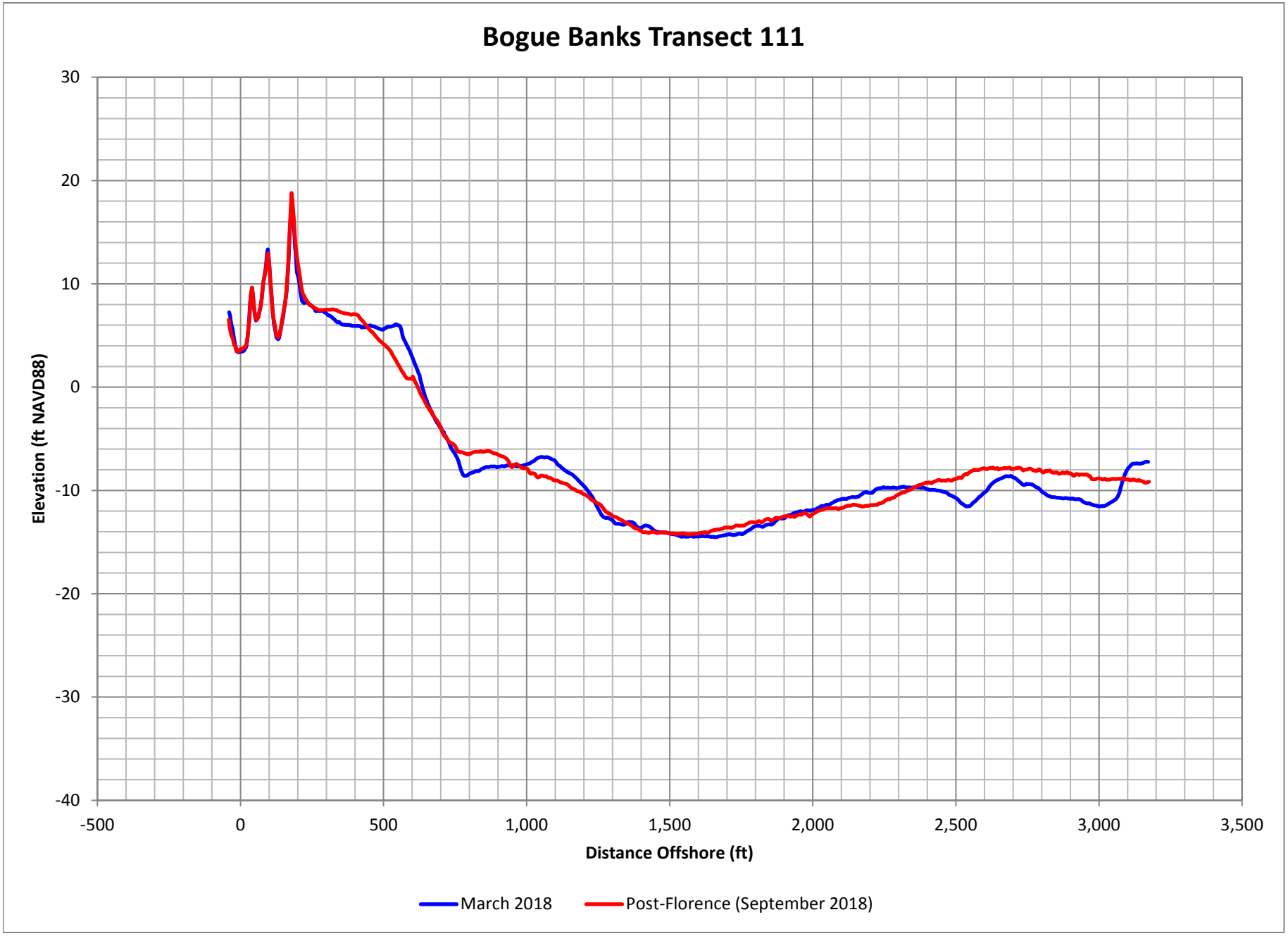

Figure D-221. Bogue Banks Profile Comparison Plot

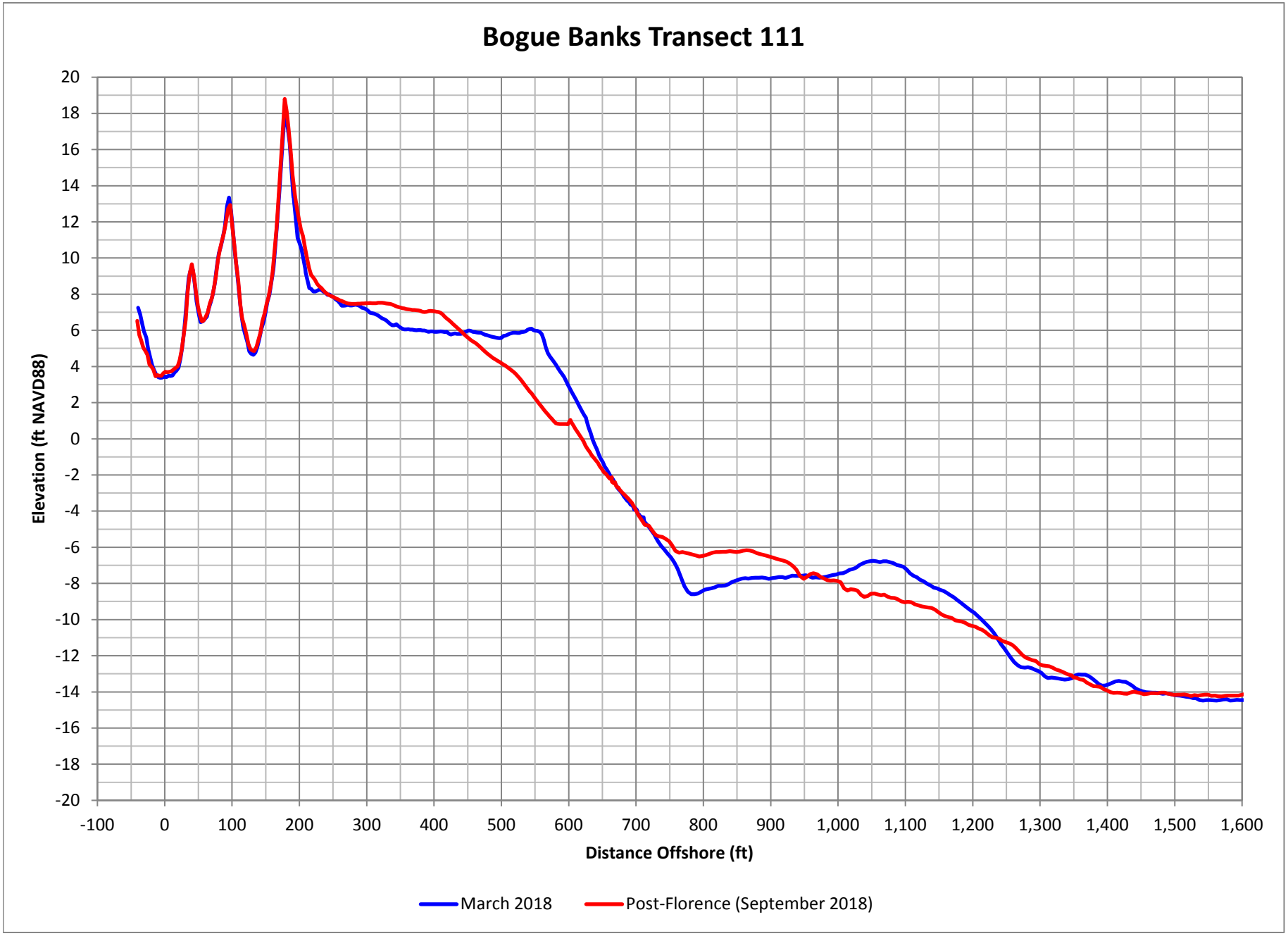

Figure D-222. Bogue Banks Profile Comparison Plot

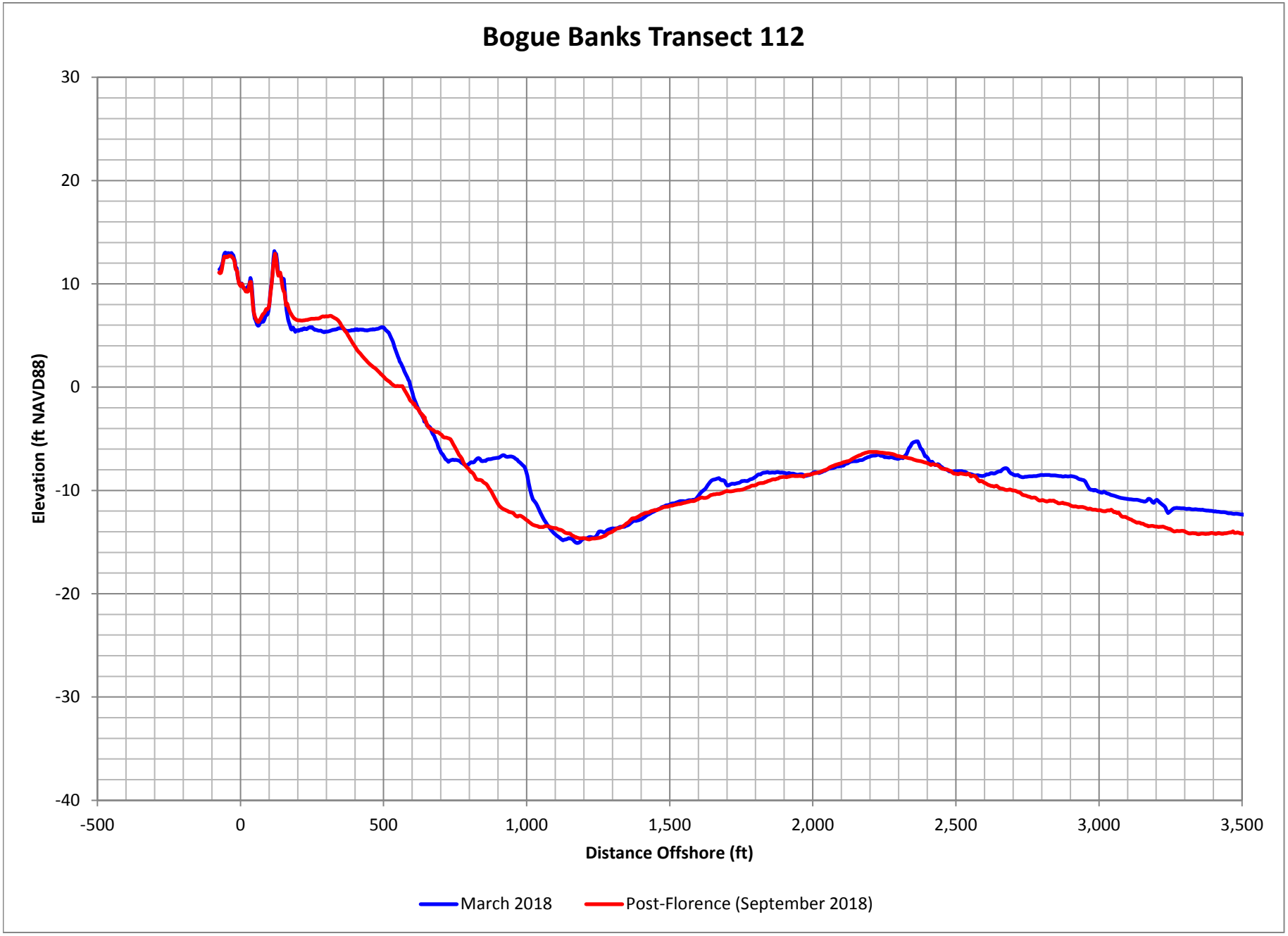

Figure D-223. Bogue Banks Profile Comparison Plot

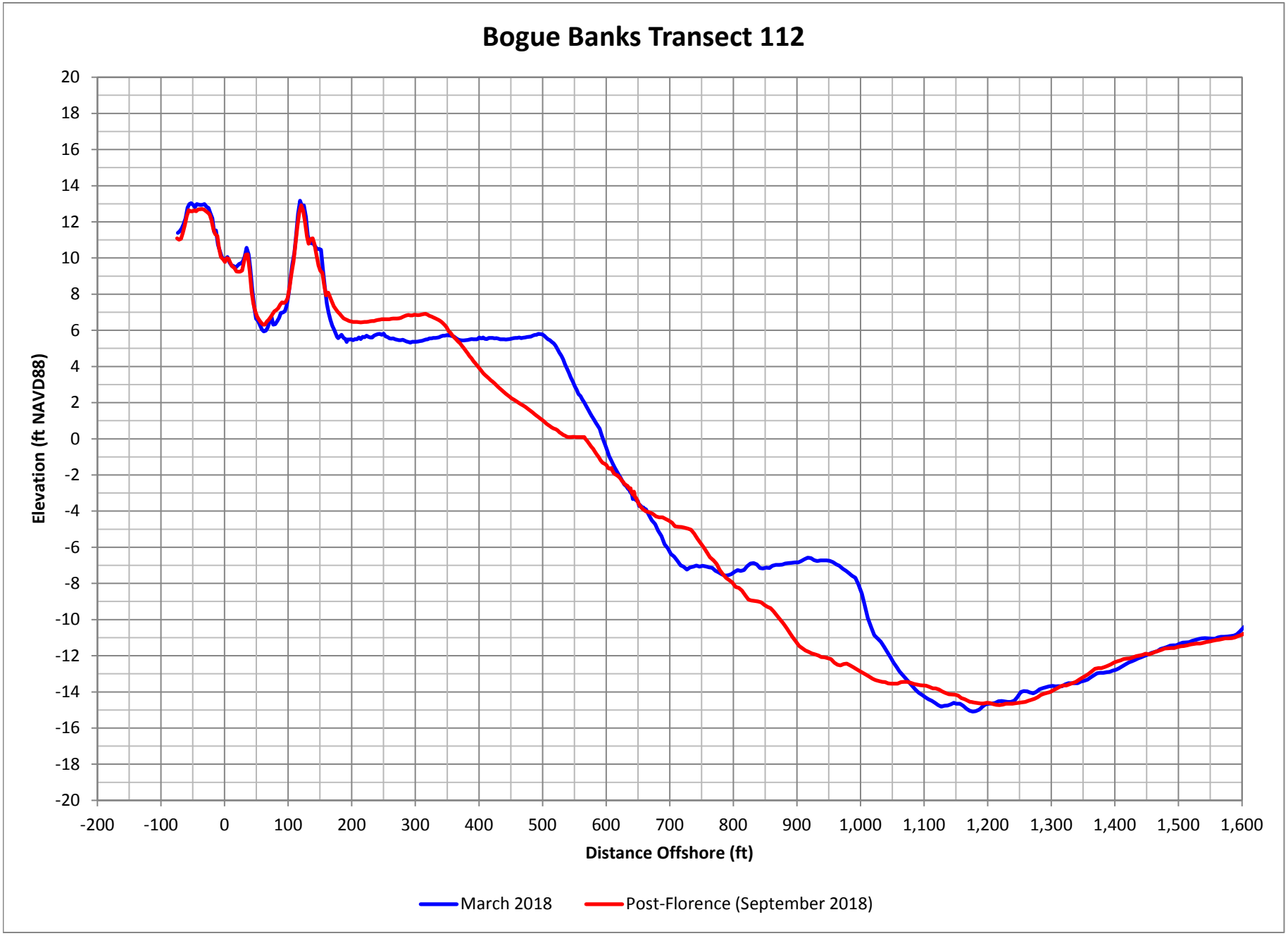

Figure D-224. Bogue Banks Profile Comparison Plot

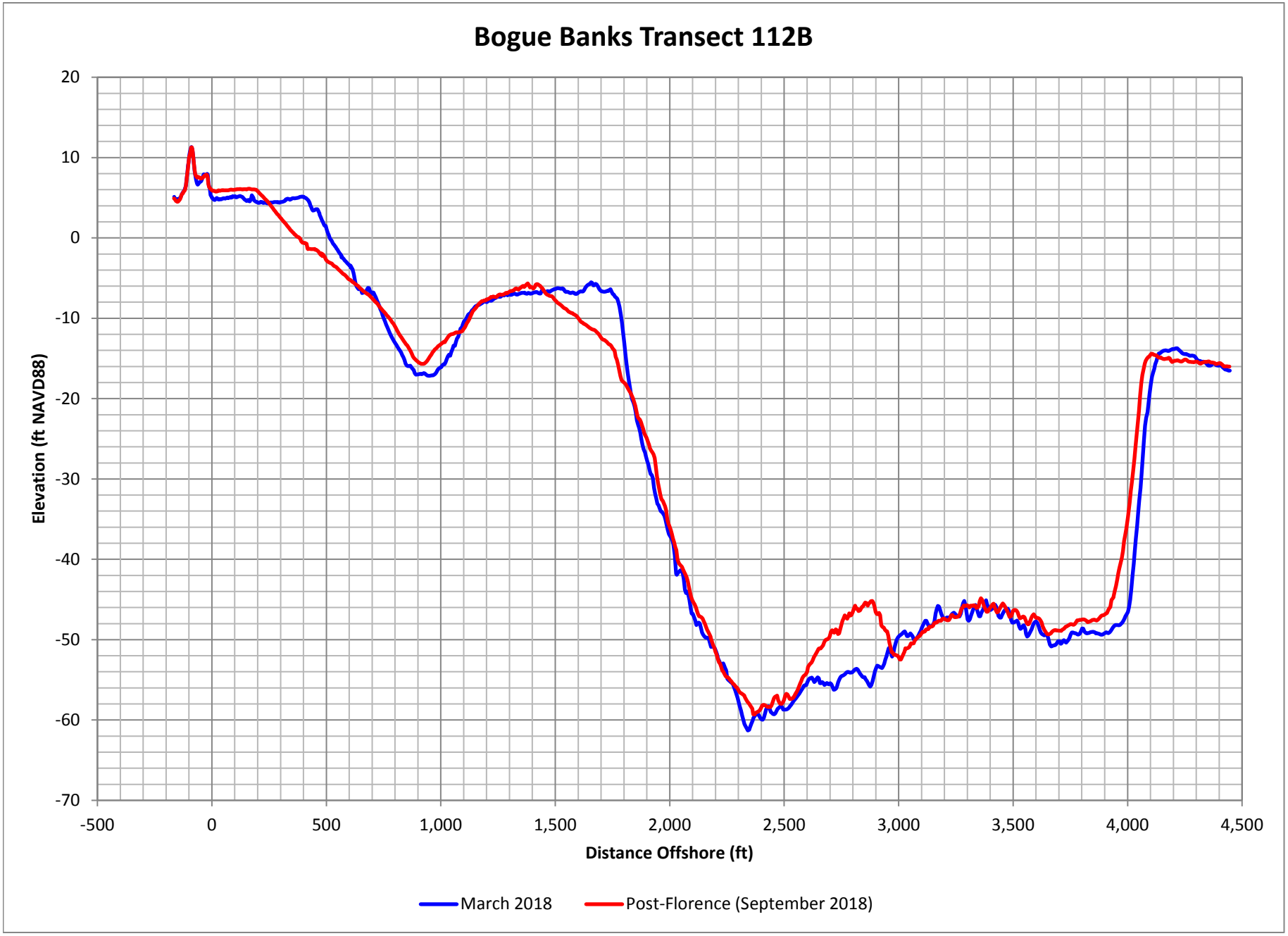

Figure D-225. Bogue Banks Profile Comparison Plot

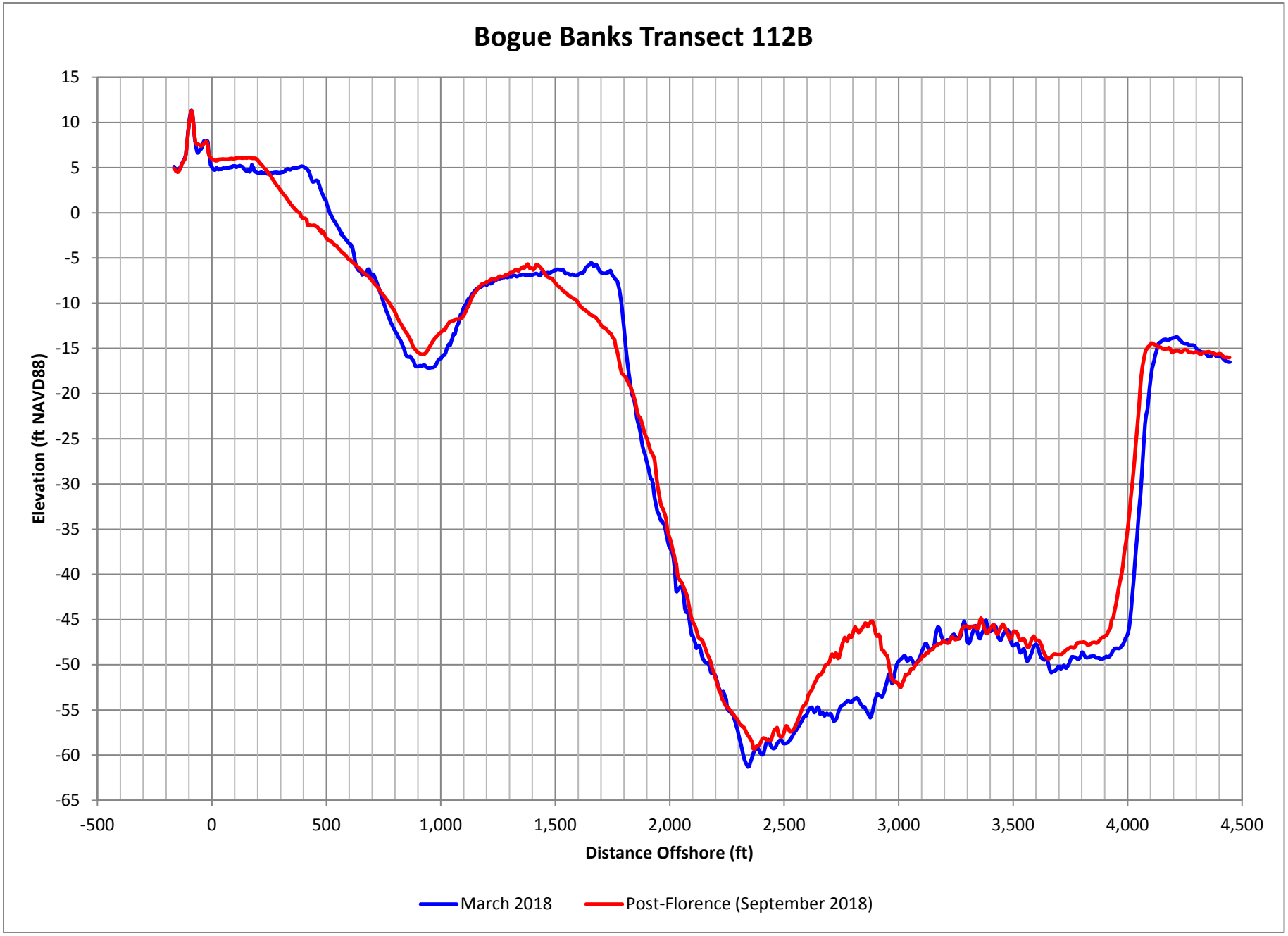

Figure D-226. Bogue Banks Profile Comparison Plot

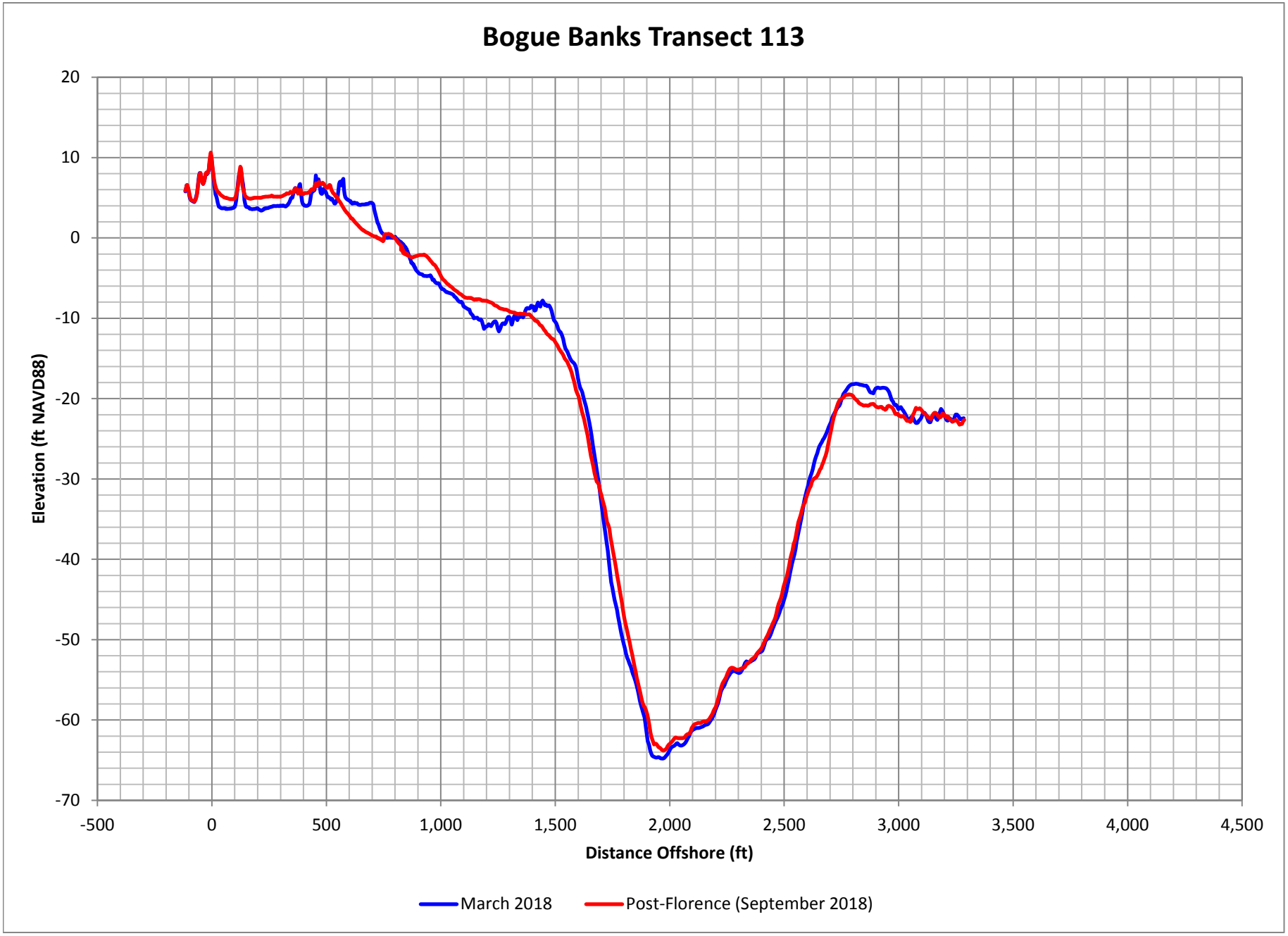

Figure D-227. Bogue Banks Profile Comparison Plot

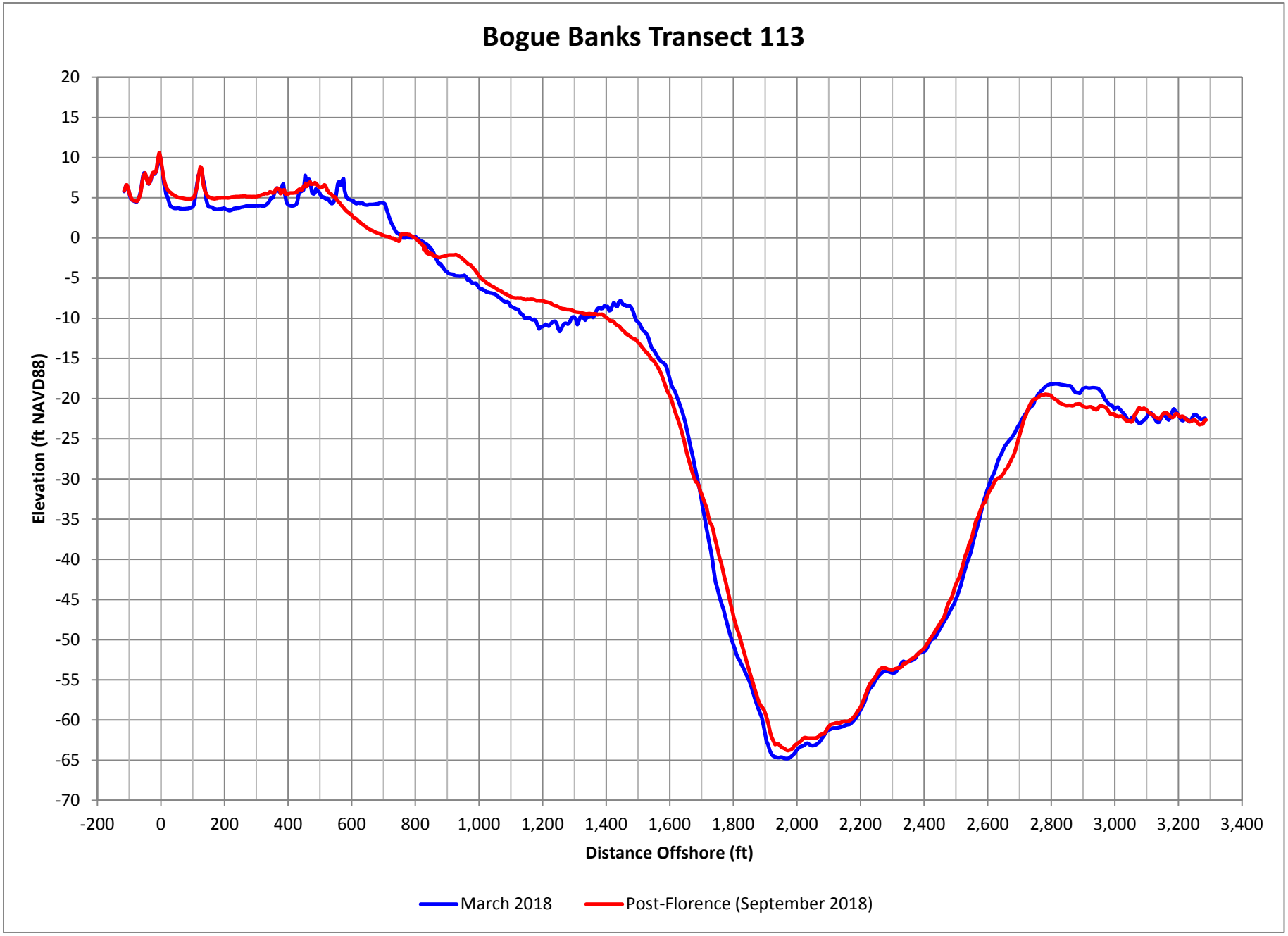

Figure D-228. Bogue Banks Profile Comparison Plot

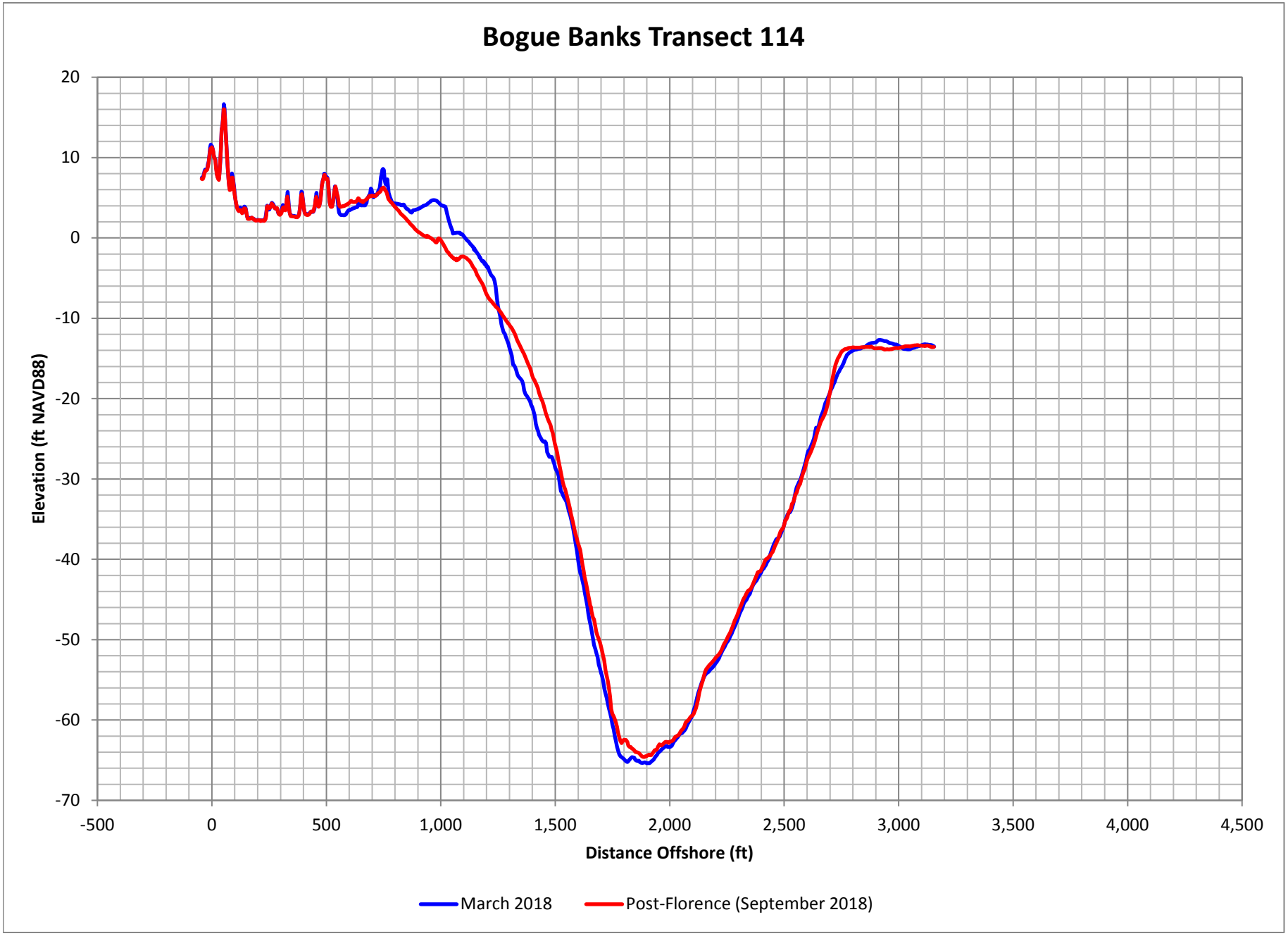

Figure D-229. Bogue Banks Profile Comparison Plot

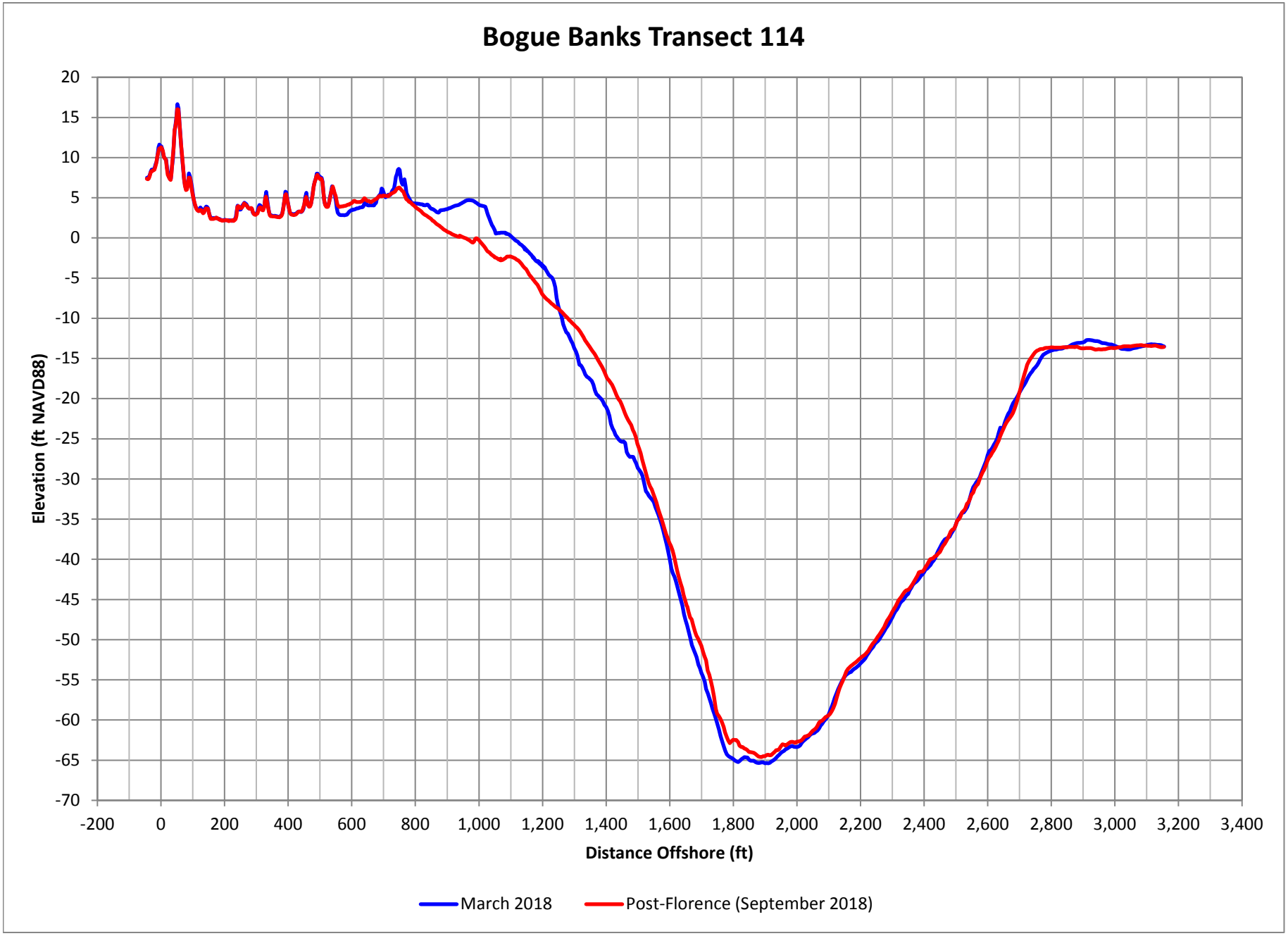

Figure D-230. Bogue Banks Profile Comparison Plot

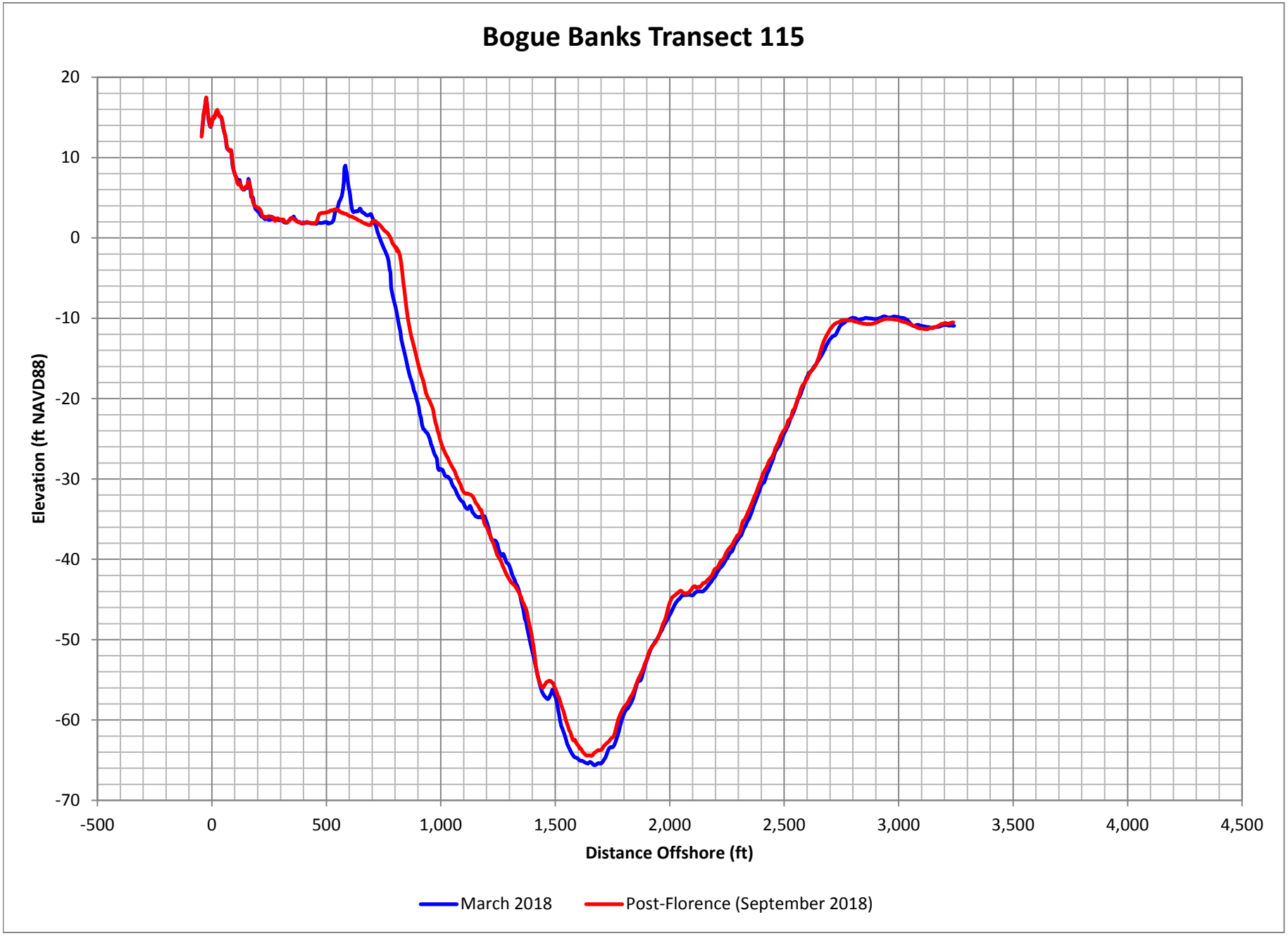

Figure D-231. Bogue Banks Profile Comparison Plot

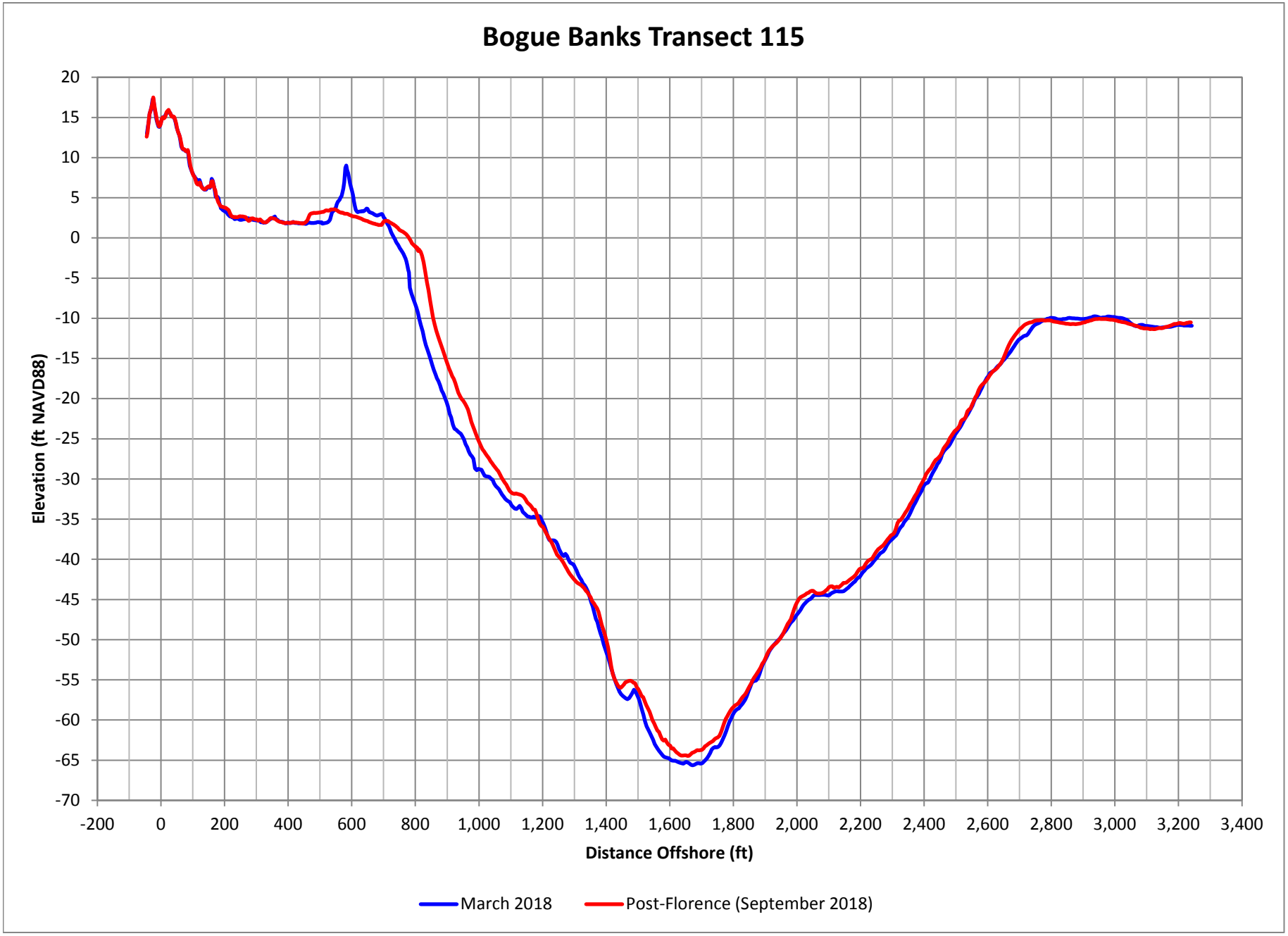

Figure D-232. Bogue Banks Profile Comparison Plot

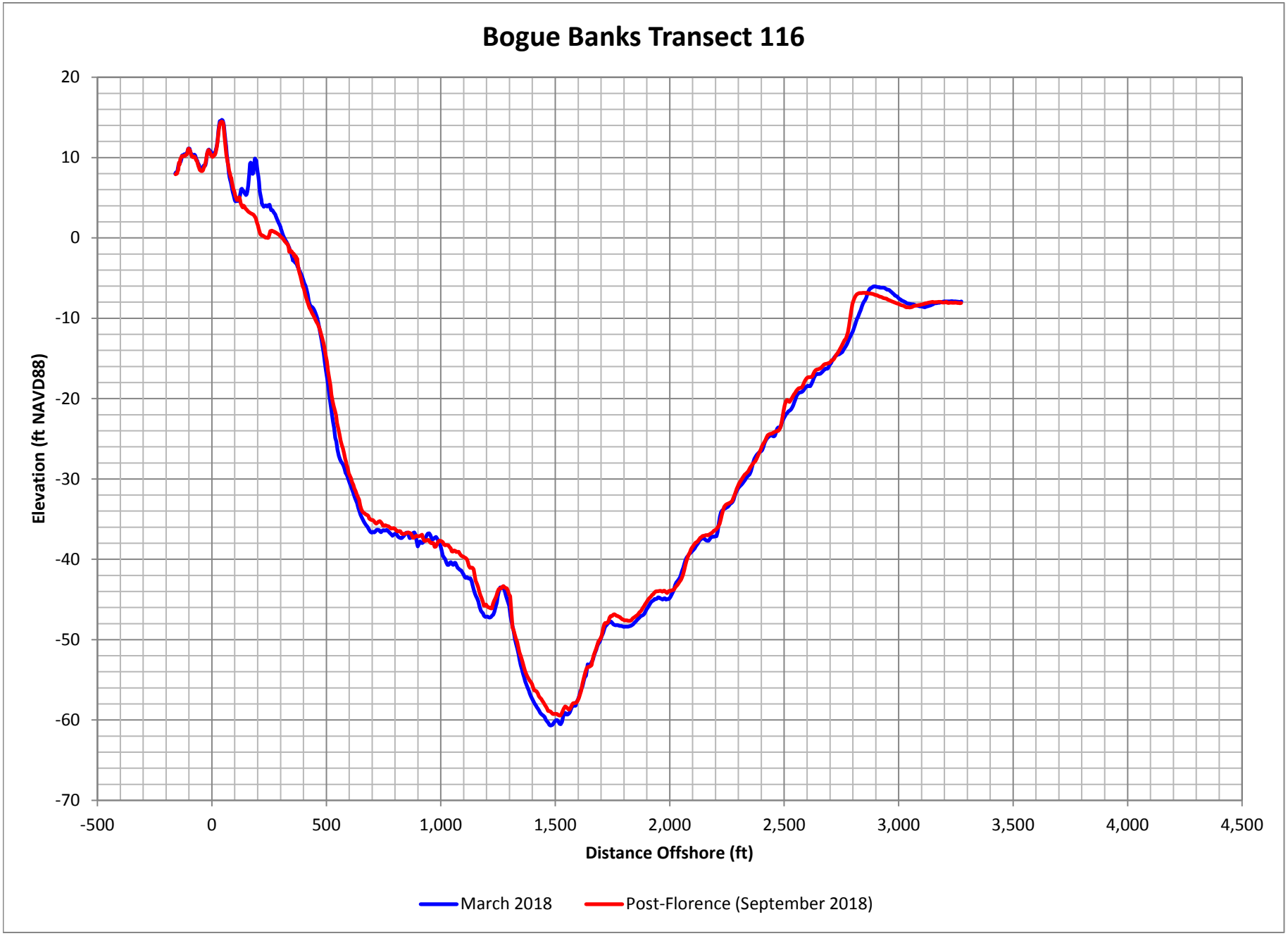

Figure D-233. Bogue Banks Profile Comparison Plot

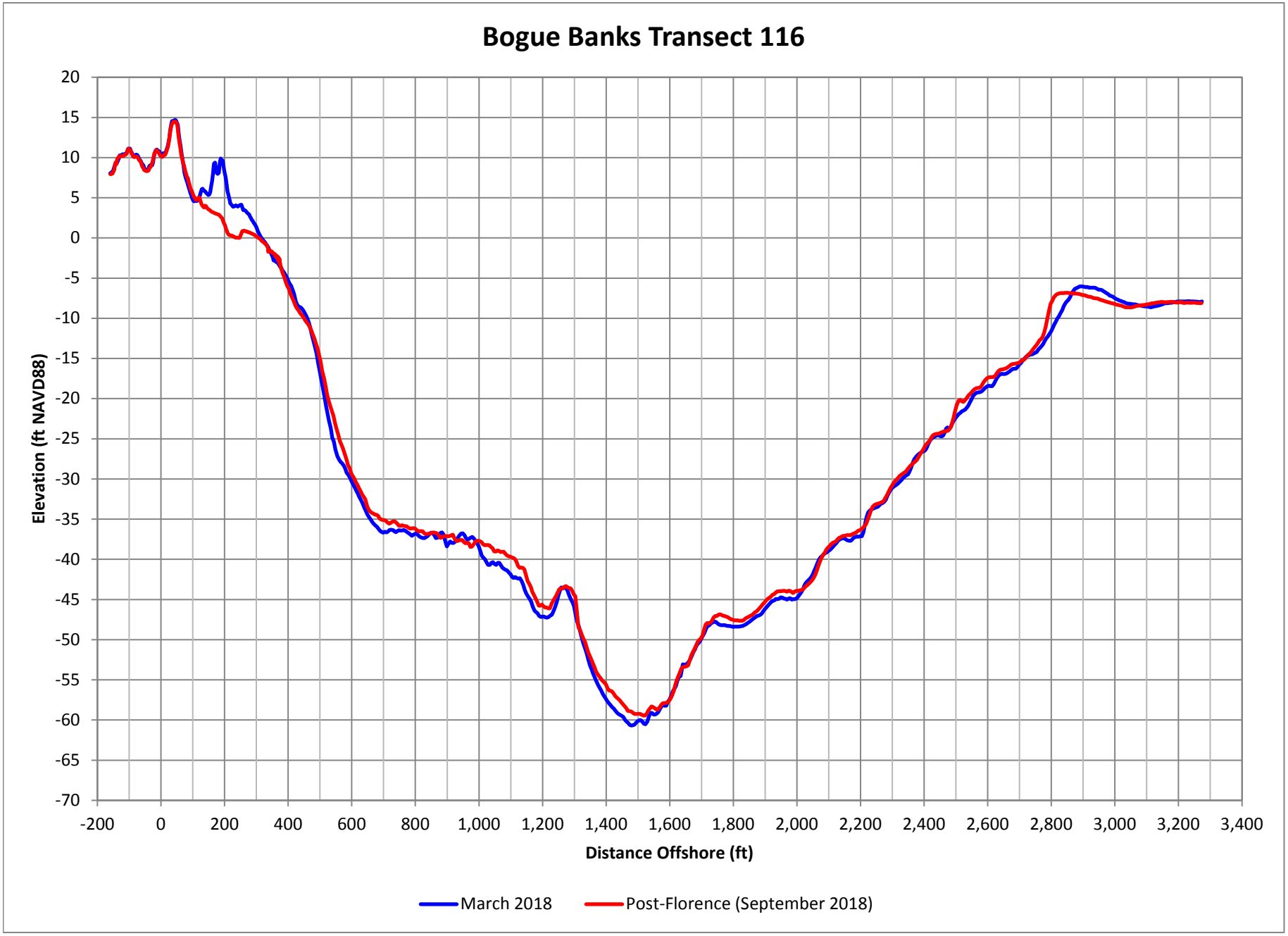

Figure D-234. Bogue Banks Profile Comparison Plot

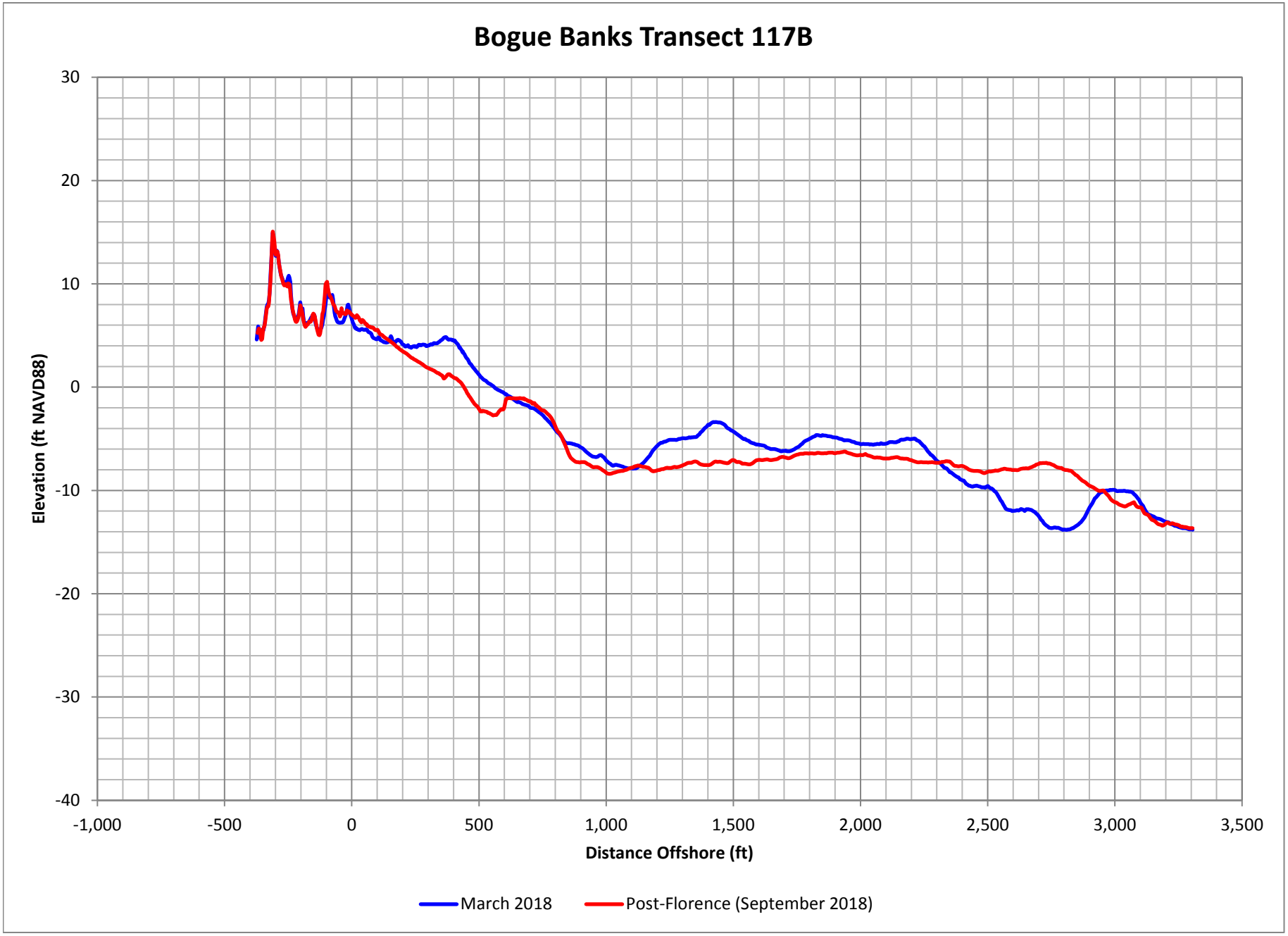

Figure D-235. Bogue Banks Profile Comparison Plot

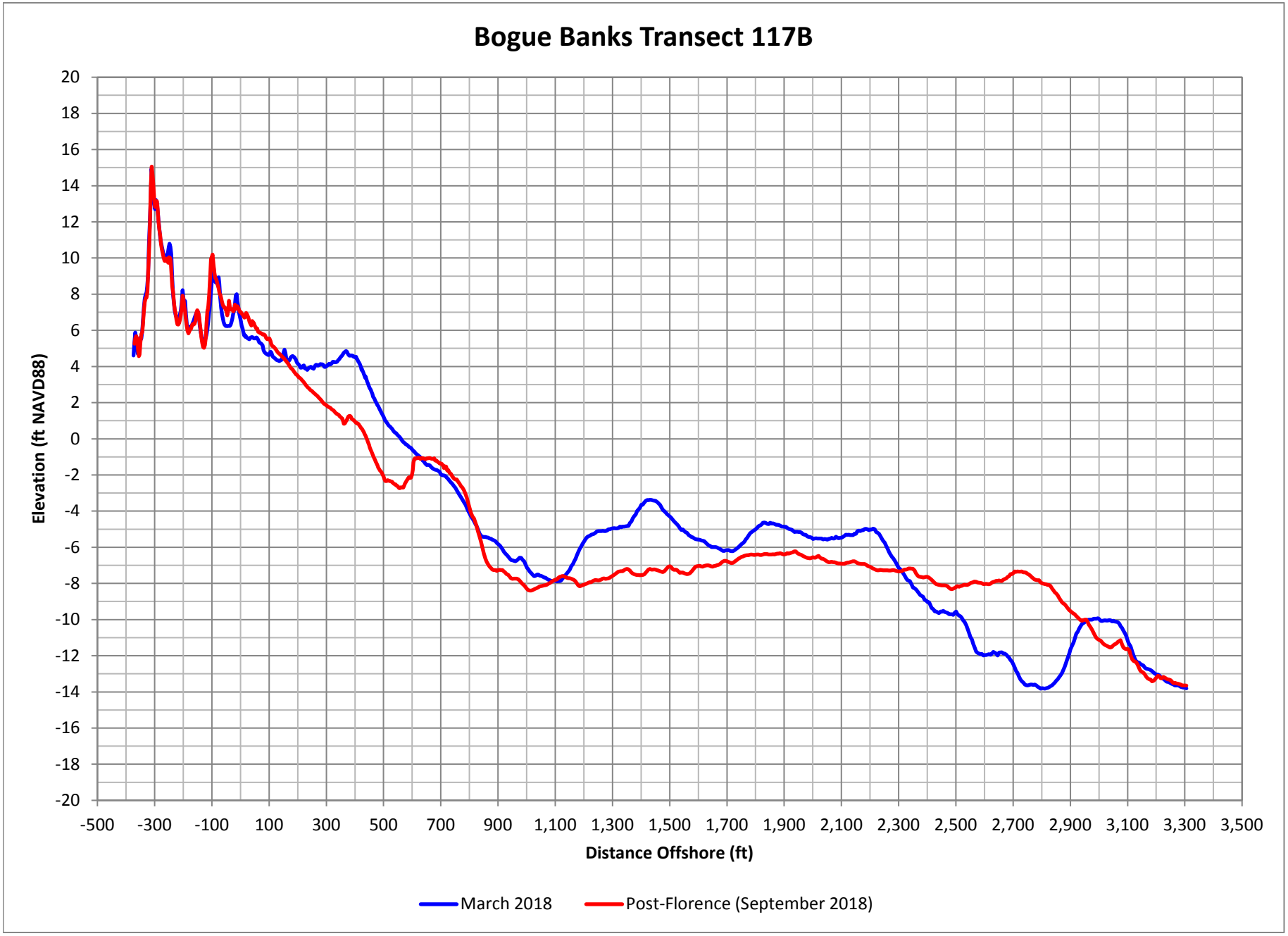

Figure D-236. Bogue Banks Profile Comparison Plot

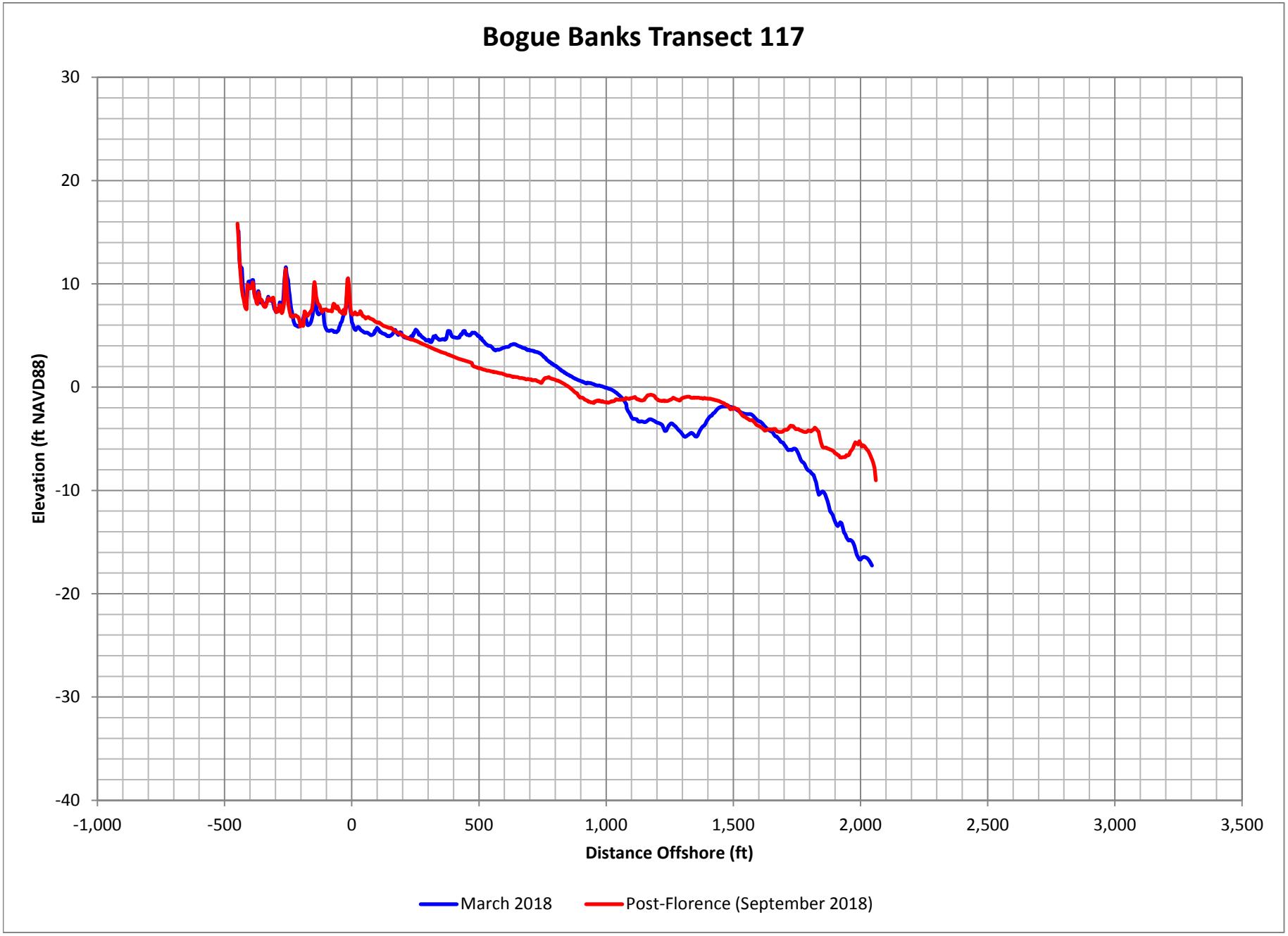

Figure D-237. Bogue Banks Profile Comparison Plot

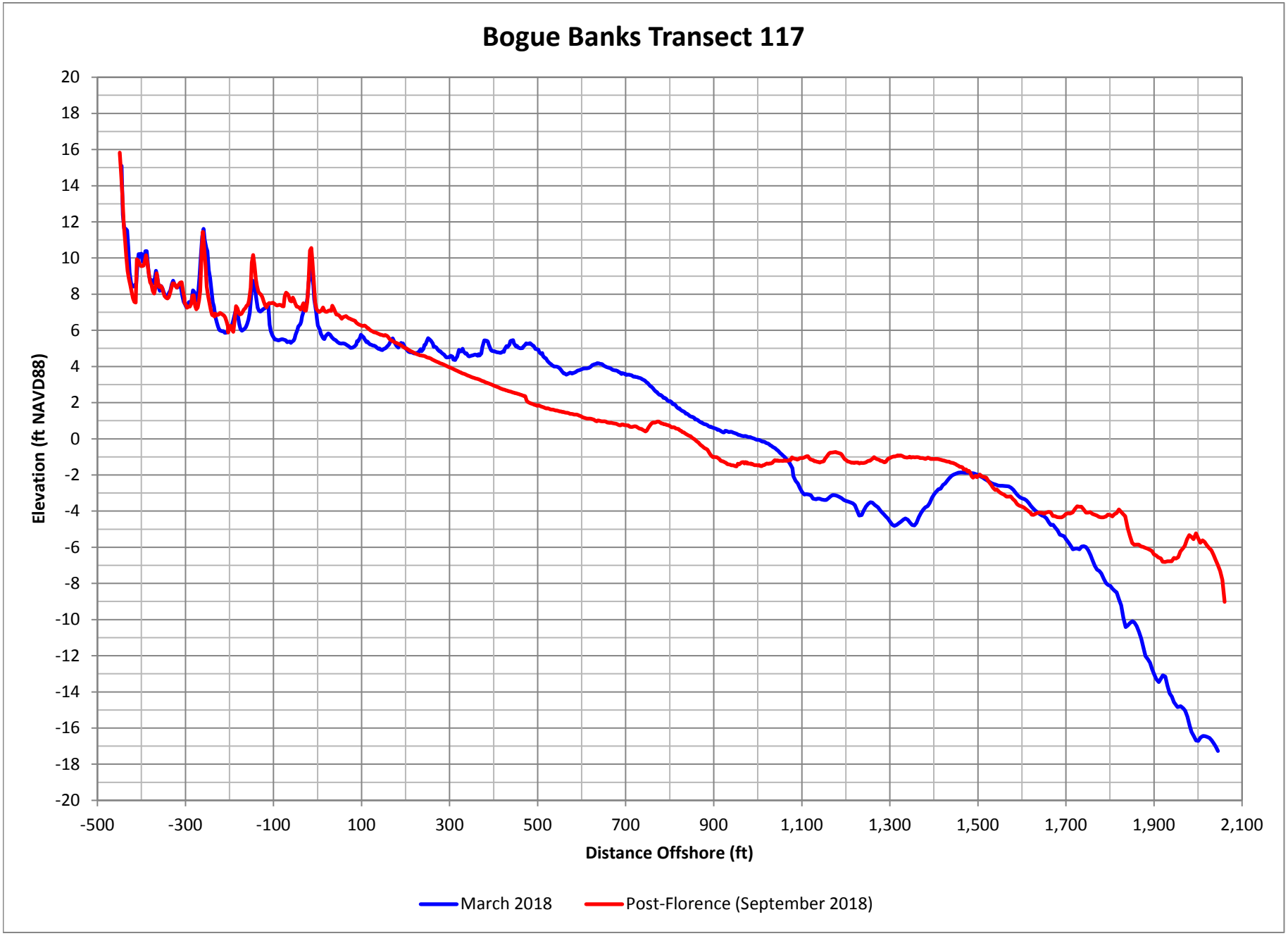

Figure D-238. Bogue Banks Profile Comparison Plot

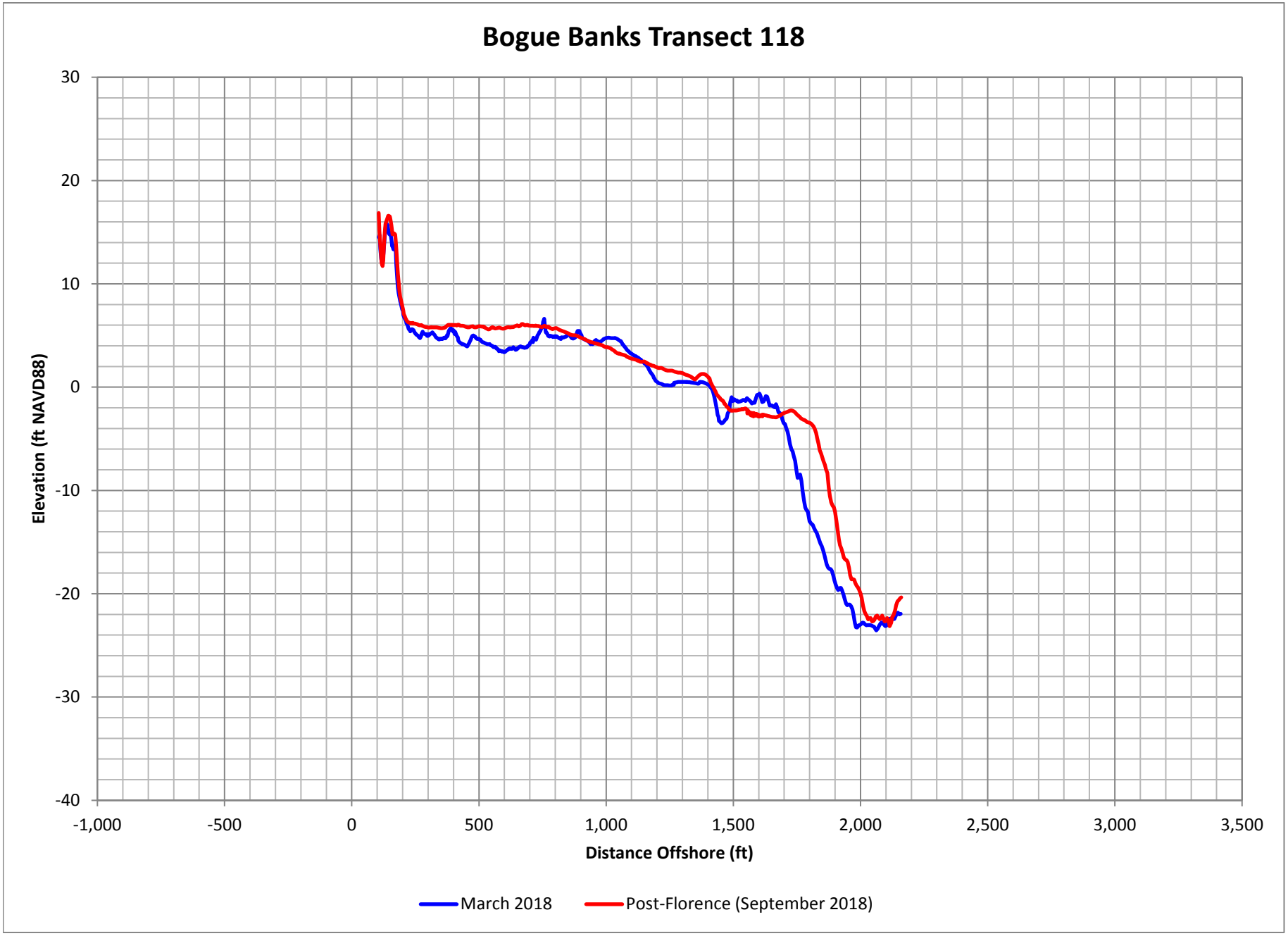

Figure D-239. Bogue Banks Profile Comparison Plot

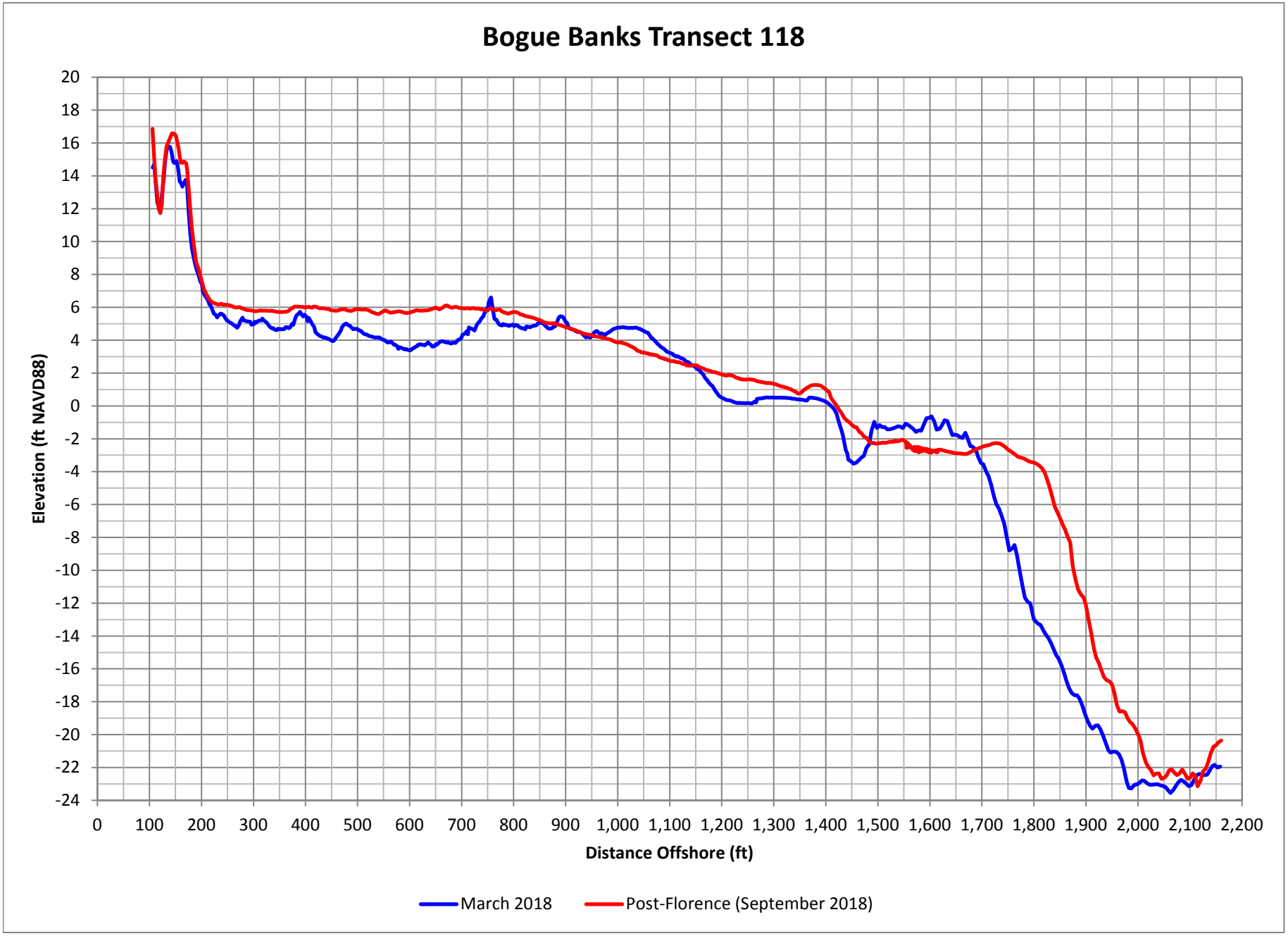

Figure D-240. Bogue Banks Profile Comparison Plot

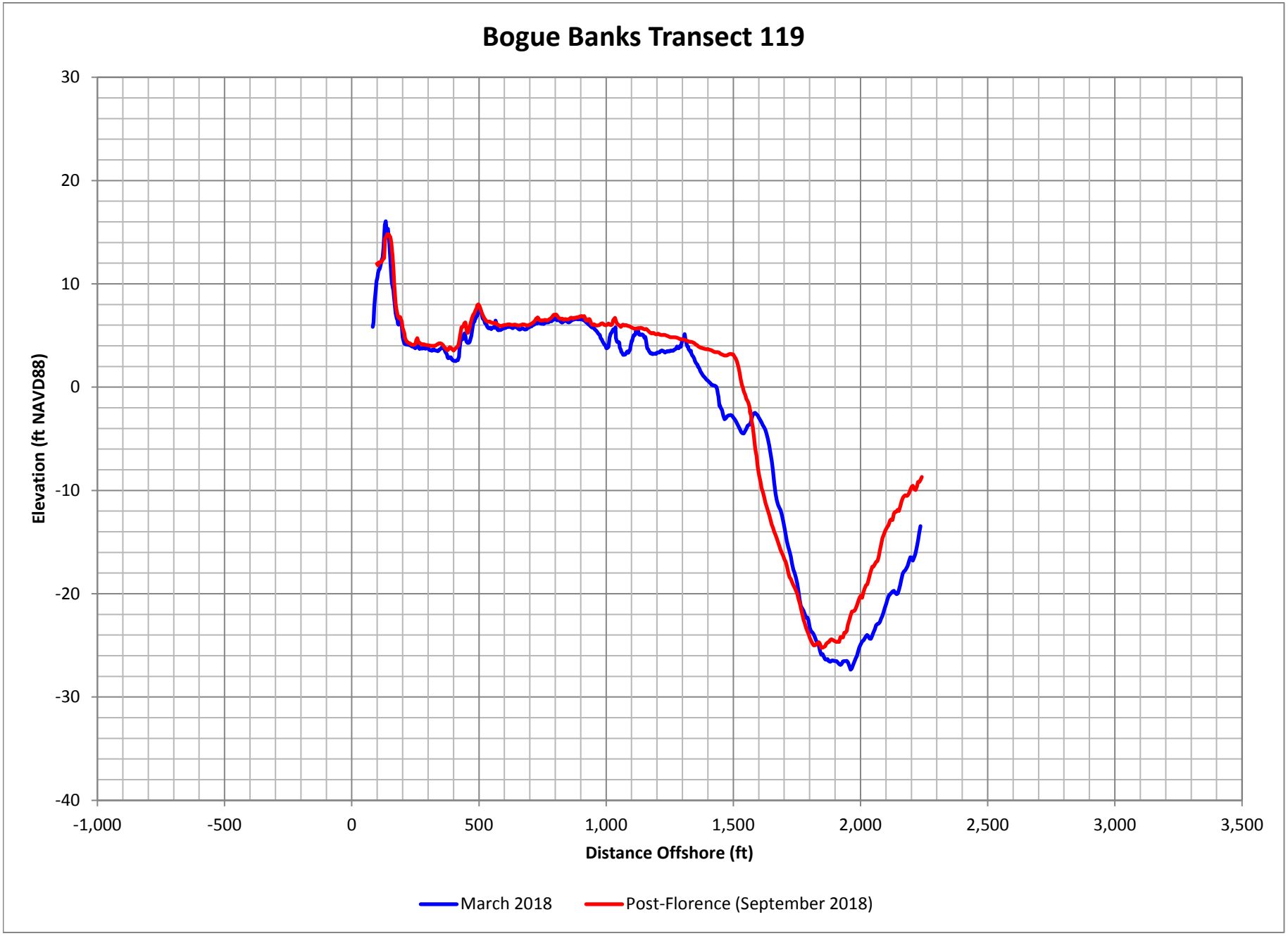

Figure D-241. Bogue Banks Profile Comparison Plot

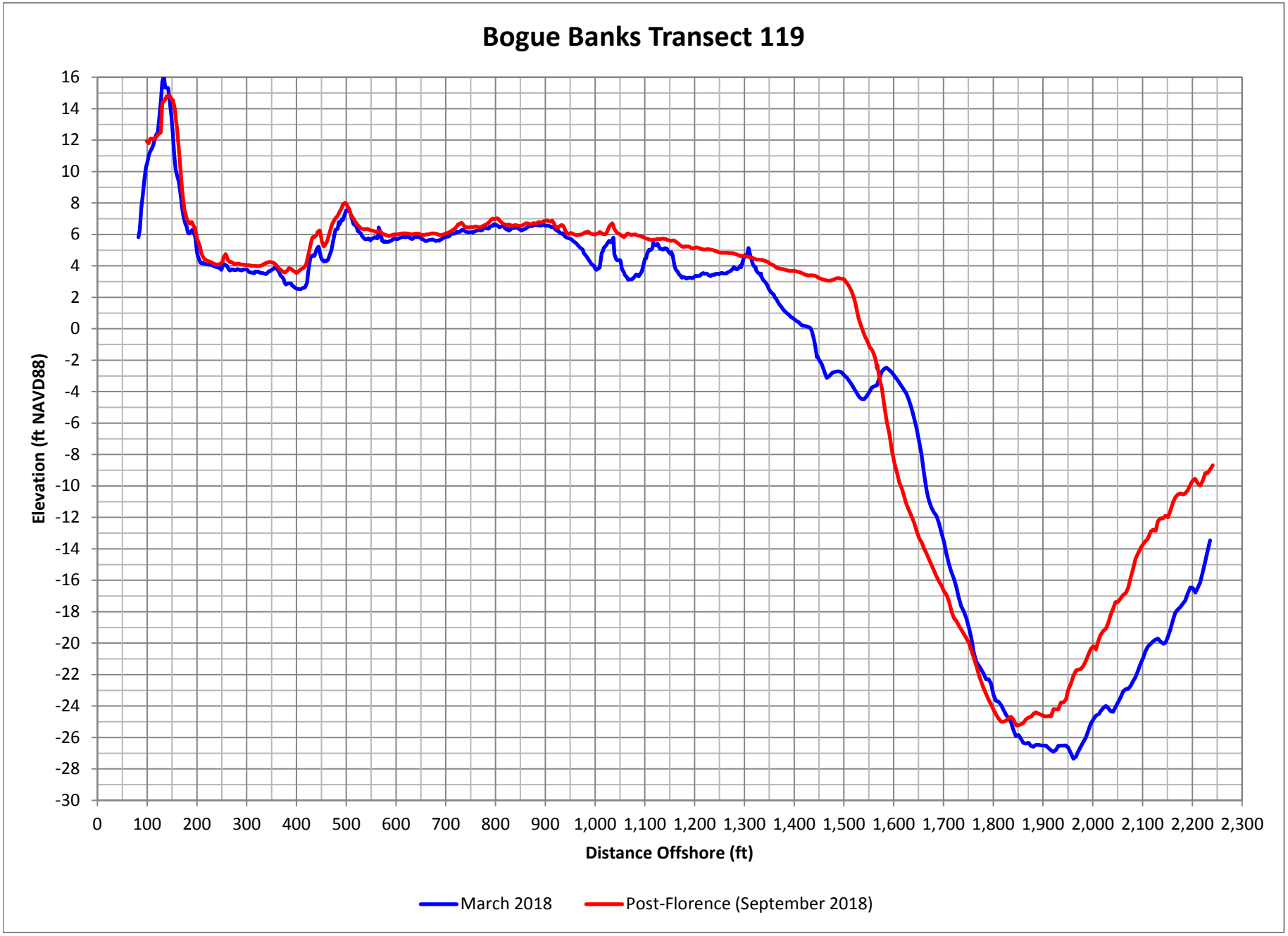

Figure D-242. Bogue Banks Profile Comparison Plot

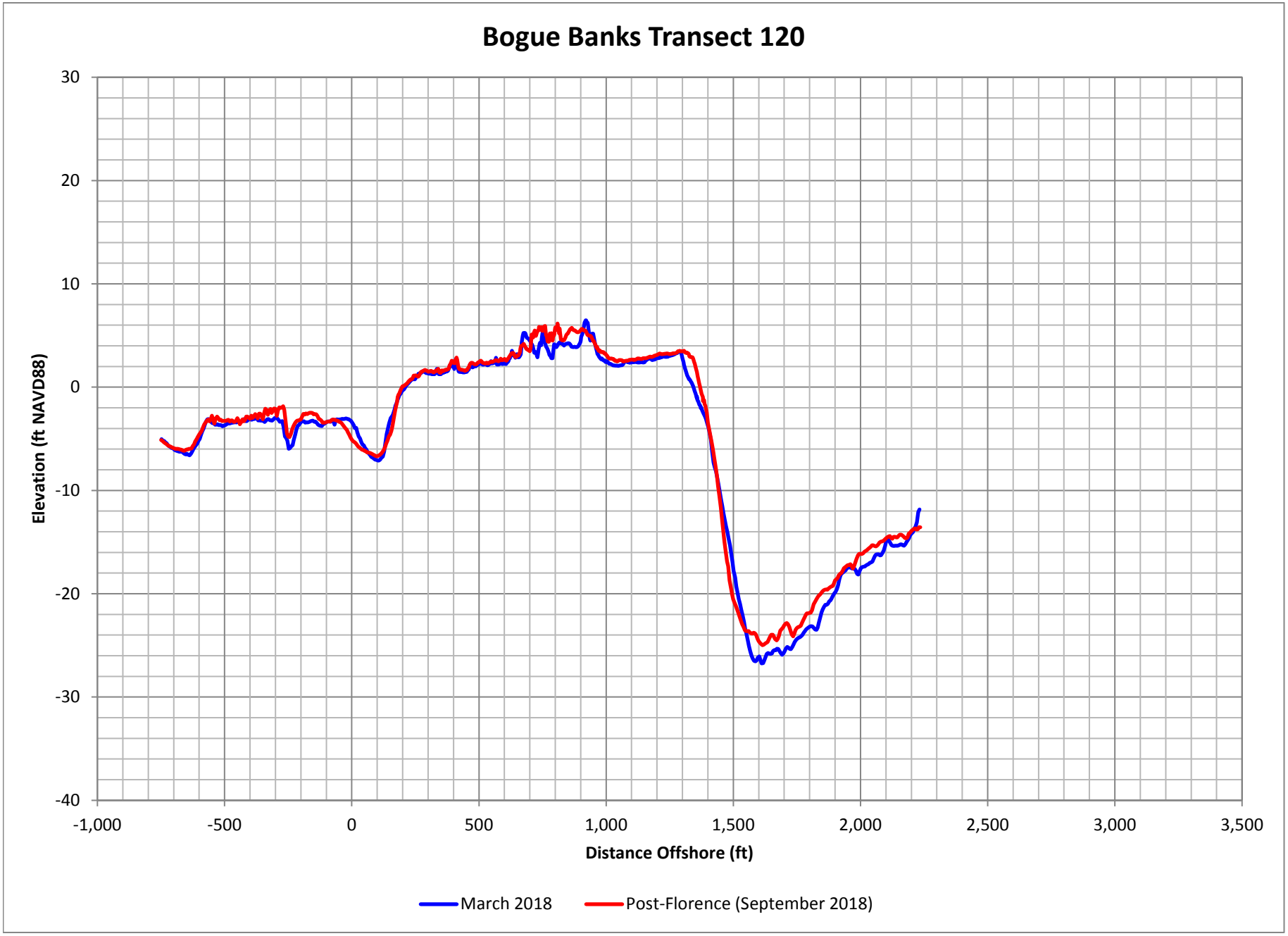

Figure D-243. Bogue Banks Profile Comparison Plot

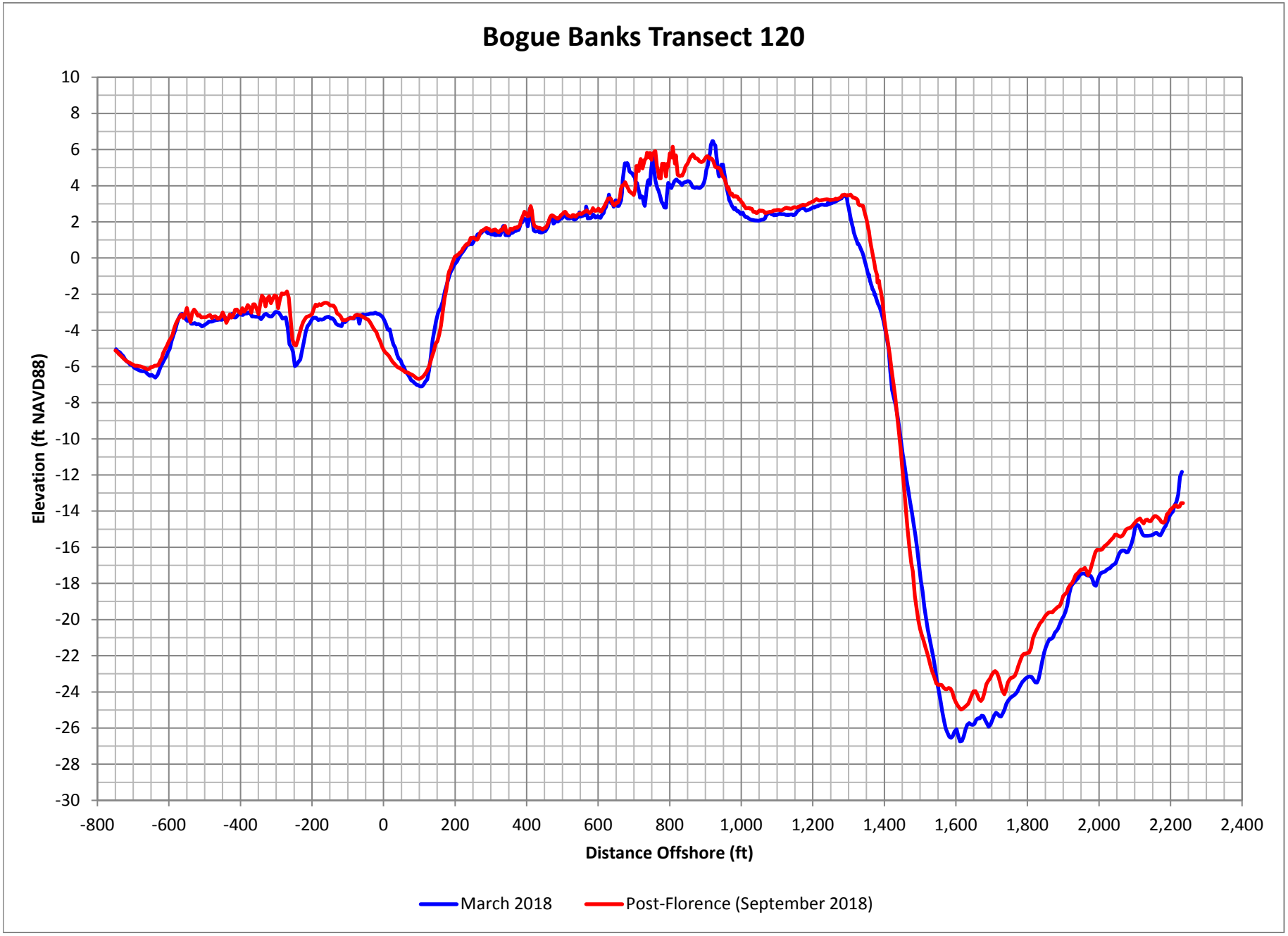

Figure D-244. Bogue Banks Profile Comparison Plot

APPENDIX E

Results Tables

Table E-1. Summary of Shoreline Change and Volume Change Along Bogue Banks (March 2018 to September 2018)

Reach	Transect Number	Station	Shoreline Change @ MHW +1.5 ft NAVD	Above MHW +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
				Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)
Bogue Inlet-Ocean/ Emerald Isle West	1	0+00	-63.96	94.78	-8.68	276.41	-16.18	644.99	35.27	1361.11	55.50	2690.31	68.45
	2	5+59	-114.60	99.76	-8.87	279.74	-10.07	595.98	27.64	1250.79	69.88	2499.12	84.78
	3	11+23	-123.15	23.80	-30.72	104.30	-48.99	297.77	-44.04	809.96	-4.85	1829.20	4.46
	4	17+39	-65.88	22.08	-16.93	114.04	-16.22	307.64	-11.10	781.89	29.55	1728.95	43.80
	5	23+22	-60.00	31.43	-35.74	116.86	-42.73	295.90	-49.69	744.29	6.05	1637.83	24.15
	6	36+28	-72.15	40.50	-35.23	119.23	-39.75	287.73	-44.94	691.75	-0.10	1504.69	25.02
	7	53+10	-20.23	46.01	-24.12	132.53	-24.53	303.23	-32.39	677.12	-8.01	1428.07	27.09
	8	67+74	-33.32	48.11	-20.63	126.64	-28.56	295.85	-46.88	686.14	-5.46	1408.40	34.70
	9	80+91	-11.91	38.00	-18.79	124.23	-16.69	280.45	-32.29	637.97	-15.30	1341.90	26.52
	10	93+40	-17.02	28.96	-24.84	96.45	-32.26	241.34	-53.90	592.19	-37.80	1271.89	-2.31
	11	108+58	-50.80	25.64	-22.64	100.02	-26.82	251.71	-44.17	564.62	-63.87	1237.89	-26.08
Emerald Isle West	12	121+18	-15.73	73.75	-16.46	150.47	-23.65	314.22	-43.11	679.71	-24.87	1368.50	18.82
	13	134+61	-31.43	41.31	-23.40	109.95	-27.09	266.22	-42.65	634.73	-13.64	1311.95	30.96
	14	146+67	6.62	40.72	-18.92	101.55	-27.16	248.80	-55.17	598.86	-41.47	1269.56	3.15
	15	160+16	-16.35	30.33	-23.77	91.98	-34.74	242.08	-54.32	593.71	-31.15	1256.22	16.15
	16	174+79	-40.57	36.31	-23.23	89.95	-46.72	244.45	-58.27	591.46	-40.66	1257.73	5.92
	17	189+23	0.84	58.52	-10.16	140.94	-13.40	318.93	-17.15	683.05	5.11	1368.50	57.32
	18	203+53	-70.19	48.22	-23.05	124.55	-37.18	288.68	-67.58	638.82	-61.80	1326.86	-7.81
	19	214+90	-16.05	37.52	-24.48	101.75	-30.40	257.57	-44.88	573.56	-57.66	1249.64	-7.52
	20	230+02	-48.63	74.99	-19.18	155.26	-28.18	325.64	-34.17	644.10	-61.52	1345.98	-9.75
	21	241+15	-48.66	45.68	-19.11	115.88	-30.87	281.74	-37.37	602.15	-57.73	1297.82	-6.43
	22	252+19	-62.15	46.38	-26.23	114.64	-35.27	276.21	-37.10	617.15	-37.45	1314.96	8.70
	23	263+24	-25.28	24.49	-20.93	77.63	-32.59	230.61	-34.48	568.51	-29.17	1250.87	16.98
	24	279+57	-2.98	88.62	-19.02	168.67	-16.50	347.20	-17.50	688.91	-32.78	1399.36	9.42
	25	290+77	-0.48	46.66	-15.40	120.31	-17.67	293.91	-20.17	633.75	-28.40	1337.24	20.63

NOTES:

1. Positive changes indicate accretion or gain in volume along the profile and negative changes indicate erosion or loss of volume along the profile.
2. Shoreline Change and Volume Change is calculated for the period between surveys from March 23, 2018 to September 26, 2018.

Table E-1. Summary of Shoreline Change and Volume Change Along Bogue Banks (March 2018 to September 2018) Cont.

Reach	Transect Number	Station	Shoreline Change @ MHW +1.5 ft NAVD	Above MHW +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
				Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)
Emerald Isle Central	26	304+77	-1.67	60.18	-16.91	130.83	-17.42	302.54	-24.59	669.82	-14.23	1380.77	35.42
	27	318+11	-53.26	60.06	-20.71	135.71	-23.90	310.56	-23.01	665.18	-30.35	1373.93	18.23
	28	329+10	-47.92	54.83	-20.69	131.64	-18.12	298.47	-27.46	644.94	-37.80	1341.50	3.45
	29	345+80	-17.66	32.37	-15.01	93.24	-21.37	250.43	-37.74	608.98	-28.06	1296.85	9.41
	30	362+22	-41.67	54.59	-20.76	125.72	-22.70	289.04	-37.11	652.67	-33.27	1349.25	4.53
	31	378+80	-51.89	35.49	-25.46	106.75	-17.34	258.31	-30.99	559.48	-77.78	1243.16	-44.45
	32	395+22	-35.00	58.35	-28.16	122.78	-41.57	281.92	-48.97	636.31	-49.05	1329.60	-4.00
	33	408+86	-60.52	54.44	-24.83	122.66	-36.78	279.32	-46.32	632.41	-44.32	1324.41	1.86
	34	422+83	-47.69	40.37	-18.46	109.86	-23.13	267.18	-31.42	609.22	-34.30	1298.68	15.35
	35	435+62	-8.77	25.83	-18.83	83.44	-22.04	221.46	-47.38	544.80	-51.70	1218.96	-12.36
	36	450+22	-13.71	33.45	-18.87	96.99	-14.43	241.17	-29.01	556.45	-50.30	1241.52	-7.72
Emerald Isle East	37	461+34	-17.06	18.15	-15.90	71.60	-16.37	212.90	-32.30	552.76	-20.80	1221.11	23.21
	38	472+44	-29.37	31.31	-23.02	87.44	-33.92	232.59	-48.25	572.13	-52.08	1250.91	-14.47
	39	483+48	-45.54	37.54	-21.27	97.59	-23.56	239.25	-55.00	588.09	-53.54	1282.49	-18.43
	40	494+44	-51.33	22.78	-21.91	76.07	-28.54	222.49	-41.67	554.02	-44.51	1219.48	-6.80
	41	505+39	-49.79	31.69	-24.21	89.59	-38.55	238.92	-54.82	574.37	-67.32	1259.10	-28.00
	42	516+57	-40.07	10.67	-16.67	66.52	-9.06	203.00	-19.33	508.09	-38.70	1167.89	3.77
	43	527+37	7.33	20.71	-16.11	83.75	-8.15	232.29	-20.08	559.02	-28.32	1230.77	12.20
	44	538+39	-14.61	44.77	-18.29	116.15	-15.02	273.63	-25.61	595.19	-57.16	1276.20	-23.27
	45	549+45	-42.97	39.87	-16.17	110.59	-21.66	270.92	-23.55	601.77	-43.65	1283.17	-9.65
	46	560+42	-15.11	41.90	-17.93	104.10	-29.99	259.01	-34.80	599.75	-44.38	1281.17	-12.25
	47	571+43	-17.68	36.27	-19.72	104.29	-19.97	260.65	-25.49	587.16	-46.04	1266.20	-14.09
	48	580+13	-17.28	30.66	-19.60	96.28	-22.67	244.75	-45.95	611.14	-30.61	1293.76	-0.32

NOTES:

1. Positive changes indicate accretion or gain in volume along the profile and negative changes indicate erosion or loss of volume along the profile.
2. Shoreline Change and Volume Change is calculated for the period between surveys from March 23, 2018 to September 26, 2018.

Table E-1. Summary of Shoreline Change and Volume Change Along Bogue Banks (March 2018 to September 2018) Cont.

Reach	Transect Number	Station	Shoreline Change @ MHW +1.5 ft NAVD	Above MHW +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
				Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)
Indian Beach/Salter Path	49	595+84	-20.91	36.38	-23.69	108.86	-19.48	257.52	-41.92	597.42	-53.09	1286.06	-23.46
	50	608+06	2.31	53.73	-20.94	124.61	-24.94	280.08	-37.58	617.34	-57.26	1318.06	-26.06
	51	620+90	-23.31	36.82	-18.05	107.79	-6.11	251.28	-17.46	596.42	-10.29	1282.39	16.19
	52	633+31	-35.92	6.52	-20.45	62.80	-17.37	191.89	-28.60	504.27	-41.43	1173.81	-9.99
	53	648+17	-51.30	67.54	-18.77	143.77	-31.06	302.71	-45.63	671.21	-40.55	1389.98	-15.25
	54	660+65	-9.60	97.48	-19.46	185.34	-30.69	356.61	-44.83	741.15	-44.51	1482.59	-16.30
	55	672+30	-9.42	38.57	-15.25	100.75	-17.51	251.05	-22.06	602.27	-15.16	1304.26	10.49
	56	683+24	-21.85	28.84	-14.87	104.52	-5.56	240.64	-24.79	577.65	-32.02	1280.14	0.06
	57	693+79	-30.76	35.84	-22.04	104.84	-14.67	242.90	-40.23	578.02	-55.35	1273.59	-36.28
	58	709+05	-44.23	32.84	-19.12	93.65	-23.35	236.85	-38.61	601.61	-19.64	1301.60	2.14
Pine Knoll Shores	59	723+93	-20.53	28.08	-19.01	87.27	-24.34	231.84	-31.65	583.11	-30.02	1279.51	-18.15
	60	736+01	25.01	21.15	-11.65	87.18	-8.57	221.93	-29.67	564.76	-27.44	1272.01	-2.16
	61	748+06	21.78	36.99	-10.97	109.20	-7.10	254.28	-31.28	619.50	-26.00	1343.60	-15.87
	62	761+80	-7.27	23.55	-20.69	87.41	-15.33	230.53	-25.58	589.05	-21.02	1305.37	-9.91
	63	774+77	-44.08	29.07	-16.74	96.29	-5.19	233.22	-20.76	589.14	-17.43	1311.84	-2.12
	64	787+61	-44.14	34.01	-19.98	97.15	-27.20	247.61	-36.06	608.54	-32.25	1336.56	-14.45
	65	800+91	18.73	34.89	-12.57	98.00	-12.33	246.30	-24.08	599.24	-25.20	1334.48	-7.12
	66	813+33	32.99	28.95	-8.09	84.97	-12.04	227.72	-23.58	588.00	-13.39	1320.78	6.79
	67	825+53	-23.58	22.06	-5.34	76.65	5.61	219.32	-0.49	556.95	-0.92	1283.18	17.43
	68	840+55	-34.22	30.74	-19.27	97.58	-9.28	245.80	-10.81	588.48	-28.74	1320.56	-24.00
	69	850+84	-8.53	29.84	-26.79	94.49	-22.20	244.30	-27.68	602.14	-27.99	1350.11	-7.55
	70	863+28	20.32	31.63	-18.92	92.01	-23.50	239.57	-35.39	613.35	-27.27	1366.91	-12.36
	71	882+23	36.78	20.51	-10.41	73.86	-14.02	224.97	-21.60	604.55	-0.70	1352.40	16.16
	72	896+24	37.38	24.77	-9.80	79.87	-9.24	226.91	-18.19	608.51	-7.62	1370.91	7.88
	73	910+53	14.78	26.74	-16.41	82.62	-20.66	228.33	-38.87	608.72	-31.37	1377.58	-9.32
	74	922+70	7.33	38.95	-10.83	101.27	-13.63	253.36	-16.67	636.77	-7.47	1428.87	26.38
	75	937+70	13.59	39.33	-14.95	106.02	-16.03	266.32	-23.74	649.14	-25.15	1434.83	-9.41
	76	948+81	44.86	29.45	-12.33	100.34	-3.63	250.80	-17.75	618.04	-25.42	1395.89	-9.81

NOTES:

1. Positive changes indicate accretion or gain in volume along the profile and negative changes indicate erosion or loss of volume along the profile.
2. Shoreline Change and Volume Change is calculated for the period between surveys from March 23, 2018 to September 26, 2018.

Table E-1. Summary of Shoreline Change and Volume Change Along Bogue Banks (March 2018 to September 2018) Cont.

Reach	Transect Number	Station	Shoreline Change @ MHW +1.5 ft NAVD	Above MHW +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
				Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)
Atlantic Beach	77	961+72	-23.19	42.39	-12.21	107.03	-12.15	263.67	-23.38	654.57	-15.62	1445.11	4.29
	78	971+20	-27.36	30.46	-13.95	92.10	-11.26	247.98	-12.78	636.58	0.47	1428.36	34.58
	79	985+64	-31.80	28.93	-13.61	86.73	-14.35	245.04	-8.31	627.22	-1.66	1416.70	20.51
	80	994+64	-15.52	49.12	-11.20	124.66	-10.42	299.76	-14.67	711.33	8.45	1526.02	40.96
	81	1005+61	-56.08	35.87	-21.94	105.25	-25.66	271.11	-38.91	679.17	-23.63	1496.81	6.69
	82	1012+68	-45.17	18.38	-19.46	80.78	-20.27	235.32	-35.37	631.15	-20.14	1431.99	5.91
	83	1022+69	-43.17	13.48	-16.24	66.26	-15.17	221.77	-18.68	619.53	4.29	1413.99	28.26
	84	1032+70	20.74	13.68	-15.39	66.04	-16.71	214.38	-30.55	609.52	-10.05	1408.46	18.27
	85	1042+73	13.86	49.37	-7.18	121.56	-9.36	296.01	-9.21	720.08	13.40	1547.44	34.17
	86	1052+75	8.19	47.95	-11.15	129.99	-11.31	299.89	-5.55	727.74	15.23	1560.83	39.02
	87	1062+69	-34.28	50.19	-11.75	129.89	-11.73	304.55	-13.25	726.99	3.63	1569.55	29.89
	88	1072+62	-44.18	72.05	-18.01	170.39	-9.79	358.65	-17.16	796.87	-6.32	1662.97	17.29
	89	1082+69	-53.25	57.47	-16.97	134.35	-13.60	304.63	-22.92	723.77	-6.66	1558.88	14.71
	90	1093+69	31.39	45.56	-12.21	145.50	-0.67	330.60	-10.42	762.30	2.30	1606.97	16.92
	91	1102+82	18.63	48.50	-13.40	122.91	-16.67	291.23	-9.57	695.30	3.39	1522.25	29.00
	92	1112+81	-58.30	46.44	-13.86	135.24	-6.92	299.26	-22.71	702.35	-8.98	1516.45	7.20
	93	1122+81	0.84	52.24	-20.77	146.81	-22.40	311.41	-37.71	713.82	-26.90	1555.22	-9.78
	94	1131+73	-43.10	63.80	-7.19	190.74	-7.03	390.41	-21.16	815.39	-21.91	1691.99	-7.19
	95	1141+97	-81.37	54.12	-19.65	148.43	-24.78	334.26	-24.32	735.48	-17.17	1570.82	-0.68
	96	1151+92	6.81	57.34	-21.61	148.87	-5.60	334.31	-3.80	724.41	6.02	1541.77	24.29
	97	1161+91	9.89	85.46	-1.65	186.58	-17.20	393.24	-19.29	815.95	-4.01	1671.65	20.62
	98	1171+91	19.71	78.27	-4.63	180.19	-10.39	384.65	-13.16	796.89	3.09	1638.02	32.86
	99	1182+17	4.05	68.96	-4.29	183.96	9.98	384.99	4.72	792.64	14.27	1656.27	44.59
	100	1191+90	-47.61	139.04	-7.43	286.59	-8.75	534.12	-11.32	984.19	-8.97	1969.04	43.66
	101	1201+93	-43.32	86.36	-19.27	195.42	-19.24	392.89	-22.33	768.25	-21.52	1706.82	11.60
	102	1211+94	-30.31	112.81	-10.83	224.12	-2.09	422.62	-1.46	796.15	10.06	1796.40	45.81

NOTES:

1. Positive changes indicate accretion or gain in volume along the profile and negative changes indicate erosion or loss of volume along the profile.
2. Shoreline Change and Volume Change is calculated for the period between surveys from March 23, 2018 to September 26, 2018.

Table E-1. Summary of Shoreline Change and Volume Change Along Bogue Banks (March 2018 to September 2018) Cont.

Reach	Transect Number	Station	Shoreline Change @ MHW +1.5 ft NAVD	Above MHW +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
				Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)	Sept 2018 Measured Volume (cy/ft)	Mar 2018 - Sept 2018 Volume Change (cy/ft)
Fort Macon	103	1222+11	-39.03	42.36	-16.91	115.67	-10.77	275.33	-1.58	615.69	9.25	1728.78	35.58
	104	1231+86	-34.14	54.15	-16.75	137.36	-12.88	308.98	-3.94	687.22	12.23	1918.79	64.54
	105	1241+79	3.51	63.08	-10.49	149.79	-3.75	332.65	22.21	762.83	46.37	1994.47	57.96
	106	1251+79	41.22	71.34	-7.45	159.09	5.88	336.05	18.29	843.23	24.84	2105.93	25.96
	107	1257+09	32.09	112.52	-5.22	224.37	-0.25	427.75	17.92	1111.35	79.95	2380.95	80.62
	108	1261+80	28.32	73.67	-4.09	168.08	-2.49	367.26	19.32	1068.19	125.64	2283.96	125.82
	109	1267+13	-0.53	106.71	0.49	230.22	3.56	456.41	22.95	1300.92	184.98	2600.85	184.43
	110	1271+73	-14.05	109.38	-4.28	233.63	-2.26	540.65	82.61	1394.13	127.84	2663.63	127.61
	111	1278+93	-54.63	76.86	-5.06	190.89	-7.36	411.77	-7.16	1376.96	33.09	2485.86	33.58
	112	1283+93	-90.67	59.84	-12.88	176.16	-17.72	358.23	-43.25	1485.50	-135.00	2774.94	-135.70
Beaufort Inlet	112B	0+00	-165.92	63.93	-11.91	195.25	-36.54	490.70	-75.78	1025.99	-66.85	1761.36	-60.21
	113	5+00	-88.98	102.69	4.66	321.04	8.80	656.32	19.67	1130.90	11.53	1757.59	5.17
	114	10+00	-166.54	84.76	-18.52	322.73	-44.56	631.40	-47.06	1026.30	-30.02	1559.27	-13.81
	115	15+00	22.19	90.47	-6.82	289.65	4.37	516.30	16.49	791.69	30.33	1172.25	49.23
	116	20+00	-96.17	28.23	-20.52	98.75	-24.67	200.58	-27.26	339.06	-25.43	534.18	-19.51
Bogue Inlet	117B	0+00	-	-	-	-	-	-	-	-	-	-	-
	117	5+00	-	-	-	-	-	-	-	-	-	-	-
	118	10+00	-	-	-	-	-	-	-	-	-	-	-
	119	15+00	-	-	-	-	-	-	-	-	-	-	-
	120	20+00	-	-	-	-	-	-	-	-	-	-	-

NOTES:

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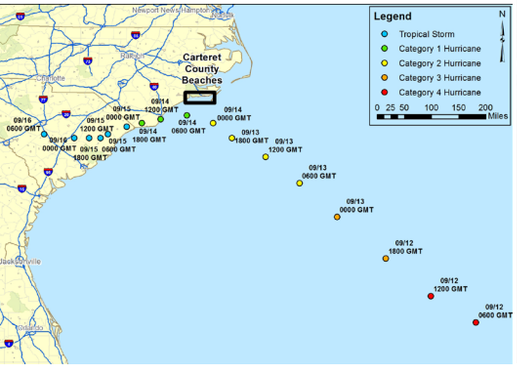

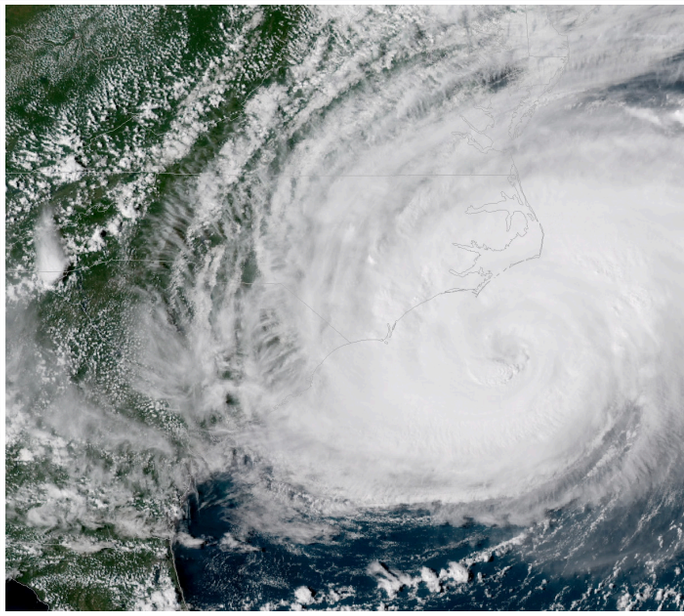

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