Bogue Banks Beach and Nearshore Mapping Program
Hurricane Irene Post-Storm Impact Evaluation

Final Report | September 2011

Shore protection office

moffatt & nichol

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 June 2011 by Geodynamics. Geodynamics conducted a post-storm survey between August 29 – September 2, 2011, immediately following the passage of Hurricane Irene. For this storm impact evaluation, the June 2011 survey was compared with the early September 2011 survey. The profile data have been used to compute shoreline change at MHW (+1.1 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 scarping or loss of the incipient dune, erosion just landward and seaward of the offshore bar, and partial capture of eroded material between the -20 ft NAVD88 and -30 ft NAVD88 contour, making it unavailable for storm protection. Key statistics were computed for defined regions along the Bogue Banks shoreline between the pre- and post-storm survey profiles including;

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Banks Oceanfront (1-112)	128,393	0.3	-4.5	-577,135	-7.8	-996,059	-15.2	-1,952,298	-19.6	-2,513,146	-5.3	-675,223
Bogue Banks County Project (9-76)	**88,094**	**0.8**	**-3.8**	**-338,030**	**-6.8**	**-602,668**	**-15.9**	**-1,403,361**	**-24.5**	**-2,160,042**	**-5.1**	**-448,393**

Based on these calculations, the Bogue Banks oceanfront, on average, experienced a small degree of shoreline accretion at MHW due to Hurricane Irene. Shoreline positions near the inlets in the Fort Macon and Bogue Inlet-Ocean regions showed the greatest amount and variability of change, as would be expected. Hurricane Irene caused a net loss of beach volume above all contours analyzed for the entire County Project area of the Bogue Banks oceanfront. Taking -12 ft NAVD88 as the practical offshore limit for material being available for storm protection and FEMA reimbursement, the volume loss to the County Project above -12 ft NAVD88 was approximately 1.40 million cubic yards (1,403,361 cy). **After subtracting the small portion of State owned shoreline within the Indian Beach/Salter Path reach, the official volume amount eligible for FEMA reimbursement is 1,344,123 cy.**

Reach (Profiles)	Volume Change (cy)	Volume Change Eligible for FEMA Reimbursement (cy)
Emerald Isle-West (9-25)	-579,219	-579,219
Emerald Isle-Central (26-36)	-216,386	-216,386
Emerald Isle-East (37-48)	-157,073	-157,073
Total Emerald Isle (9-48)	***-952,679***	***-952,679***
Indian Beach-Salter Path (49-58)	***-235,939***	***-176,701***
Pine Knoll Shores-West (59-65)	-102,188	-102,188
Pine Knoll Shores-East (66-76)	-112,555	-112,555
Total Pine Knoll Shores (59-76)	***-214,744***	***-214,744***
Overall Total	**-1,403,361**	**-1,344,123**

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.

Table of Contents

Appendices

List of Figures

List of Tables

List of Photos

1.0 Objective

Hurricane Irene made landfall at Cape Lookout, NC on August 27, 2011. All of the beaches overseen by the Carteret County Shore Protection Office fall within 30 miles of the hurricane's landfall point. 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 erosion of the incipient and primary frontal dunes with significant profile volume loss above -12 ft NAVD88. The federal government has declared Hurricane Irene as a federal disaster within Carteret County, and FEMA Category A through G public assistance was authorized on August 31, 2011. The objective of this report is to document field inspections and survey data collected immediately following Hurricane Irene 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 June 2011.

Federal Category G public assistance is intended to assist public authorities to repair or replace public infrastructure damaged or lost in a federally declared disaster within the authority's jurisdiction. A primary intent of this report is to supply the required pre- and post-storm beach cross-sections and supporting volume change calculations and engineering analysis for submittal to FEMA in requesting Category G public assistance for damages to the 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 2**).

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

The Carteret County Shore Protection Office oversees and coordinates the design, monitoring, and maintenance, including initial nourishment and planned renourishments, of a public "improved beach" project along 16.7 miles of Bogue Banks. The remaining portions (≈7.7 miles) of Bogue Banks (Atlantic Beach, Fort Macon, and the area immediately adjacent to Bogue Inlet) 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 were begun in 2002 (Phase I) and 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 (referred to collectively in this report as the **County Project**). The most recent

regular survey was completed in June 2011 by Geodynamics LLC (Geodynamics), and a post-storm survey was conducted in September 2011 immediately following the passage of Hurricane Irene. This report documents the data sources, methods, and results of a survey evaluation performed to compare the September 2011 post-storm survey with the immediately prior June 2011 survey.

A beach maintenance plan has been in effect since 2003-2004, with triggers for beach renourishment 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. 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) and Hurricane Ophelia (2005, with renourishment completed in 2007). 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). Most recently, the USACE placed material on Atlantic Beach and Fort Macon for Year 1 of the USACE Interim Operation Plan for the Morehead City Harbor Dredged Material Management Plan (DMMP) which is located outside the County Project.

Table 1 and **Table 2** summarize the recent nourishment projects in the study area along with a breakdown of which government entity paid for the project (please note that local includes towns, county, and State). Atlantic Beach has received the most nourishment followed by Emerald Isle and Pine Knoll Shores.

Table 1. Nourishment Volumes by Project

Year	Project	Reach	Total In-Place Volume (cy)	Local (cy)	USACE (cy)	FEMA (cy)
2002	County Phase 1	Pine Knoll Shores - East & West	1,276,586	1,276,586	-	-
2002	County Phase 1	Indian Beach/Salter Path	456,994	456,994	-	-
2002	USACE Disposal	Fort Macon	209,348	-	209,348	-
2003	County Phase 2	Emerald Isle - East & Central	1,746,413	1,746,413	-	-
2003	County Phase 2	Emerald Isle - East & West (dune)	101,349	101,349	-	-
2004	USACE Section 933	Indian Beach/Salter Path & Pine Knoll Shores - West	699,282	244,749	454,533	-
2004	FEMA Post Isabel	Emerald Isle - East & Central	156,000	-	-	156,000
2005	Brandt Island Pump Out	Atlantic Beach	2,920,729	-	2,920,729	-
2005	Inner Harbor Dredging Displosal	Fort Macon	300,000	-	300,000	-
2005	County Phase 3	Emerald Isle - West	690,868	690,868	-	-
2007	USACE Section 933	Pine Knoll Shores - East & West	507,939	177,779	330,160	-
2007	FEMA Post Ophelia	Emerald Isle, Pine Knoll Shores, & Indian Beach/Salter Path	1,229,836	-	-	1,229,836
2007	USACE Disposal	Fort Macon	211,000	-	211,000	-
2011	USACE Disposal	Atlantic Beach	799,504	-	799,504	-
2011	USACE Disposal	Fort Macon	547,196	-	547,196	-
		Total	**11,853,044**	**4,694,737**	**5,772,471**	**1,385,836**

Table 2. Nourishment Volumes by Reach (cy)

Reach	Nourishment Volume
Bogue Inlet - Ocean	59,272
Emerald Isle - West	935,633
Emerald Isle - East & Central	2,348,172
Indian Beach/Salter Path	1,358,842
Pine Knoll Shores	2,163,348
Atlantic Beach	3,720,233
Fort Macon	1,267,544
Overall Total	**11,853,044**
County Project Total	**6,805,995**

3.0 Pre- and Post-Storm Surveys and Field Inspections: Overview

Geodynamics conducted a survey of Bogue Banks in June 2011 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 June 2011 survey. Most recently, Geodynamics conducted a post-storm survey in September 2011 after Hurricane Irene. All of the profile lines and origins used in the BBBNMP monitoring program were used for the post-storm survey except within Atlantic Beach, Fort Macon, and Beaufort Inlet. In these three reaches, a limited number of post-storm surveys were taken because they are not eligible for FEMA reimbursement. **Figure 1** shows the location of the profile lines and origins applied by Geodynamics for the BBBNMP survey in June 2011 and the post-storm survey in September 2011. 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 ISRP (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 June 2011 and post-storm survey (September 2011) 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 pre-storm monitoring report (MN, 2011).

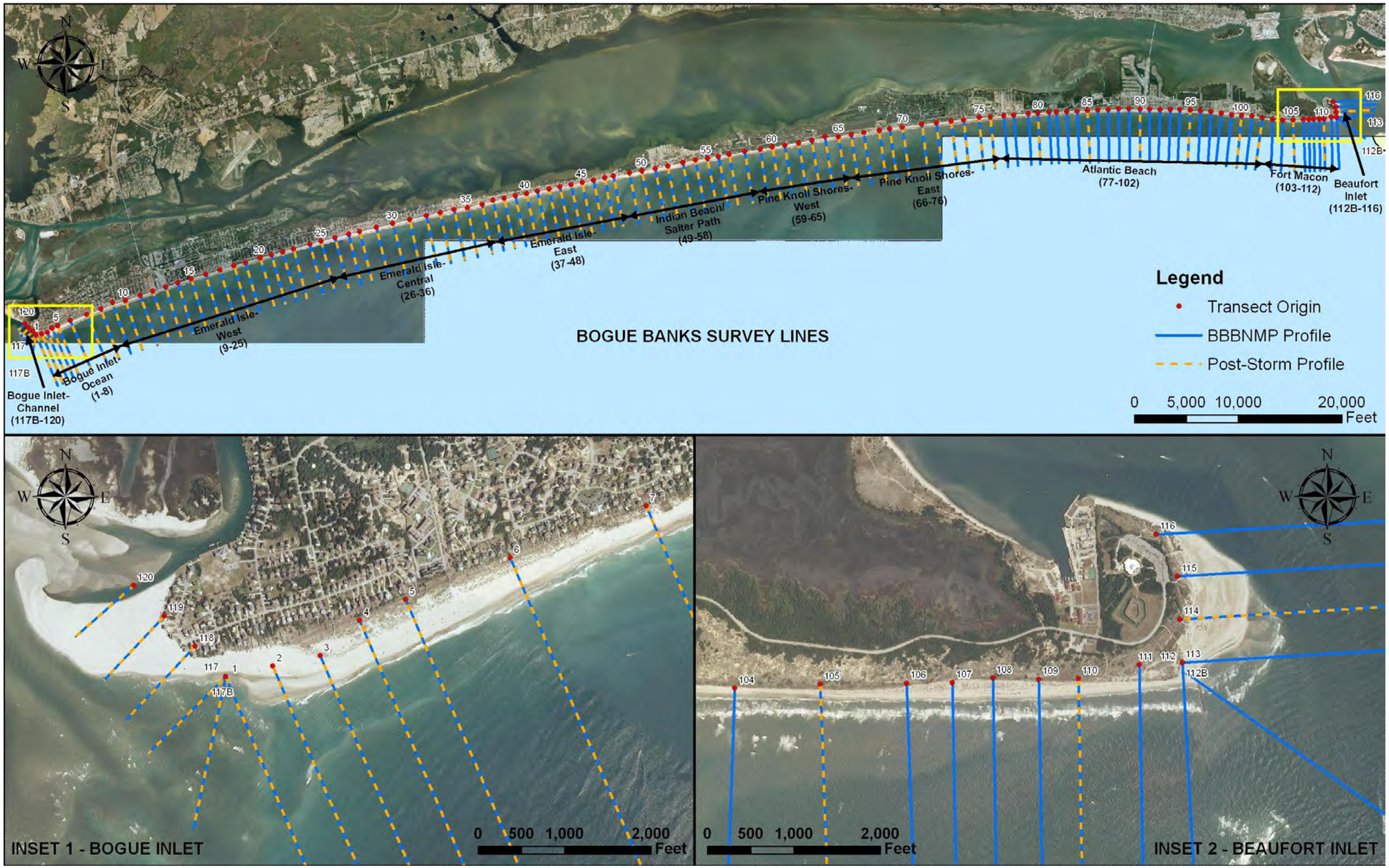

Figure 1. BBBNMP and Post-Storm Profile Line Locations – Bogue Banks

4.0 Survey Evaluation Methods

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. Excel files containing the summer 2011 (June 2011) and post-storm (September 2011) beach profiles being used for the comparison were then formatted and imported into Beach Morphology Analysis Package (BMAP). Using BMAP, two indicators of shoreline change were calculated for each transect.

First, shoreline change designated at the mean high water (MHW) contour, defined as +1.1 ft NAVD88 (based on NOAA tidal benchmark at Morehead City, equivalent to +2.1 ft NGVD29), was calculated at each transect between the June 2011 and September 2011 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 June 2011 and September 2011. 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 (+1.1 ft NAVD88), above -5 ft NAVD88 (wading depth/recreational beach), above -12 ft NAVD88 (outer bar), above -20 ft NAVD88, and above -30 ft NAVD88 (**Figure 2**). Upon inspection of recent survey data, it appears the depth of closure is somewhere between -20 ft NAVD88 and -30 ft NAVD88 (likely closer to -20 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.

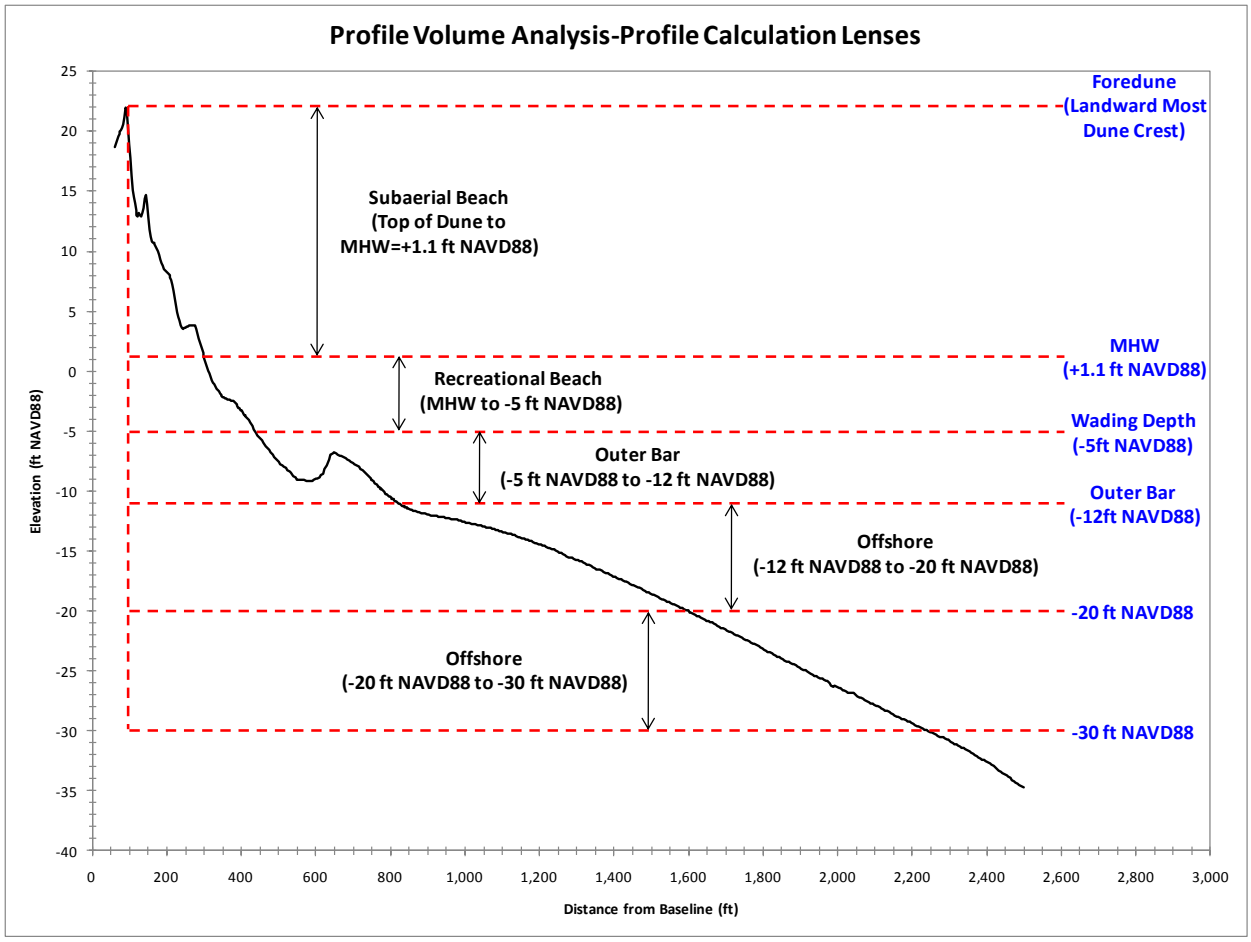

Figure 2. Profile Calculation Lenses

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 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.

5.0 Discussion of Hurricane Irene and Post-Storm Field Inspection

5.1. Hurricane Irene

After clearing the Bahamas late on August 25, 2011, Hurricane Irene approached the North Carolina coast on a general northerly track, eventually making landfall at Cape Lookout at approximately 11:30 am GMT (Greenwich Mean Time) or 7:30 am local time on August 27 as illustrated in **Figure 3** and **Figure 4.** 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 3**, this almost due north oriented hurricane track caused the storm to approach nearly shore-normal to the beaches of Carteret County, and the hurricane eye made landfall within 0 and 30 miles of all beaches overseen by the Carteret County Shore Protection Office, including Bogue Banks.

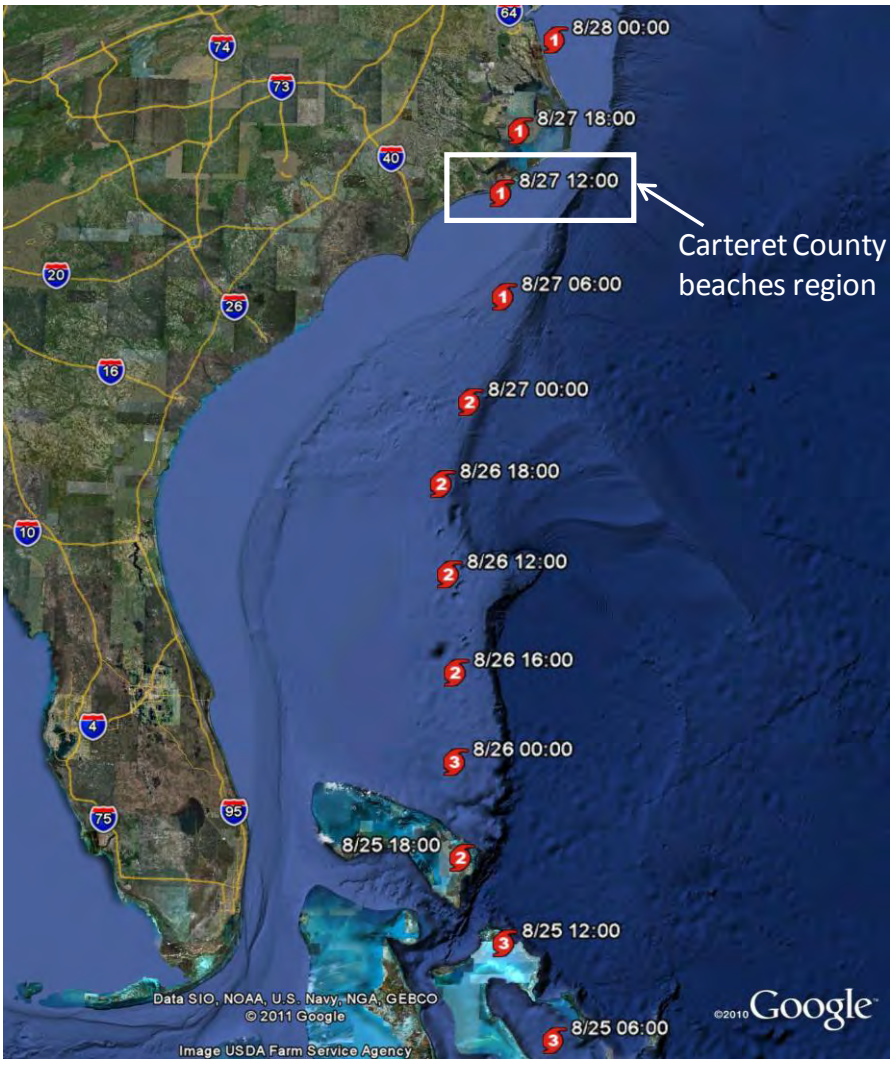

Figure 3. Hurricane Irene Track Between the Bahamas and the North Carolina Coast

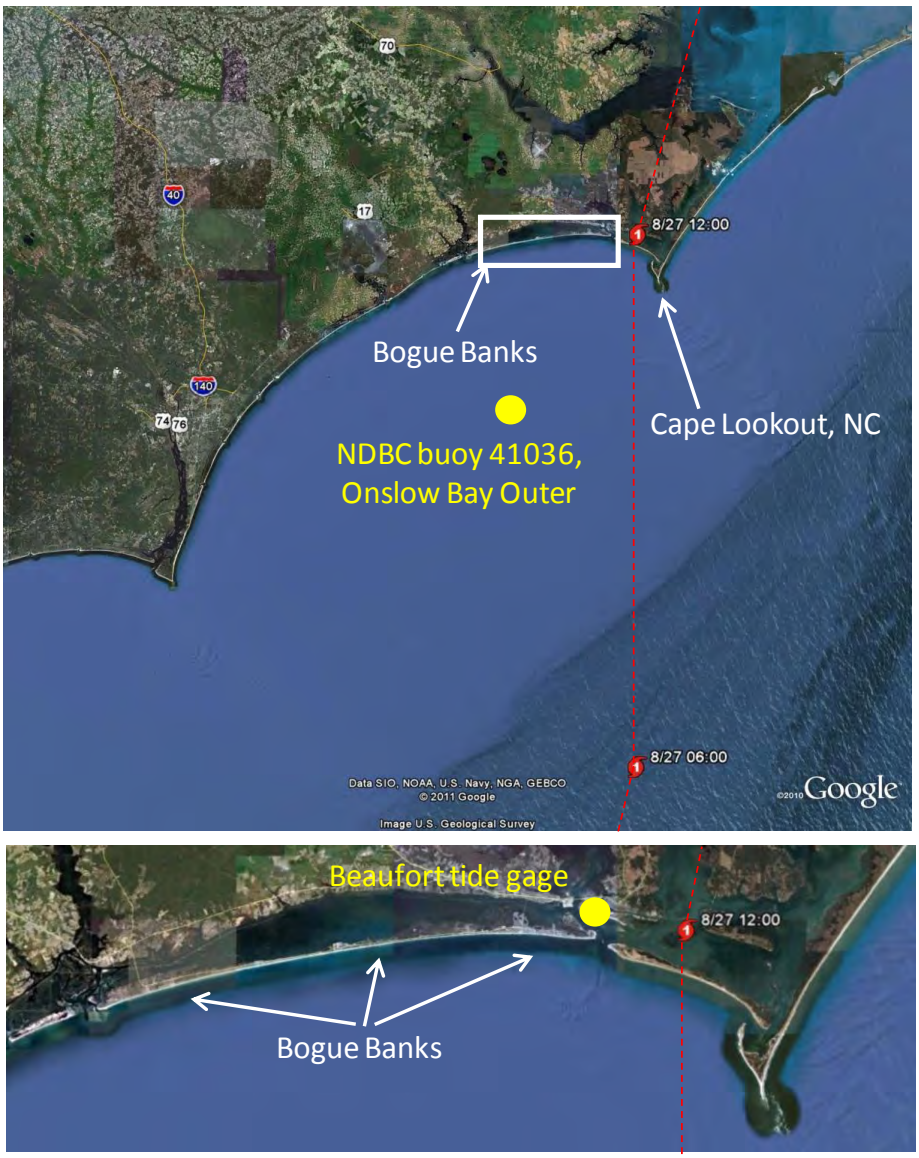

Figure 4. Bogue Banks Beaches Location With Respect To Hurricane Irene Track and Landfall

At landfall, Hurricane Irene was a Category 1 hurricane with sustained wind speeds between 80 to 85 mph and a minimum pressure of approximately 952 millibars. Reported wind gusts reached between 100 – 110 mph at Atlantic Beach and the Cedar Island ferry terminal. National Data Buoy Center buoy 41036 – Onslow Bay Outer (position in **Figure 4**) measured wind and wave conditions continuously through the approach and passage of Hurricane Irene. **Figure 5** charts the measured wind speeds and directions from buoy 41036, with wind speeds in mph and time in local time. The buoy, located approximately 25 miles west of the central hurricane track line (on the "weak" side), measured average wind speeds up to 55 mph and peak wind gusts between 65 and 70 mph. The passage of the eye of the storm past the buoy can be clearly seen as a sharp shift in wind direction and drop in wind speeds about mid-day on August 27. The hurricane winds produced very large waves offshore, as indicated in **Figure 6**. Significant wave heights at buoy 41036 increased steadily as the storm approached, peaking at approximately H_s =

28.4 ft early on August 27 (just before landfall). The mean wave direction indicates a predominantly southeasterly wave approach direction throughout the storm, except for a brief period of locally generated northwesterly waves just after landfall on August 27. **Figure 7** shows the water levels measured at Beaufort during the same time period as the NDBC buoy data, and the data indicate that Hurricane Irene caused a surge of approximately 2 ft above astronomical tidal levels over at least two high tides on August 26 and August 27. 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 (historic measurements of MHHW at the Atlantic Beach Triple S Pier were 0.6' higher than Beaufort), and wave setup effects would have been significant on the beaches.

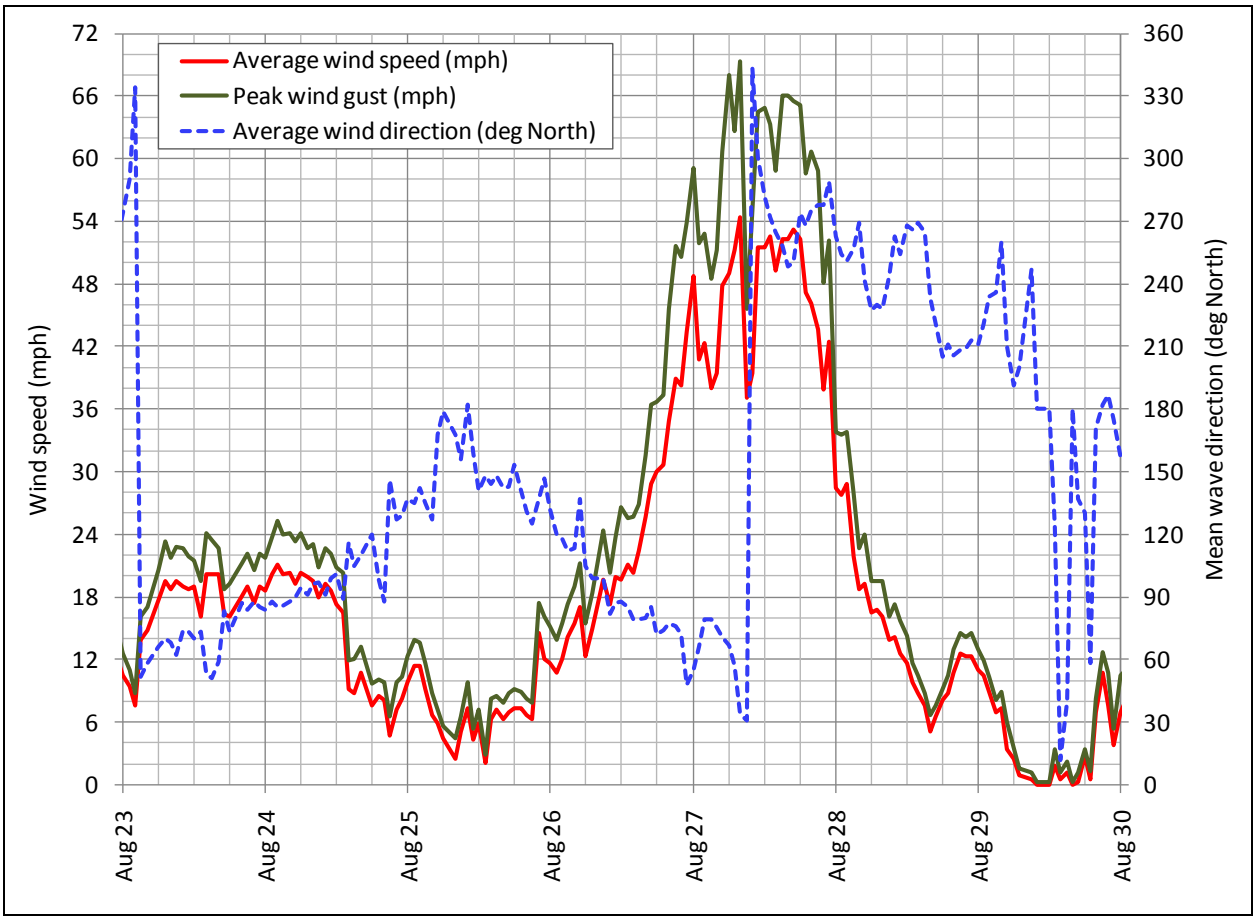

Figure 5. Measured Wind Conditions During Hurricane Irene At NDBC 41036 Onslow Bay Outer

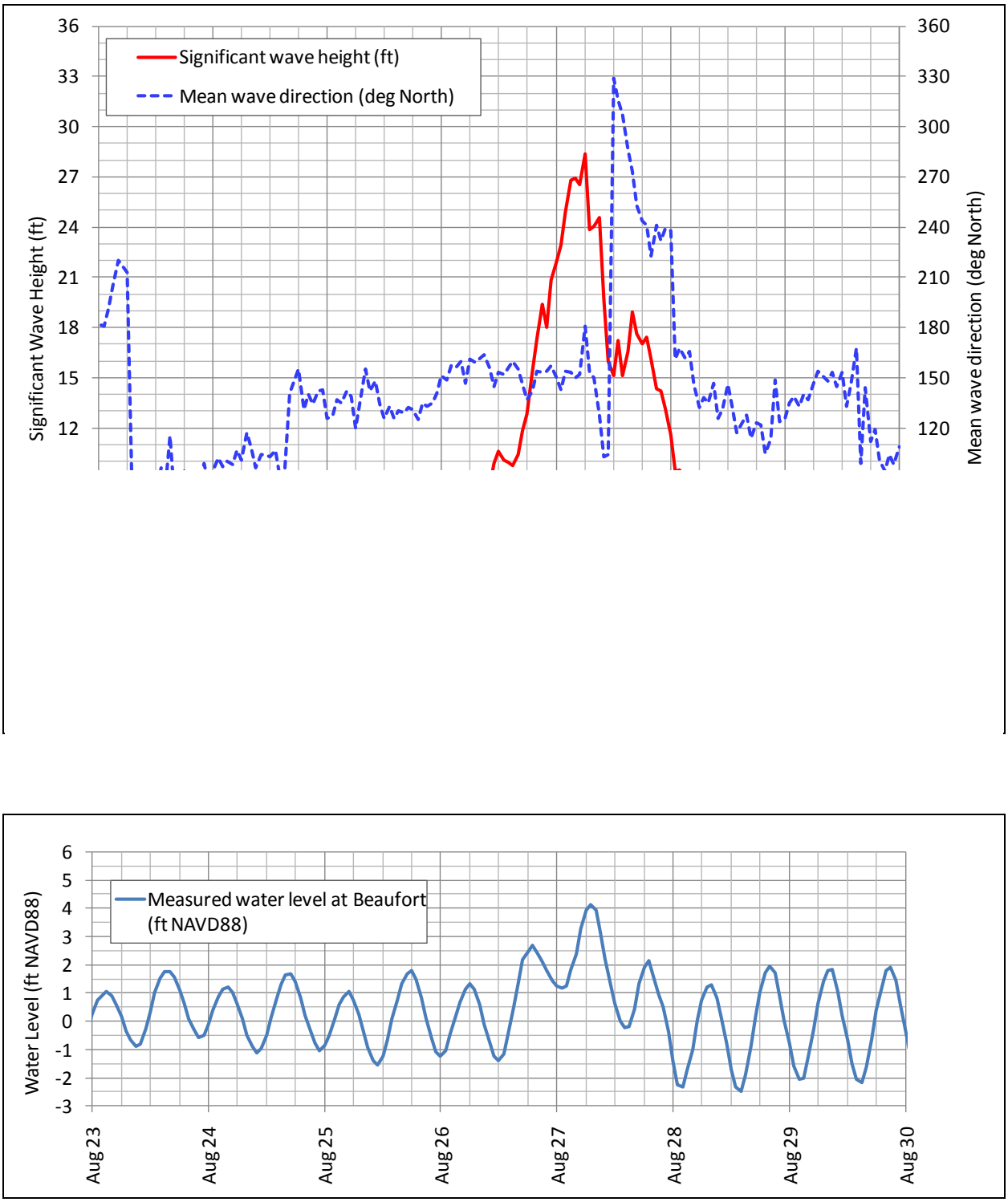

Figure 7. Measured Water Levels During Hurricane Irene at Beaufort, NC

Lastly, it is also important to note that the wave periods experienced during Irene were quite long which also leads to increased wave setup and erosion. **Figure 8** shows the dominant and average wave periods measures at the Onslow Bay Outer gauge during Hurricane Irene. Note the

average wave periods (averaged over a 20 minute interval) during Irene reached 9.7 seconds while the dominant wave periods (associated with the highest waves measured during a 20 minute interval) reached 16 seconds. For a comparison, during Hurricane Ophelia, the largest offshore waves (at another nearby gauge – Station 41035 – Onslow Bay Inner) were measured to have a peak significant wave height of nearly 19 feet and a dominant wave period of 11 seconds with a similar duration of significantly elevated wave conditions (36 – 48 hours). Between these measurements and the fact that none of the ocean side piers sustained damage during Ophelia, it would appear that that Hurricane Irene was a more significant event in terms of damage potential.

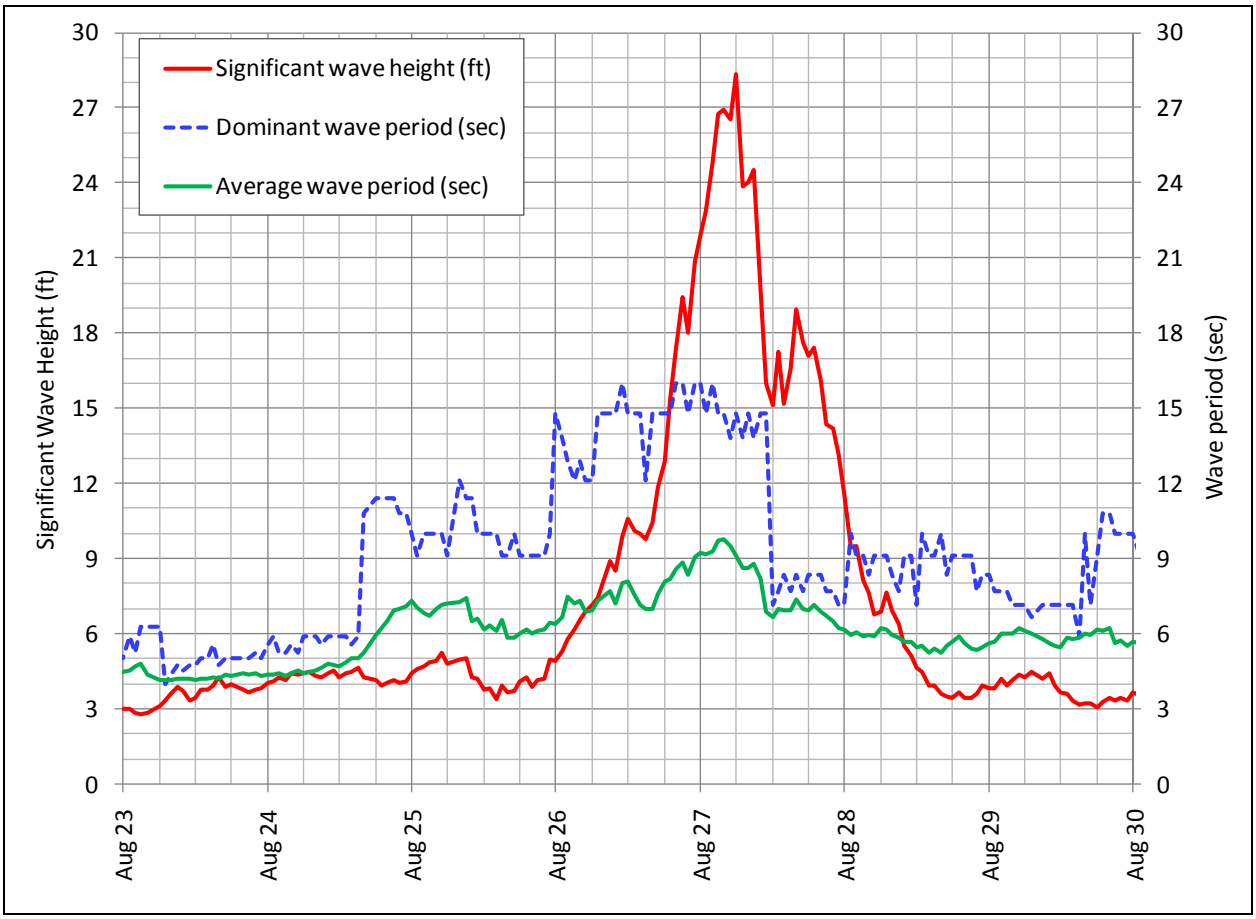

Figure 8. Measured Wave Conditions During Hurricane Irene at NDBC 41036 Onslow Bay Outer

5.2. Post-Storm Field Inspection

After Hurricane Irene passed, a post-storm field inspection was completed by County and M&N staff during August 28-29, 2011. On August 28, a post-storm photo and visual observation survey was completed at 32 locations along Bogue Banks. **Table 3** outlines the locations, photos taken and notes describing the visual observations in the field. **Figure 9** shows the locations where the photos were taken and observations made. A video of the entire oceanfront shoreline was also recorded on August 28th. Links to the photos and videos can be found at http://www.protectthebeach.com/temp/irene.html. Detailed discussion of the observations as

well as the accompanying photos can be found in **Section 6.2** of the report which outlines the impacts to the beach by reach.

On August 29, an aerial survey of the ocean and soundfront shorelines was completed. Links to these videos can also be found at http://www.protectthebeach.com/temp/irene.html.

General observations during the field inspections were as follows: 1) the primary dunes appeared to weather the storm well, but the incipient dunes in front of the primary dune were significantly damaged, 2) all existing oceanfront fishing piers sustained significant damage with the ends of each being lost, 3) tires from manmade offshore reefs were deposited onto the beach in varying density, and 4) many soundside piers also sustained damage.

Table 3. Notes Taken During Hurricane Irene Post-Storm Field Inspection

FIELD NOTES FOR: HURRICANE IRENE POST-STORM INSPECTION
DATE/TIME: 8/28/11 - 12:30 - 5:30 PM
COMPLETED BY: RUDI RUDOLPH AND JOHNNY MARTIN, PE

LOCATION	LOCATION DESC	NORTHING	EASTING	PRE PHOTOS	POST PHOTOS	NOTES
1	EI Point #1	331,154.5	2,572,121.9	17, 18, 19 on 8/26	1,2,3	On Point Near Inlet - Facing Inlet
2	EI Point #2	331,340.8	2,571,455.6	20-26 on 8/26	4,5,6	On Point Near Inlet - Facing Inlet
3	Channel Drive	330,970.6	2,573,878.0	NA	7,8	On Point Near Inlet - Facing Ocean - 9' Scarp of Main Frontal Dune - Secondary Dunes OK
4	Channel Drive	331,181.0	2,574,312.7	NA	9	9' Scarp - Frontal Dune Breached in Many Locations Along Stretch - Secondary Dunes OK
5	Lands End Clubhouse	332,525.3	2,577,341.5	NA	10,11,12,13,14	Near Lands End Clubhouse - Frontal Dune Damaged But No Breach
6	Randy's Way	333,604.0	2,580,129.7	NA	15,16	4'-6' Scarp - Small Breach of Frontal Dune - Secondary Dunes Fine
7	Ocean Oaks	333,974.5	2,581,169.0	13,14,15,16 on 8/26	17,18,19,20	4'-6' Scarp - Small Breach of Frontal Dune - Secondary Dunes Fine
8	Bogue Inlet Pier	336,708.6	2,589,592.0	NA	21	@ Bogue Pier - View From West Side
9	Bogue Inlet Pier	337,145.0	2,591,058.6	9,10,11,12 on 8/26	22,23,24,25	@ Bogue Pier - 2' - 4' Scarp of Incipient Dune
10	Bogue Inlet Pier	337,255.7	2,591,469.0	NA	26	@ Bogue Pier
11	Pinta Dr.	339,310.0	2,598,541.5	5,6,7,8 on 8/26	27,28,29,30	2'-4' Scarp of Incipient Dune
12	4205 Ocean Dr	342,001.4	2,609,400.2	1,2,3,4 on 8/16	31,32,33,34	1'-3' Scarp of Incipient Dune
13	Old EI Pier	343,051.5	2,614,267.6	59-62 on 8/25	35,36,37,38,39	2'-4' Scarp of Incipient Dune - In Areas Just East of Ocean Reef Waves Reached to Within 3' of Top of Primary Dune
14	23rd Street	343,329.0	2,615,616.7	NA	40,41	5'-7' Scarp of Primary Dune - Little Incipient Dune Present
15	12th Street	344,725.0	2,622,131.5	48-53 on 8/25	42,43,44,45	@ 12th Street - 4'-6' Scarps on Small Incipient Dunes (Man-made with Sand Fencing) - Small Dune Gone On Other Side of 12th Street
16	11th Street	344,861.9	2,622,762.3	NA	46,47,48	6'-9' Scarp of Primary Dune - No Incipient Dunes Present
17	4t Street	345,559.6	2,626,295.7	NA	49,50,51	4'-6' Scarp of Primary Dune - No Incipient Dunes Present - One House Had Primary Dune Slightly Breached Here & Overwash
18	Indian Beach 4WD Ramp	347,062.3	2,633,379.1	39-42 on 8/25	10-12 on 8/27	2'-4' Scarp of Incipient Dune
19	Colony by the Sea	347,955.0	2,638,628.6	35-38 on 8/25	52,53,54,55	4'-6' Scarp of Incipient Dune
20	Trinity Center	348,478.8	2,641,666.7	34-31 on 8/25	13-16 on 8/27	2'-4' Scarp of Incipient Dune
21	Clamdigger	349,484.0	2,647,631.4	27-30 on 8/25	17-20 on 8/27	Incipient Dune Completely Gone - Slight Damage to Primary Dune
22	Iron Steamer	350,251.8	2,652,802.4	23-26 on 8/25	21-23 on 8/27	@ Iron Steamer Seawall - Incipient Dune Completely Gone - Slight Damage to Primary Dune
23	Pine Knoll Townes	350,728.4	2,655,966.5	NA	24 on 8/27	@ Condos - Primary Dune 3' From Breaching - 4'-6' Scarp
24	Memorial Park	351,191.2	2,659,574.5	18-22 on 8/25	25-30 on 8/27	4'-6' Scarp of Incipient Dune
25	Knollwood	351,554.3	2,662,741.2	NA	56,57	@ Access B Dogwood - 4'-6' Scarp of Incipient Dune
26	Sheraton	352,026.2	2,667,404.2	14-17 on 8/25	31-37 on 8/27	@ Sheraton - Incipient Dune Gone - 2'-4' Scarp of Primary Dune for 1000' then 2'-4' Scarp of Incipient Dune
27	Coral Bay Club	352,232.2	2,670,843.3	NA	58,59,60	4'-6' Scarp of Primary Dune - Small Breach at Ramp - Sand in Parking Lot
28	Ocean Ridge	352,365.3	2,673,803.2	NA	61,62,63,64	4'-6' Scarp of Primary Dune - Primary Dune is Low, Flat and Wide
29	Circle	352,478.9	2,678,986.1	9-13 on 8/25	65,66,67,68	@ Circle - Waves Reached within 3'-4' of Top of Primary Dune - Primary Dune is Low, Flat and Wide - Up to Seawall @ Circle
30	Oceanna Pier	352,416.0	2,682,926.3	NA	69,70	@ Oceanna Pier - Waves Reached within 3'-4' of Top of Primary Dune - Primary Dune is Low, Flat and Wide
31	Club Colony Drive	352,126.1	2,686,216.3	6-9 on 8/25	71,72,73	Waves Reached within 3'-4' of Top of Primary Dune - Primary Dune is Low, Flat and Wide
32	Fort Macon Bath House	351,568.2	2,692,189.2	1-5 on 8/25	74,75,76,77	@ Fort Macon Bath House - Pushed 3-4' of Sand Up Onto Walkway and Stairs - 6-10' Scarp of Primary Dune

Figure 9. Map of Field Inspection Observation Locations

6.0 Discussion of Beach Changes Attributed to Hurricane Irene

This section outlines observations from the field inspections conducted immediately following the storm and from comparison of the pre- and post-storm survey data. Plots of the shoreline and volume changes at each transect for Bogue Banks are presented in **Appendix A**. Profile comparison plots for individual transects which include the June 2011 (pre-storm) and September 2011 post-storm profiles are presented in **Appendix B**. The computed shoreline changes and volume changes at each individual transect for the time periods being covered are tabulated in **Appendix C**.

6.1. Regional Shoreline and Volume Change Trends

Key statistics were calculated to describe the average shoreline and volume changes over the entire shoreline as well as for each region of the shoreline. Computed statistics include average shoreline change, average volume change, and cumulative volume change (e.g. total volume of material lost or gained along a section of shoreline). A summary of the resulting statistics for the pre-storm to post-storm comparison are presented in **Table 4**. Evaluation of the computed statistics will take into account volume changes computed for portions of the profile above MHW (+1.1 ft NAVD88), above -5 ft NAVD 88, above -12 ft NAVD88, above -20 ft NAVD88, and above -30 ft NAVD88 in order to better understand onshore and offshore processes. Since each reach consists of a different length of shoreline, a weighted average for unit shoreline change (ft) and unit volume change (cy/ft) at each transect was calculated for the Bogue Banks Oceanfront and County Project based on the length of each reach.

Table 4. Bogue Banks Regional Shoreline and Volume Change Statistics (June 2011 – September 2011 Comparison)

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Inlet-Ocean (1-8)	7,432	8.5	-4.1	-30,297	-10.1	-75,280	-18.6	-138,201	-5.2	-38,663	13.7	101,935
Emerald Isle-West (9-25)	22,344	-5.5	-4.4	-98,004	-10.0	-222,862	-25.9	-579,219	-21.9	-489,290	-2.2	-48,471
Emerald Isle-Central (26-36)	15,802	-0.7	-3.4	-53,055	-5.2	-81,696	-13.7	-216,386	-27.2	-429,866	-6.7	-106,286
Emerald Isle-East (37-48)	13,220	-3.8	-3.5	-45,723	-9.3	-122,432	-11.9	-157,073	-18.8	-249,104	1.3	17,312
Indian Beach-Salter Path (49-58)	12,850	-2.4	-5.5	-70,567	-10.4	-133,830	-18.4	-235,939	-30.3	-389,783	-6.7	-86,084
Pine Knoll Shores-West (59-65)	9,063	6.4	-3.6	-32,250	-3.8	-34,590	-11.3	-102,188	-32.8	-297,329	-16.2	-147,017
Pine Knoll Shores-East (66-76)	14,815	15.5	-2.6	-38,432	-0.5	-7,258	-7.6	-112,555	-20.6	-304,670	-5.3	-77,848
Atlantic Beach (77-102)	26,176	6.8	-6.0	-156,328	-7.5	-197,552	-13.9	-362,678	-15.1	-395,857	-18.8	-490,869
Fort Macon State Park (103-112)	6,691	-41.1	-7.8	-52,480	-18.0	-120,558	-7.2	-48,058	12.2	81,416	24.2	162,104
Beaufort Inlet (113-116)	2,000	-88.3	0.5	952	-11.5	-23,020	-29.6	-59,154	-40.3	-80,600	-43.0	-86,054
Bogue Inlet-Channel (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
County Project (9-76)	**88,094**	**0.8**	**-3.8**	**-338,030**	**-6.8**	**-602,668**	**-15.9**	**-1,403,361**	**-24.5**	**-2,160,042**	**-5.1**	**-448,393**
Oceanfront (1-112)	128,393	0.3	-4.5	-577,135	-7.8	-996,059	-15.2	-1,952,298	-19.6	-2,513,146	-5.3	-675,223

*Notes: 1. Due to the dynamic nature of Bogue Inlet, shoreline and volume calculations were not performed

According to **Table 4**, shoreline movement at MHW was minimal due to the storm. Upon inspection of the profile plots in **Appendix B**, it appears that there were major change to the beach profiles above and below MHW, but the shoreline position itself did not show significant retreat during the storm. An exception is the area encompassing Fort Macon and the eastern end of Atlantic Beach which had recently received nourishment between November 2010 and April 2011, noting that increased erosion of the subaerial and recreational beach following nourishment projects is an expected behavior of the beach as it equilibrates.

The computed volume changes indicate that Hurricane Irene had a large impact on the Bogue Banks oceanfront. A net volumetric loss was calculated above all elevations for the County Project and the entire oceanfront. Material above -12 ft NAVD88, which captures the offshore bar, is considered to provide storm protection as the engineered beach for FEMA purposes. Presence of material on the subaerial beachface as well as the at the offshore bar helps to break the waves, while material on the recreational beach provides a last line of defense for homes and infrastructure along Bogue Banks. Volumetric calculations indicate that the County Project (i.e. the engineered beach) lost approximately 1.40 million cy (1,403,361 cy) of material above -12 ft NAVD88 due to Hurricane Irene. The entire oceanfront of Bogue Banks lost approximately 1.95 million cy (1,952,298 cy) of material. Profile plots in **Appendix B** show erosion of the beachface above the berm (approximately +7 ft NAVD88), including the small incipient dune which had developed over time in front of the primary dune. The beach also experienced large amounts of erosion between the shoreline and the offshore bar.

It appears that approximately 75% of the material eroded from above -20 ft NAVD88 was captured between -20 ft and -30 ft NAVD88, as the cumulative erosion calculated above -30 ft NAVD88 was generally much smaller than above -20 ft NAVD88. However, sand remaining in the system below -20 ft NAVD does not provide direct storm protection for Bogue Banks and based on past studies has not shown that it will ever move back onshore.

Figure 10 displays the trends in **Table 4** with a bar plot of the cumulative volume changes at each reach, as well as aggregate volume changes along the County Project and entire Bogue Banks oceanfront.

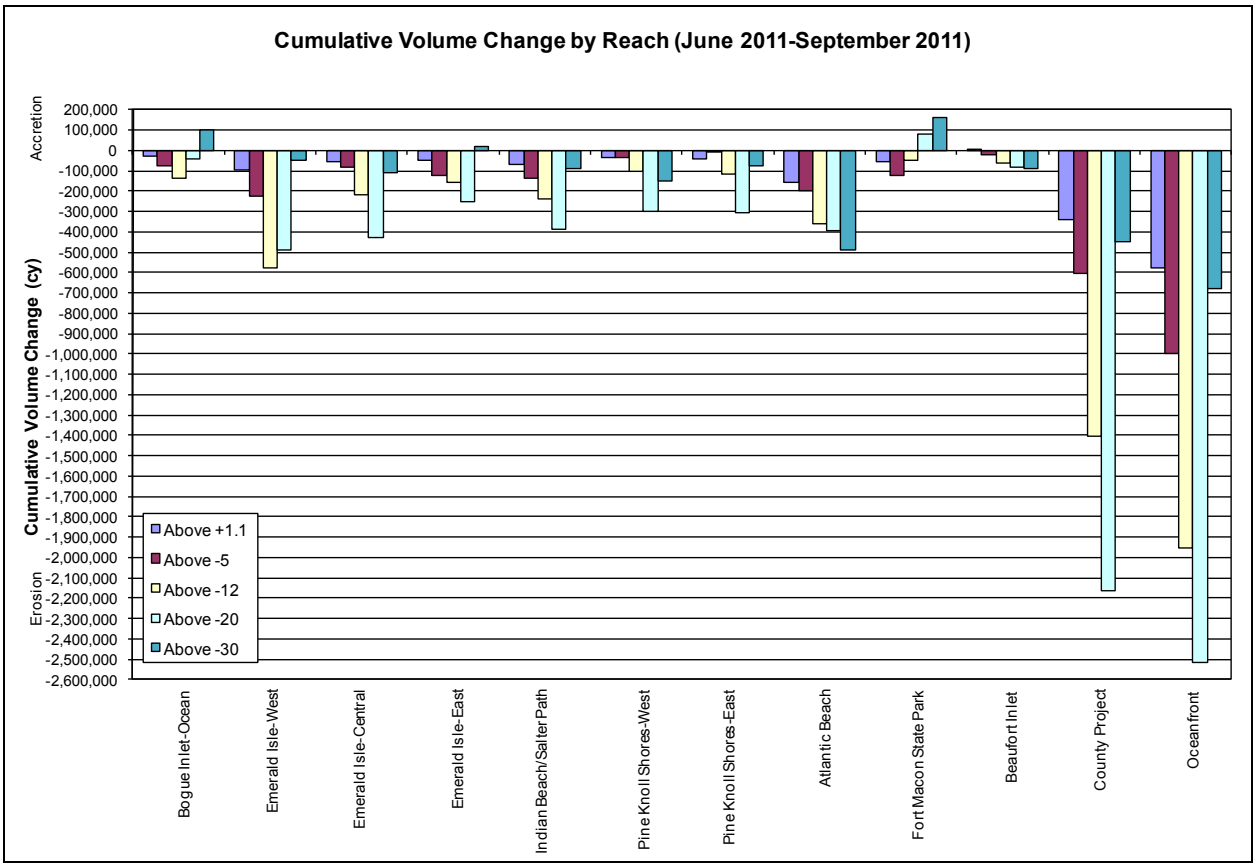

Figure 10. Cumulative Volume Change by Reach

Figure 10 shows the fact that nearly all of Bogue Banks has suffered volume losses above all elevations from Hurricane Irene. Most importantly, volume losses above -12 ft NAVD88 which approximates the volume of sand available for storm protection, were substantial in each reach. As mentioned previously, the smaller amounts of erosion indicated above -30 ft NAVD88, indicate that much of the material which eroded from above -20 ft NAVD88, moved offshore of this area, but it is not available for storm protection.

A target minimum volume for each profile from the foredune (landward most crest of the primary dune) to the outer bar (above -12 ft NAVD88) was established at 225 cy/ft during the formulation of the Bogue Banks Beach Restoration Project. **Figure 11** displays the average profile volume to the outer bar per transect within each reach of shoreline for summer 2008, summer 2009, summer 2010, summer 2011, and post-storm (September 2011). Values displayed in the graph are tabulated in **Table 5**. Due to the change in the number of surveying transects at Atlantic Beach and Fort Macon, values for these reaches were not comparable with previous surveys and are thus not reflected in the plot. As shown in **Figure 11**, Emerald Isle East, Pine Knoll Shores West, and Pine Knoll Shores East had been moving toward the 225 cy/ft threshold prior to Hurricane Irene. However, the storm caused (on average) as much or more profile volume loss than observed in each of the recent survey years.

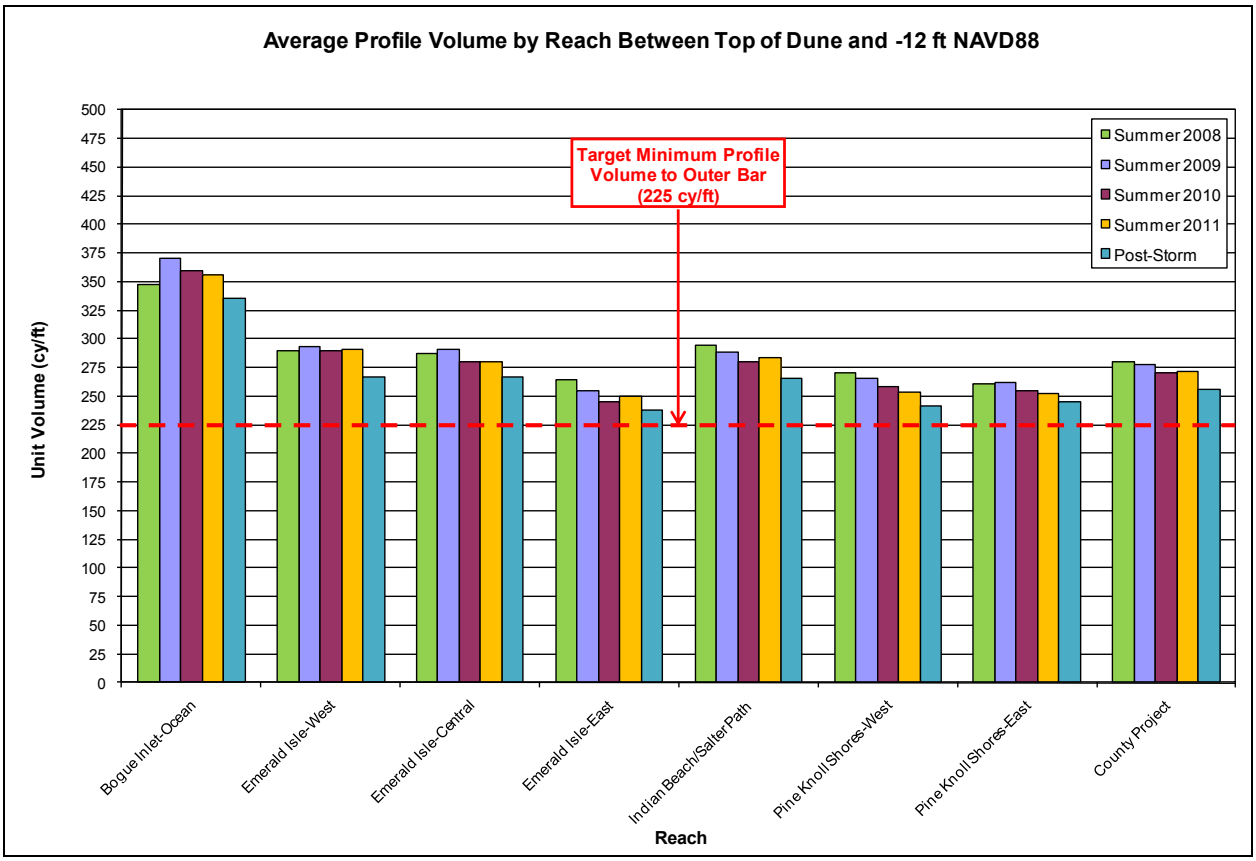

Figure 11. Average Profile Volume From Foredune to Outer Bar by Reach

Table 5. Average Profile Volume From Foredune to Outer Bar by Reach

Reach	July 2008	June 2009	June 2010	June 2011	Post-Storm
Bogue Inlet-Ocean	348	371	359	356	335
Emerald Isle-West	290	294	289	291	267
Emerald Isle-Central	288	291	280	281	267
Emerald Isle-East	265	255	245	250	238
Indian Beach/Salter Path	294	289	280	284	265
Pine Knoll Shores-West	270	265	258	253	242
Pine Knoll Shores-East	261	262	255	253	245
County Project	**280**	**278**	**271**	**271**	**256**

6.2. Storm Impacts by Management Reach

Local shoreline and beach profile change trends and post-storm inspection observations are discussed below for the defined reaches of Bogue Banks (**Figure 1**). A summary of the information in **Table 4** and **Appendix A** has been created for each region of study.

6.2.1. Emerald Isle

The Emerald Isle region extends over approximately 9.4 miles of shoreline, represented by survey transects 9 through 48, and it is fully within the County Project. Eleven locations within the Emerald Isle region were field inspected immediately following Hurricane Irene. Since

monitoring began in 1999, Emerald Isle has received a total of 3.28 million cy of nourishment material as a result of the Bogue Banks Beach Restoration Project and FEMA funded post-storm work (Hurricanes Isabel and Ophelia). A summary of average shoreline and volume changes between June 2011 and September 2011 for the Emerald Isle region are presented in **Table 6**.

Table 6. Average Shoreline and Volume Change for Emerald Isle

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Emerald Isle-West (9-25)	22,344	-5.5	-4.4	-98,004	-10.0	-222,862	-25.9	-579,219	-21.9	-489,290	-2.2	-48,471
Emerald Isle-Central (26-36)	15,802	-0.7	-3.4	-53,055	-5.2	-81,696	-13.7	-216,386	-27.2	-429,866	-6.7	-106,286
Emerald Isle-East (37-48)	13,220	-3.8	-3.5	-45,723	-9.3	-122,432	-11.9	-157,073	-18.8	-249,104	1.3	17,312
Total	**51,366**	**-3.6**	**-3.8**	**-196,782**	**-8.3**	**-426,991**	**-18.5**	**-952,679**	**-22.7**	**-1,168,259**	**-2.7**	**-137,445**

Overall, Emerald Isle lost approximately 953,000 cy of storm protection material above -12 ft NAVD88, with the largest losses occurring at Emerald Isle West. Emerald Isle West also experienced the largest shoreline erosion within the County Project with an average loss of -5.5 ft. Profile plots in **Appendix B** indicate scarping of the incipient dune in many cases. **Figure 12** shows a representative profile for the Emerald Isle region, indicating the incipient dune scarp, erosion landward and seaward of the offshore bar, and the partial capture of eroded material offshore as indicated by the volume calculations in **Table 6**.

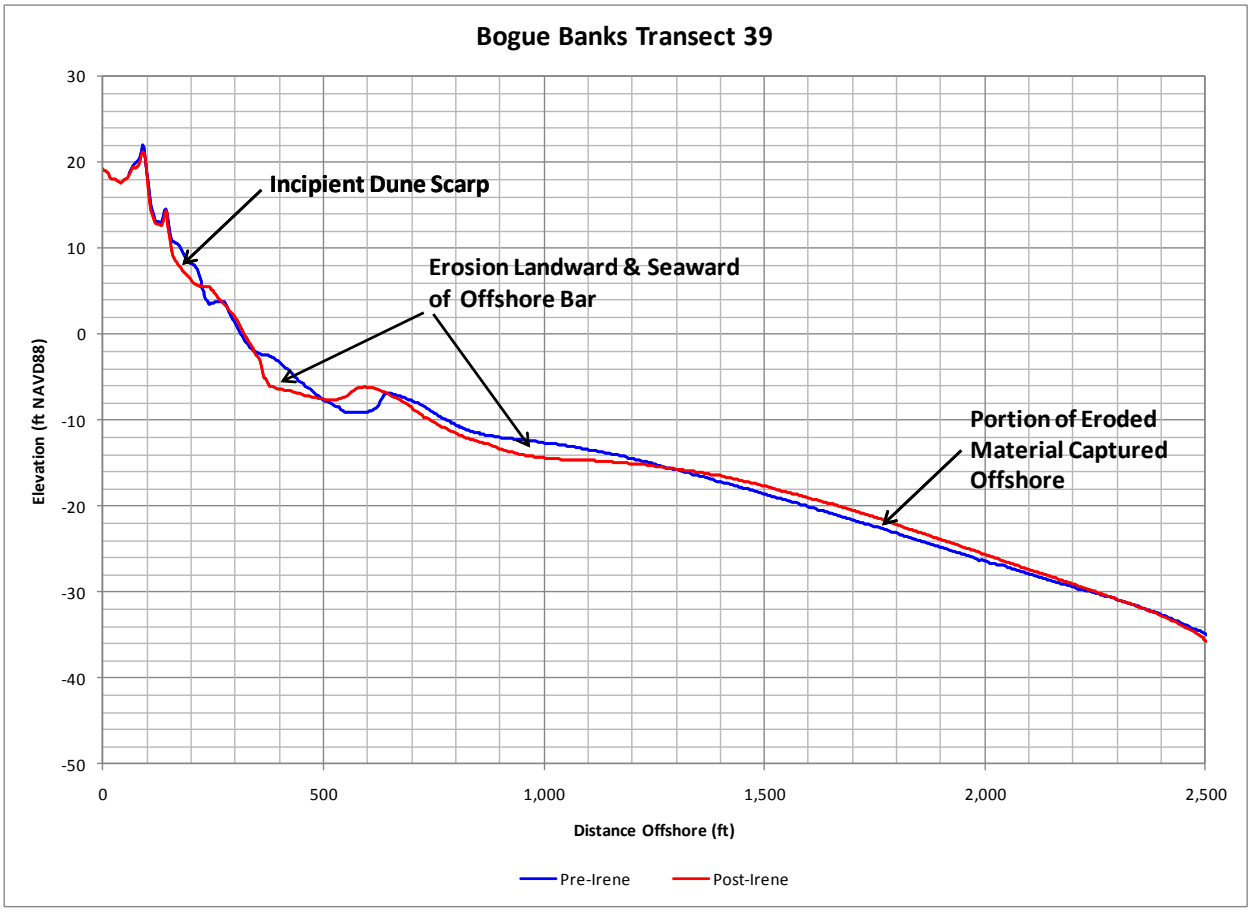

Figure 12. Emerald Isle Representative Profile

Figure 13 displays the unit volume change at each transect above the five elevations that were analyzed.

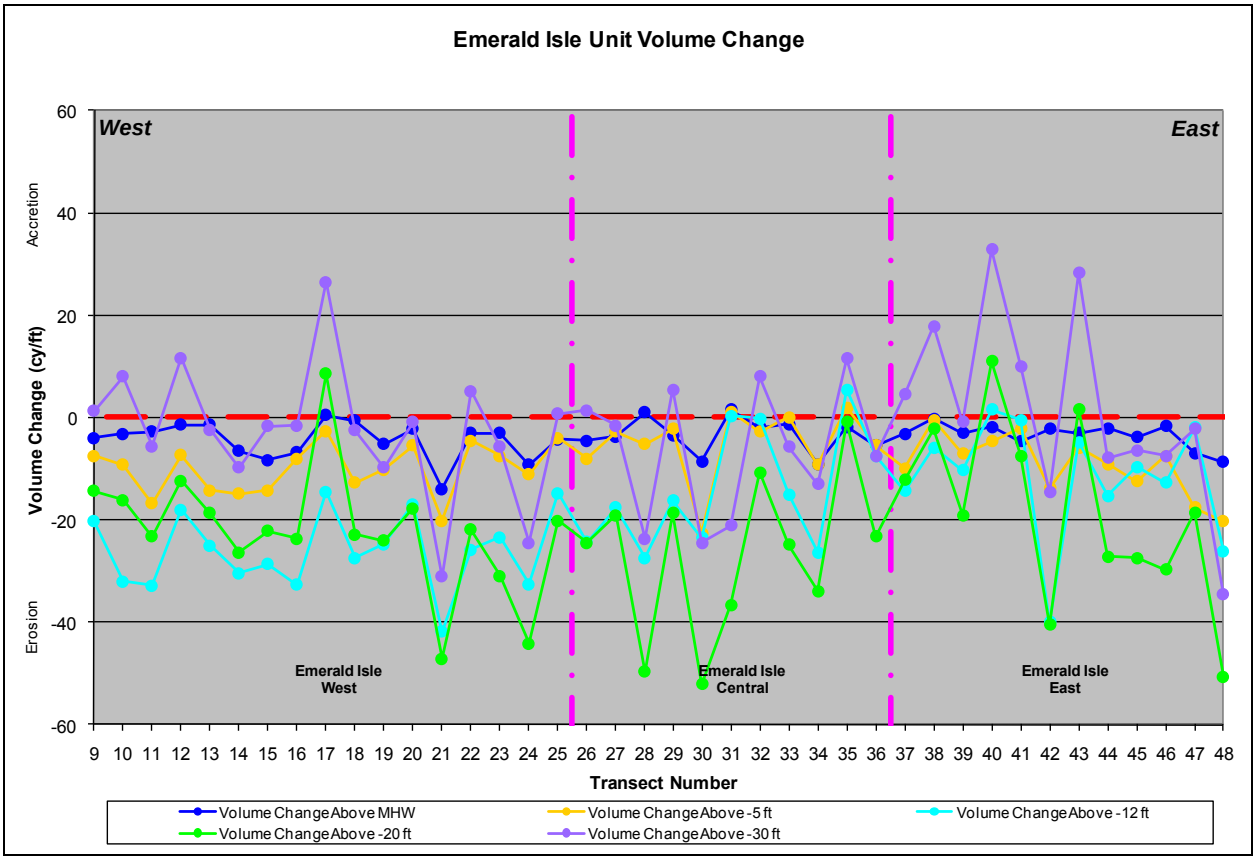

Figure 13. Emerald Isle Unit Volume Change (June 2011 – September 2011)

The field inspection showed that storm impacts in this reach are generally characterized by significant erosion of the incipient vegetated dunes, with complete removal of incipient dunes and erosion of the primary frontal dune at some locations. At Randy's Way and Ocean Oaks (Transects 6 through 10), the frontal dune shows a 4 to 6 ft scarp as illustrated by **Photo 1**. The survey profiles at these locations show significant volume loss between 0 and -12 ft NAVD88, with some gain seaward of -12 ft NAVD88.

Photo 1. In front of Ocean Oaks looking north

Similar impacts were noted near the Bogue Inlet Pier (Transects 17 and 18 - **Photo 2**) and Pinta Drive (Transects 23 and 24), with a 2 to 4 ft scarp of the frontal dune. The survey profiles at this location are similar to the previous location, with obvious profile steepening and significant volume loss between approximately +2 and -15 ft NAVD88. The pier also suffered serious structural damage (**Photo 3**).

Photo 2. Bogue Inlet Pier looking east

Photo 3. Bogue Inlet Pier damage

Near the former Old Emerald Isle Pier location (Transects 34 through 37), the frontal dune shows a 2 to 4 ft scarp (**Photo 4**) with retreat of the dune to landward of the dune overwalk and sand fencing. The survey profiles at these locations show retreat and steepening of the beach between +6 and -8 ft NAVD88 and significant volume loss between -10 and -16 ft NAVD88.

Photo 4. Former Old Emerald Isle Pier location looking west

Between 12th Street and 4th Street in Emerald Isle (Transects 41 through 46), the frontal dune shows a 4 to 6 ft scarp of the incipient dune (**Photo 5**) transitioning to a 6 to 9 ft scarp of the primary frontal dune (**Photo 6**). The survey profiles vary considerably among each other landward of -10 ft NAVD, but all show an obvious net loss of volume landward of -12 ft NAVD.

Photo 5. Near 12th Street in Emerald Isle, looking west

Photo 6. Near 12th Street in Emerald Isle, looking northwest

6.2.2. Indian Beach/Salter Path

The Indian Beach region covers transects 49 through 58, and it is fully within the County Project. Since monitoring efforts began in 1999, this region has received 1.36 million cy of nourishment material from the Bogue Banks Beach Restoration Project, USACE Section 933 projects, and FEMA funded post-storm work (Hurricane Ophelia). A summary of average shoreline and volume changes between June 2011 and September 2011 for the Indian Beach/Salter Path region are presented in **Table 7**.

Table 7. Average Shoreline and Volume Change for Indian Beach/Salter Path

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Indian Beach-Salter Path (49-58)	**12,850**	**-2.4**	**-5.5**	**-70,567**	**-10.4**	**-133,830**	**-18.4**	**-235,939**	**-30.3**	**-389,783**	**-6.7**	**-86,084**

Shoreline change in the Indian Beach/Salter Path area showed a recession of approximately -2.4 ft due to Hurricane Irene. **Table 7** indicates that the area followed the island wide trend of volumetric erosion above all elevations considered. Approximately 236,000 cy of material was lost above -12 ft NAVD88. **Of that total, approximately 176,700 cy is eligible for FEMA reimbursement due to the exclusion of a small portion of State owned land at Transects 53 and 54.** The Indian Beach/Salter Path reach showed the second largest average unit volume change amongst all reaches in the County Project, with an average loss of -18.4 cy/ft at each transect. The profile plots in **Appendix B** indicate losses of the incipient dune at almost every transect as well as erosion landward and seaward of the offshore bar and partial capture of material offshore. **Figure 14** shows a representative profile in the Indian Beach/Salter Path reach which displays the previously mentioned characteristics.

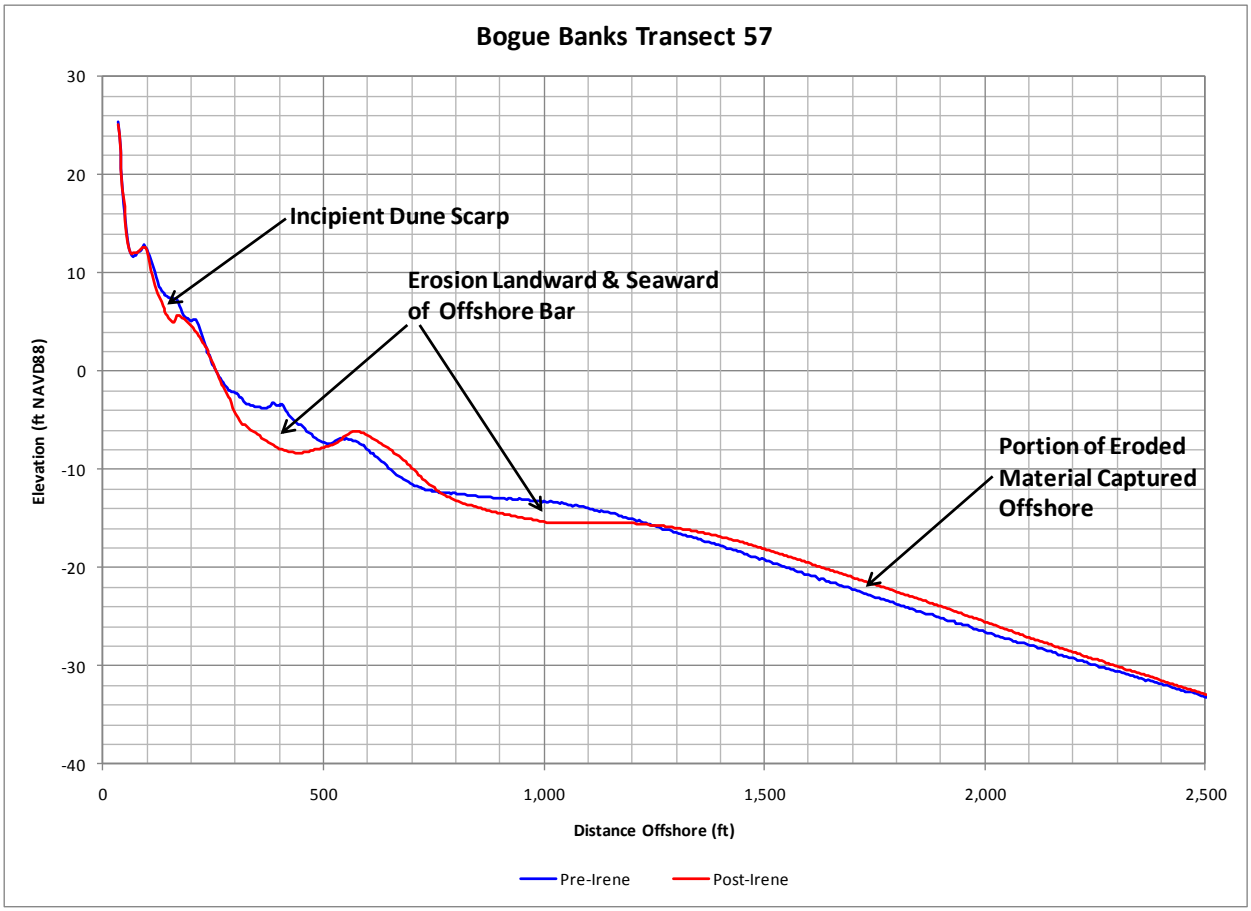

Figure 14. Indian Beach/Salter Path Representative Profile

Figure 15 displays the unit volume change at each transect for the Indian Beach/Salter Path region. Significant erosion occurred within the reach, with much of the material being captured offshore between -20 ft NAVD88 and -30 ft NAVD88.

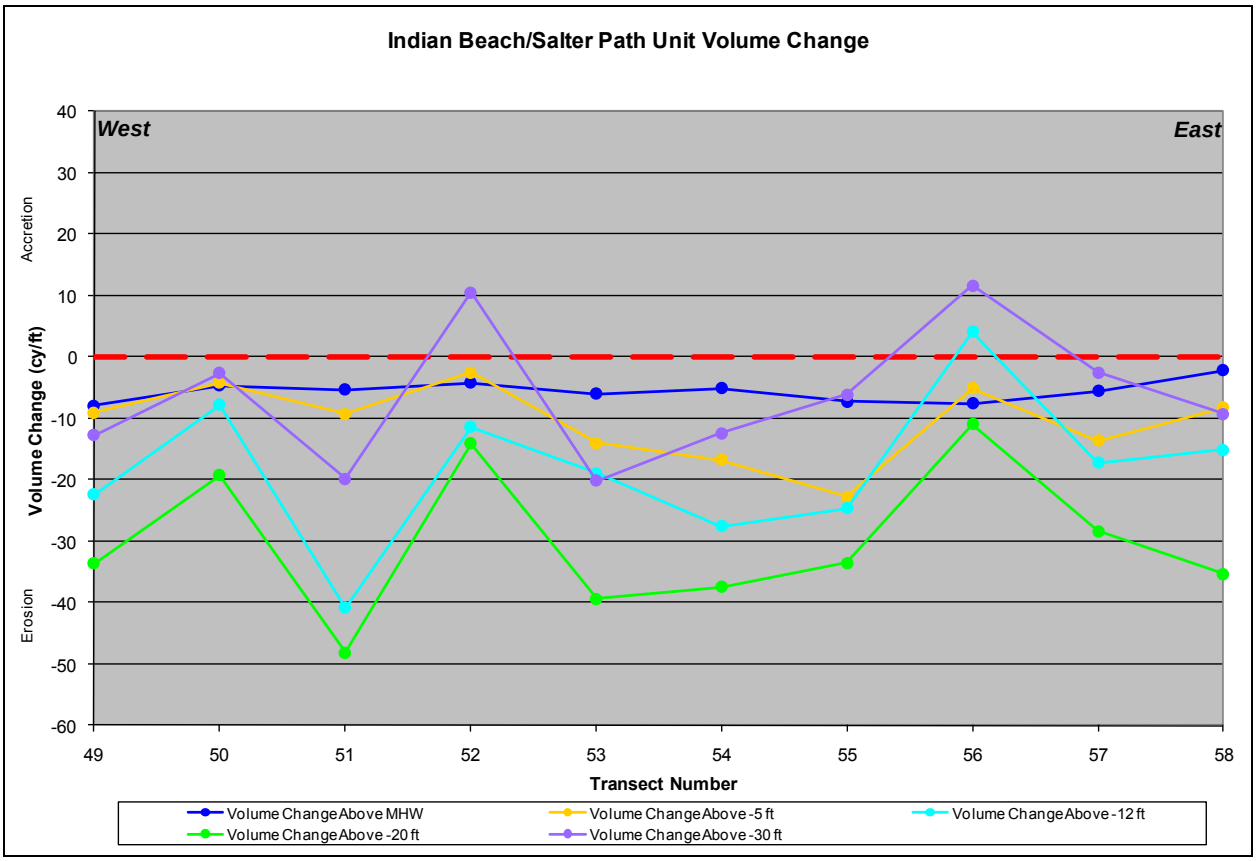

Figure 15. Indian Beach/Salter Path Unit Volume Change (June 2011 – September 2011)

At post-storm inspection locations in this reach (Transects 49 through 58), the incipient dune generally shows a 2 to 4 ft scarp, though a slightly larger scarp and greater landward impact to the incipient dune was noted in front of the Colony by the Sea (**Photo 7**) near Transect 56.

The survey profiles all show a prominent bar formed between 500 and 800 feet offshore of the survey baseline in depths of -8 to -10 ft NAVD. Significant volume loss occurred seaward of the bar between -10 ft and -16 ft NAVD, with some volume gain to the profile seaward of -16 ft NAVD. The profiles along this reach show varying degrees of volume loss landward of the bar, with most of the obvious loss concentrated between -2 ft and -8 ft NAVD.

Photo 7. Colony by the Sea looking west

6.2.3. Pine Knoll Shores

The Pine Knoll Shores region covers transects 59 through 76, and it is also fully within the County Project. Since monitoring efforts began in 1999, the Pine Knoll Shores region has received 2.16 million cy of nourishment material as a result of the Bogue Banks Beach Restoration Project, USACE Section 933 projects, and FEMA funded post-storm work (Hurricane Ophelia). A summary of average shoreline and volume changes between June 2011 and September 2011 for the Pine Knoll Shores region are presented in **Table 8**.

Table 8. Average Shoreline and Volume Change for Pine Knoll Shores

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Pine Knoll Shores-West (59-65)	9,063	6.4	-3.6	-32,250	-3.8	-34,590	-11.3	-102,188	-32.8	-297,329	-16.2	-147,017
Pine Knoll Shores-East (66-76)	14,815	15.5	-2.6	-38,432	-0.5	-7,258	-7.6	-112,555	-20.6	-304,670	-5.3	-77,848
Total	**23,878**	**12.1**	**-3.0**	**-70,681**	**-1.8**	**-41,848**	**-9.0**	**-214,744**	**-25.2**	**-601,999**	**-9.4**	**-224,865**

The Pine Knoll Shores shoreline generally advanced seaward due to Hurricane Irene, especially within Pine Knoll Shores East. This shoreline progression was mainly due to the erosion of the incipient dune with this material flattening and slightly widening the beach at the MHW line. The profile plots in **Appendix B** show slight accretion of the recreational beachface and erosion of the incipient dune throughout the Pine Knoll Shores region. **Figure 16** shows a representative profile for the Pine Knoll Shores region, indicating the above mentioned characteristics.

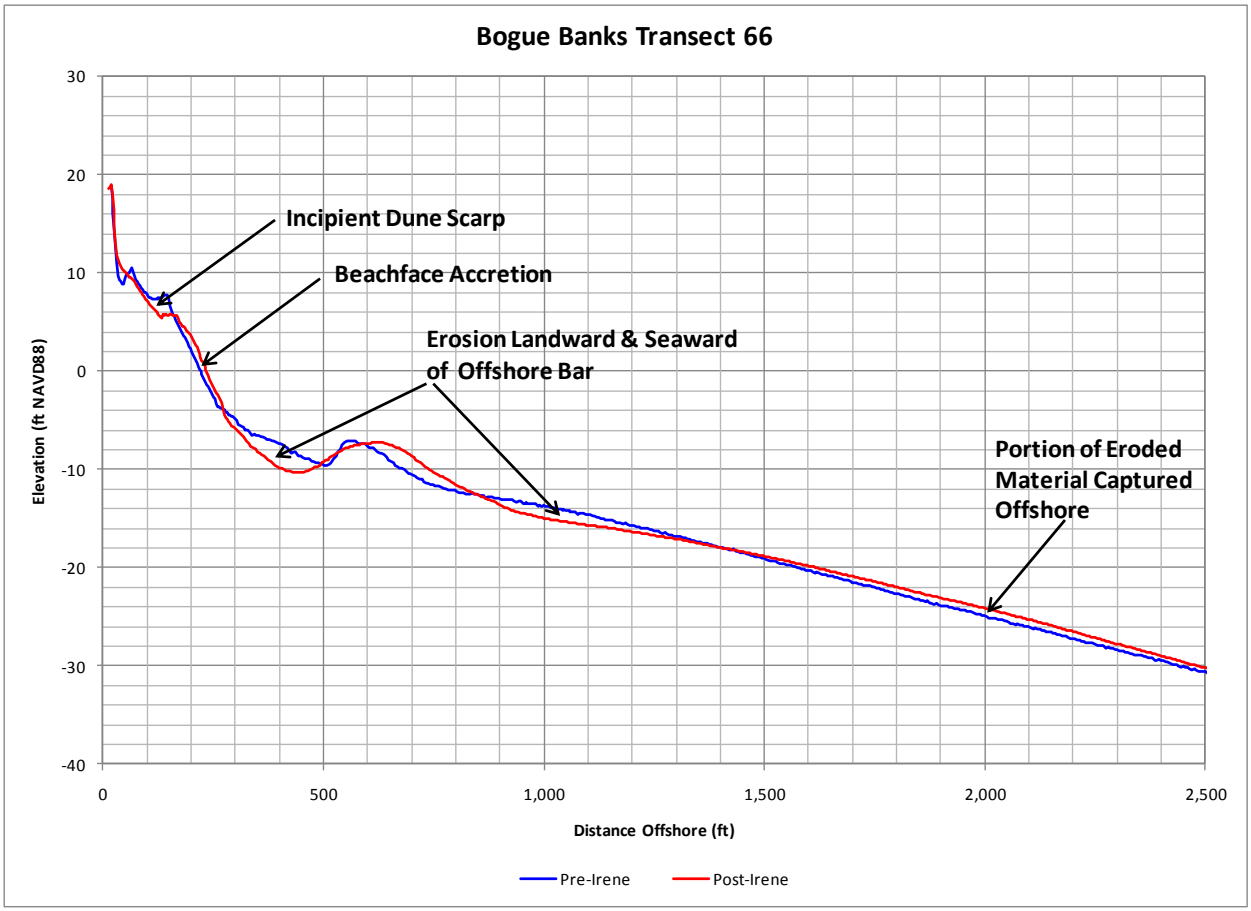

Figure 16. Pine Knoll Shores Representaive Profile

Despite accretion of the recreational beachface, **Table 8** indicates a trend of net volume loss similar to the reaches discussed above, with net erosion above all elevations considered. Pine Knoll Shores lost a total of 215,000 cy of material above -12 ft NAVD88 due to Hurricane Irene. Still, the average unit volume changes for this reach are the lowest out of those reaches included within the County Project, losing approximately -11.3 cy/ft on average at Pine Knoll Shores West and -7.6 cy/ft on average at Pine Knoll Shores East. **Figure 17** displays the unit volume change at each transect for the Pine Knoll Shores region. The profile plots in **Appendix B** show that the incipient dune was eroded in most profiles with erosion both landward and seaward of the offshore bar in many cases (**Figure 16**).

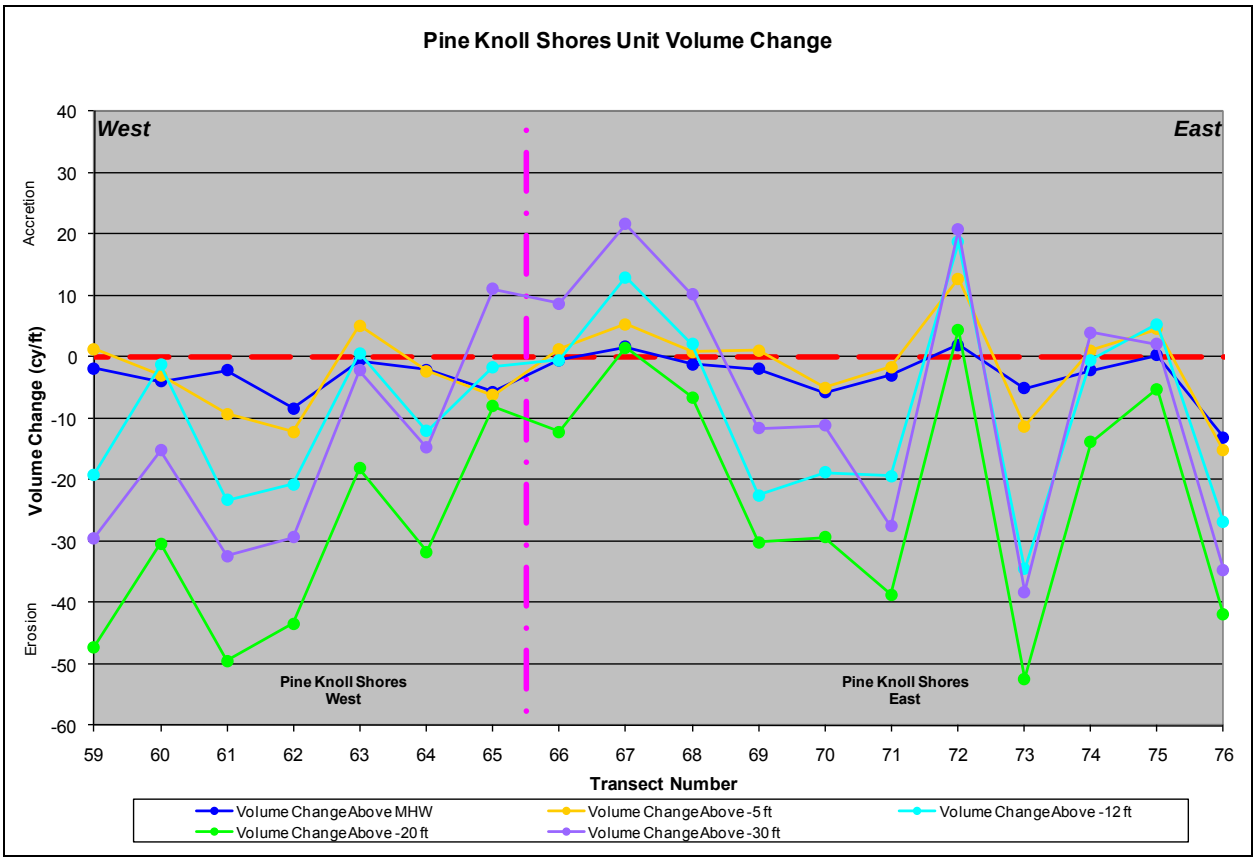

Figure 17. Pine Knoll Shores Unit Volume Change (June 2011 – September 2011)

Post-storm inspection shows damage to the incipient and/or primary frontal dunes was generally consistent with impacts described for Indian Beach / Salter Path. The post-storm inspection indicated severe scarping (4 to 6 ft vertical) to complete removal of the incipient dune, with slight damage to the frontal dune in some locations. At the Clamdigger Hotel (**Photo 8**) and Memorial Park (**Photo 9**), the incipient dune was completely removed and the frontal dune was slightly damaged. However, between these locations at the Pine Knoll Townes condos the primary dune was within 3 ft of breaching (**Photo 10**).

Photo 8. Clamdigger looking west

The survey profiles adjacent to Clamdigger (Transects 61 through 64) showed volume change trends similar to those observed in Emerald Isle and Indian Beach / Salter Path, with significant erosion between -3 ft and -9 ft NAVD88 followed by a prominent bar between -8 ft and -10 ft NAVD88. Significant additional volume loss occurred between -12 ft and -16 ft NAVD88.

At Pine Knoll Townes and Memorial Park (Transects 69 through 73) the profiles indicate less volume loss than in the more western reaches of Pine Knoll Shores (e.g. near and west of Clamdigger).

Photo 9. Memorial Park looking west

Photo 10. Pine Knoll Townes looking north

A low-crested concrete seawall exists at the Iron Steamer, near Transect 66 between the Clamdigger and Pine Knoll Townes condos. The post-storm inspection showed that the wall was clearly overtopped and the incipient dune was removed (**Photo 11**). The primary dune was also damaged somewhat (**Photo 12**, background), and the overwalk was lifted off its vertical supports. Interestingly, the survey profiles in this vicinity (Transects 65 through 68) show comparatively less net volume change between +4 ft and -12 ft NAVD88 than transects to the west.

Photo 11. Iron Steamer looking west

Photo 12. Iron Steamer looking north

6.2.4. Atlantic Beach

The Atlantic Beach region covers transects 77 through 102. This reach is not within the County Project, but is instead the recipient of material dredged from the USACE's Morehead City Harbor navigation project. Since monitoring began in 1999, Atlantic Beach has received 3.72 million cy of nourishment material from the Brandt Island Pump Out and USACE dredge disposal. Most recently, Atlantic Beach was nourished from Transect 90 through 102 with approximately 800,000 cy of material from November 2010 through April 2011 as part of Year 1 of the USACE Interim Operations Plan for the Morehead City Harbor Dredged Material Management Plan (DMMP). A summary of average shoreline and volume changes between June 2011 and September 2011 for the Atlantic Beach region are presented in **Table 9**.

Table 9. Average Shoreline and Volume Change for Atlantic Beach

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Atlantic Beach (77-102)	**26,176**	**6.8**	**-6.0**	**-156,328**	**-7.5**	**-197,552**	**-13.9**	**-362,678**	**-15.1**	**-395,857**	**-18.8**	**-490,869**

It is important to note that since Atlantic Beach is not included within the County Project and is therefore not eligible for FEMA reimbursement, the number of transects surveyed post-storm is less than the number surveyed for the BBBNMP. Therefore, the uncertainty associated with the aggregate volume change estimates of this long of a distance (≈5 miles) is significantly higher. Based on the six transects surveyed post-storm, Atlantic Beach experienced slight accretion of the shoreline with volumetric erosion above all elevations considered. Atlantic Beach lost approximately 363,000 cy of material above -12 ft NAVD88. **Along the reach that was nourished (Transects 90-102), the loss is approximately 234,630 cy.** Upon

inspection of the profile plots in **Appendix B**, and according to **Table 9**, the material eroded from above -20 ft NAVD88 was not as well captured offshore above -30 ft NAVD88, as compared to the reaches encompassed by the County Project. Profile plots in **Appendix B** show erosion of the incipient dune and offshore bar, similar to the other reaches. **Figure 18** shows a representative profile for Atlantic Beach.

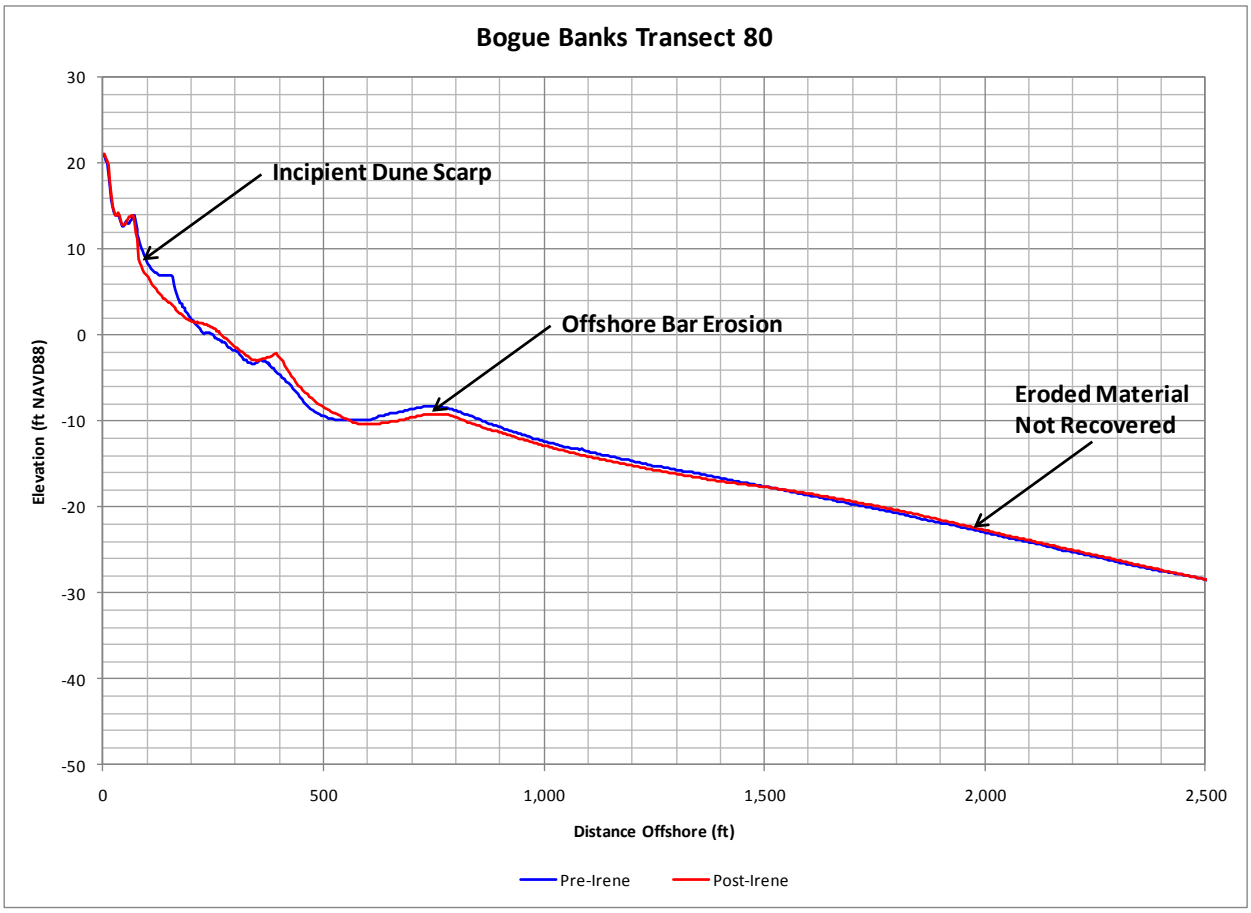

Figure 18. Atlantic Beach Representative Profile

Figure 19 shows the trends presented in **Table 9**, indicating a high degree of variability in the storm's impacts to the Atlantic Beach profiles.

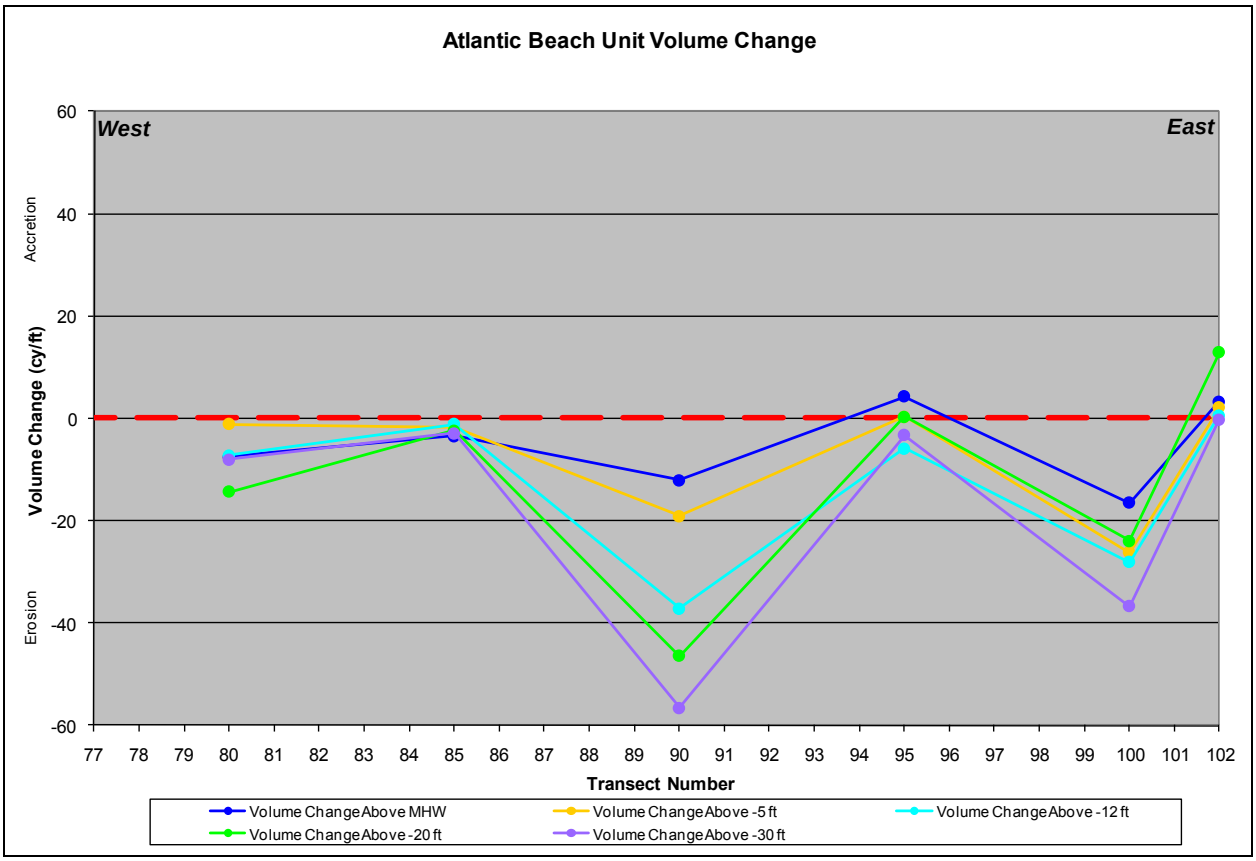

Figure 19. Atlantic Beach Unit Volume Change (June 2011 – September 2011)

Observations from the post-storm field inspection include the following. Near the Sheraton in Atlantic Beach (transects 78 and 79), the incipient dune was removed and the primary dune showed a scarp of 2 to 4 ft vertical (**Photo 13**). The Sheraton pier also sustained damage during the storm (**Photo 14**) with the ocean end being completely removed.

Photo 13. Sheraton beach access looking east

Photo 14. Sheraton pier damage

The pre-storm frontal dune between the Coral Bay Club and the Club Colony Drive (Transects 80 through 100) was generally low-crested and wide, in contrast to some further western areas of Bogue Banks with steeper, higher frontal dune profiles. The impacts of the storm at Coral Bay Club (Transect 80) included a 4 to 6 ft scarp (**Photo 15**) and overwash of sand into the parking lot behind the frontal dune (**Photo 16**).

Photo 15. Coral Bay Club looking north

Photo 16. Coral Bay Club AB parking lot showing sand overwash

At Ocean Ridge (Transect 85), the Circle (Transect 90) and Oceanna Pier (Transect 95), the storm caused a 2 to 4 ft scarp to develop along stretches of the primary dune (**Photo 17** and **Photo 18**). Waves appear to have impacted the dune to within 3 ft (vertical) of the dune crest, and the survey profiles 90 and 95 indicate net volume loss landward of -10 ft NAVD88.

Photo 17. Ocean Ridge looking west

Photo 18. The Circle in Atlantic Beach looking west

6.2.5. Fort Macon State Park

The Fort Macon State Park region covers transects 103 through 112. This reach is not within the County Project, 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 1.27 million cy of nourishment material from USACE Inner Harbor Dredging Disposal. Most recently, 550,000 cy of material was placed at Fort Macon from November 2010 through April 2011 as part of the USACE Phase I Interim Operations Plan. A summary of average shoreline and volume changes between June 2011 and September 2011 for the Fort Macon State Park region are presented in **Table 10**.

Table 10. Average Shoreline and Volume Change for Fort Macon State Park

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Fort Macon State Park (103-112)	**6,691**	**-41.1**	**-7.8**	**-52,480**	**-18.0**	**-120,558**	**-7.2**	**-48,058**	**12.2**	**81,416**	**24.2**	**162,104**

It is important to note that only 2 profiles were surveyed at Fort Macon since it is not included within the County Project and not eligible for FEMA reimbursement. Therefore, the uncertainty with aggregated volume calculations is significantly higher. The westernmost transect showed considerable erosion of the recent nourishment project while the transect closest to the terminal groin showed accretion. It is possible the new nourishment material was transported east towards the terminal groin in this region. Based on the two transects, Fort Macon lost approximately 48,000 cy of material above -12 ft NAVD88 but gained material overall above -20 ft NAVD88 and -30 ft NAVD88. This is likely the result of erosion of the recent beach nourishment material from Atlantic Beach being transported east to the eastern end of Fort Macon through inlet-influenced transport processes. **Figure 20** displays the unit volume change at each transect in the Fort Macon State Park region.

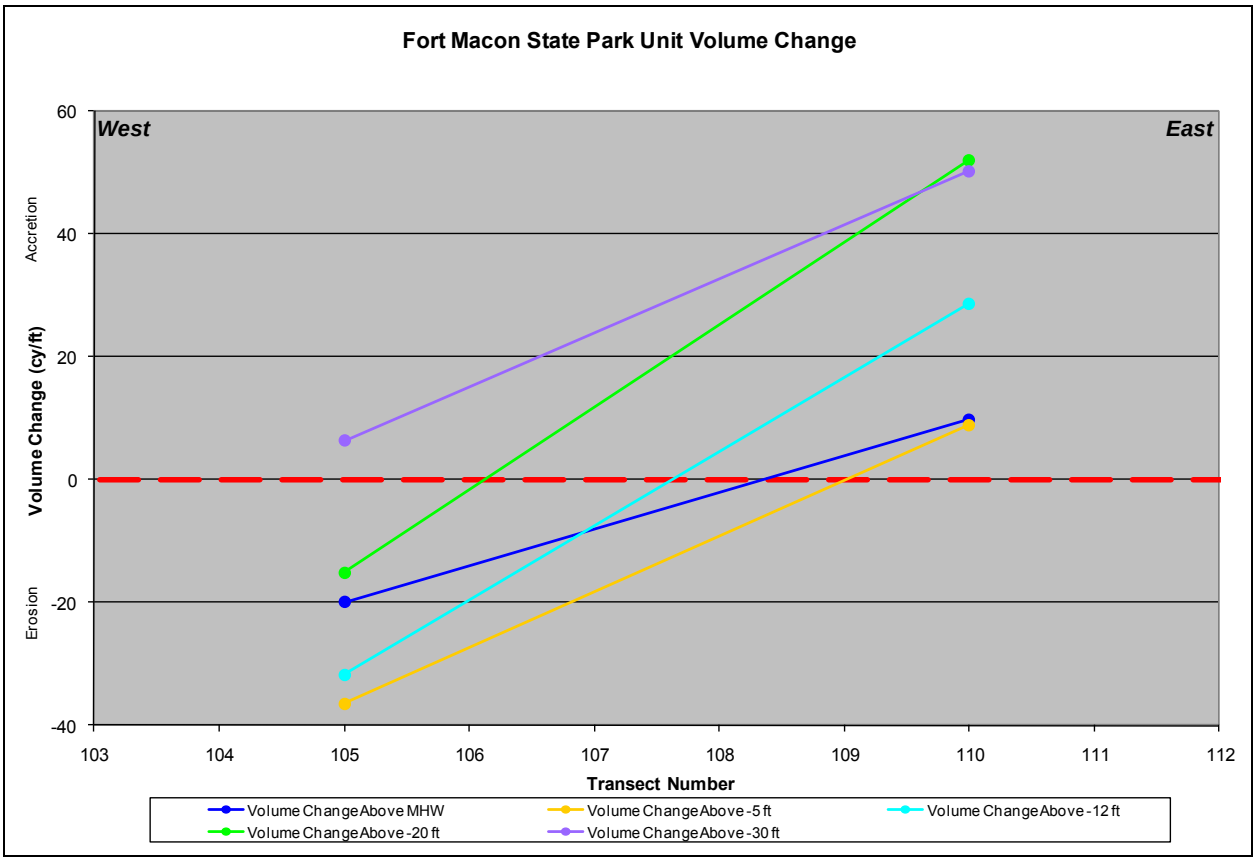

Figure 20. Fort Macon State Park Unit Volume Change (June 2011 – September 2011)

6.2.6. Bogue Inlet

The Bogue Inlet region is comprised of an area along the oceanfront at the extreme western end of Emerald Isle, covered by transects 1 through 8 and an area along the eastern side of Bogue Inlet covering transects 117 through 120. This oceanfront immediately adjacent to Bogue Inlet is not within the bounds of the County Project engineered beach. A summary of average shoreline and volume changes between June 2011 and September 2011 for the Bogue Inlet region are presented in **Table 11**.

Table 11. Average Shoreline and Volume Change for Bogue Inlet

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Inlet-Ocean (1-8)	7,432	8.5	-4.1	-30,297	-10.1	-75,280	-18.6	-138,201	-5.2	-38,663	13.7	101,935
Bogue Inlet-Channel (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

This region is highly dynamic due to the inlet. This can be seen in the survey evaluation plots in the profiles presented in **Appendix B**. Due to the quickly changing extents of the shoreline located along the Bogue Inlet Channel region, calculations were not performed at transect 117 through 120. However, by inspection of the the profile plots in **Appendix B**, it appears the seaward side of the "Point" experienced accretion (transects 117B and 117) but erosion occurred further towards the sound (transect 118).

The computed average MHW shoreline change rate of +8.5 ft (seaward) is not very representative of the individual transects in the reach. Transects 1 and 2 shorelines (nearest the inlet) advanced 124 ft and 34 ft, respectively. Transects 3 and 4 showed marked shoreline retreat of approximately 70 ft. Transects 5 shoreline retreated 7 ft and transects 7 and 8 shorelines moved less than 3 ft in either direction. Transect 6 shoreline advanced approximately 14 ft. Again, this type of behavior is not uncommon near dynamic inlets.

Overall, the Bogue Inlet-Ocean oceanfront reach lost approximately 138,000 cy of material above -12 ft NAVD88 due to Hurricane Irene. However, the material appears to have been captured offshore above -30 ft NAVD88. The "Point" experienced some accretion during Hurricane Irene while the remainder of the reach experienced the characteristic loss of the incipient dune and erosion on either side of the bar. **Figure 21** displays the unit volume change at each transect for the Bogue Inlet Ocean region.

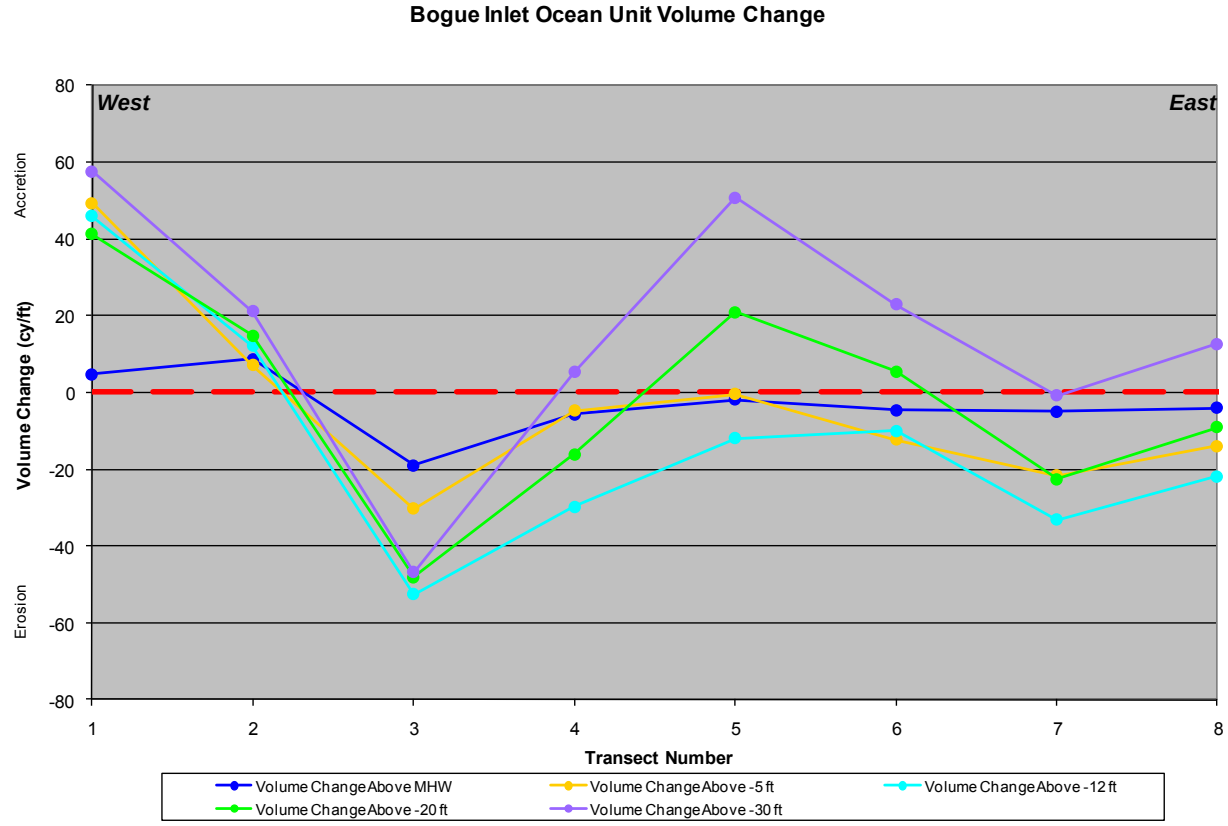

Figure 21. Bogue Inlet Ocean Unit Volume Change (June 2011 – September 2011)

6.2.7. Beaufort Inlet

The Beaufort Inlet region is comprised of an area along the western side of Beaufort Inlet which covers transects 113 through 116. A summary of average shoreline and volume changes between June 2011 and September 2011 for the Beaufort Inlet region are presented in **Table 12**. It is important to note that only one transect was surveyed post-storm along Beaufort Inlet.

Table 12. Average Shoreline and Volume Change for Beaufort Inlet

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Beaufort Inlet (113-116)	**2,000**	**-88.3**	**0.5**	**952**	**-11.5**	**-23,020**	**-29.6**	**-59,154**	**-40.3**	**-80,600**	**-43.0**	**-86,054**

The one transect survey in this reach shows significant erosion of the shoreline, with some of the material being pushed further onshore. This transect lost approximately 29.6 cy/ft of material above -12 ft NAVD88 which would equate to a loss of approximately 59,000 cy of material along the 2,000 ft stretch of beach if all areas along the reach experienced similar erosion.

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 June 2011 by Geodynamics. Geodynamics conducted a post-storm survey between August 29 – September 2, 2011, immediately following the passage of Hurricane Irene. For this storm impact evaluation, the June 2011 survey was compared with the early September 2011 survey. The profile data have been used to compute shoreline change at MHW (+1.1 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 13** below.

Table 13. Average Shoreline and Volume Change Attributable to Hurricane Irene Along Bogue Banks Entire and the Bogue Banks County Project

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Banks Oceanfront (1-112)	128,393	0.3	-4.5	-577,135	-7.8	-996,059	-15.2	-1,952,298	-19.6	-2,513,146	-5.3	-675,223
Bogue Banks County Project (9-76)	**88,094**	**0.8**	**-3.8**	**-338,030**	**-6.8**	**-602,668**	**-15.9**	**-1,403,361**	**-24.5**	**-2,160,042**	**-5.1**	**-448,393**

Based on these calculations, the Bogue Banks oceanfront, on average, experienced a small degree of shoreline accretion at MHW due to Hurricane Irene. Shoreline positions near the inlets in the Fort Macon and Bogue Inlet-Ocean regions showed the greatest change and variability of change, as would be expected. Hurricane Irene caused a net loss of beach volume above all contours analyzed for the entire County Project area of the Bogue Banks oceanfront. Taking -12 ft NAVD88 as the practical offshore limit for material being available for storm protection and

FEMA reimbursement, the volume loss to the County Project above -12 ft NAVD88 was approximately 1.40 million cubic yards (1,403,361 cy). **After subtracting the small portion of State owned shoreline within the Indian Beach/Salter Path reach, the official volume amount eligible for FEMA reimbursement is 1,344,123 cy.** A breakdown of this volume is shown in **Table 14**.

Table 14. Volume Change From Top of Dune to -12 ft NAVD88 for County Project (FEMA Reimbursement)

Reach (Profiles)	Volume Change (cy)	Volume Change Eligible for FEMA Reimbursement (cy)
Emerald Isle-West (9-25)	-579,219	-579,219
Emerald Isle-Central (26-36)	-216,386	-216,386
Emerald Isle-East (37-48)	-157,073	-157,073
Total Emerald Isle (9-48)	***-952,679***	***-952,679***
Indian Beach-Salter Path (49-58)	***-235,939***	***-176,701***
Pine Knoll Shores-West (59-65)	-102,188	-102,188
Pine Knoll Shores-East (66-76)	-112,555	-112,555
Total Pine Knoll Shores (59-76)	***-214,744***	***-214,744***
Overall Total	**-1,403,361**	**-1,344,123**

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.

Appendix A
Shoreline & Volume Change Plots

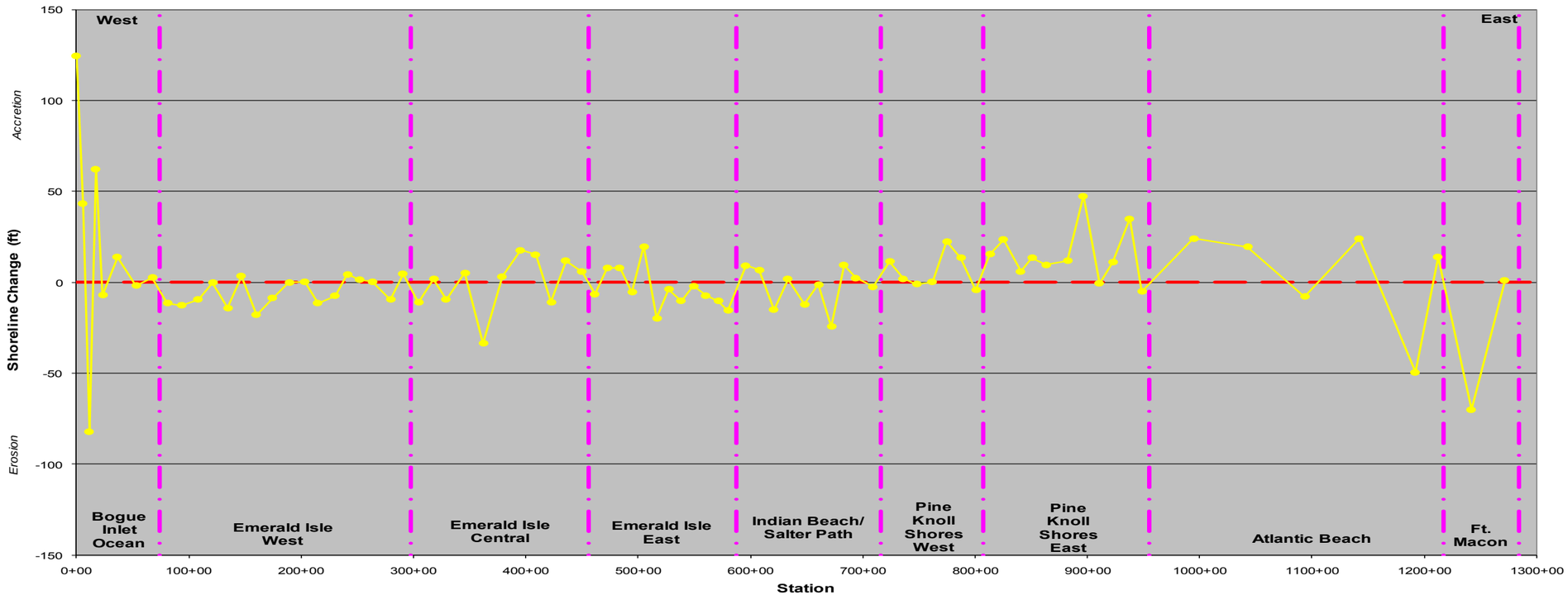

Figure A-1. Shoreline Change for Bogue Banks (June 2011-September 2011)

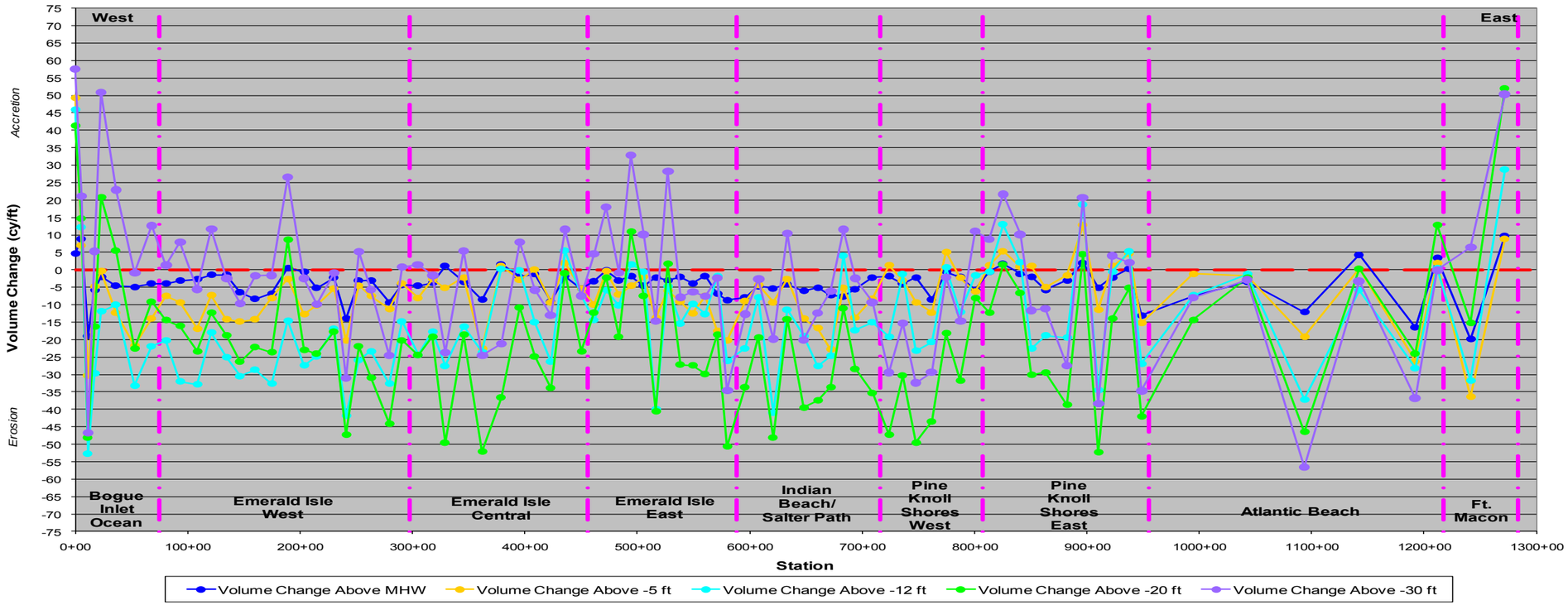

Figure A-2. Volume Change for Bogue Banks (June 2011-September 2011)

Appendix B
Profile Comparison Plots

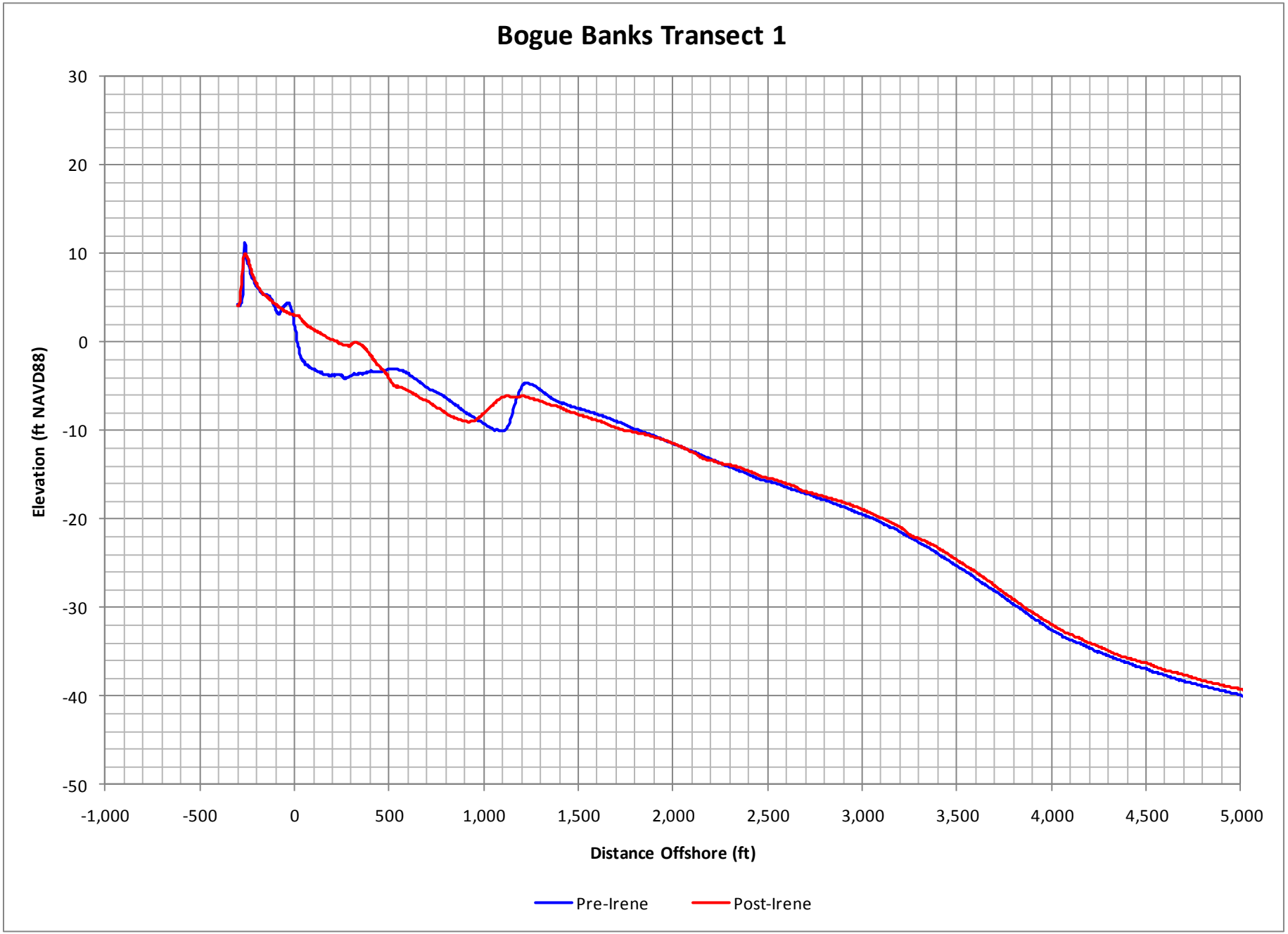

Figure B-1. Bogue Banks Profile Comparison

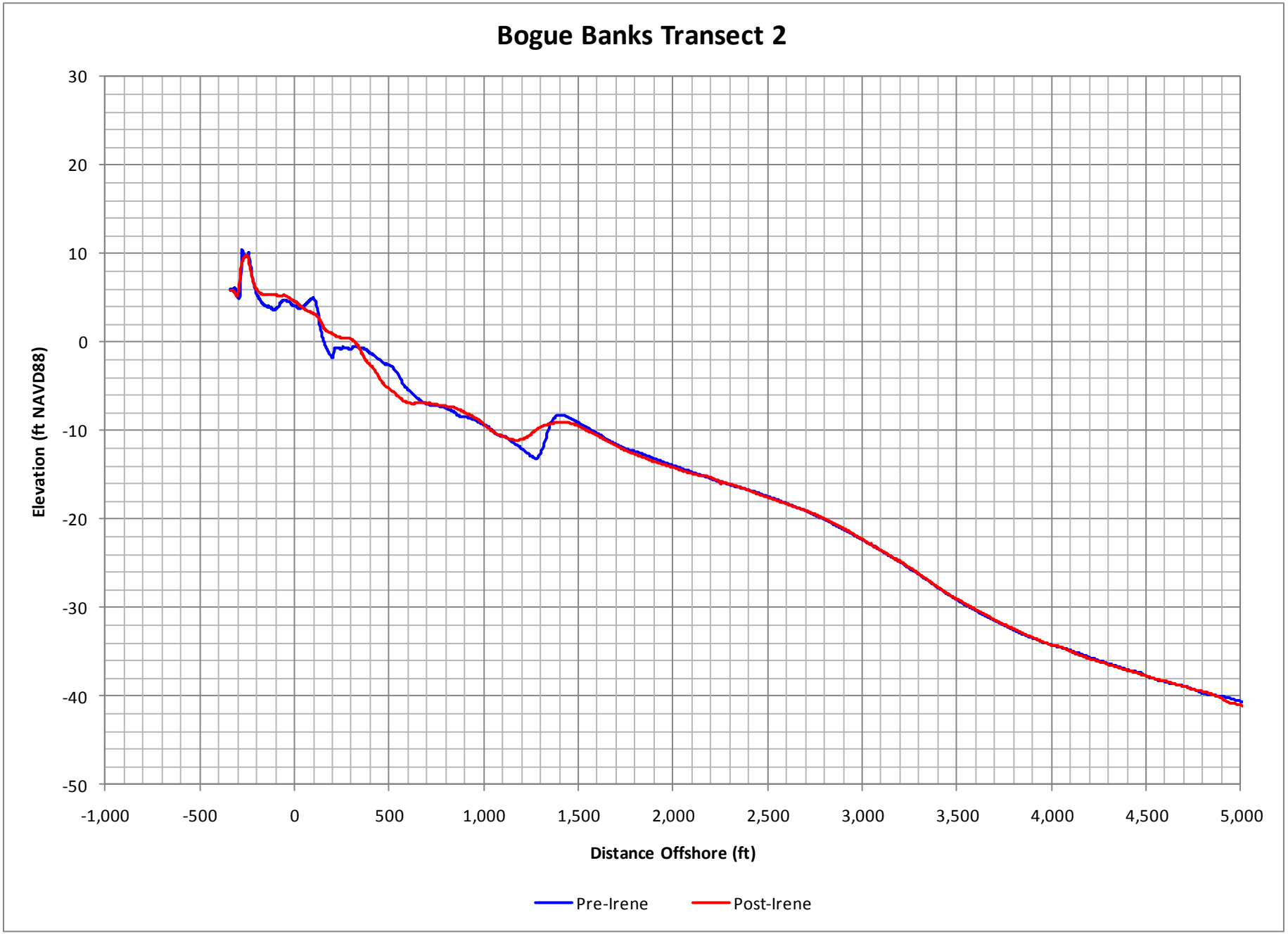

Figure B-2. Bogue Banks Profile Comparison

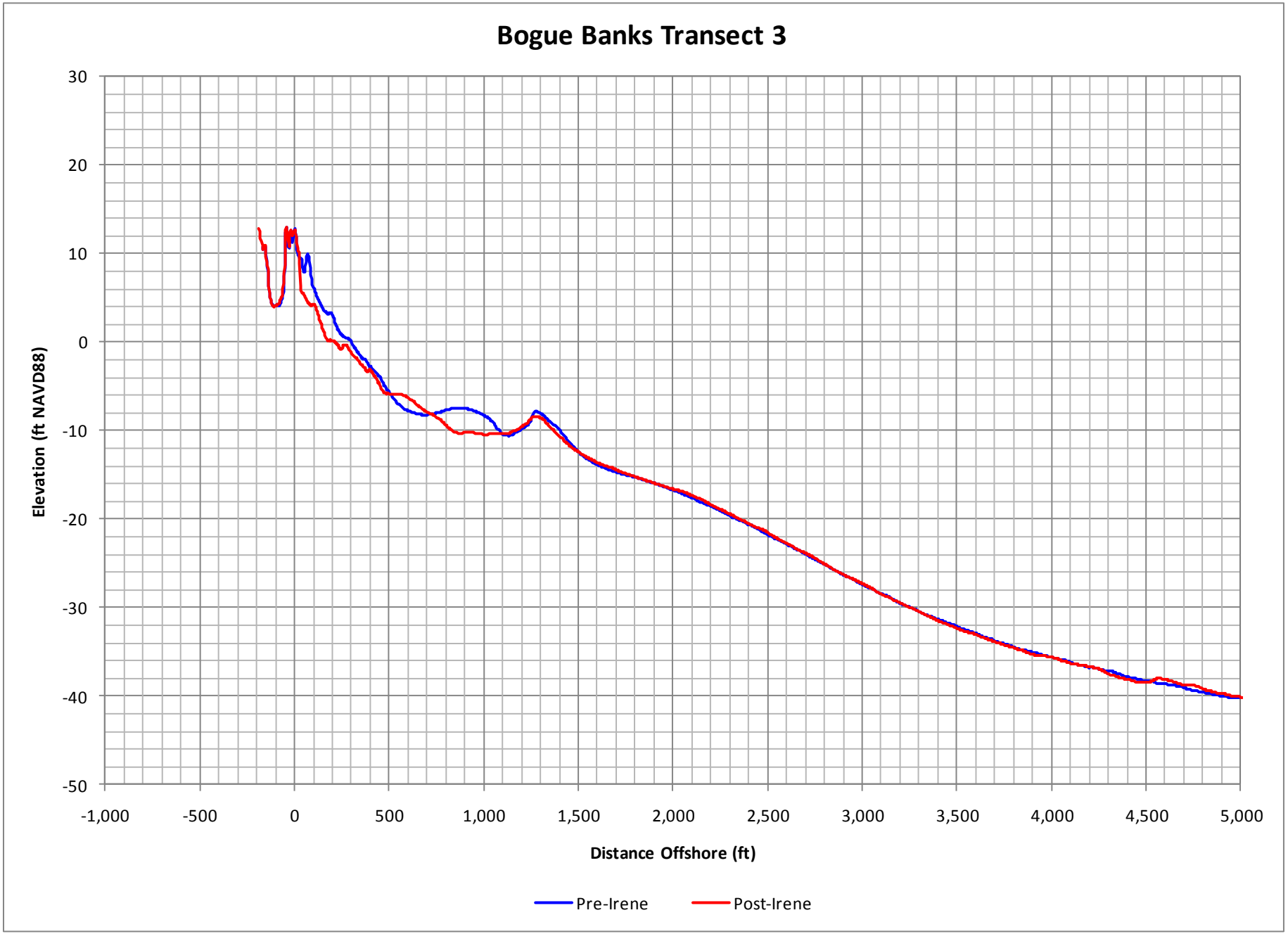

Figure B-3. Bogue Banks Profile Comparison

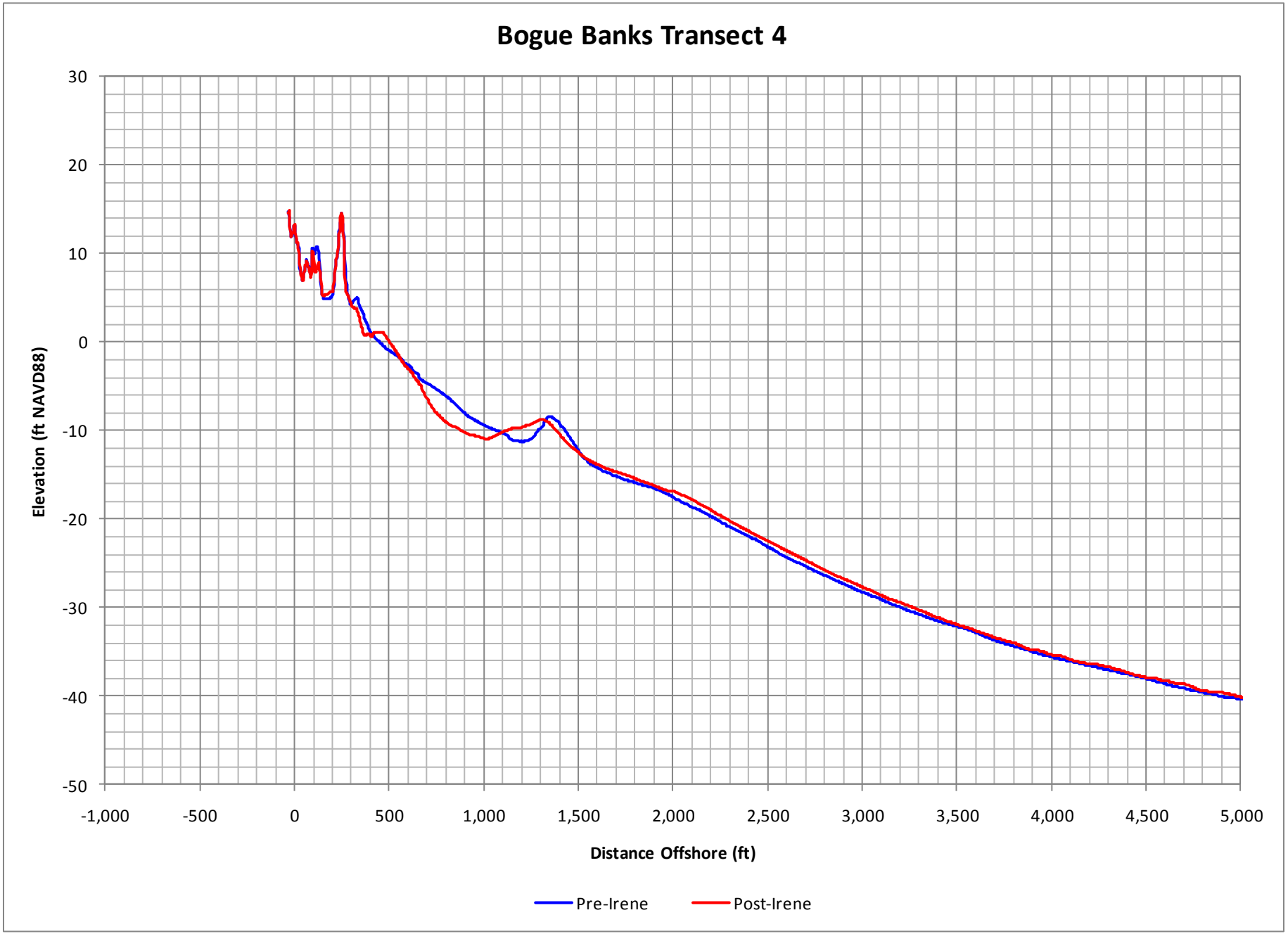

Figure B-4. Bogue Banks Profile Comparison

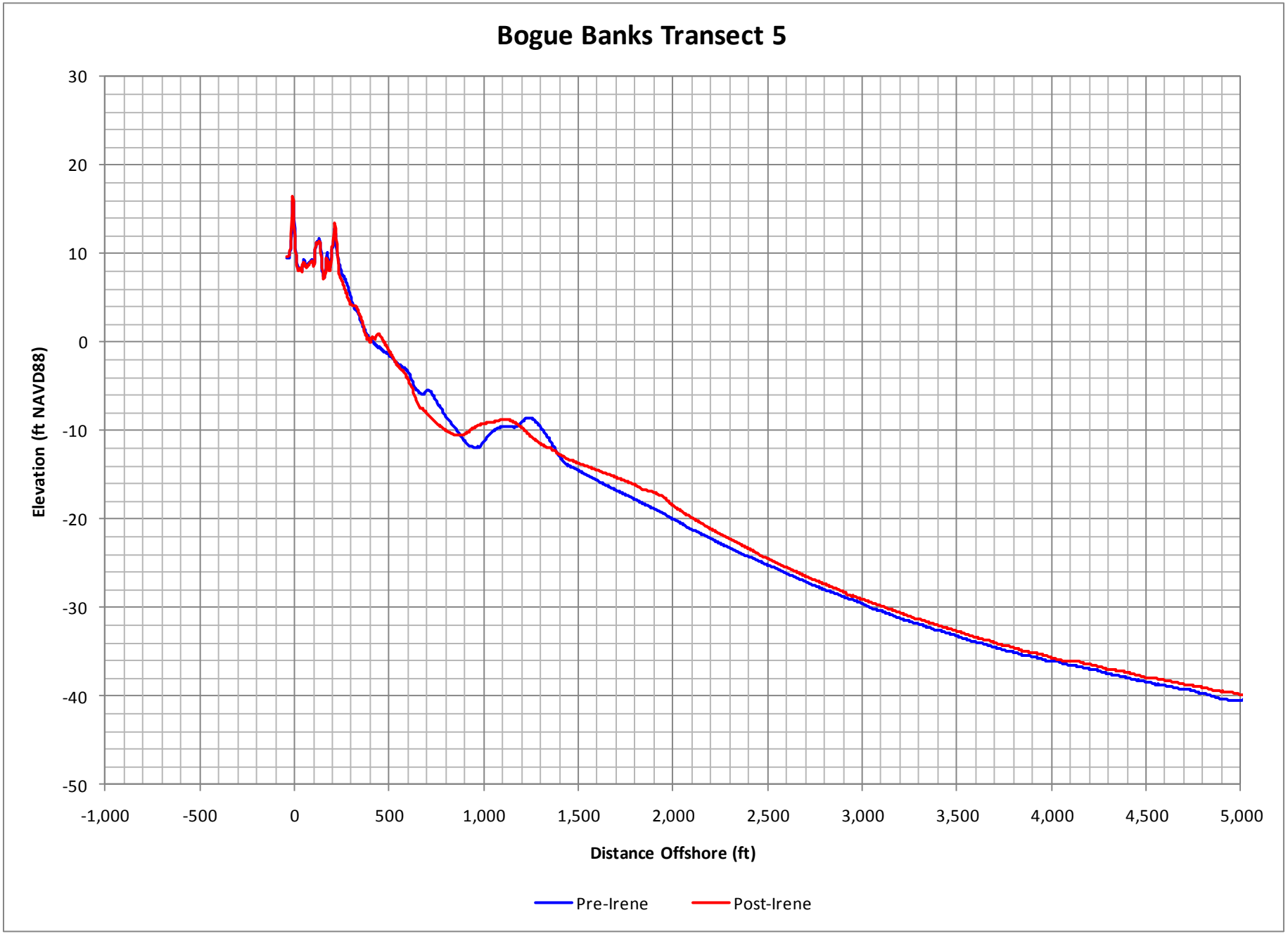

Figure B-5. Bogue Banks Profile Comparison

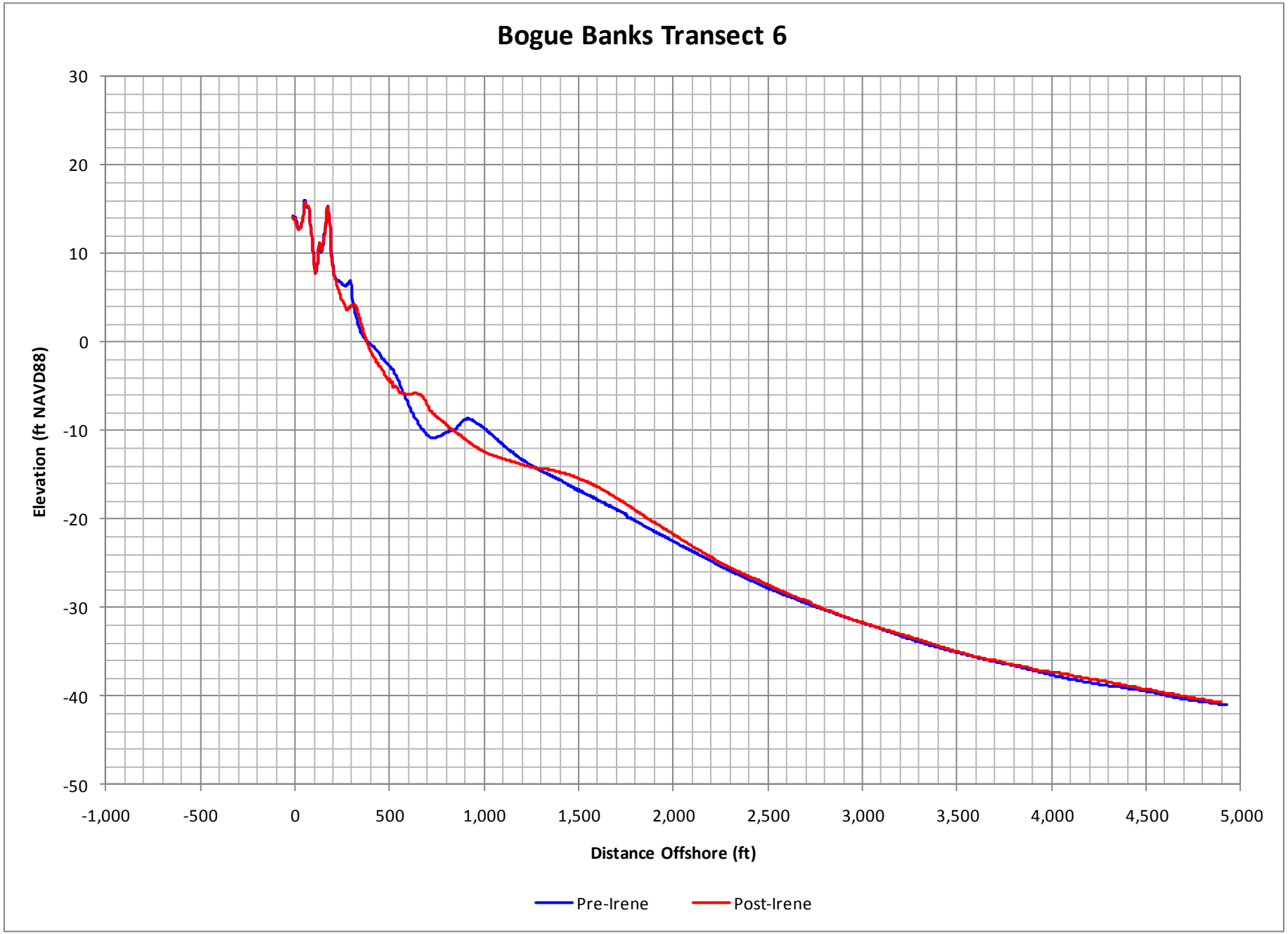

Figure B-6. Bogue Banks Profile Comparison

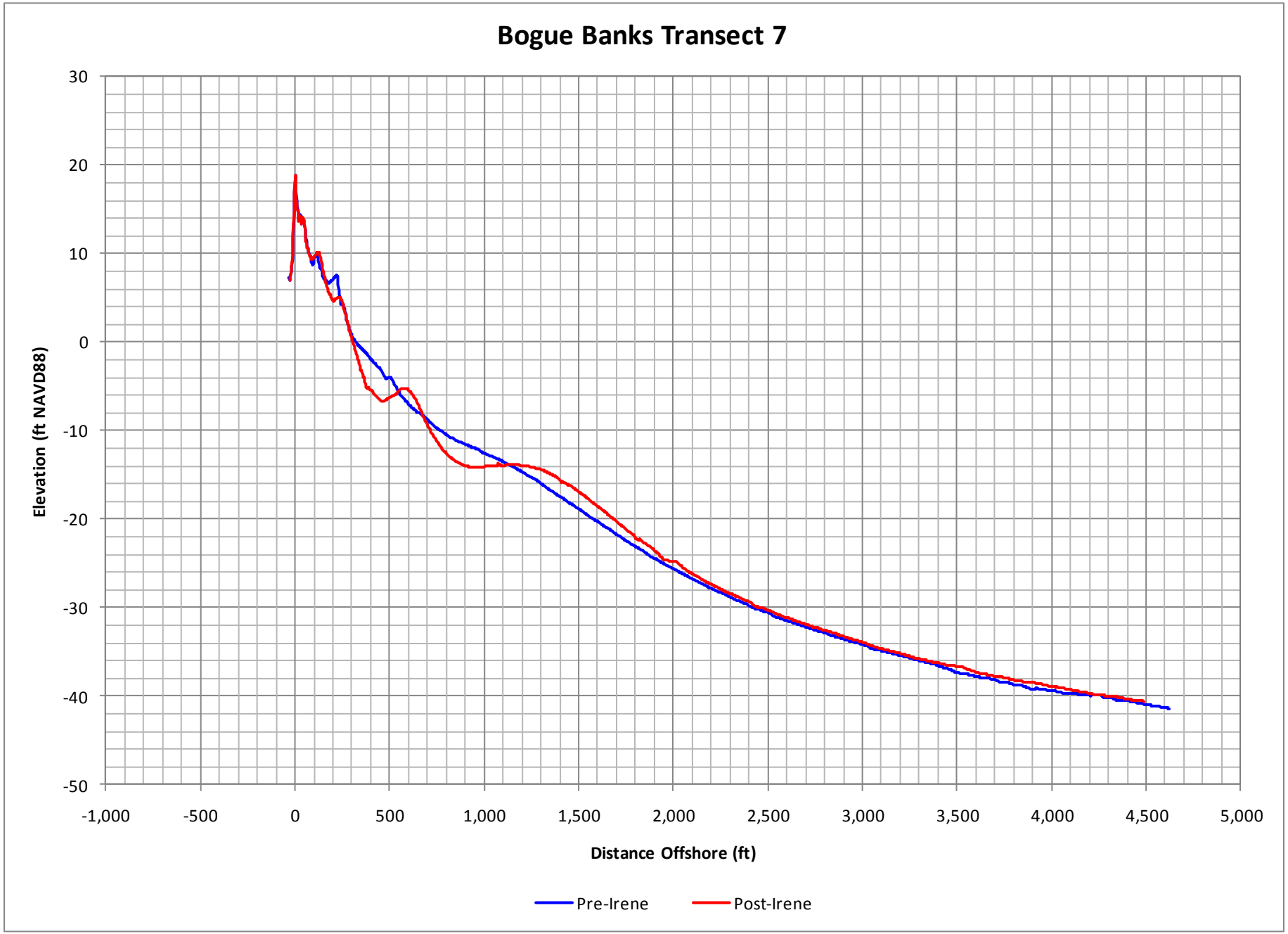

Figure B-7. Bogue Banks Profile Comparison

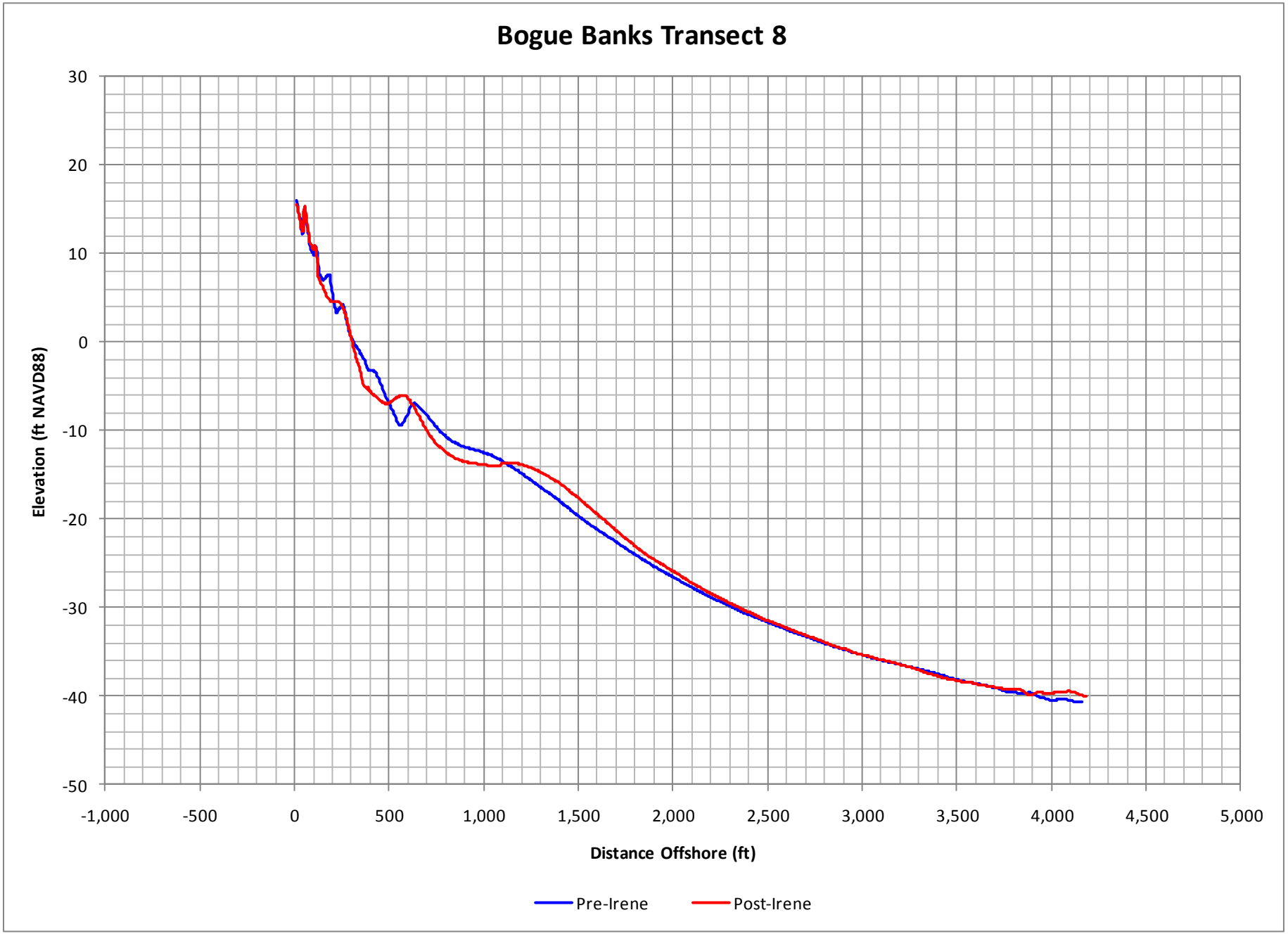

Figure B-8. Bogue Banks Profile Comparison

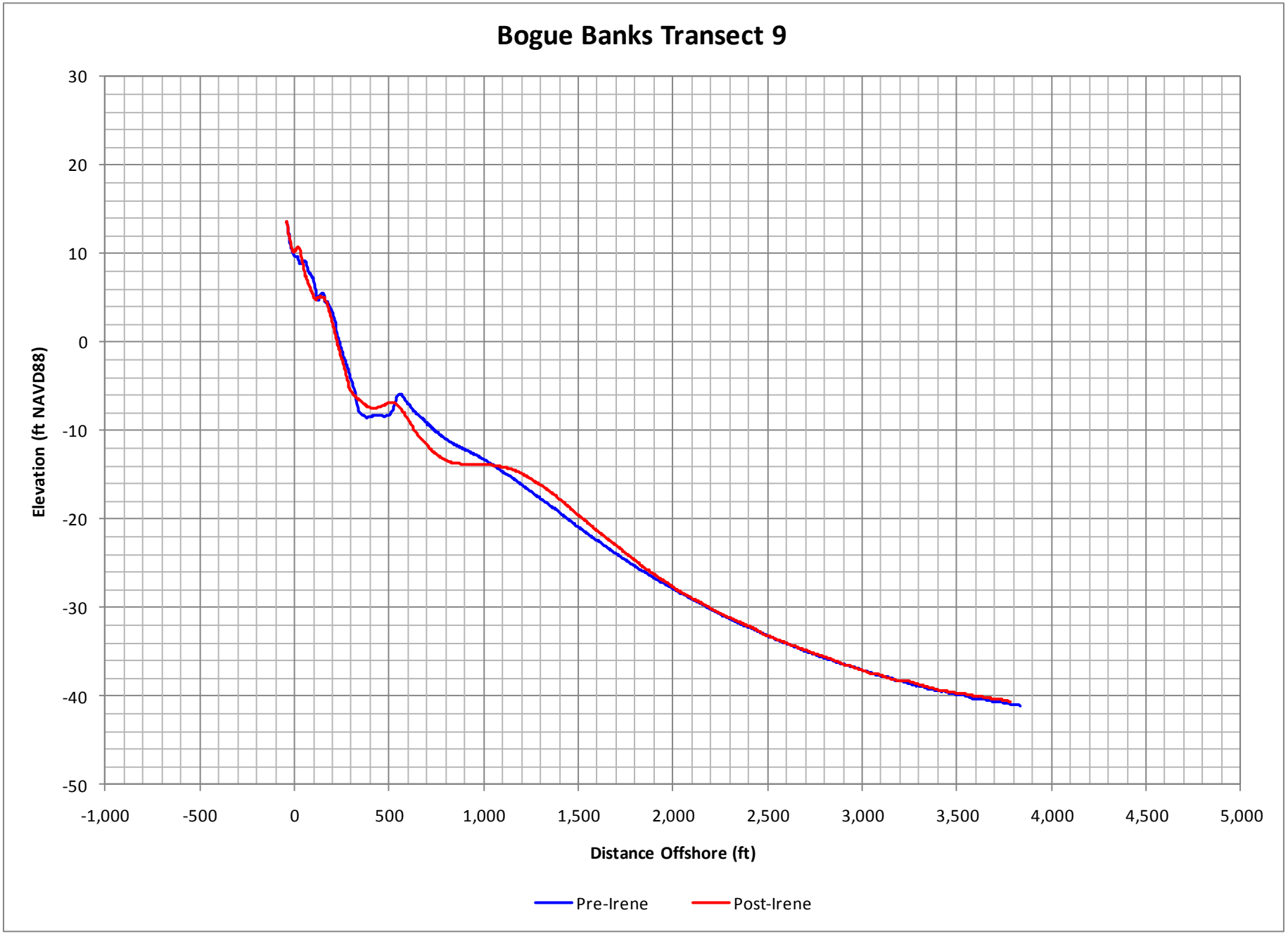

Figure B-9. Bogue Banks Profile Comparison

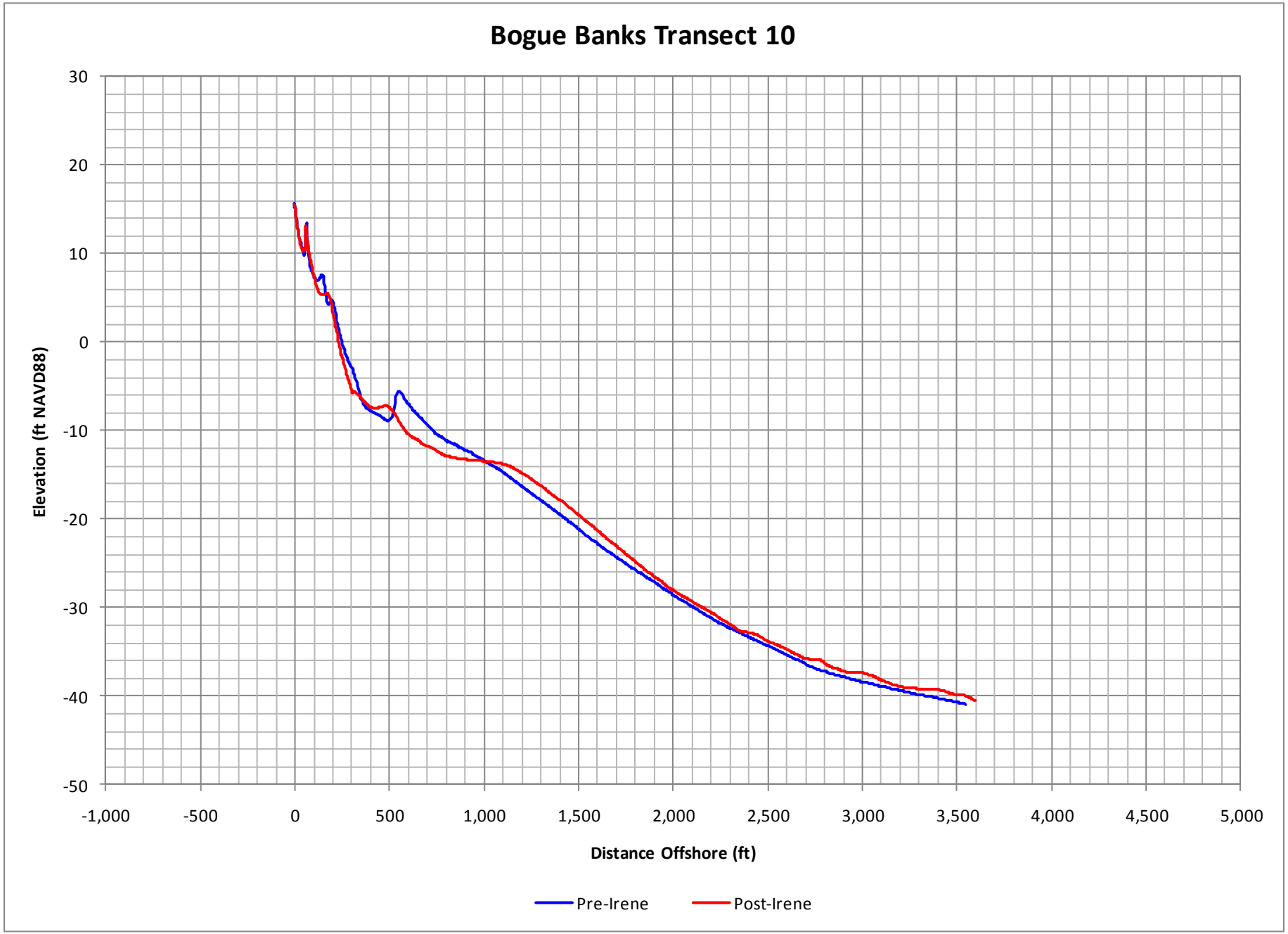

Figure B-10. Bogue Banks Profile Comparison

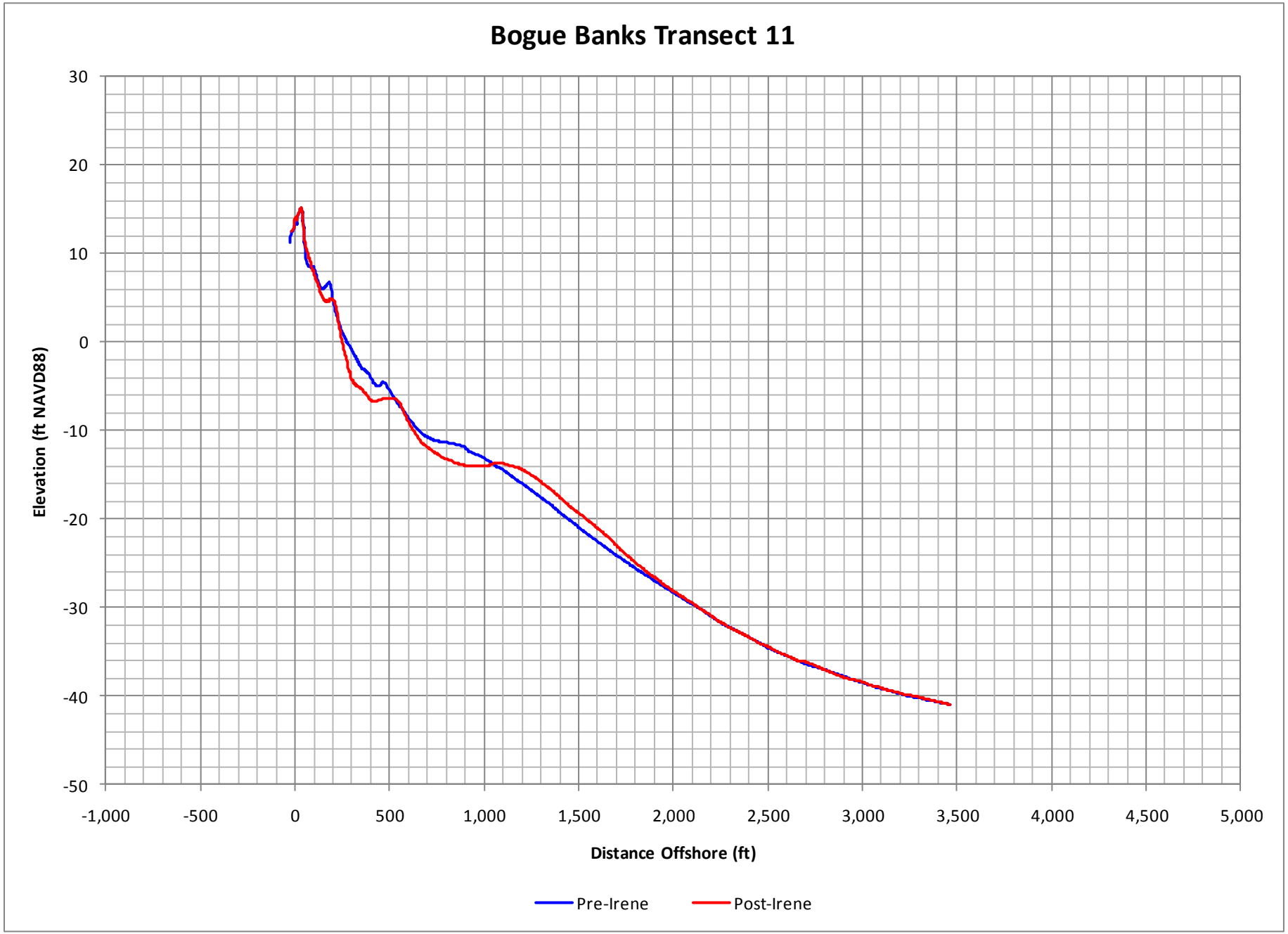

Figure B-11. Bogue Banks Profile Comparison

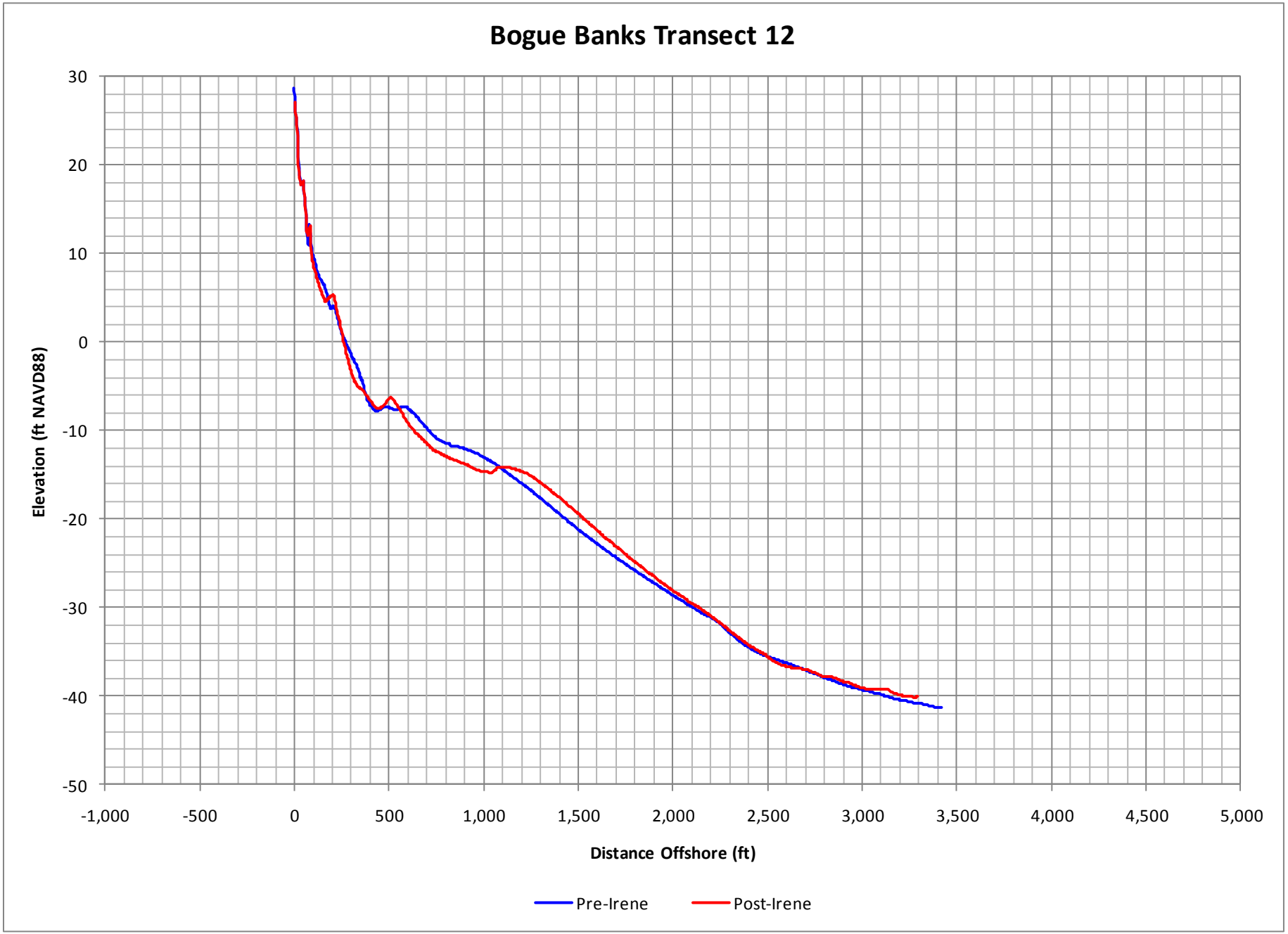

Figure B-12. Bogue Banks Profile Comparison

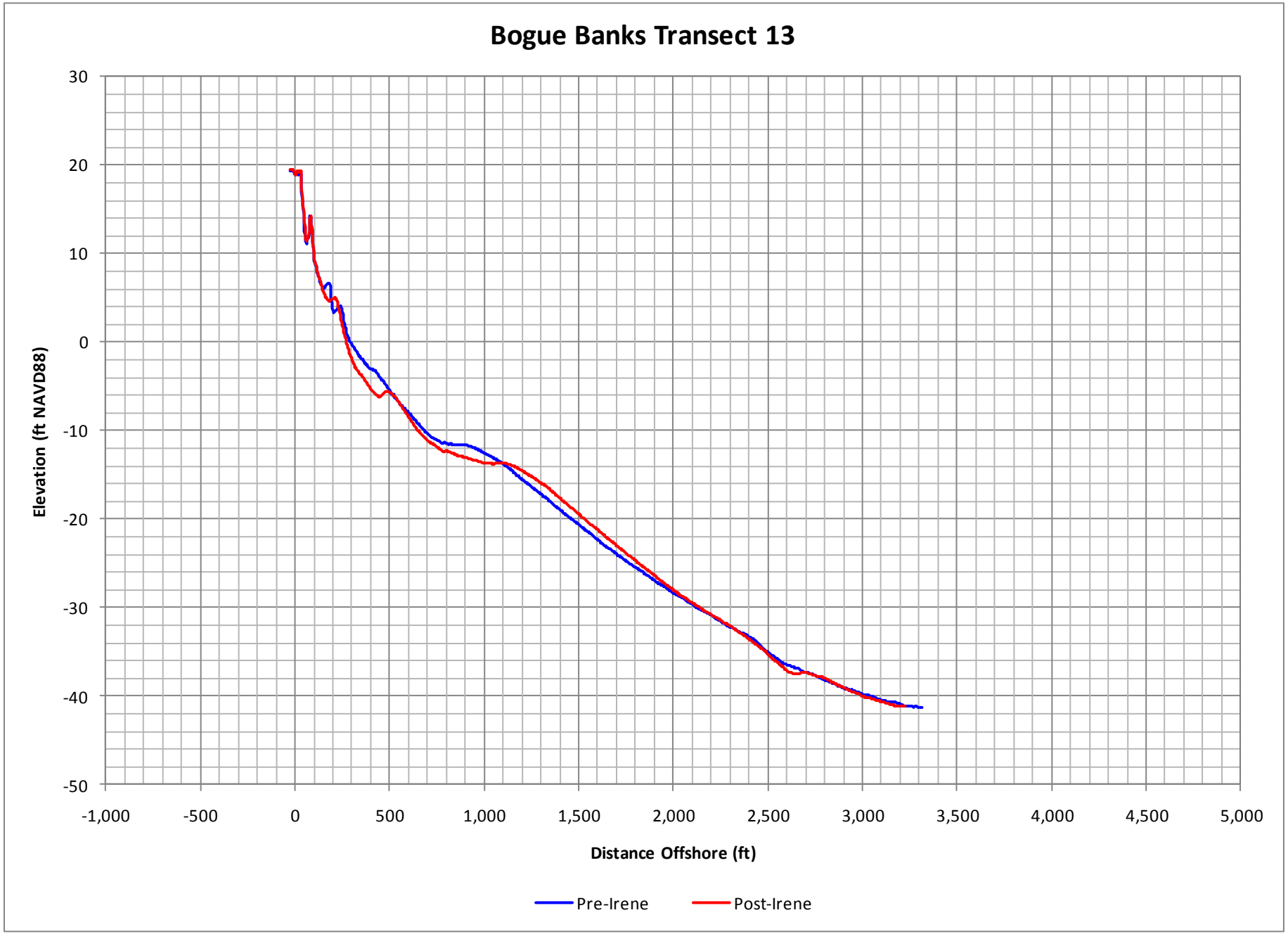

Figure B-13. Bogue Banks Profile Comparison

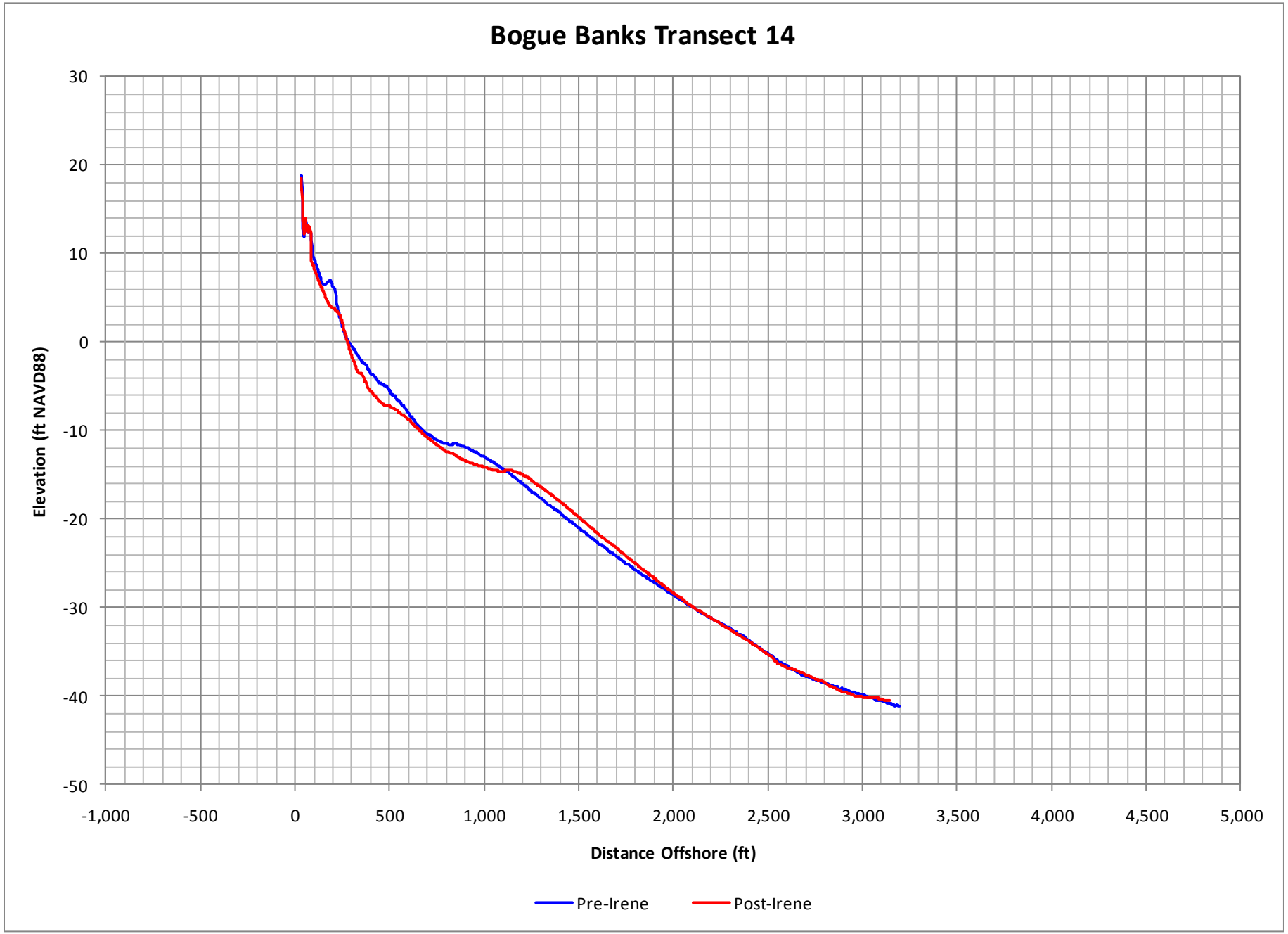

Figure B-14. Bogue Banks Profile Comparison

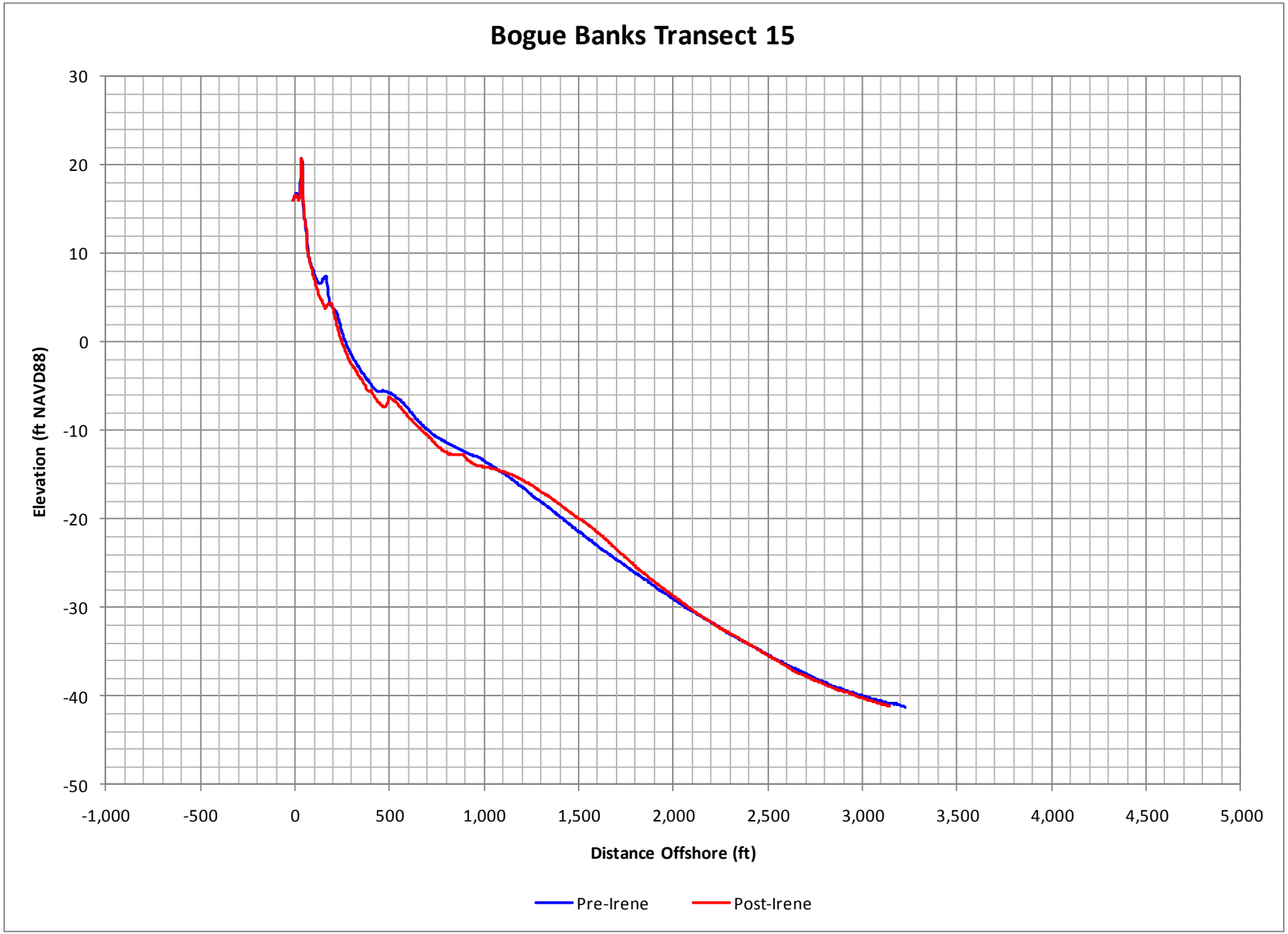

Figure B-15. Bogue Banks Profile Comparison

Figure B-16. Bogue Banks Profile Comparison

Figure B-17. Bogue Banks Profile Comparison

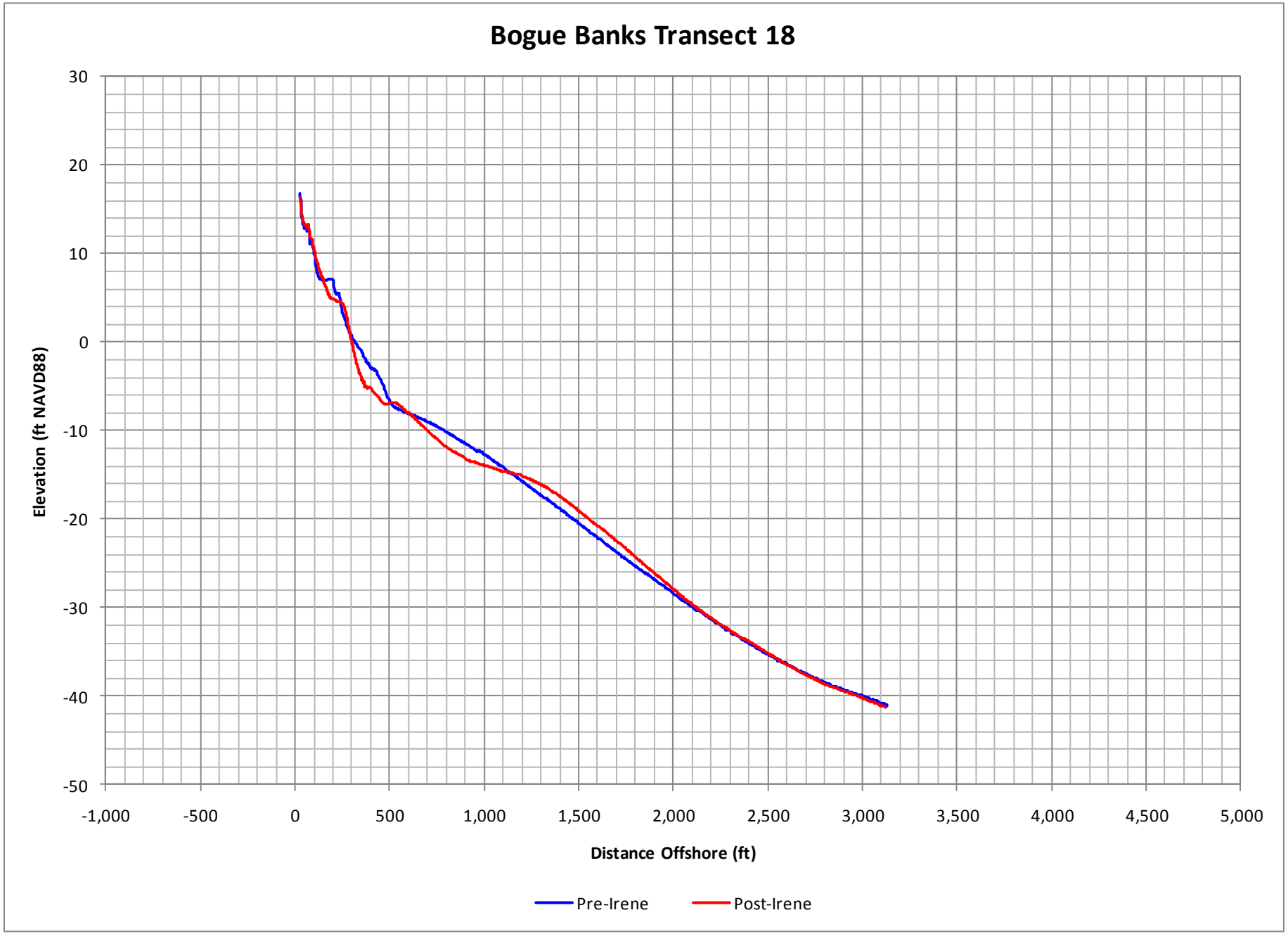

Figure B-18. Bogue Banks Profile Comparison

Figure B-19. Bogue Banks Profile Comparison

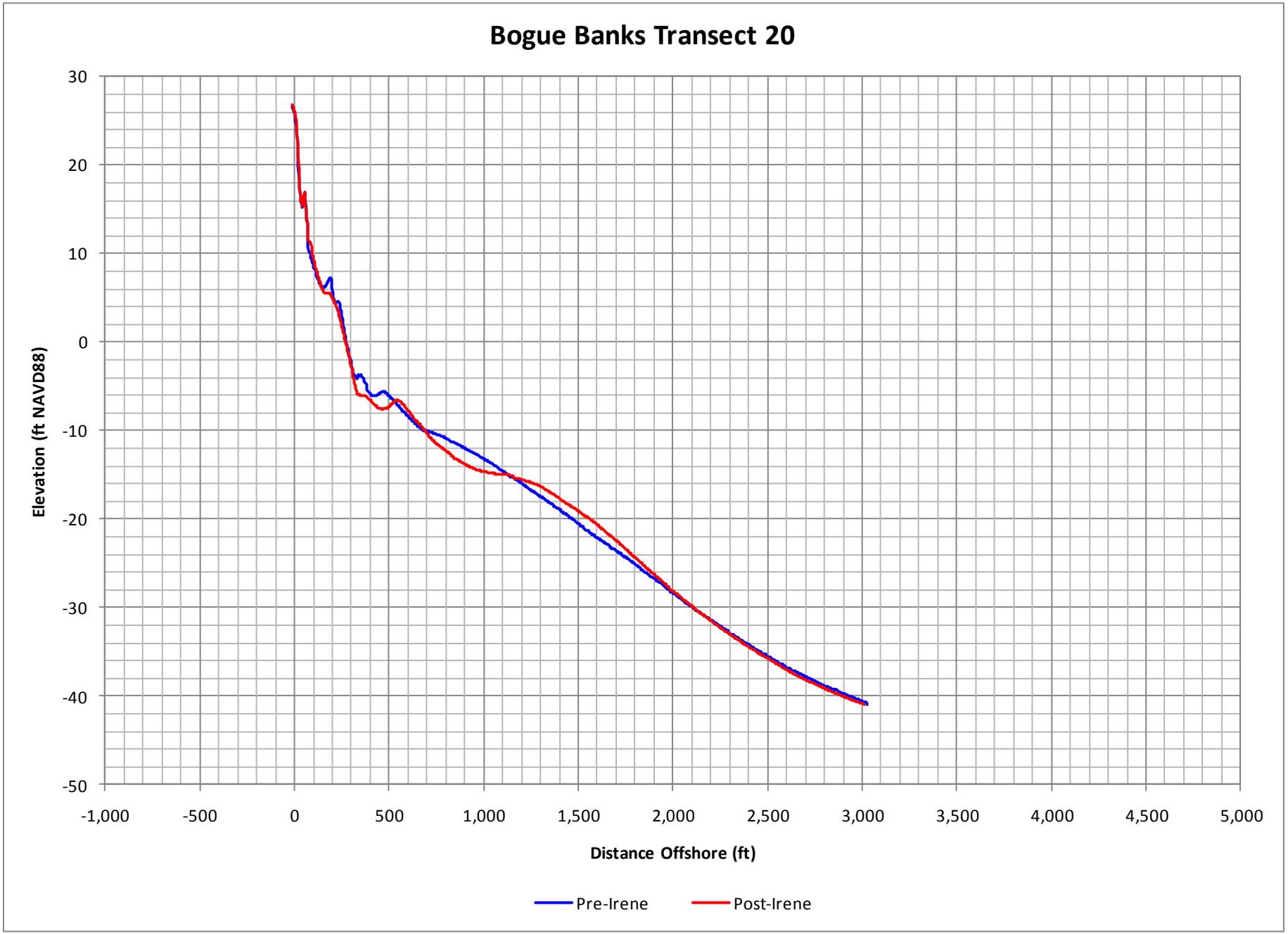

Figure B-20. Bogue Banks Profile Comparison

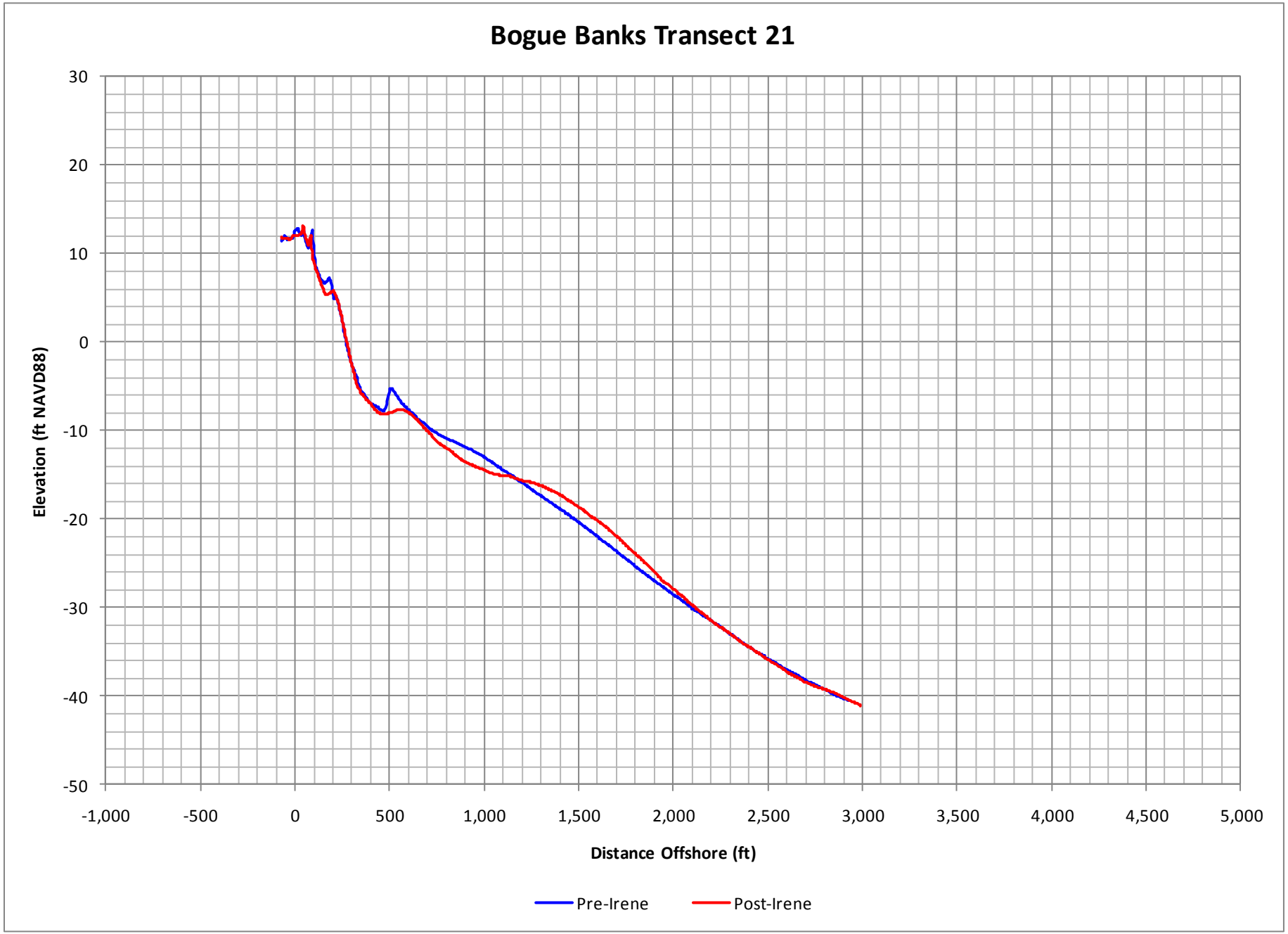

Figure B-21. Bogue Banks Profile Comparison

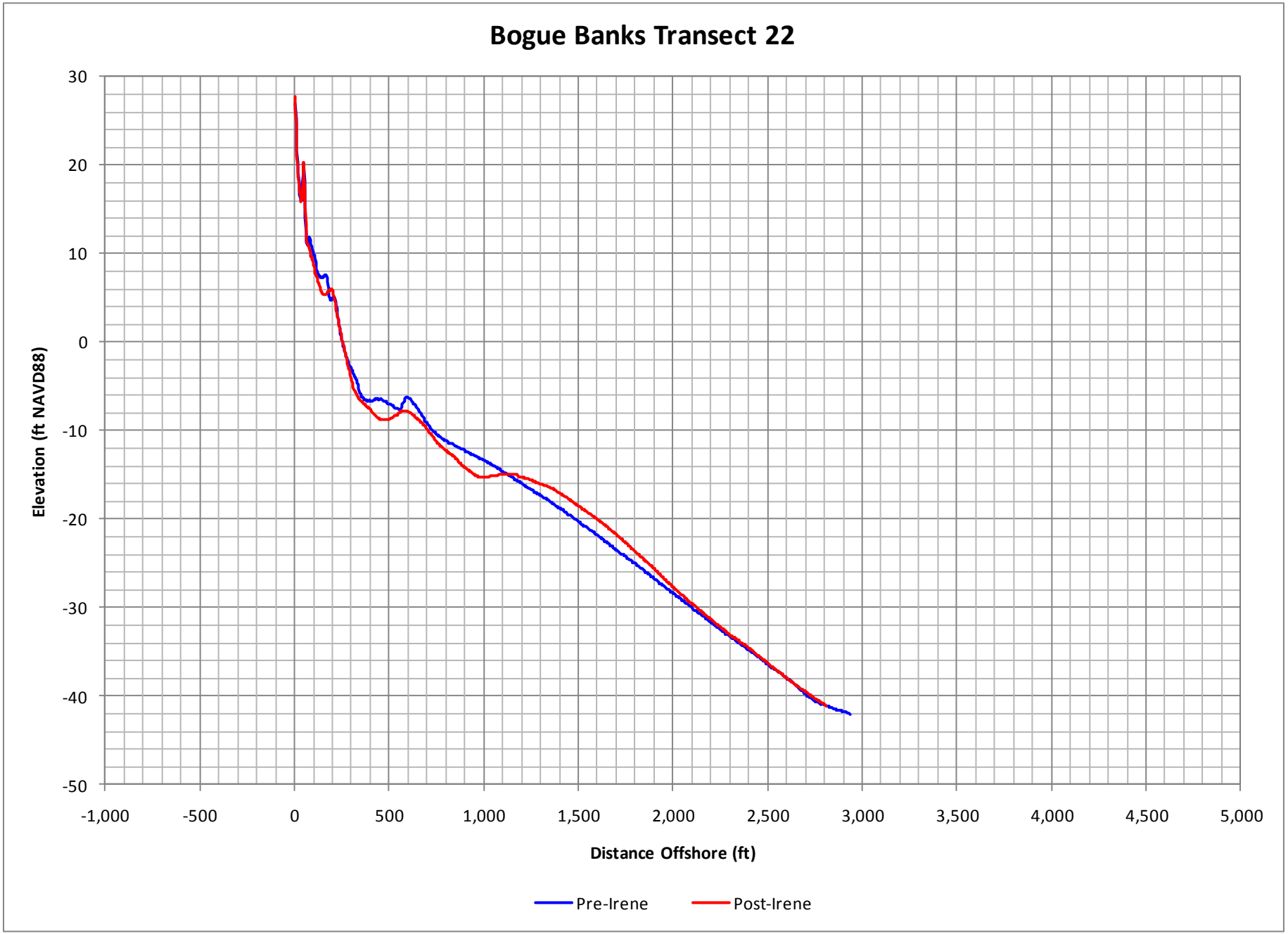

Figure B-22. Bogue Banks Profile Comparison

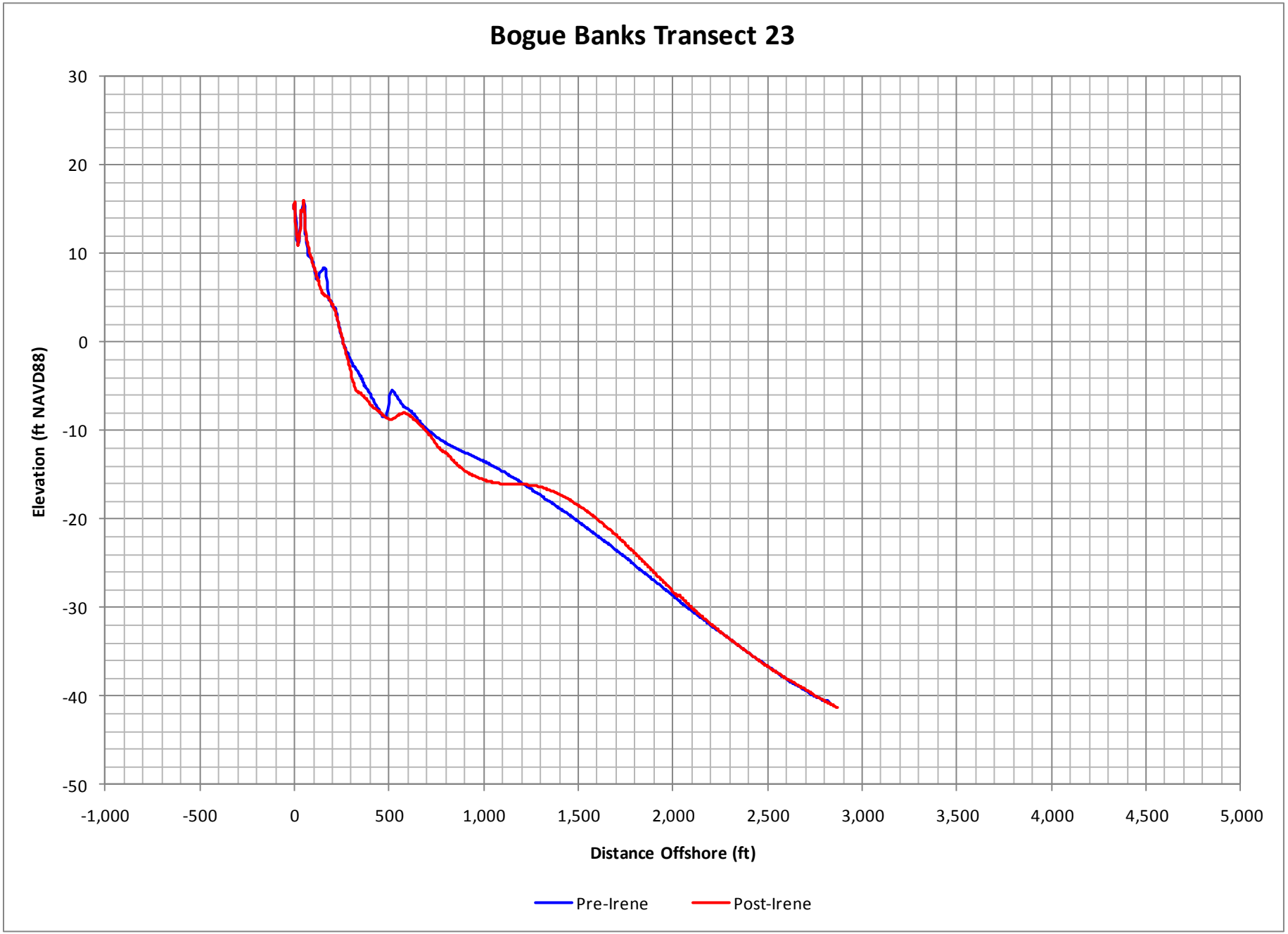

Figure B-23. Bogue Banks Profile Comparison

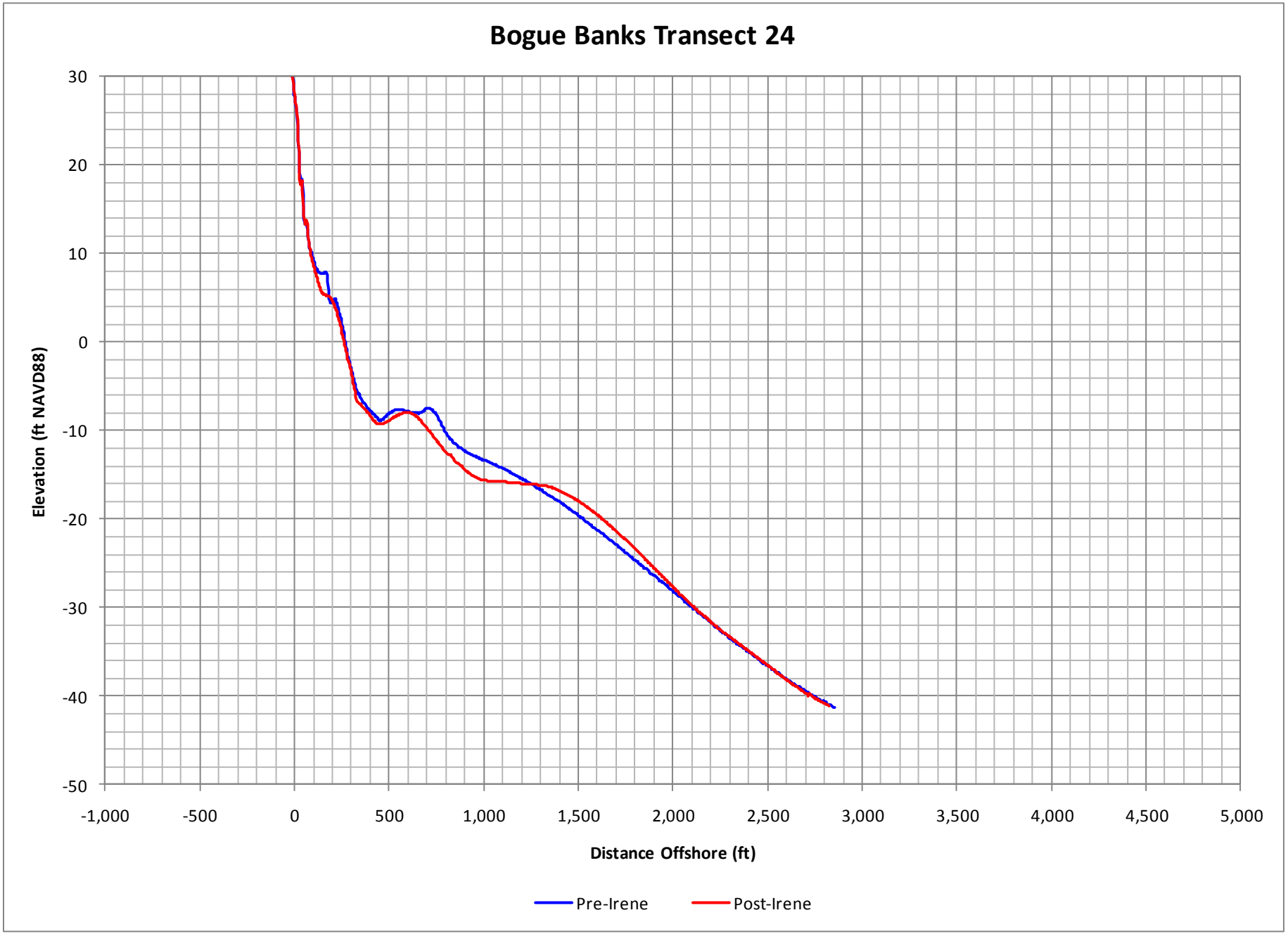

Figure B-24. Bogue Banks Profile Comparison

Figure B-25. Bogue Banks Profile Comparison

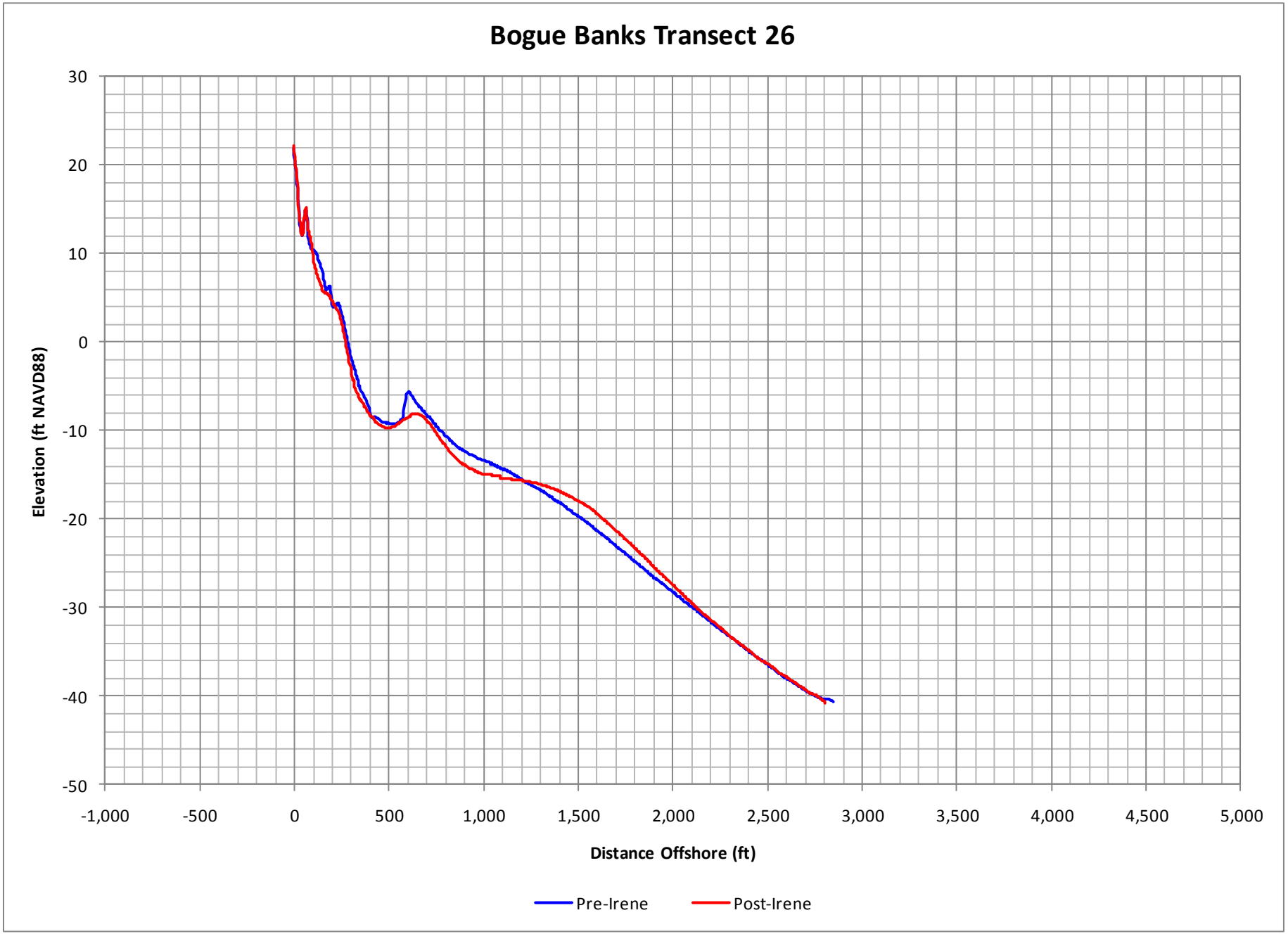

Figure B-26. Bogue Banks Profile Comparison

Figure B-27. Bogue Banks Profile Comparison

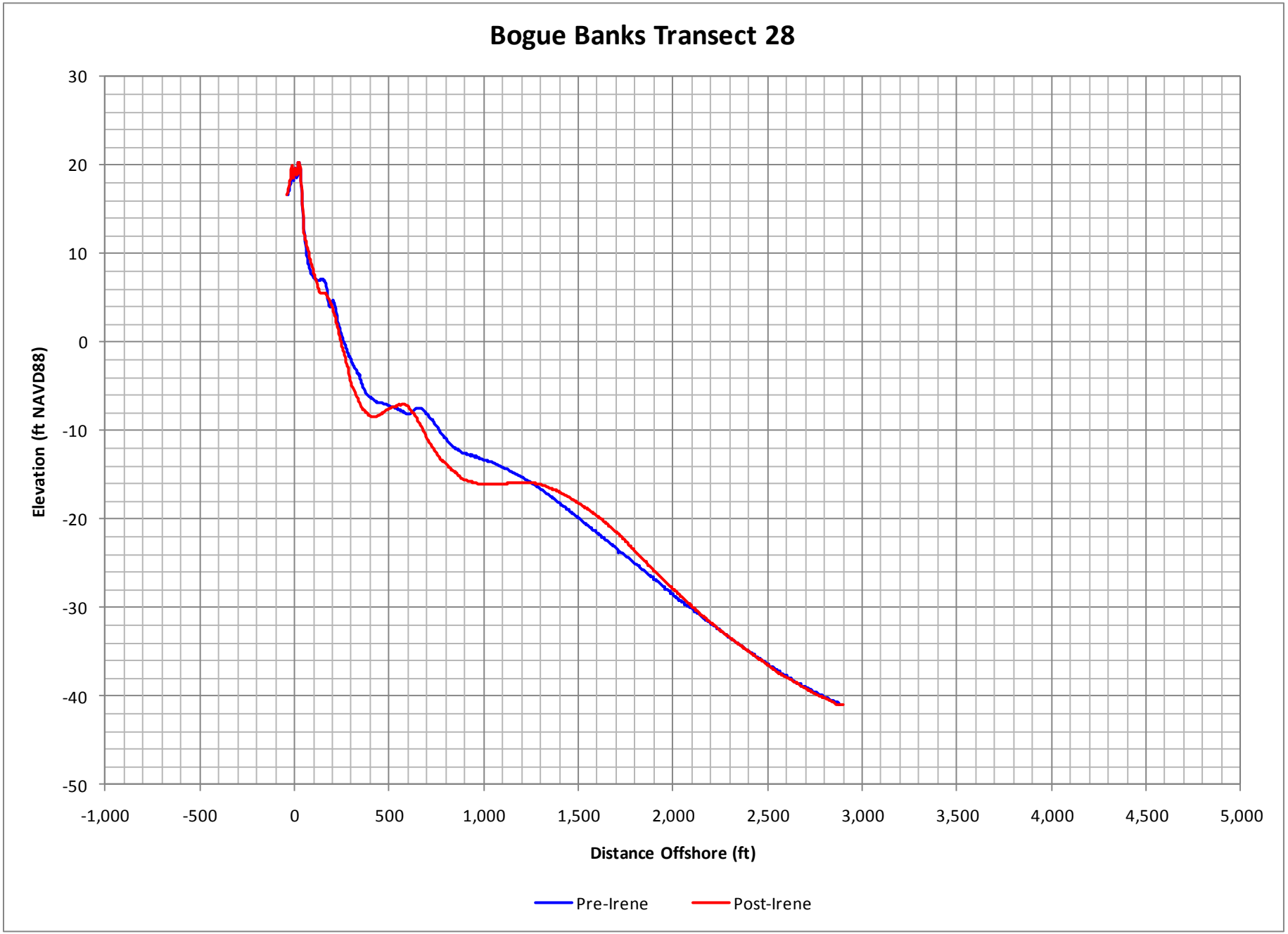

Figure B-28. Bogue Banks Profile Comparison

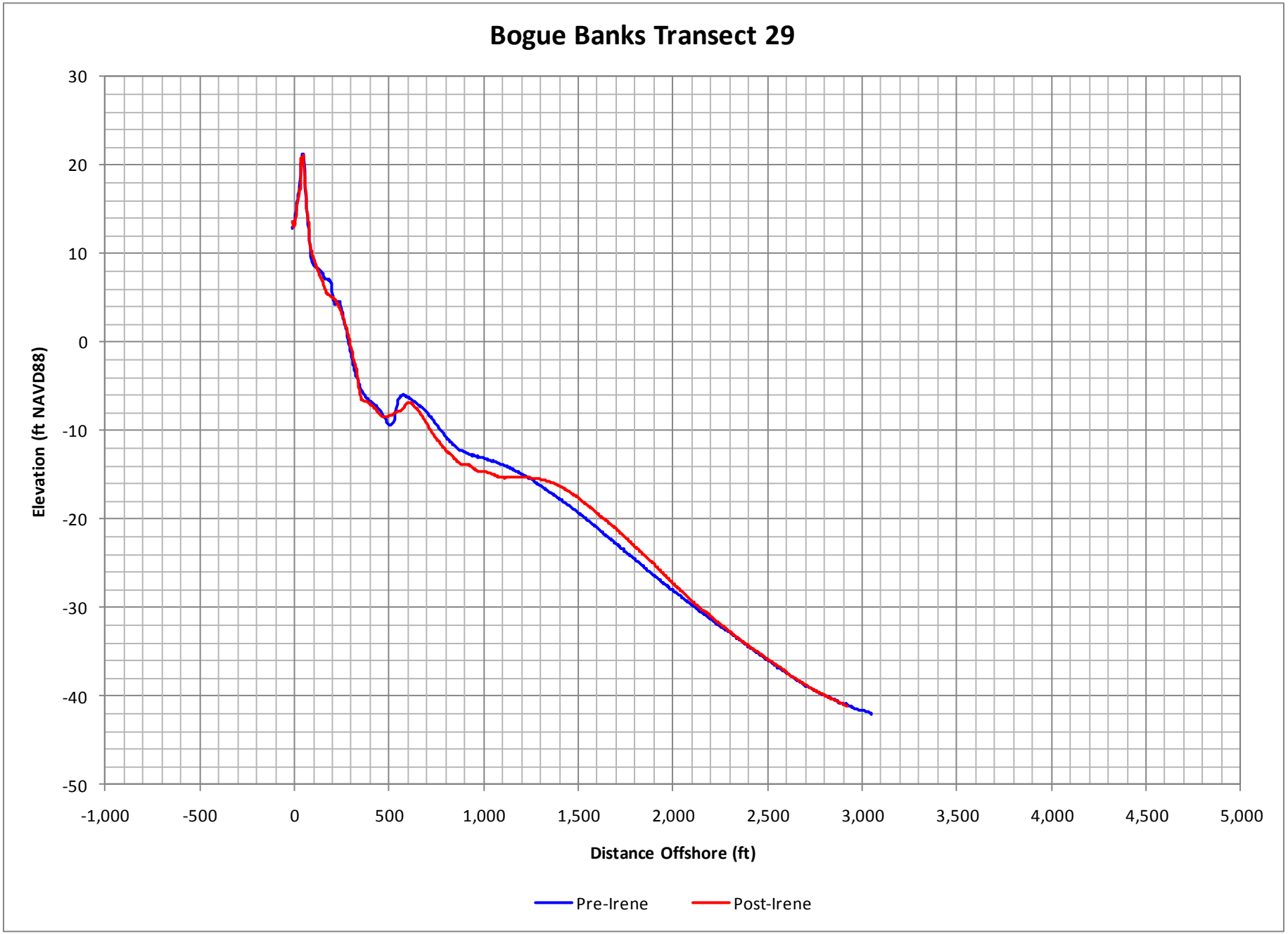

Figure B-29. Bogue Banks Profile Comparison

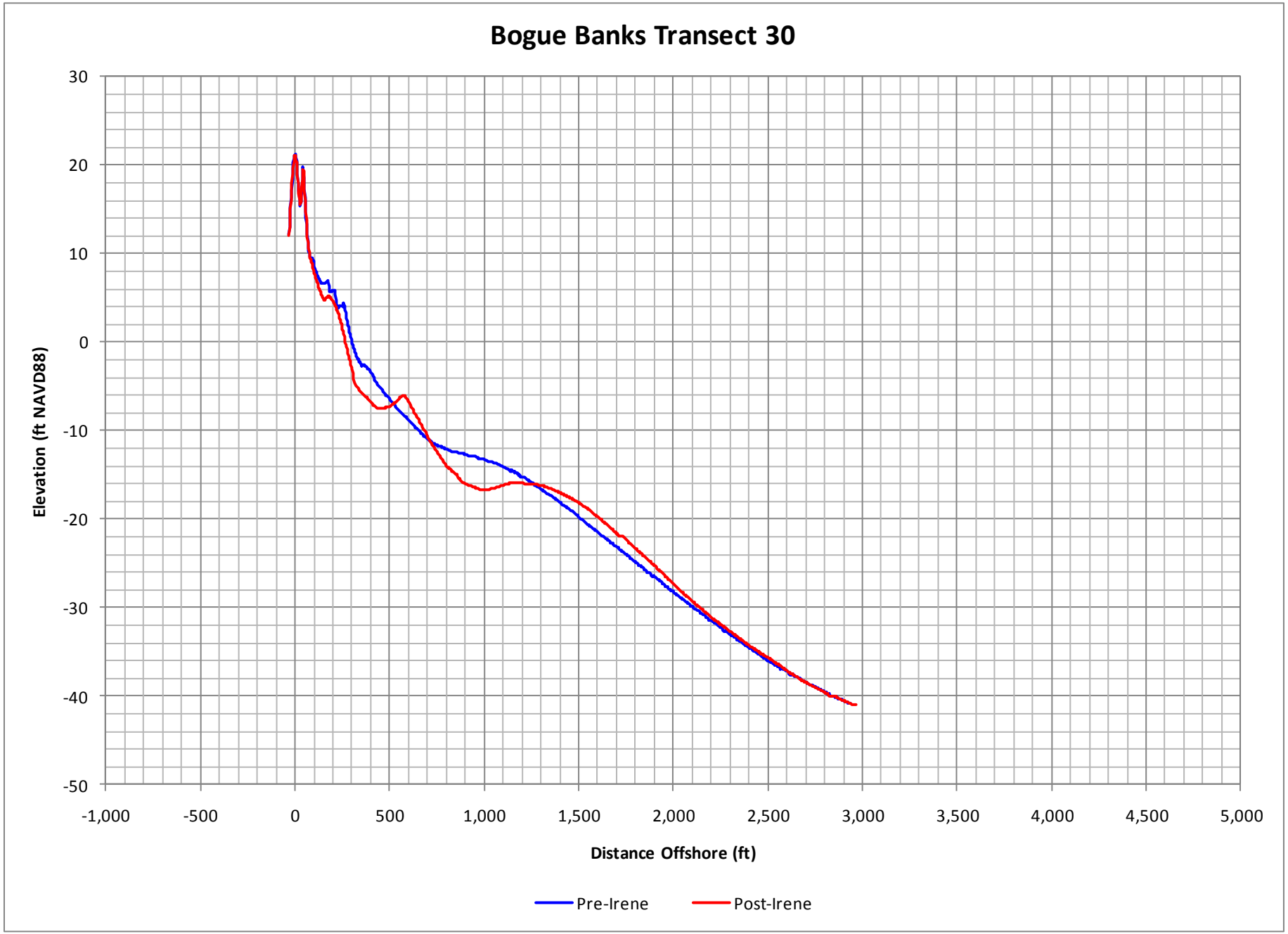

Figure B-30. Bogue Banks Profile Comparison

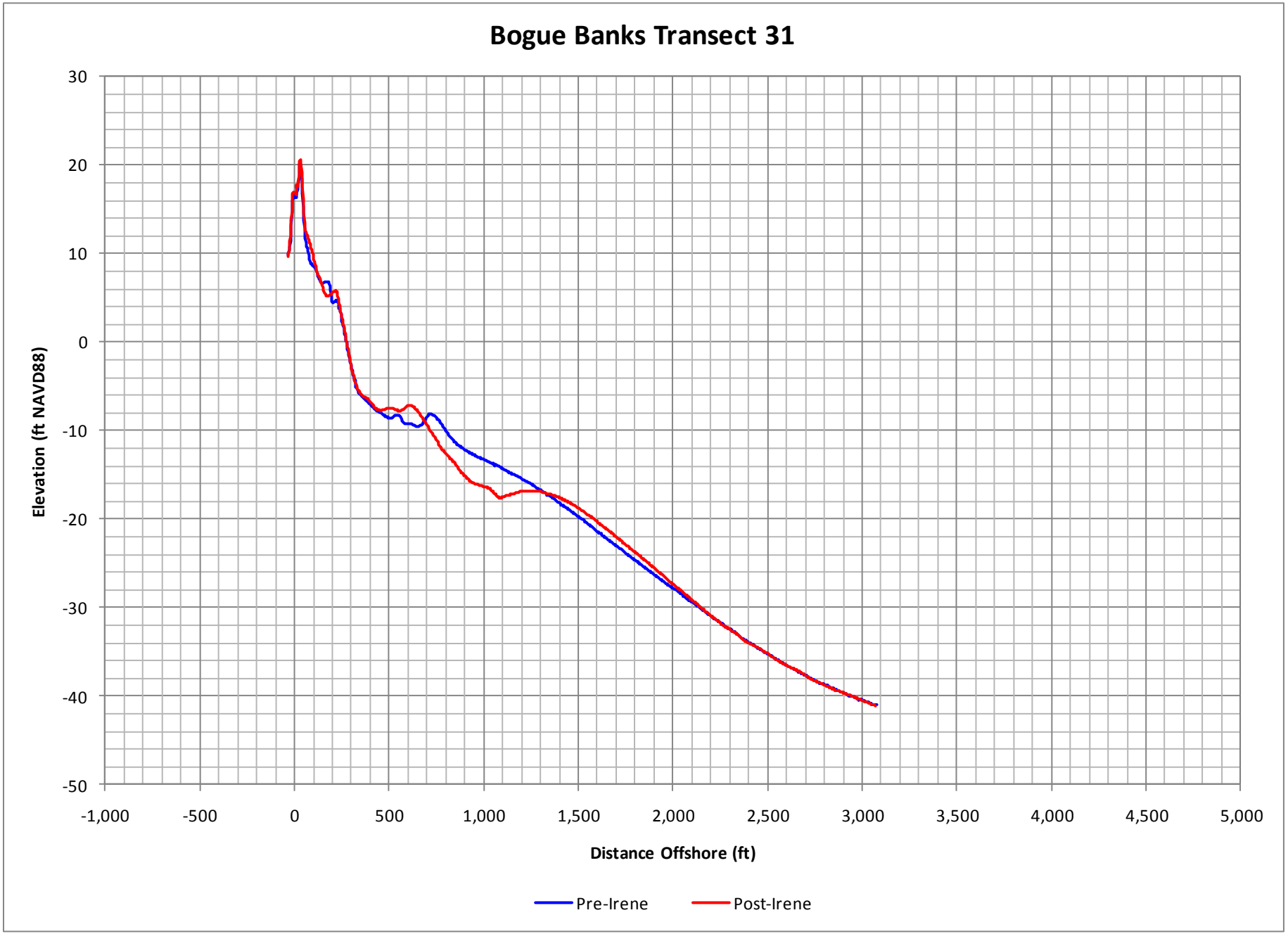

Figure B-31. Bogue Banks Profile Comparison

Figure B-32. Bogue Banks Profile Comparison

Figure B-33. Bogue Banks Profile Comparison

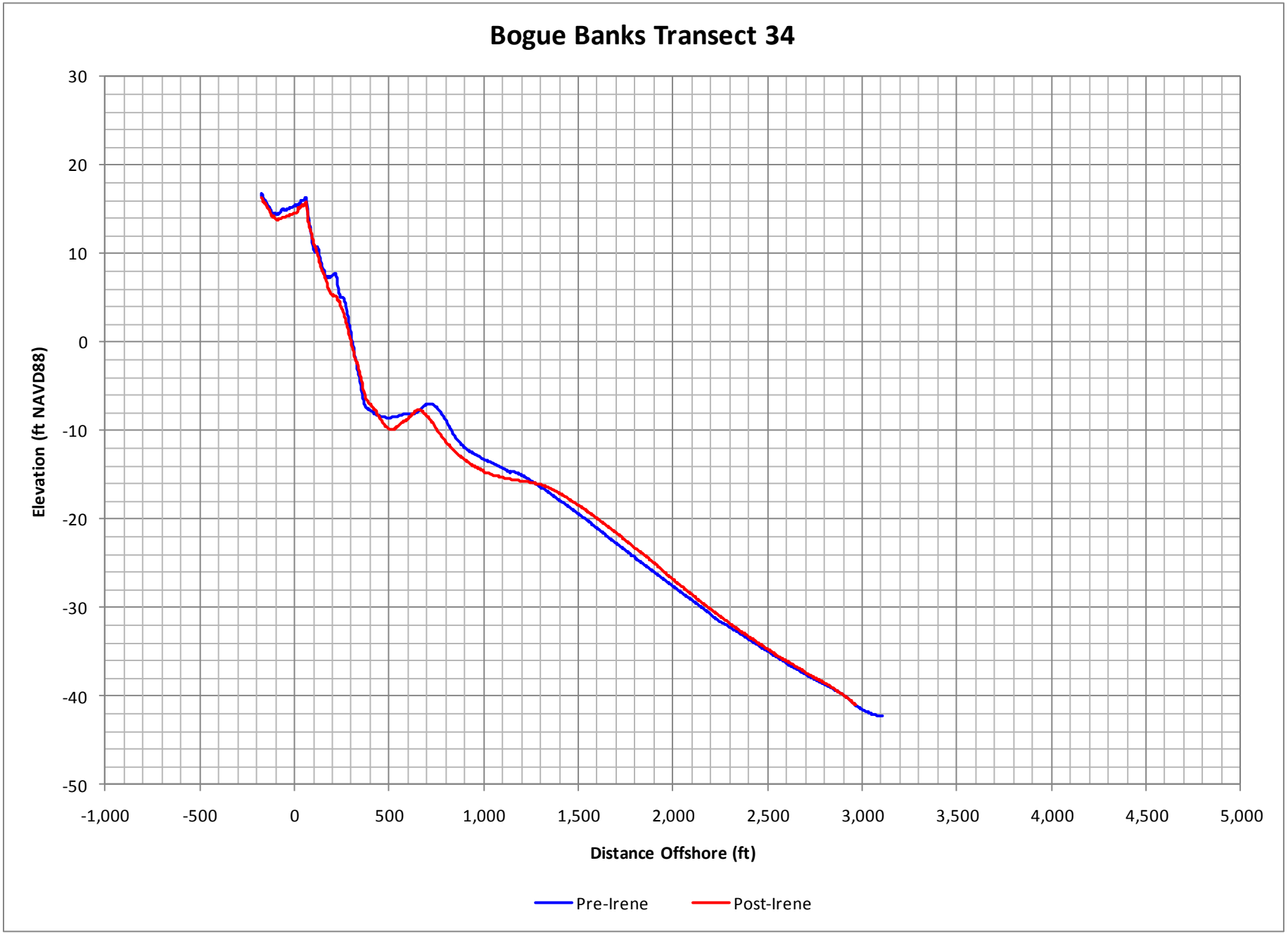

Figure B-34. Bogue Banks Profile Comparison

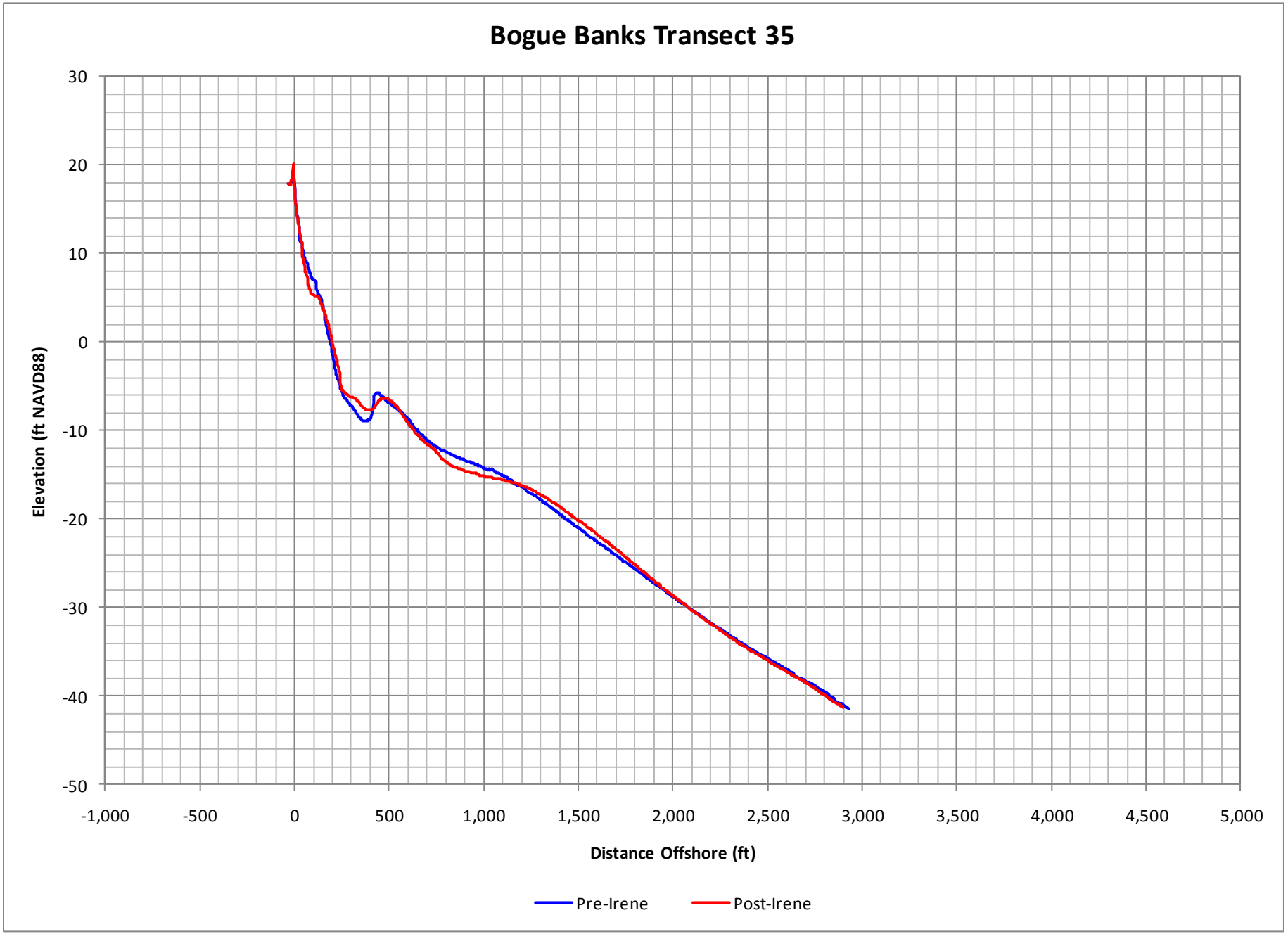

Figure B-35. Bogue Banks Profile Comparison

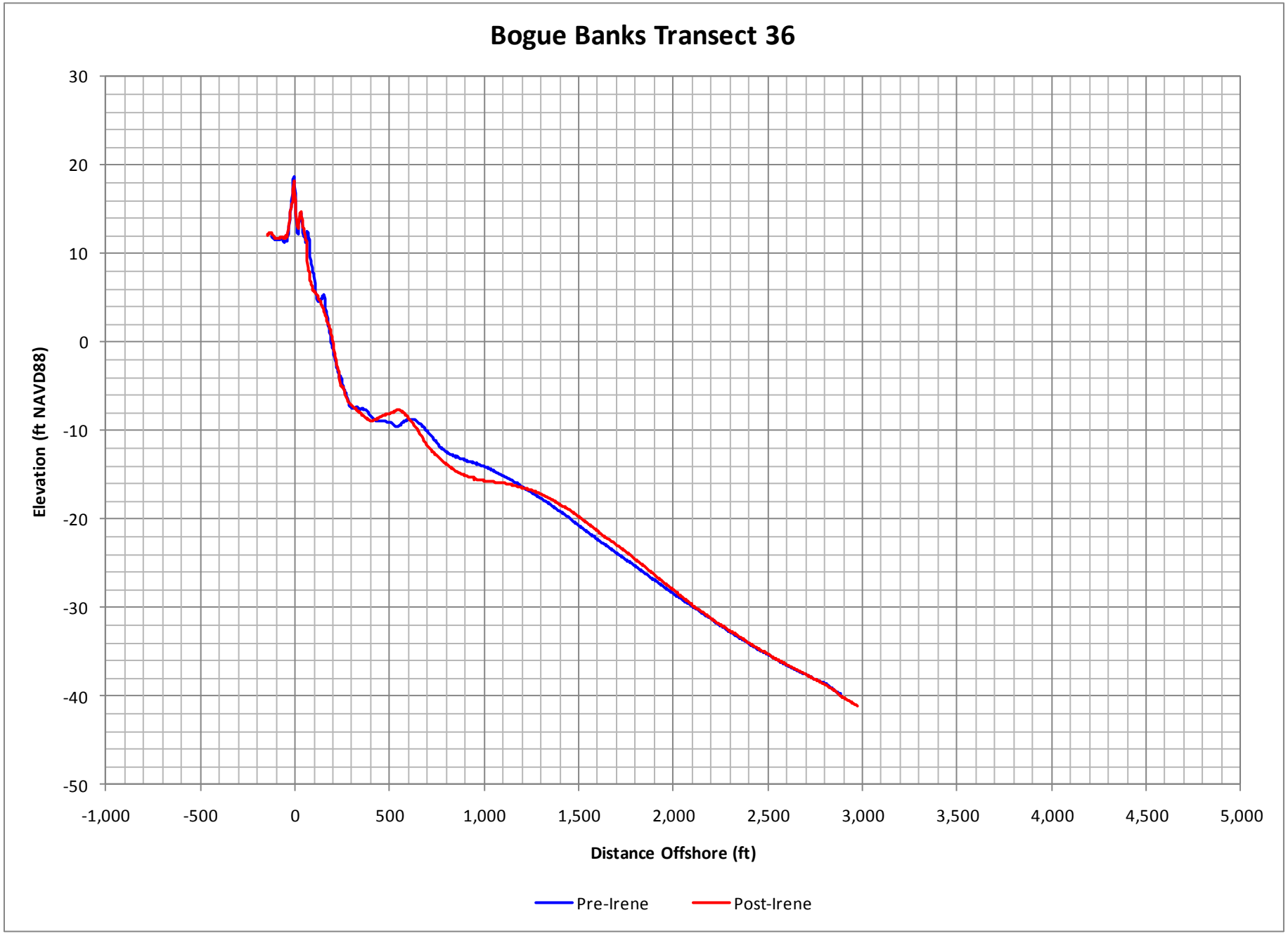

Figure B-36. Bogue Banks Profile Comparison

Figure B-37. Bogue Banks Profile Comparison

Figure B-38. Bogue Banks Profile Comparison

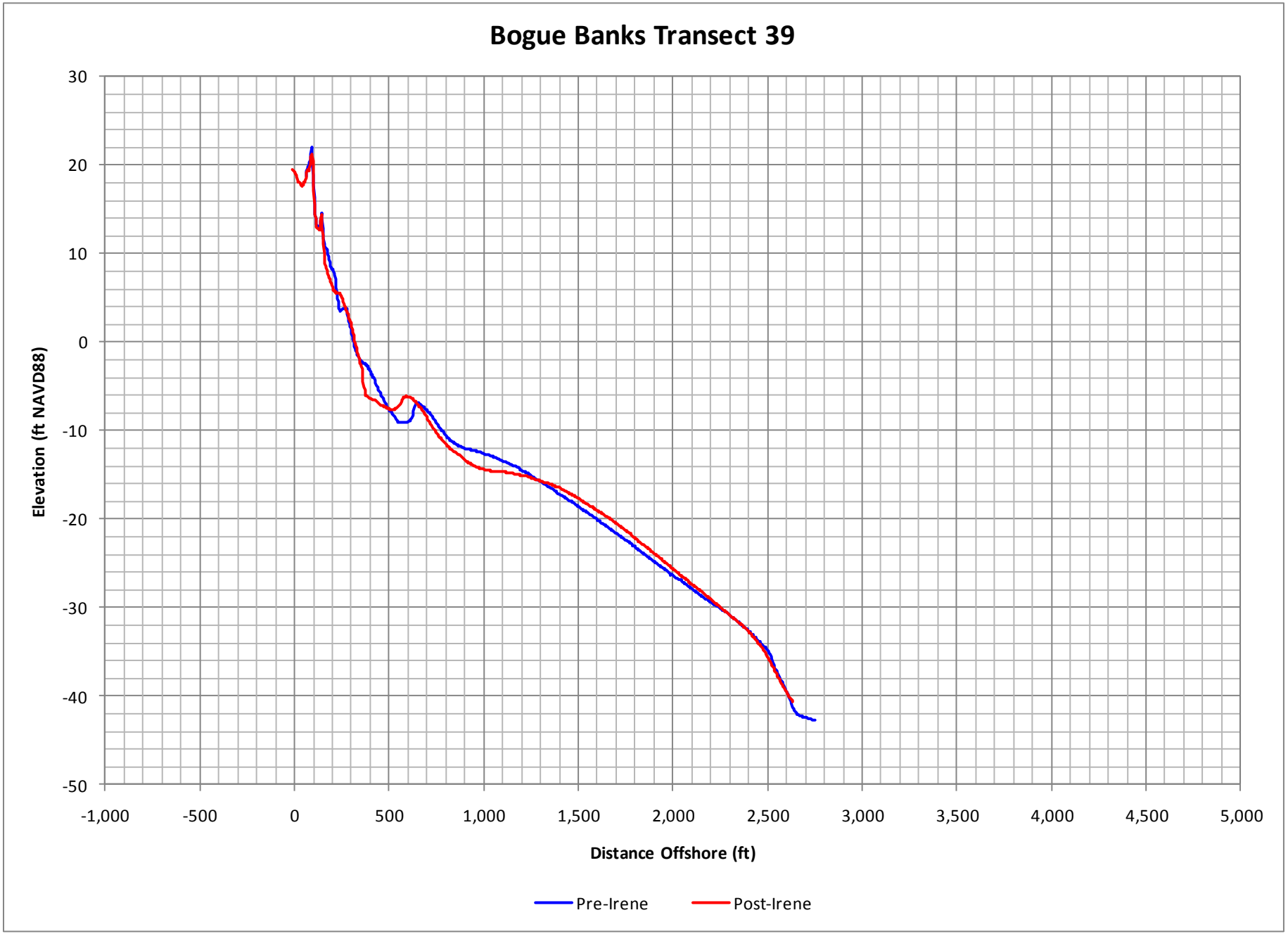

Figure B-39. Bogue Banks Profile Comparison

Figure B-40. Bogue Banks Profile Comparison

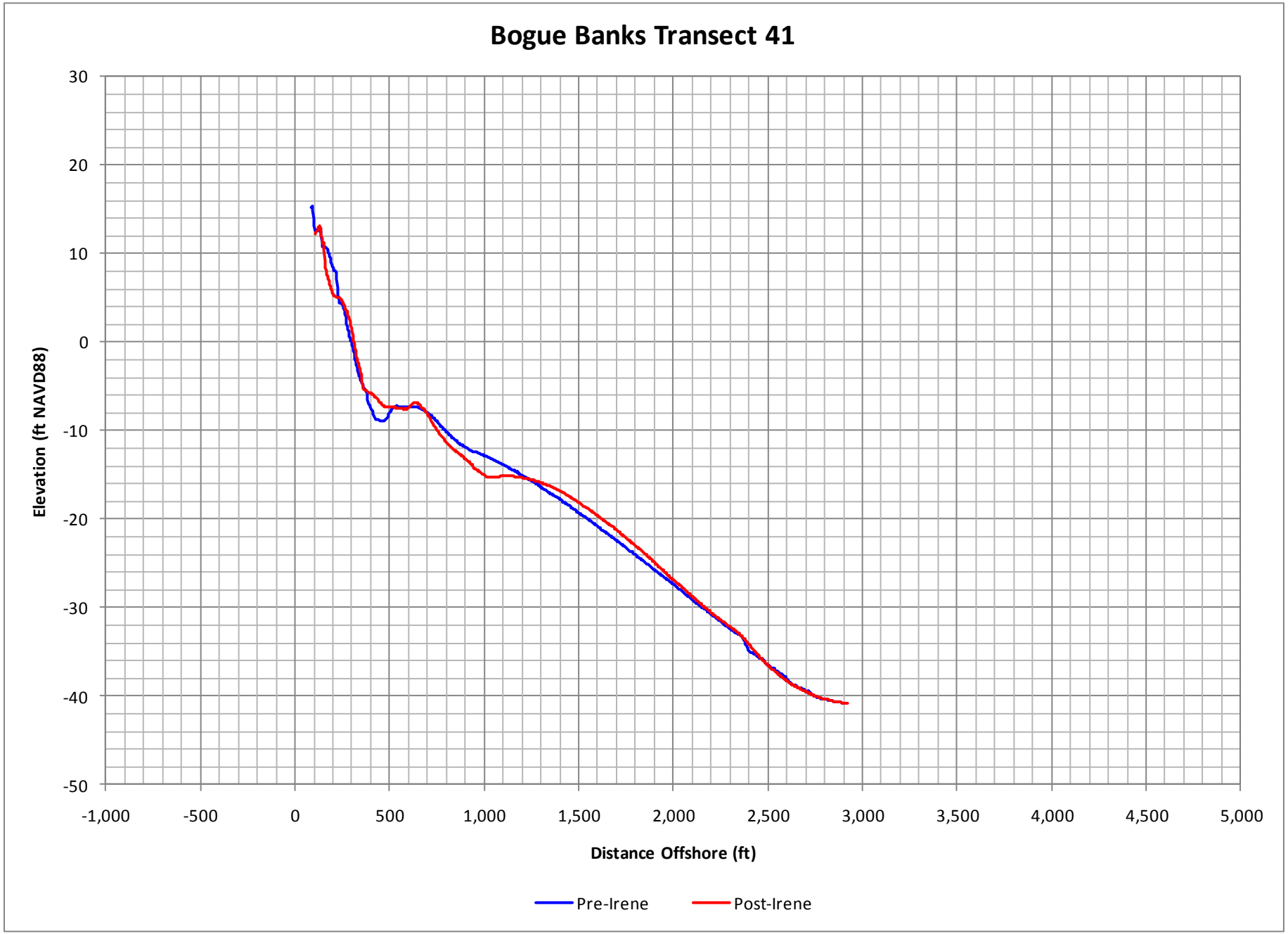

Figure B-41. Bogue Banks Profile Comparison

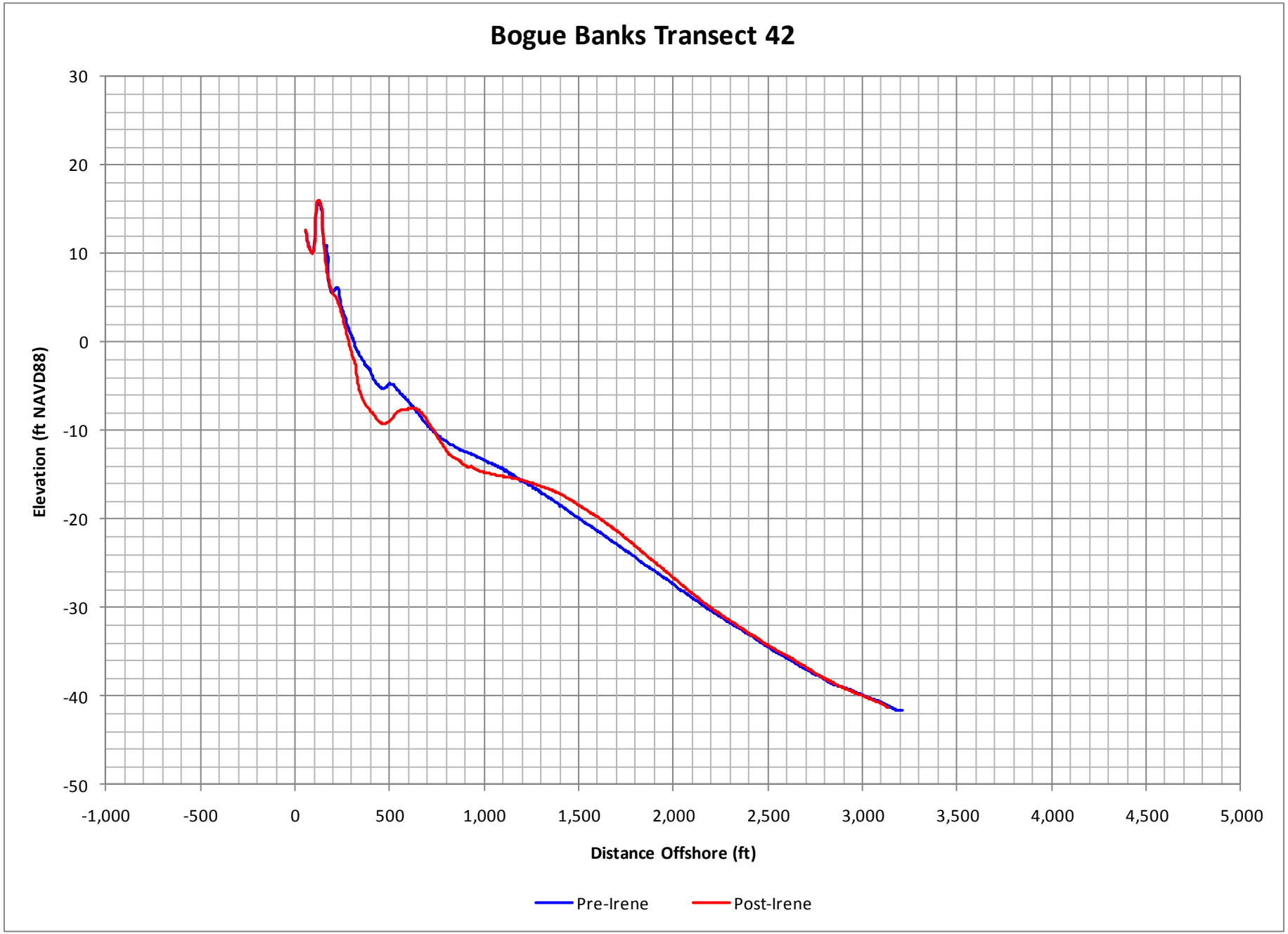

Figure B-42. Bogue Banks Profile Comparison

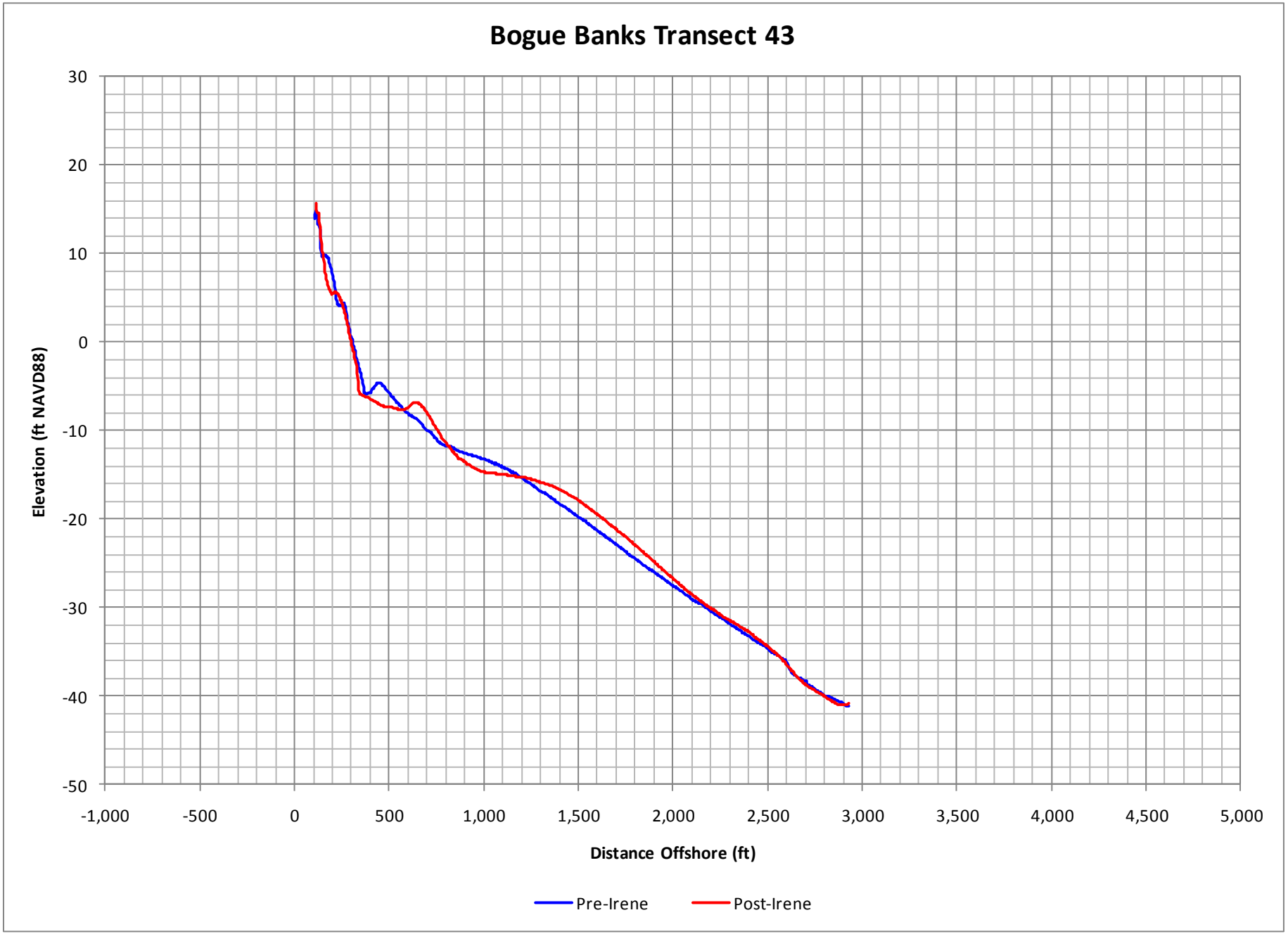

Figure B-43. Bogue Banks Profile Comparison

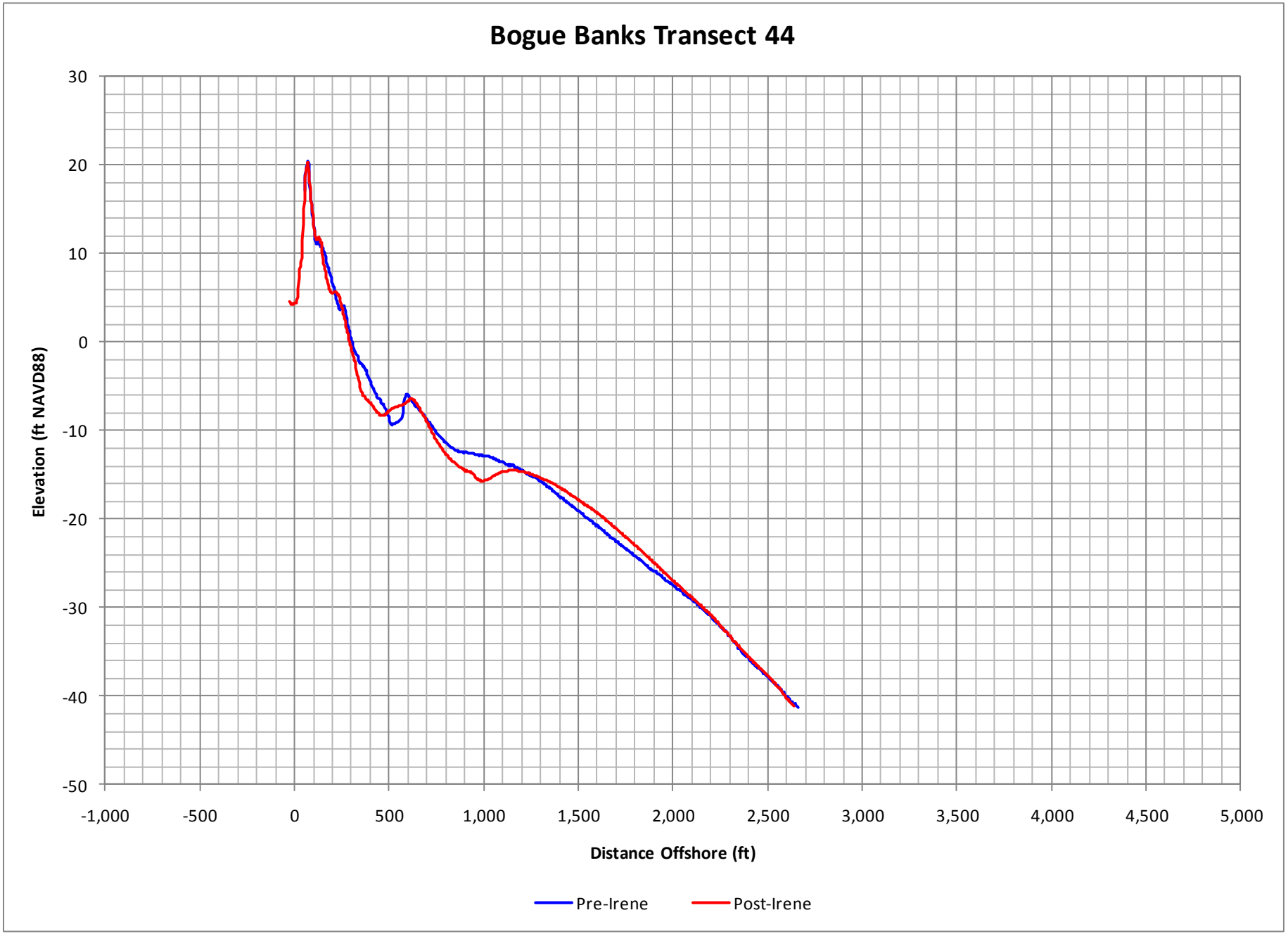

Figure B-44. Bogue Banks Profile Comparison

Figure B-45. Bogue Banks Profile Comparison

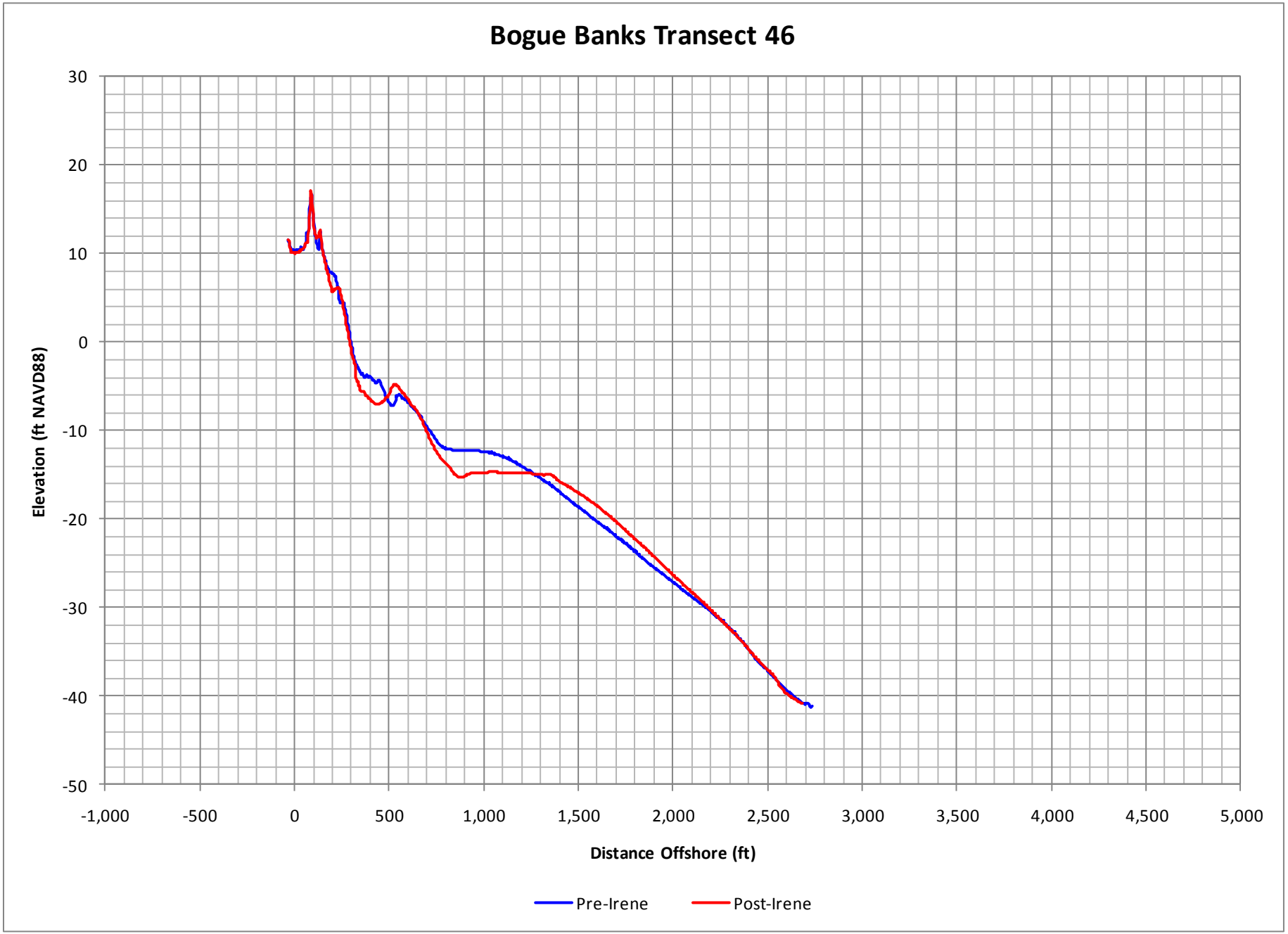

Figure B-46. Bogue Banks Profile Comparison

Figure B-47. Bogue Banks Profile Comparison

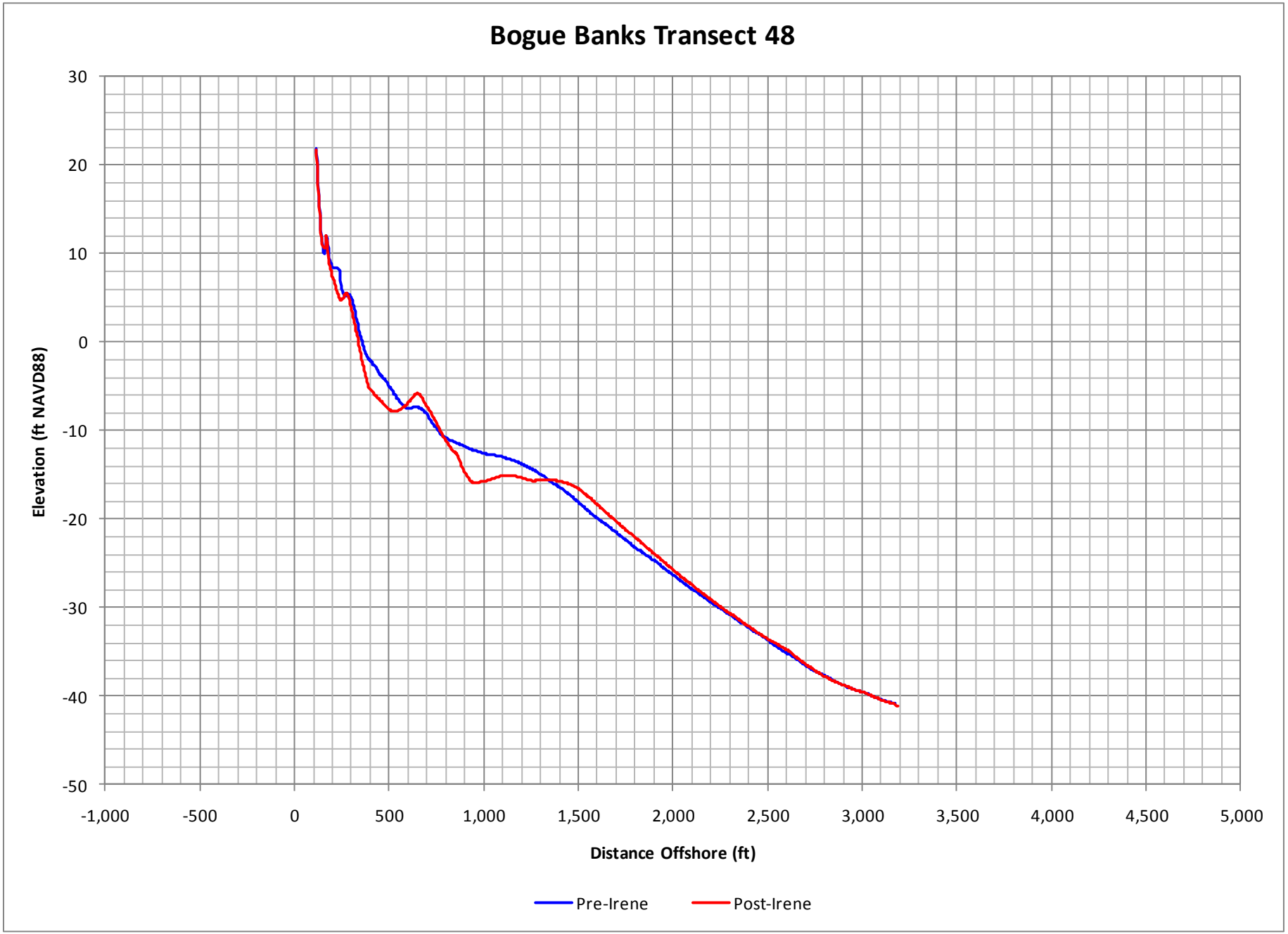

Figure B-48. Bogue Banks Profile Comparison

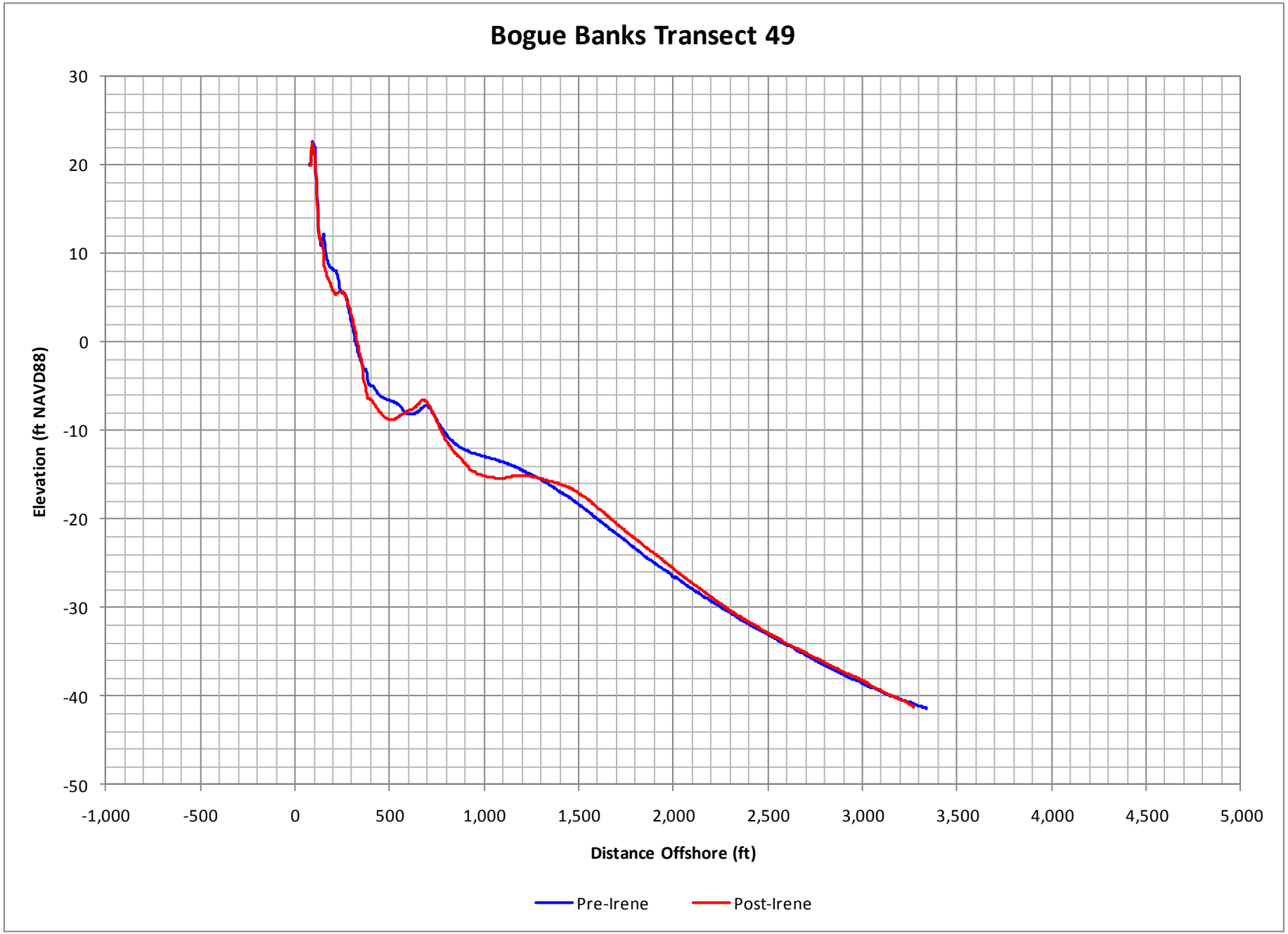

Figure B-49. Bogue Banks Profile Comparison

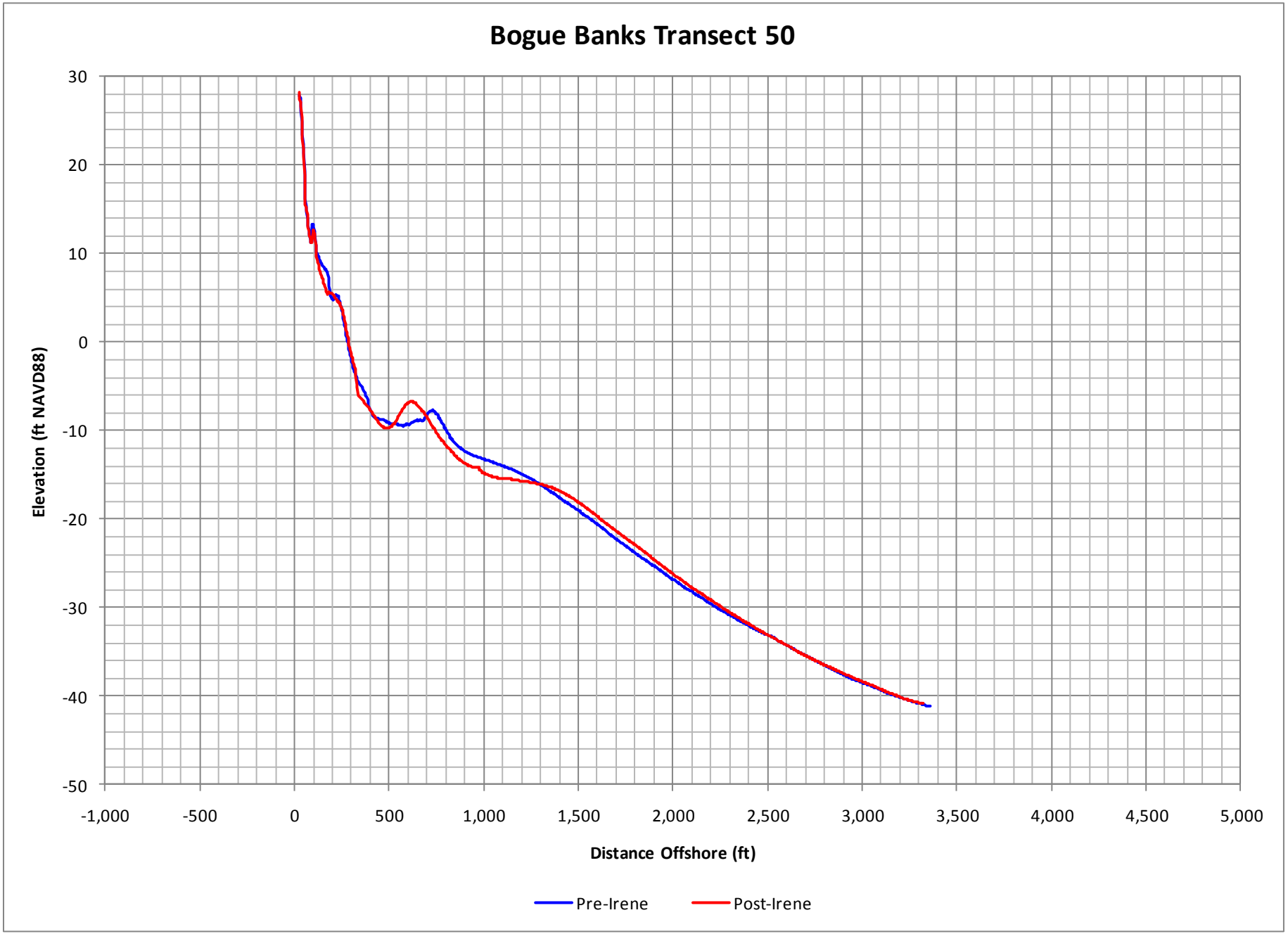

Figure B-50. Bogue Banks Profile Comparison

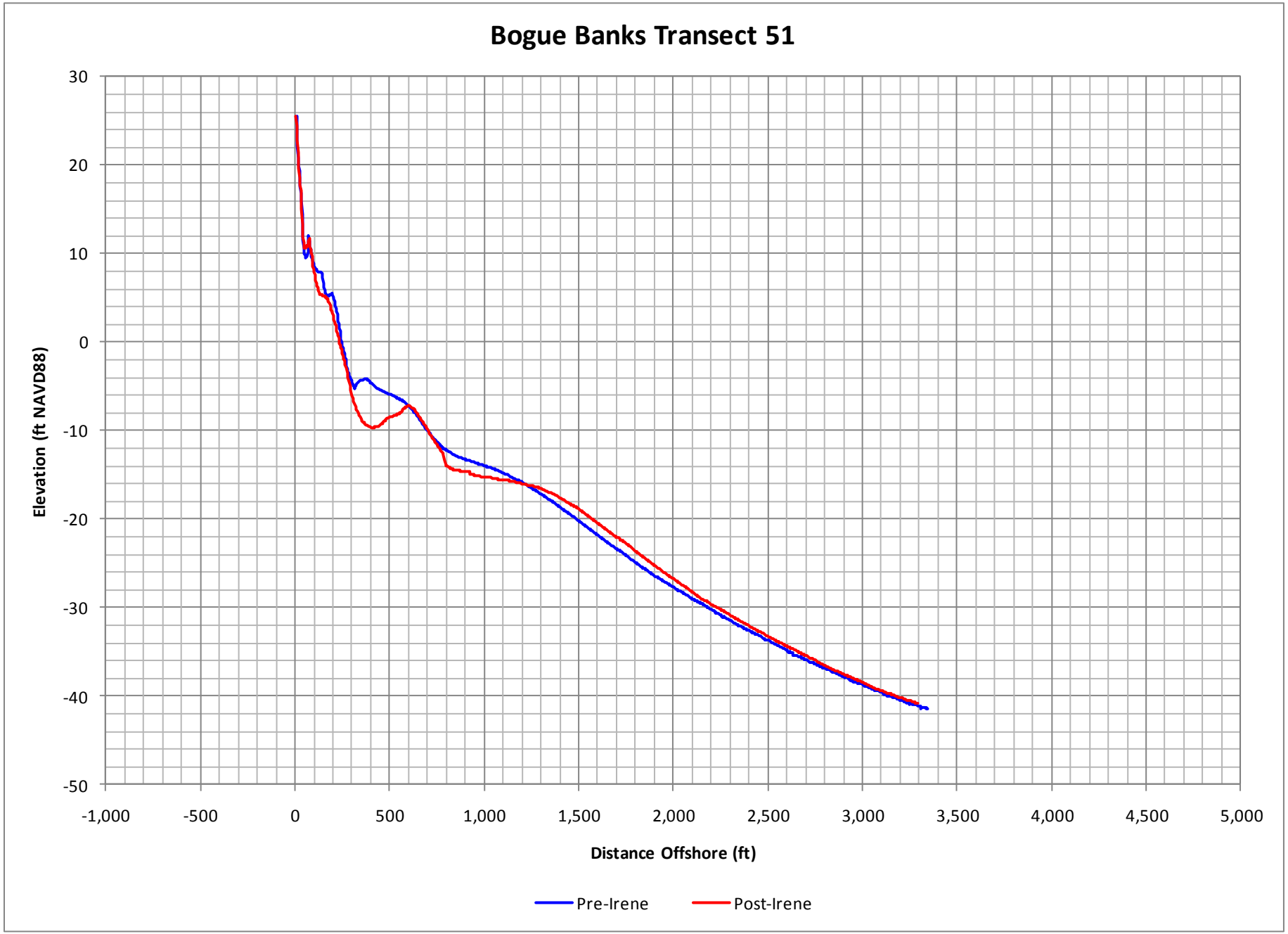

Figure B-51. Bogue Banks Profile Comparison

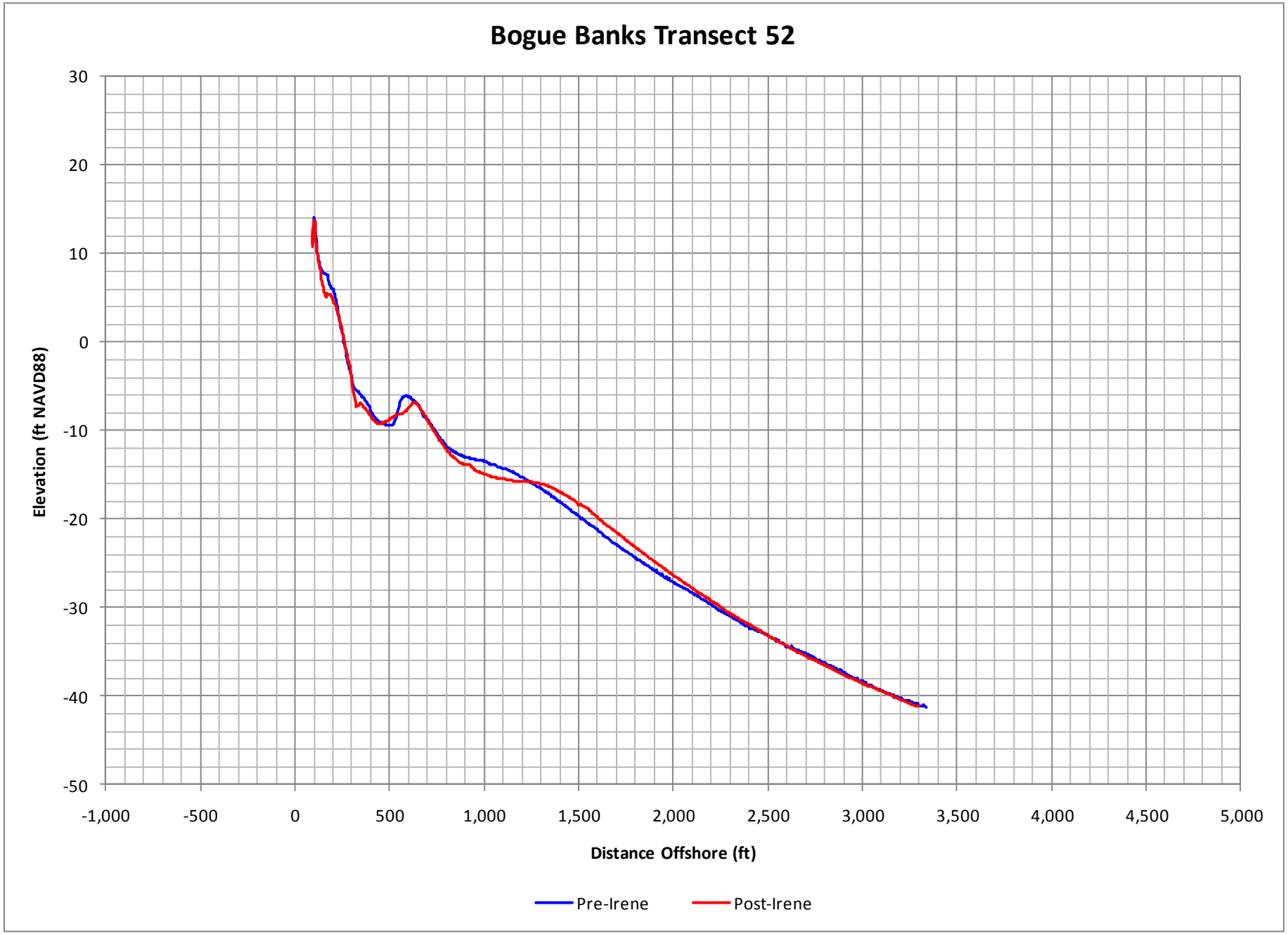

Figure B-52. Bogue Banks Profile Comparison

Figure B-53. Bogue Banks Profile Comparison

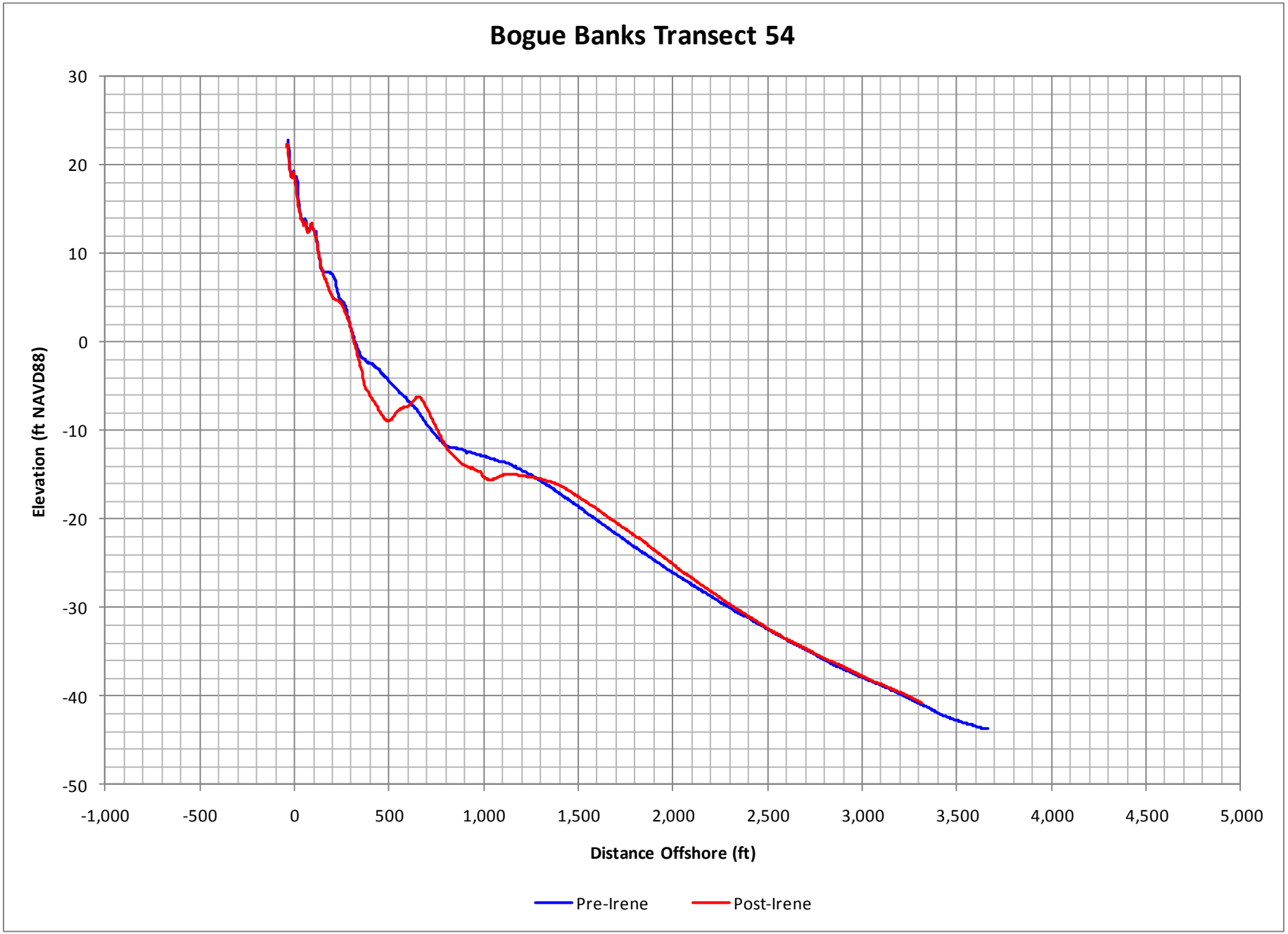

Figure B-54. Bogue Banks Profile Comparison

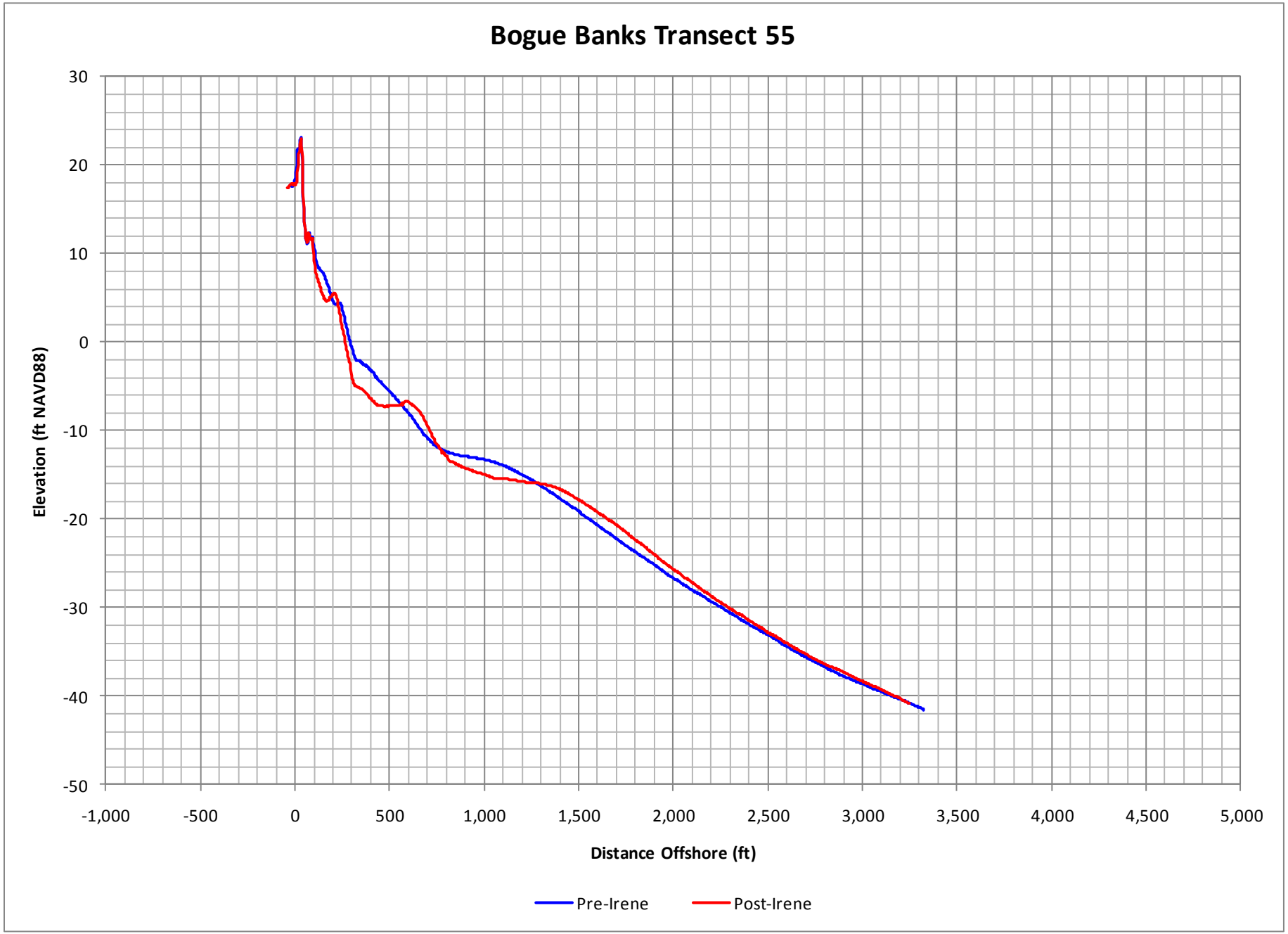

Figure B-55. Bogue Banks Profile Comparison

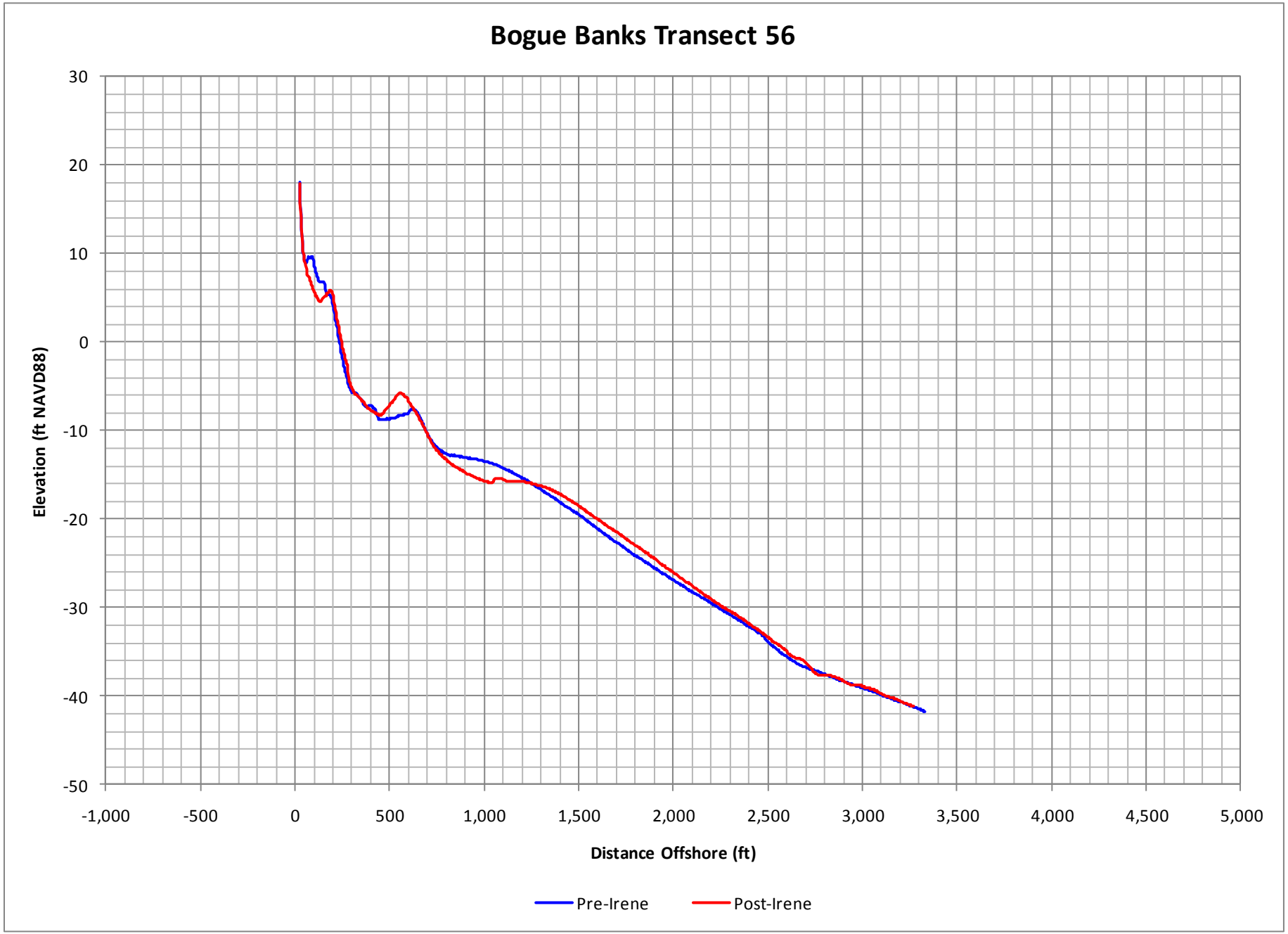

Figure B-56. Bogue Banks Profile Comparison

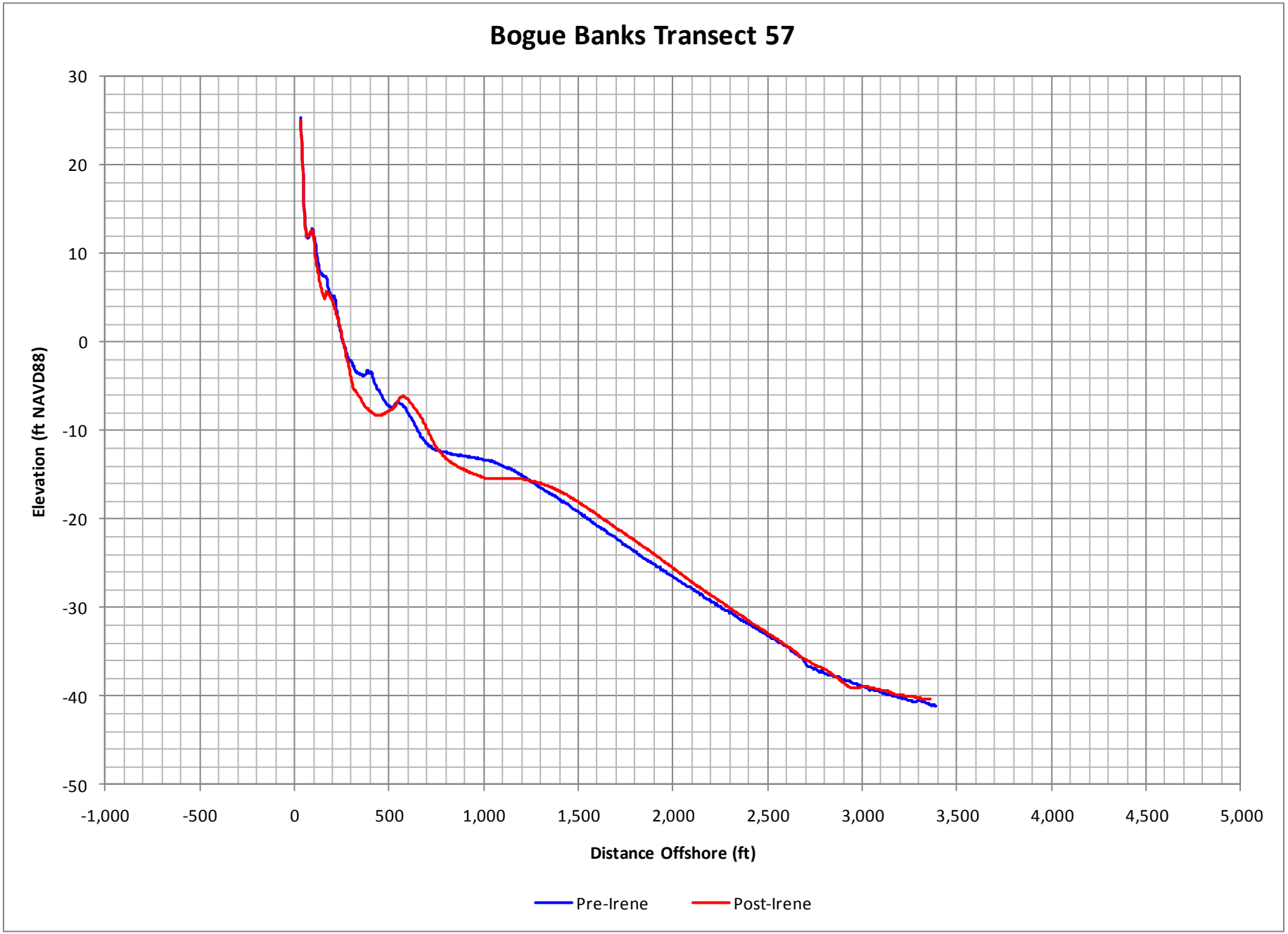

Figure B-57. Bogue Banks Profile Comparison

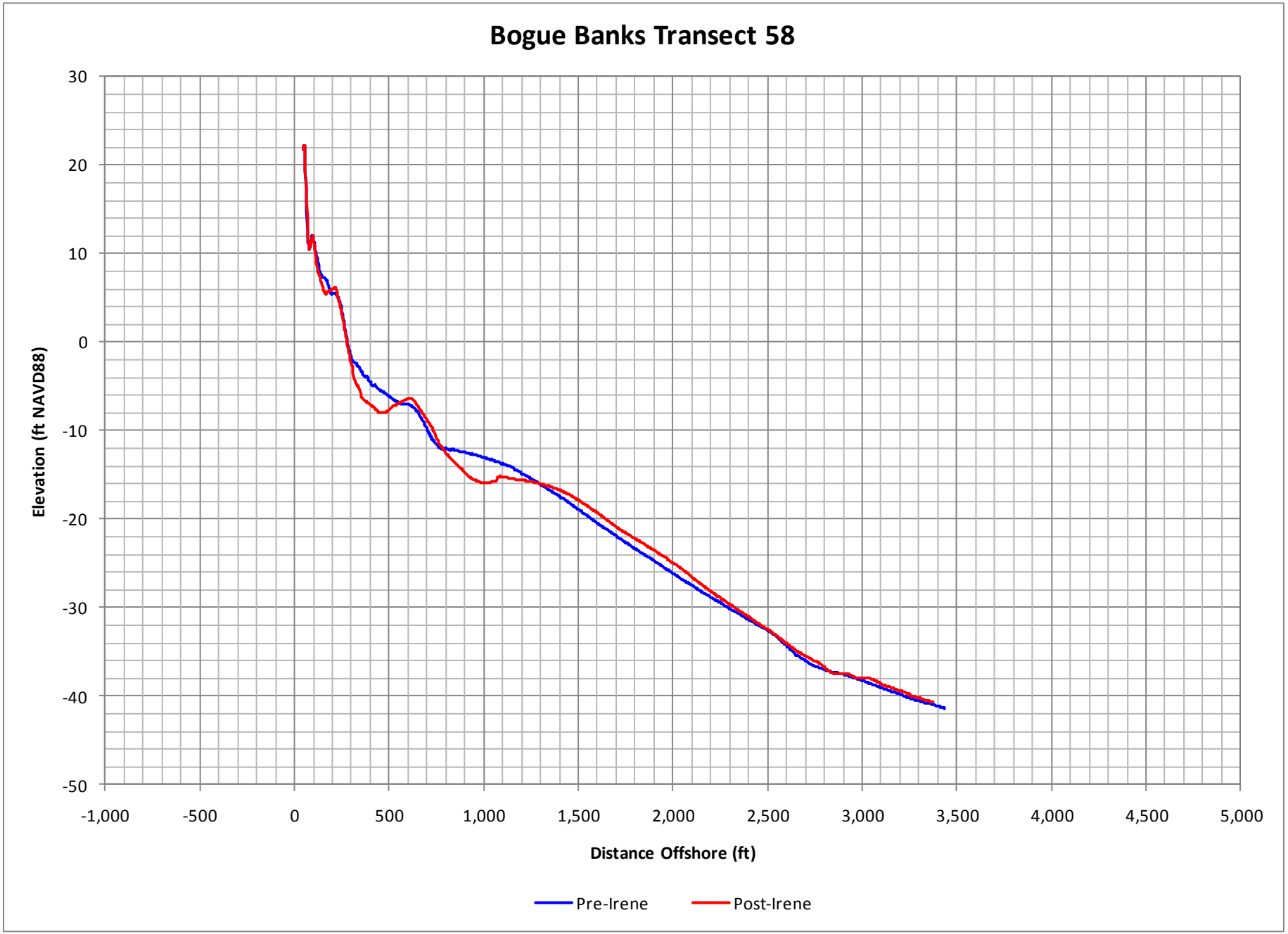

Figure B-58. Bogue Banks Profile Comparison

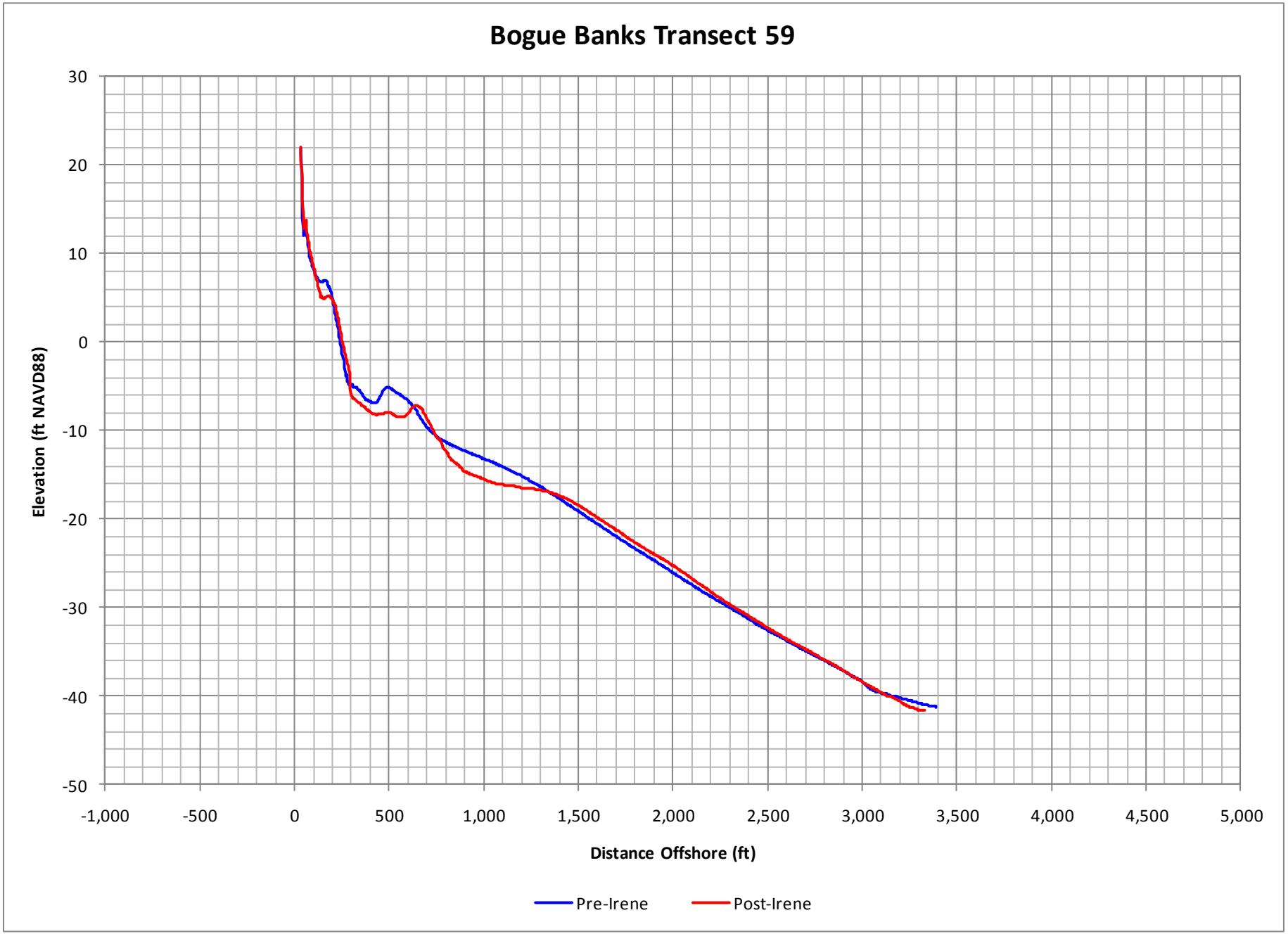

Figure B-59. Bogue Banks Profile Comparison

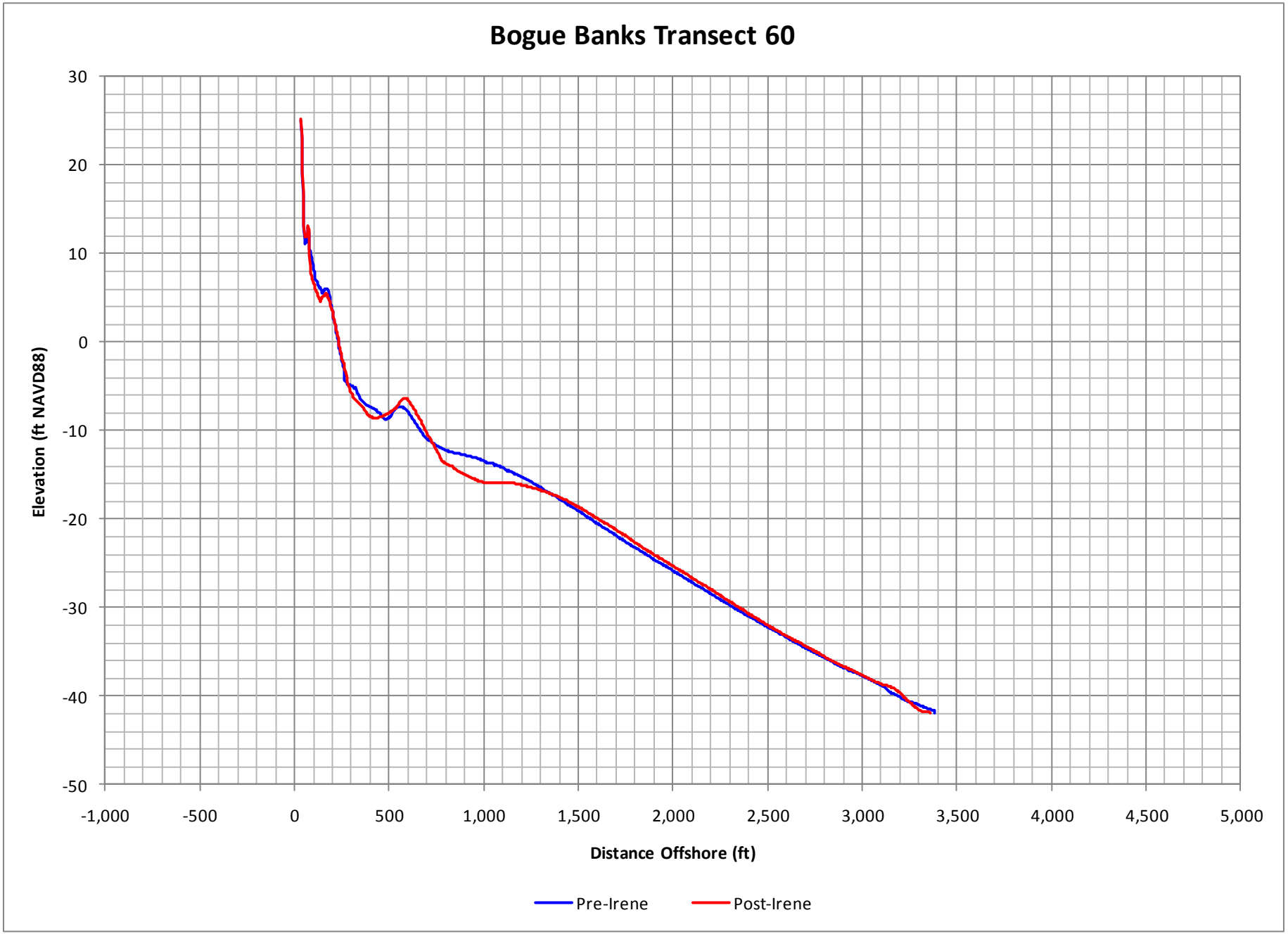

Figure B-60. Bogue Banks Profile Comparison

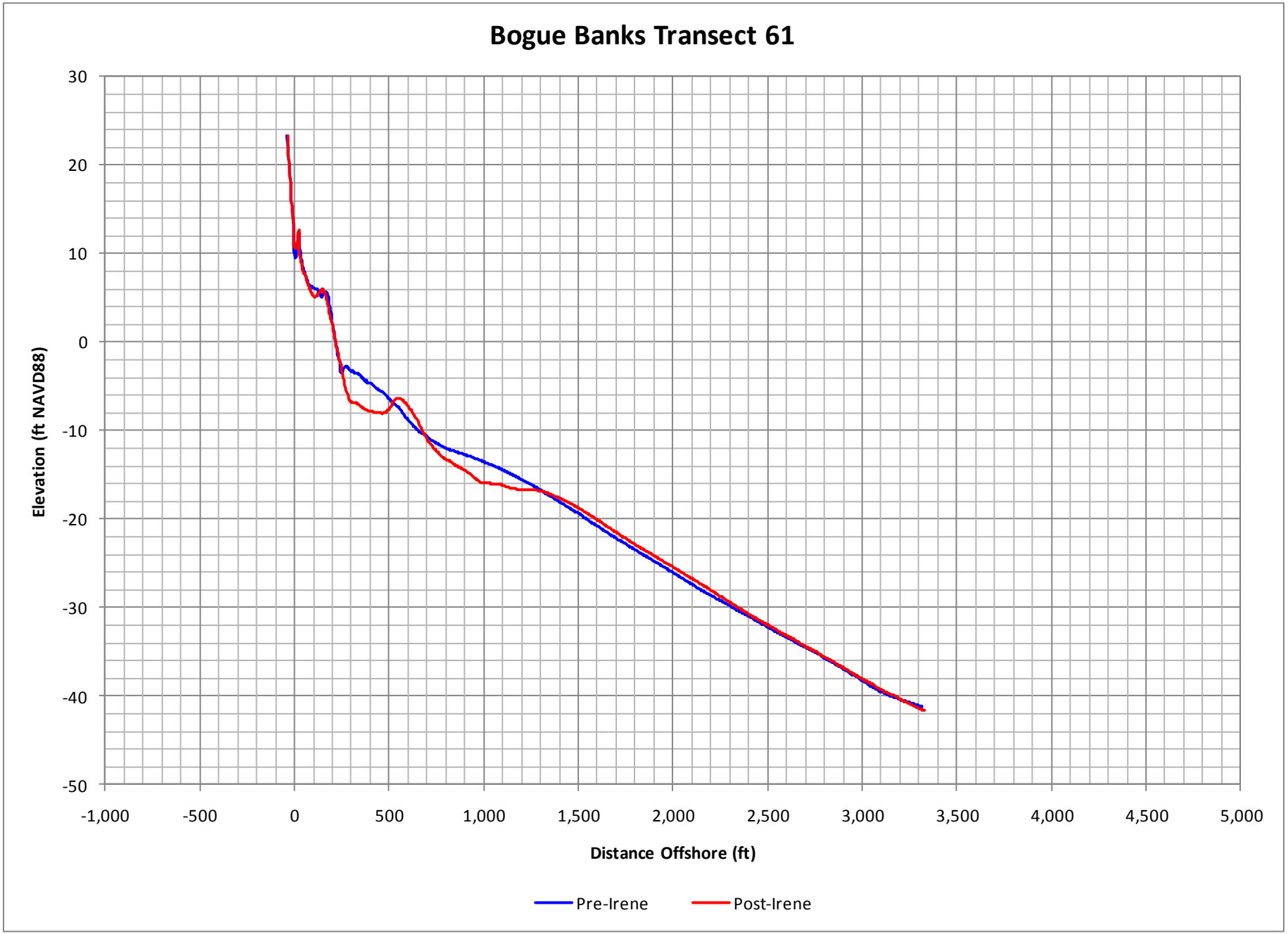

Figure B-61. Bogue Banks Profile Comparison

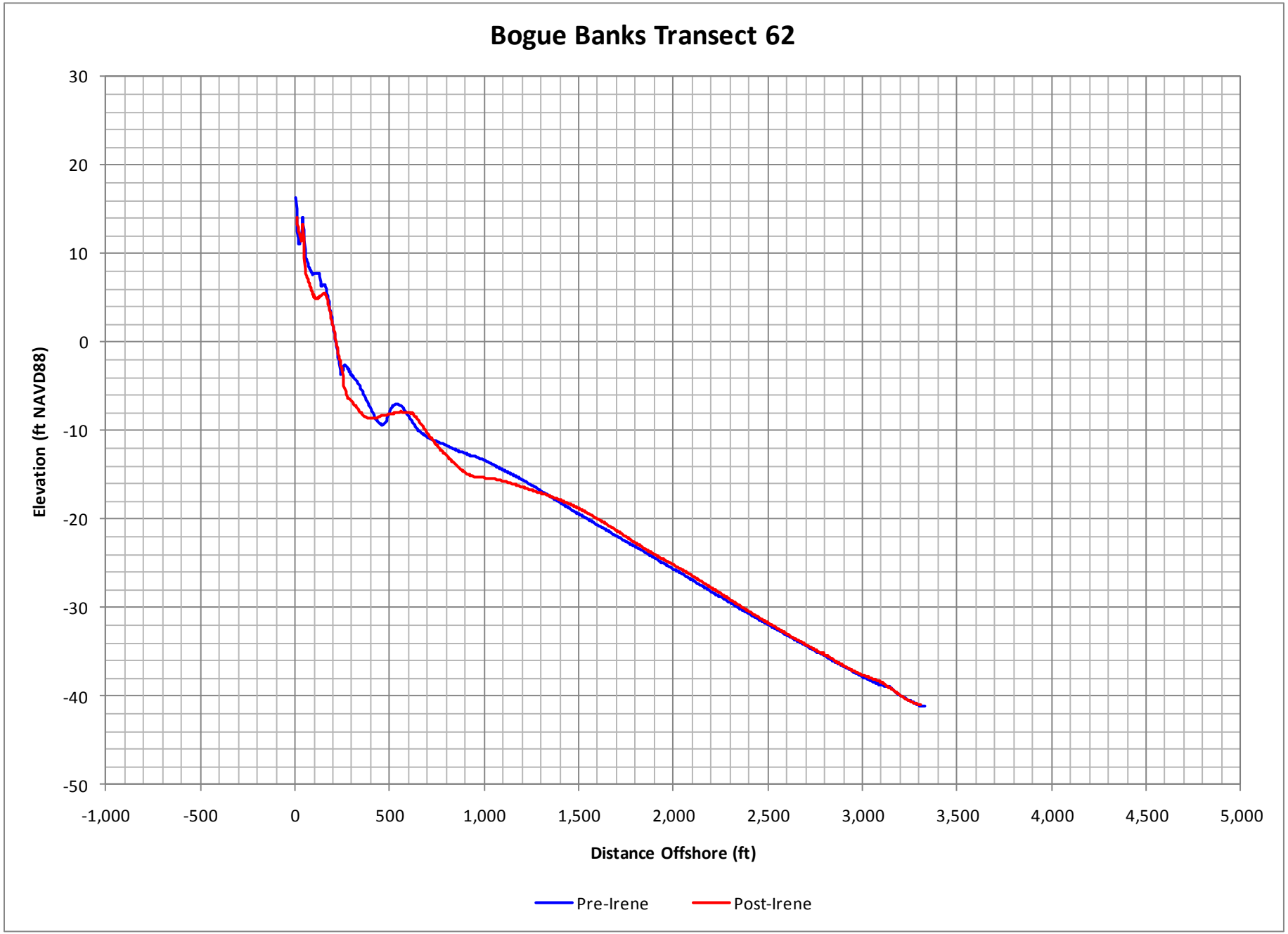

Figure B-62. Bogue Banks Profile Comparison

Figure B-63. Bogue Banks Profile Comparison

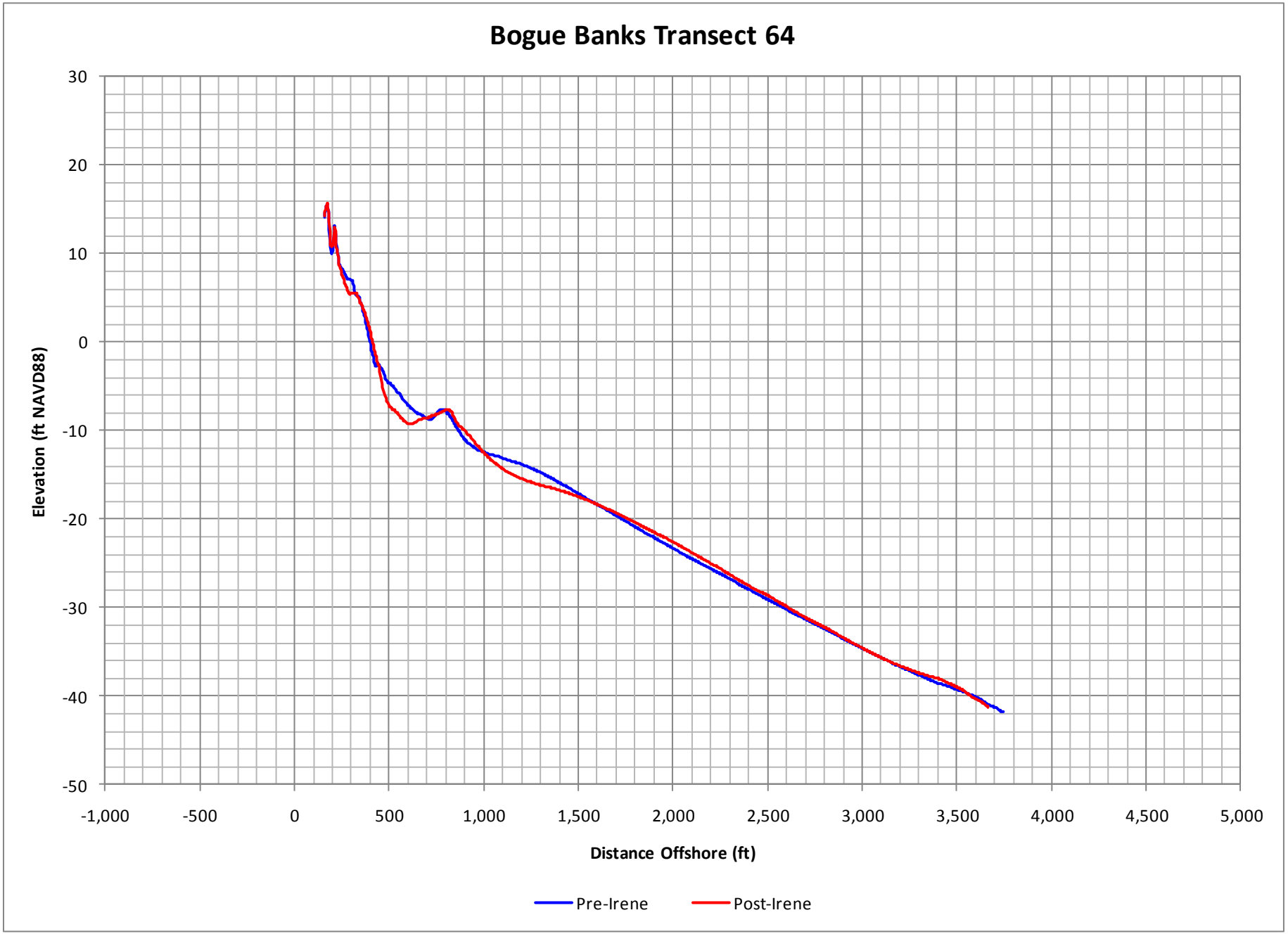

Figure B-64. Bogue Banks Profile Comparison

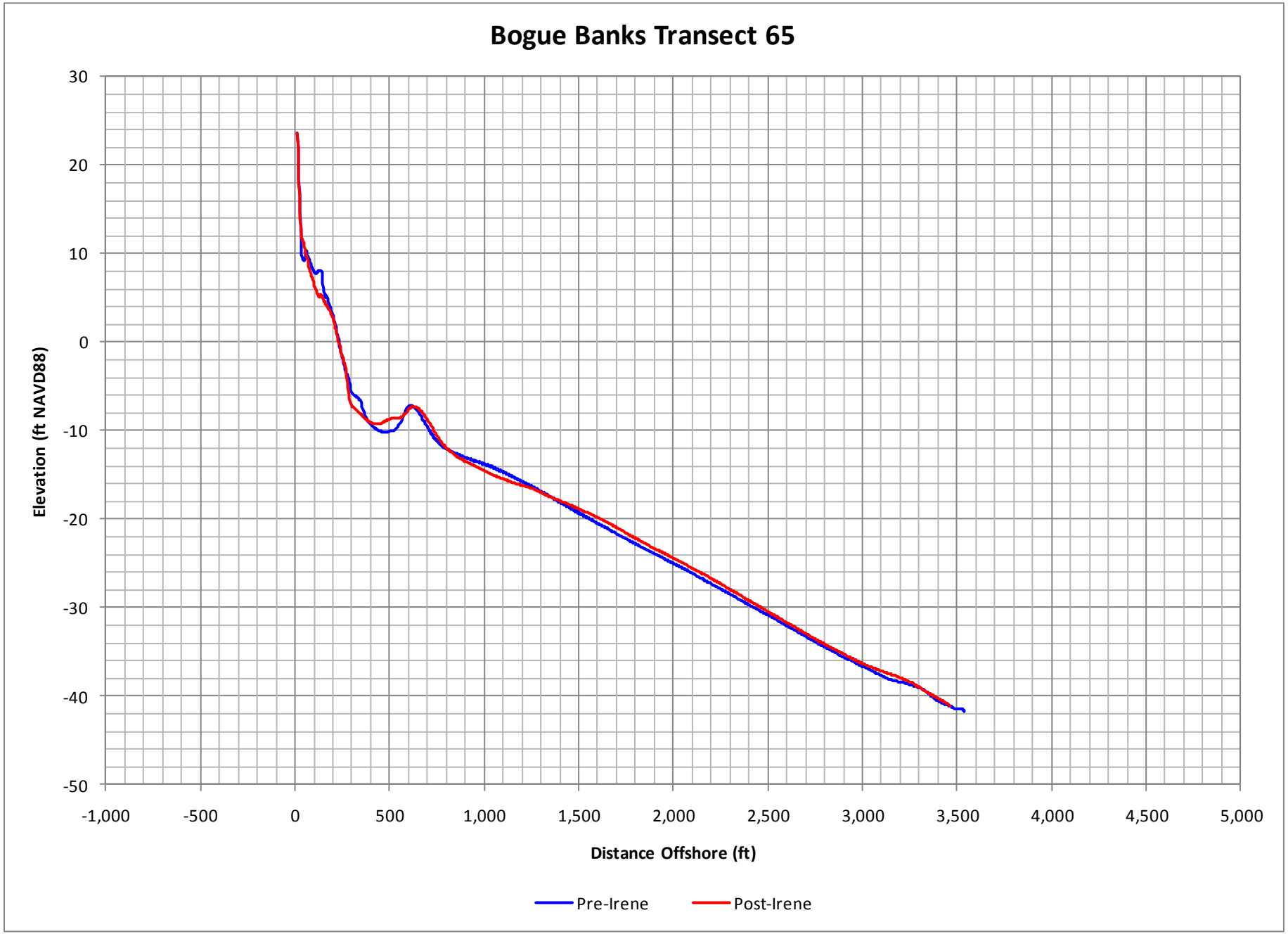

Figure B-65. Bogue Banks Profile Comparison

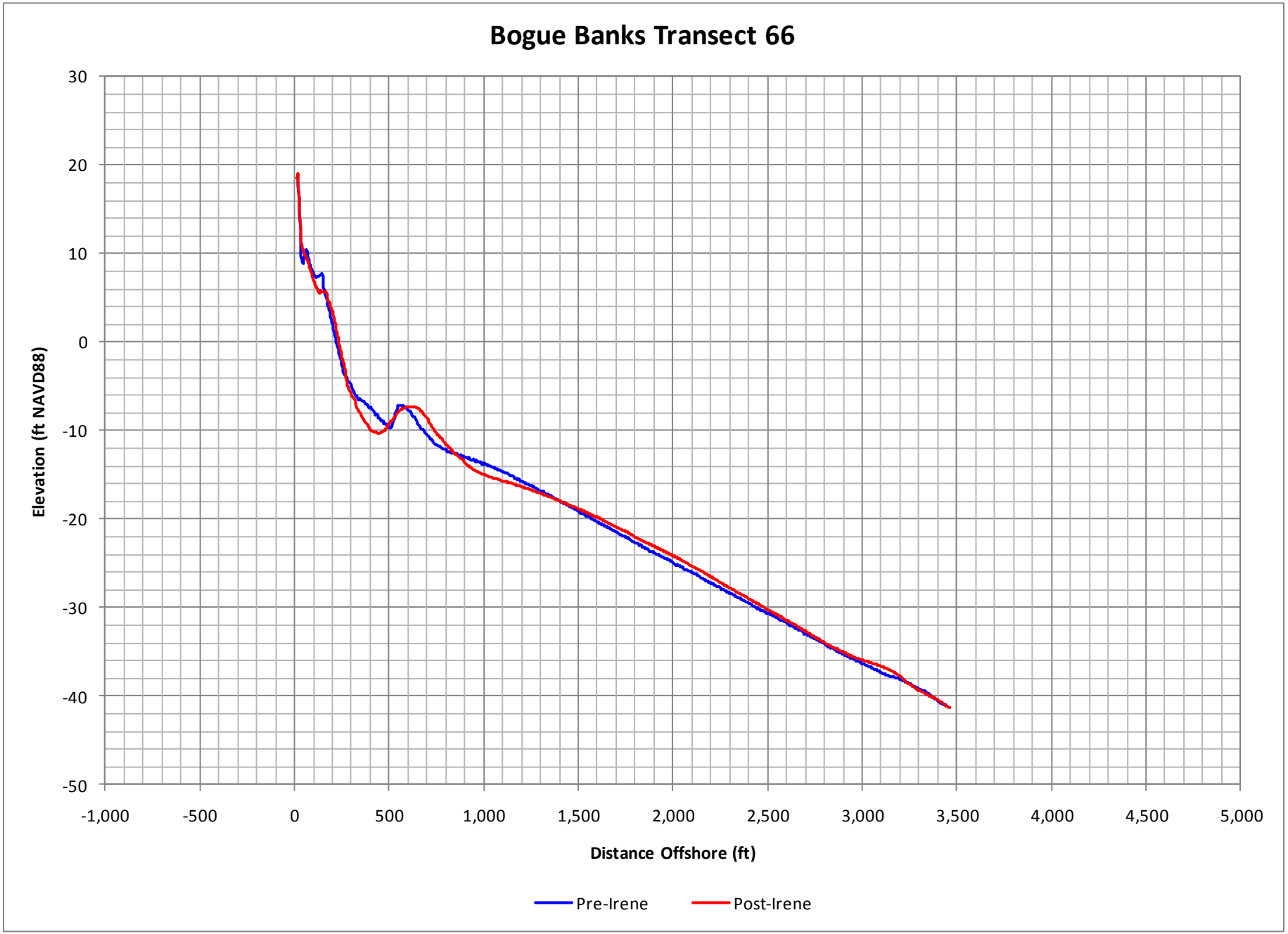

Figure B-66. Bogue Banks Profile Comparison

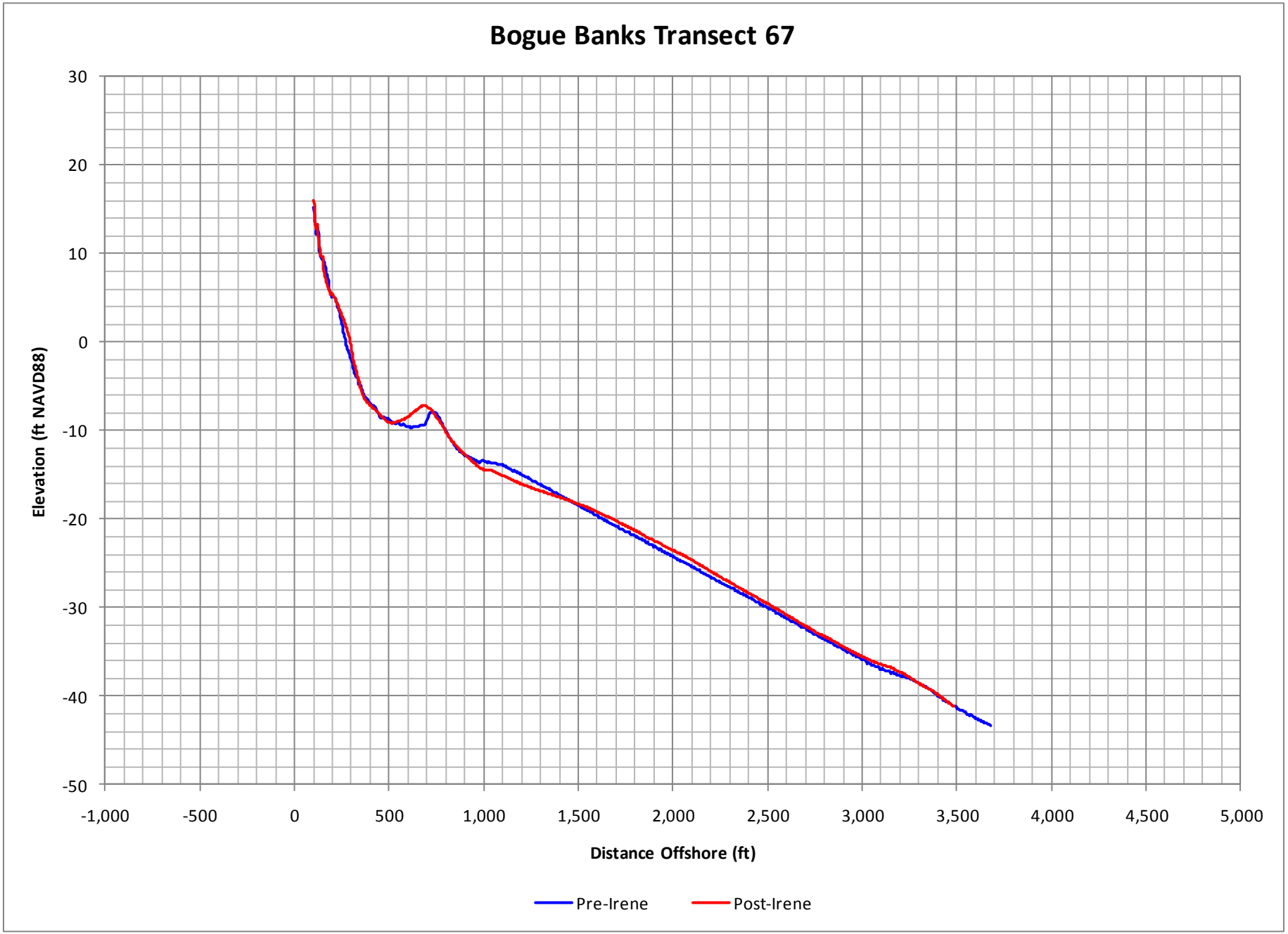

Figure B-67. Bogue Banks Profile Comparison

Figure B-68. Bogue Banks Profile Comparison

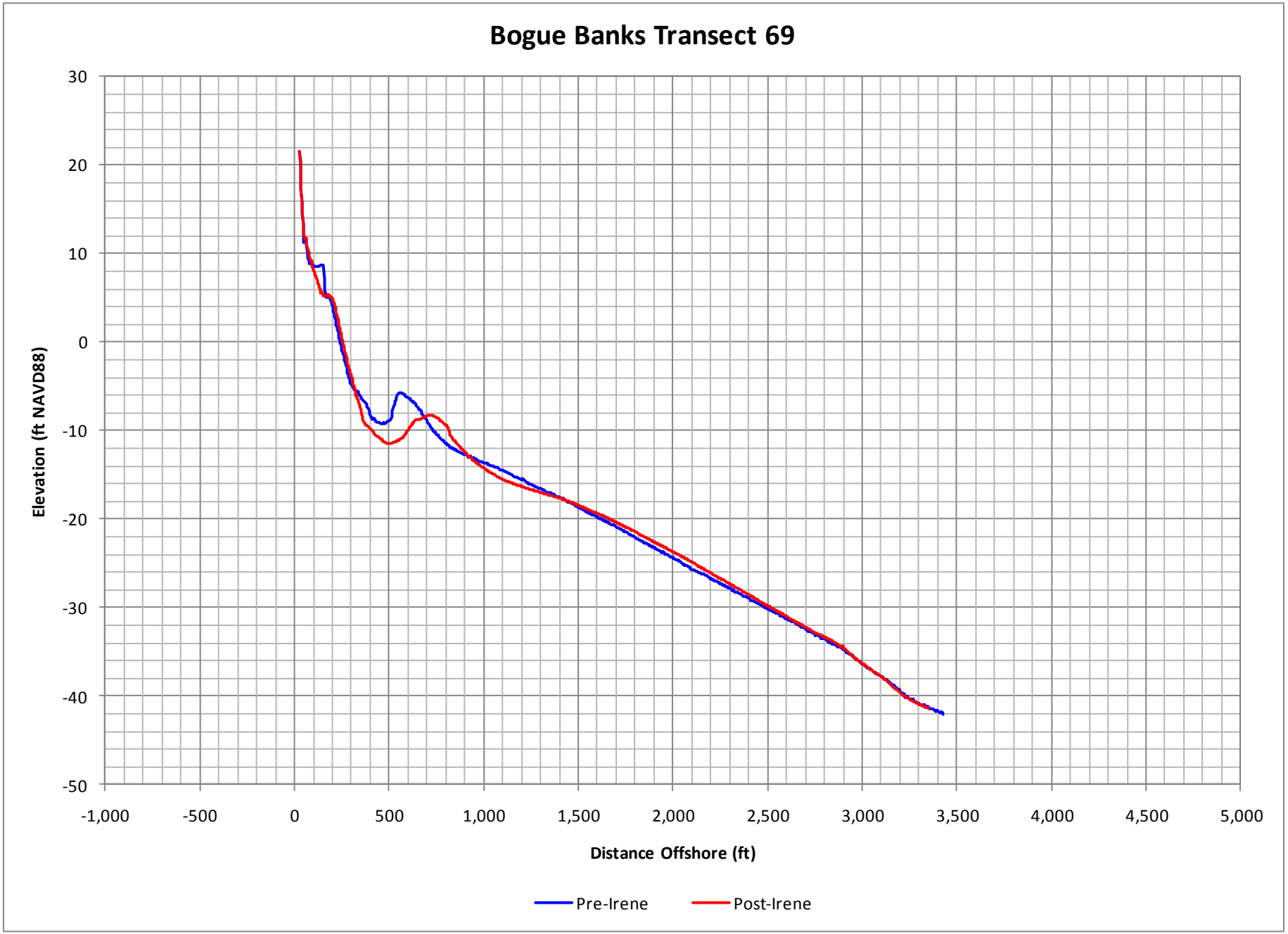

Figure B-69. Bogue Banks Profile Comparison

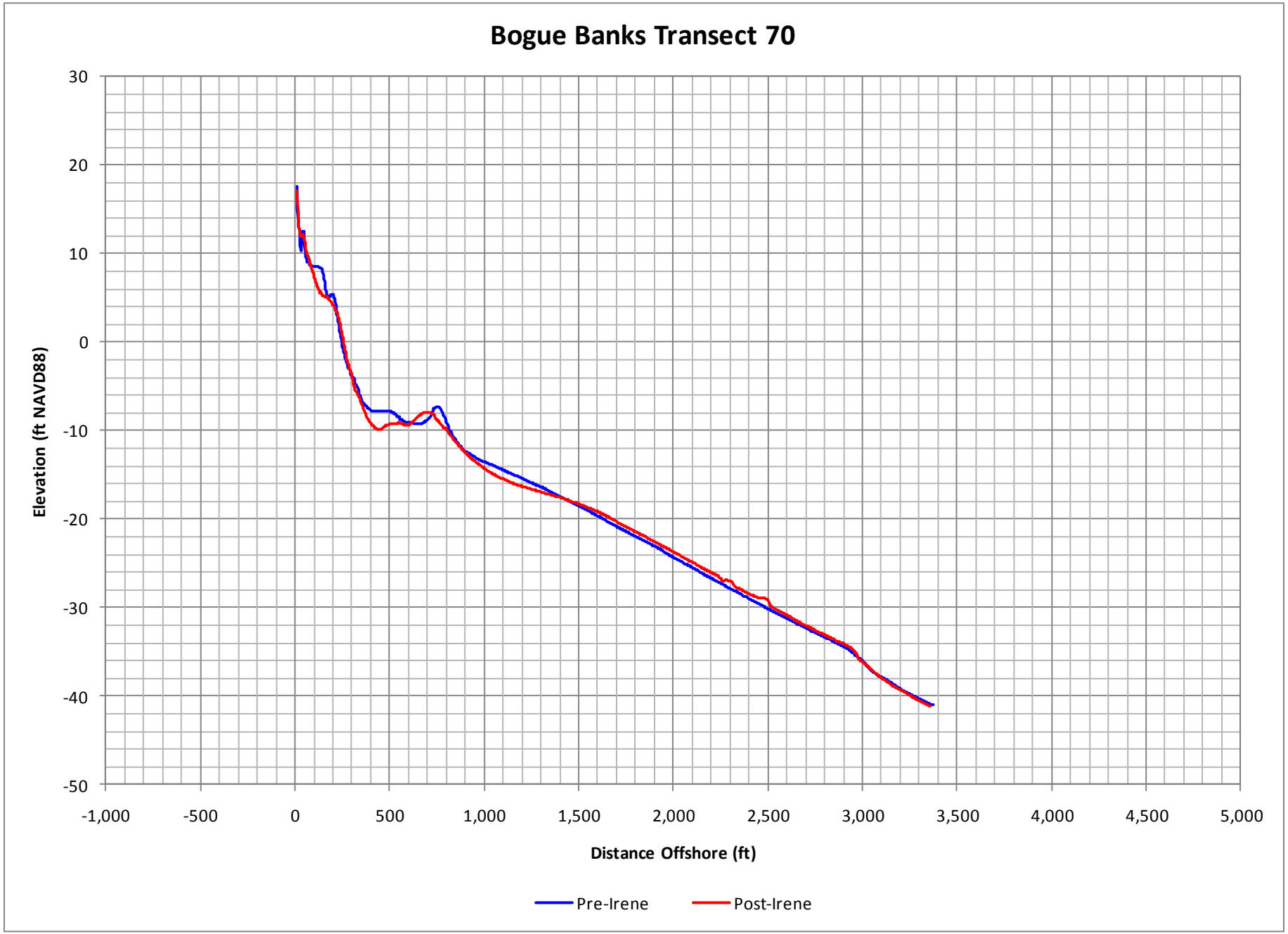

Figure B-70. Bogue Banks Profile Comparison

Figure B-71. Bogue Banks Profile Comparison

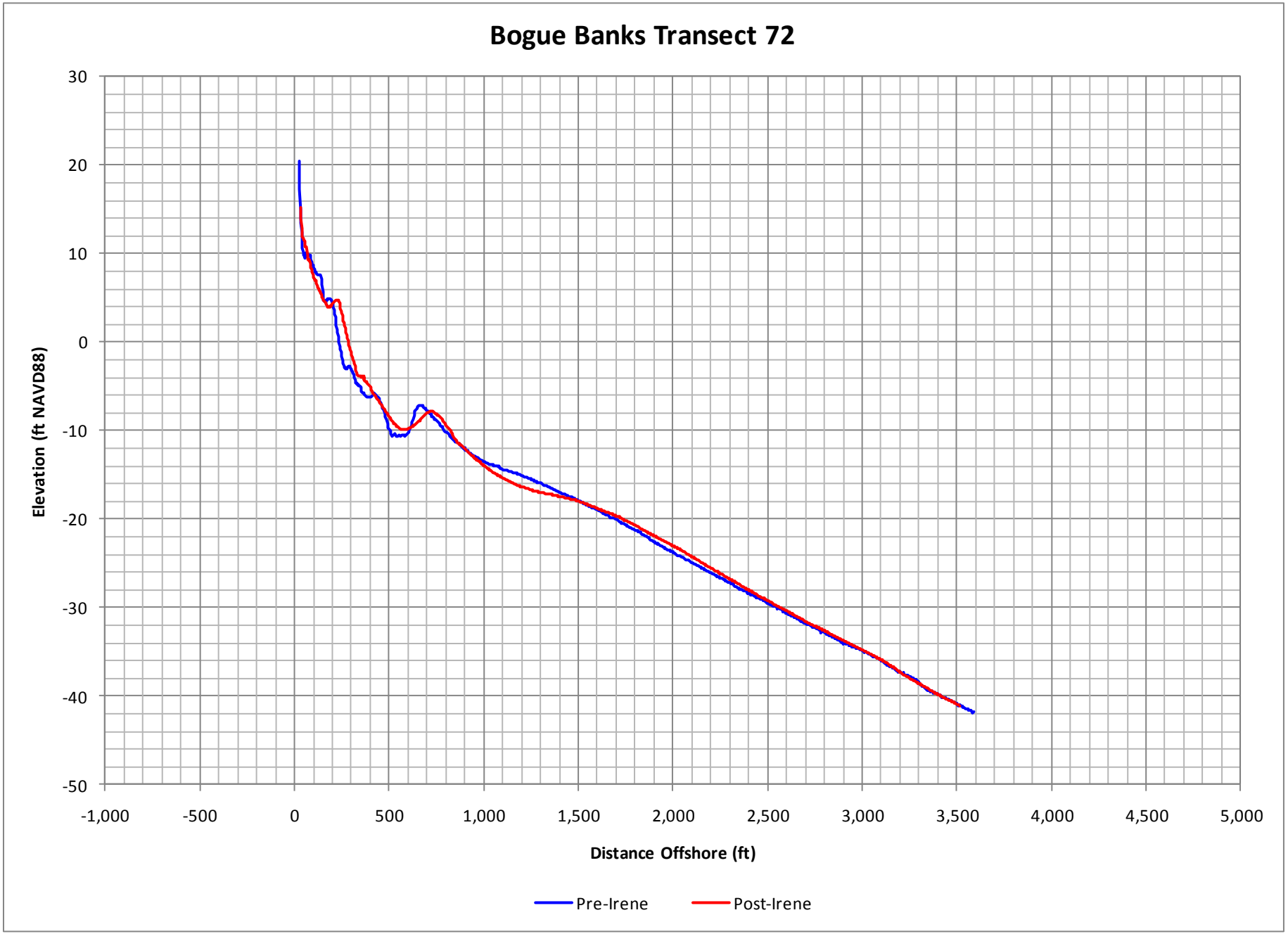

Figure B-72. Bogue Banks Profile Comparison

Figure B-73. Bogue Banks Profile Comparison

Figure B-74. Bogue Banks Profile Comparison

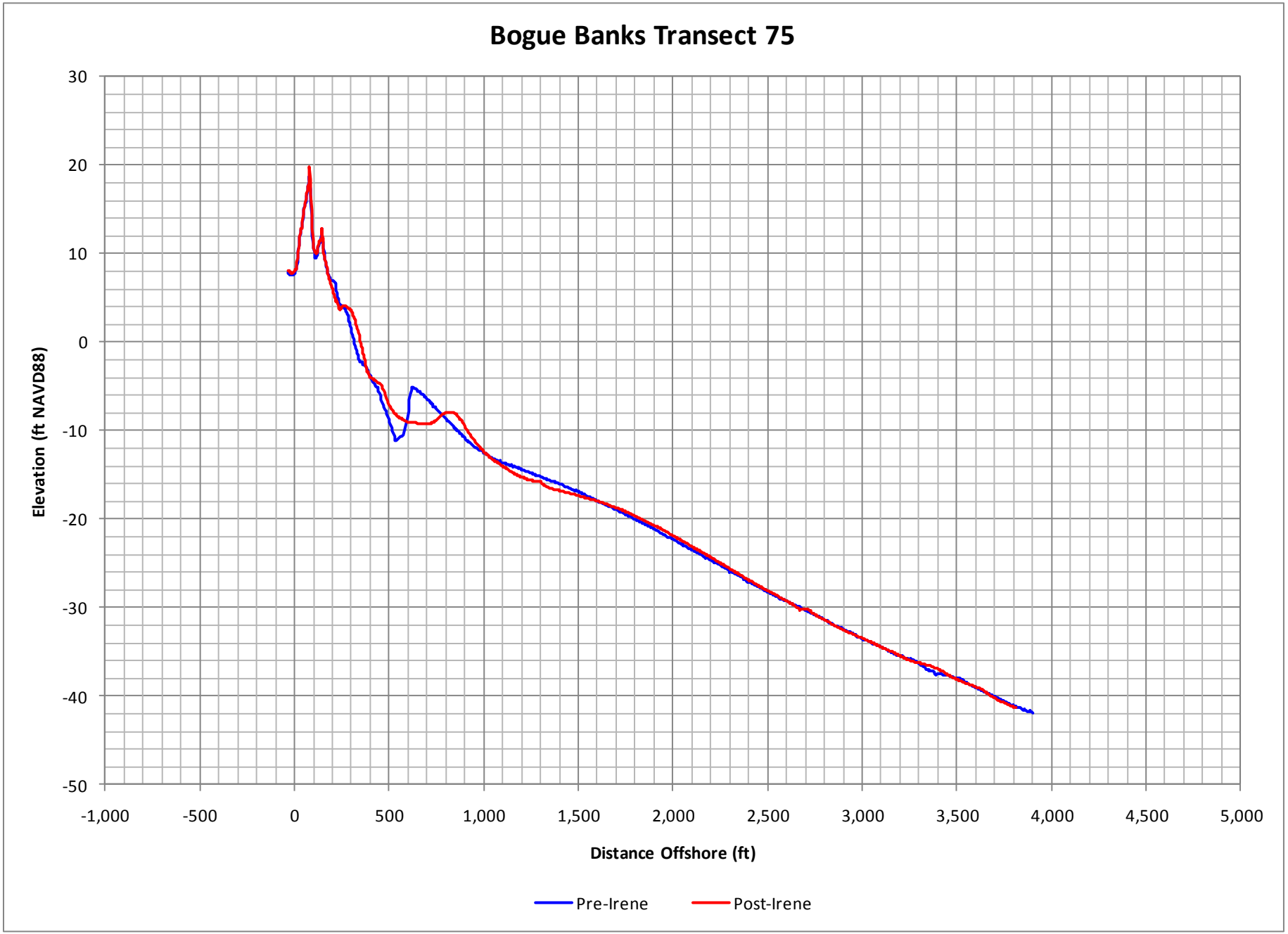

Figure B-75. Bogue Banks Profile Comparison

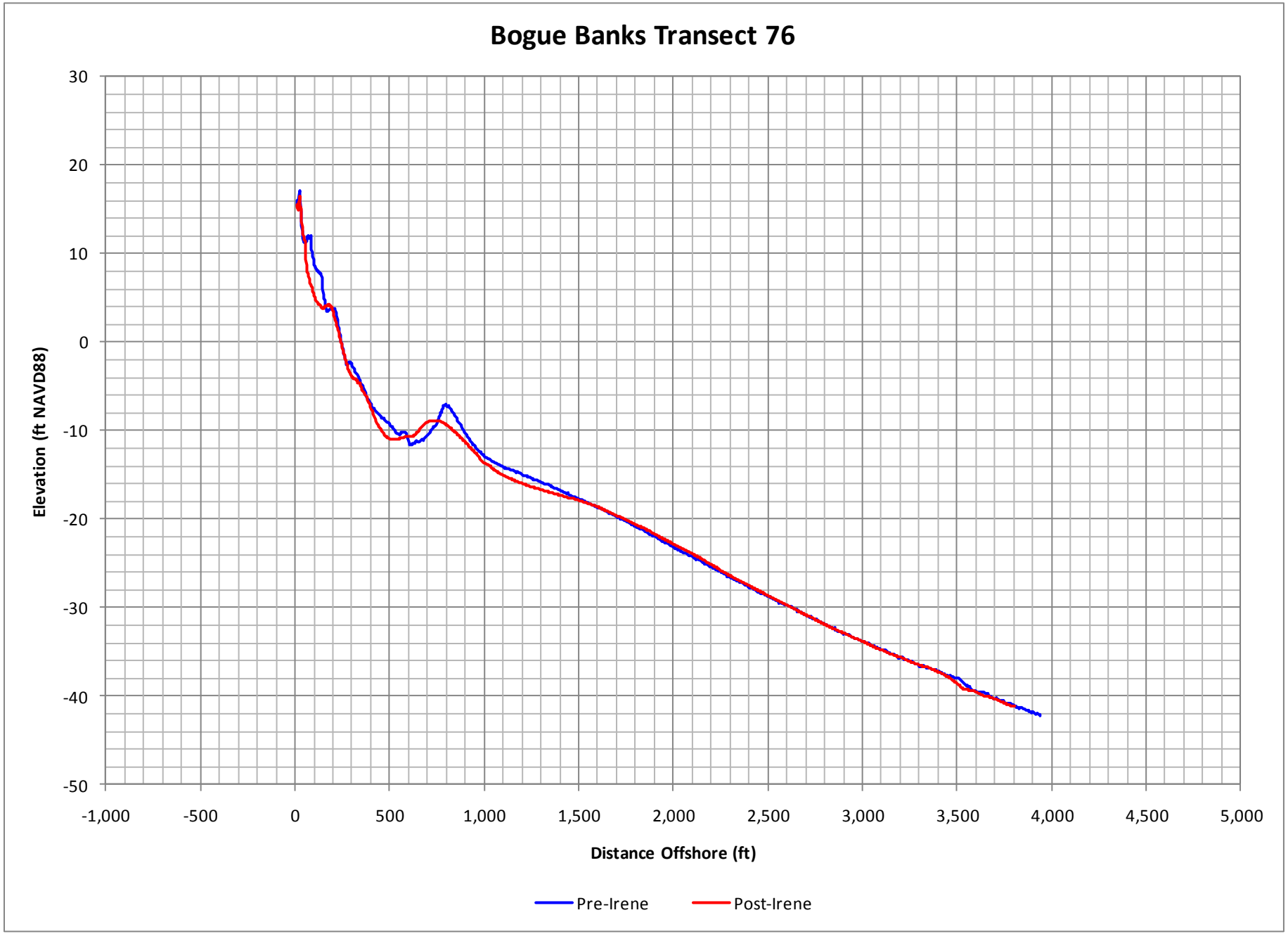

Figure B-76. Bogue Banks Profile Comparison

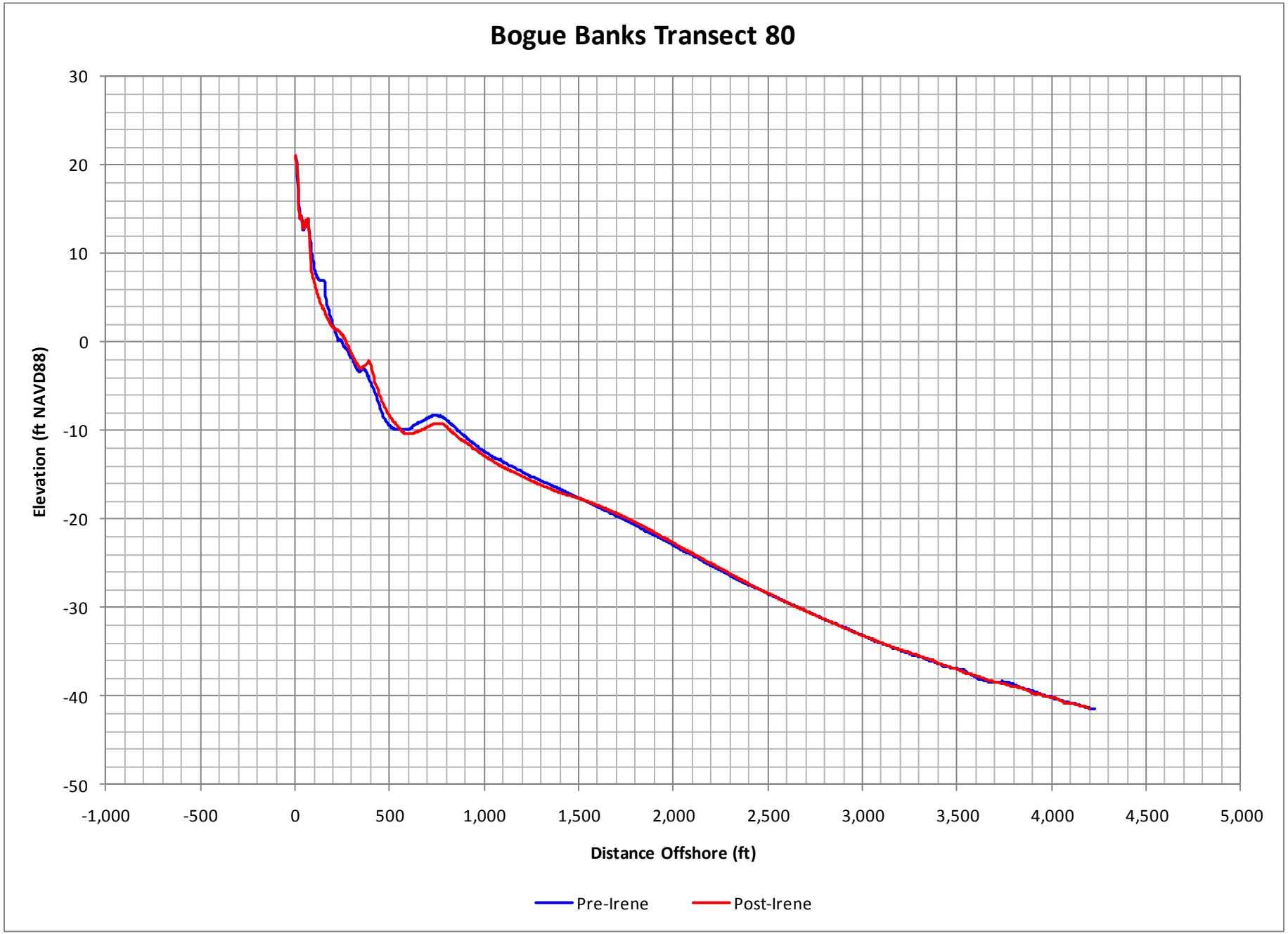

Figure B-77. Bogue Banks Profile Comparison

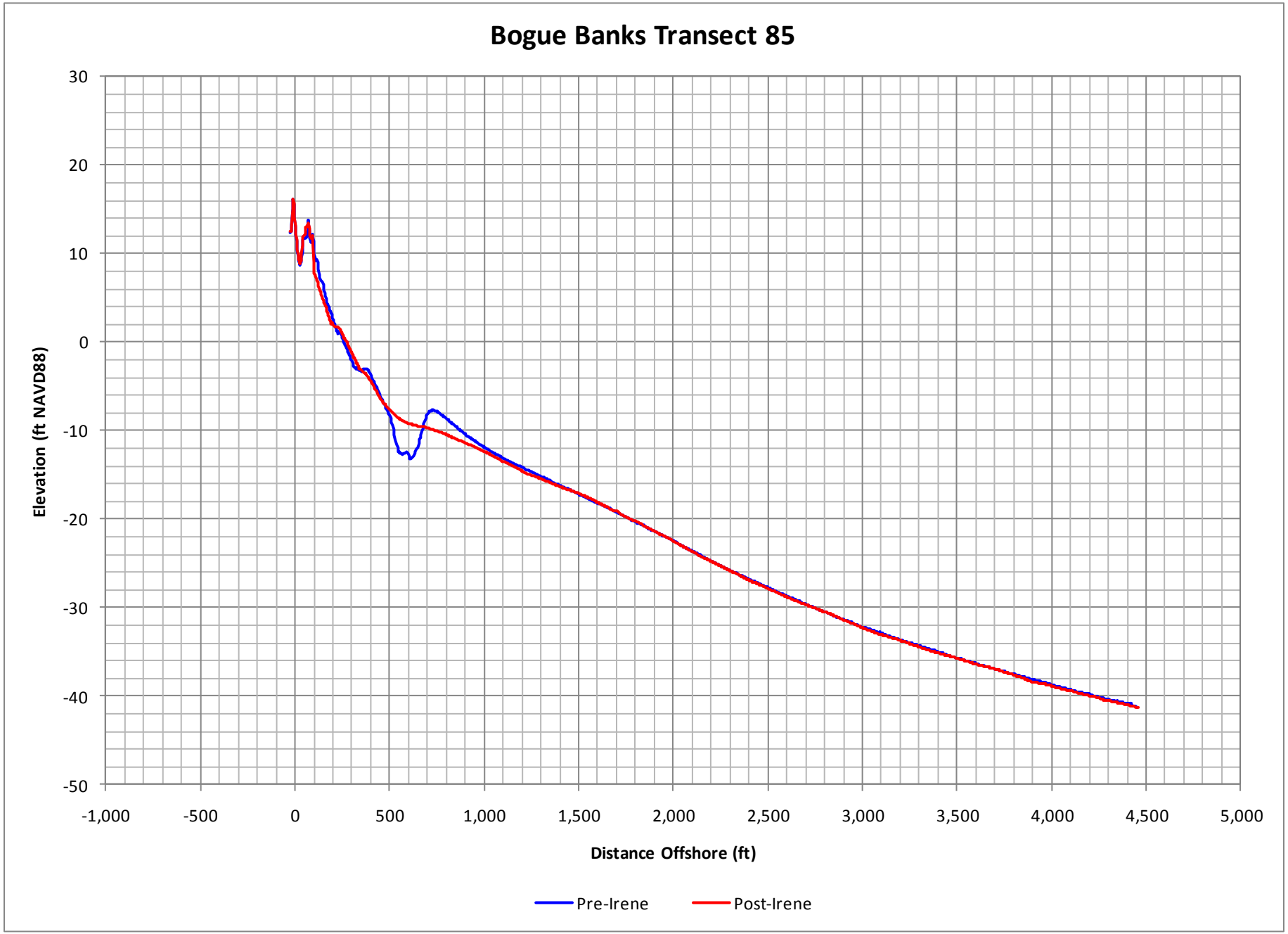

Figure B-78. Bogue Banks Profile Comparison

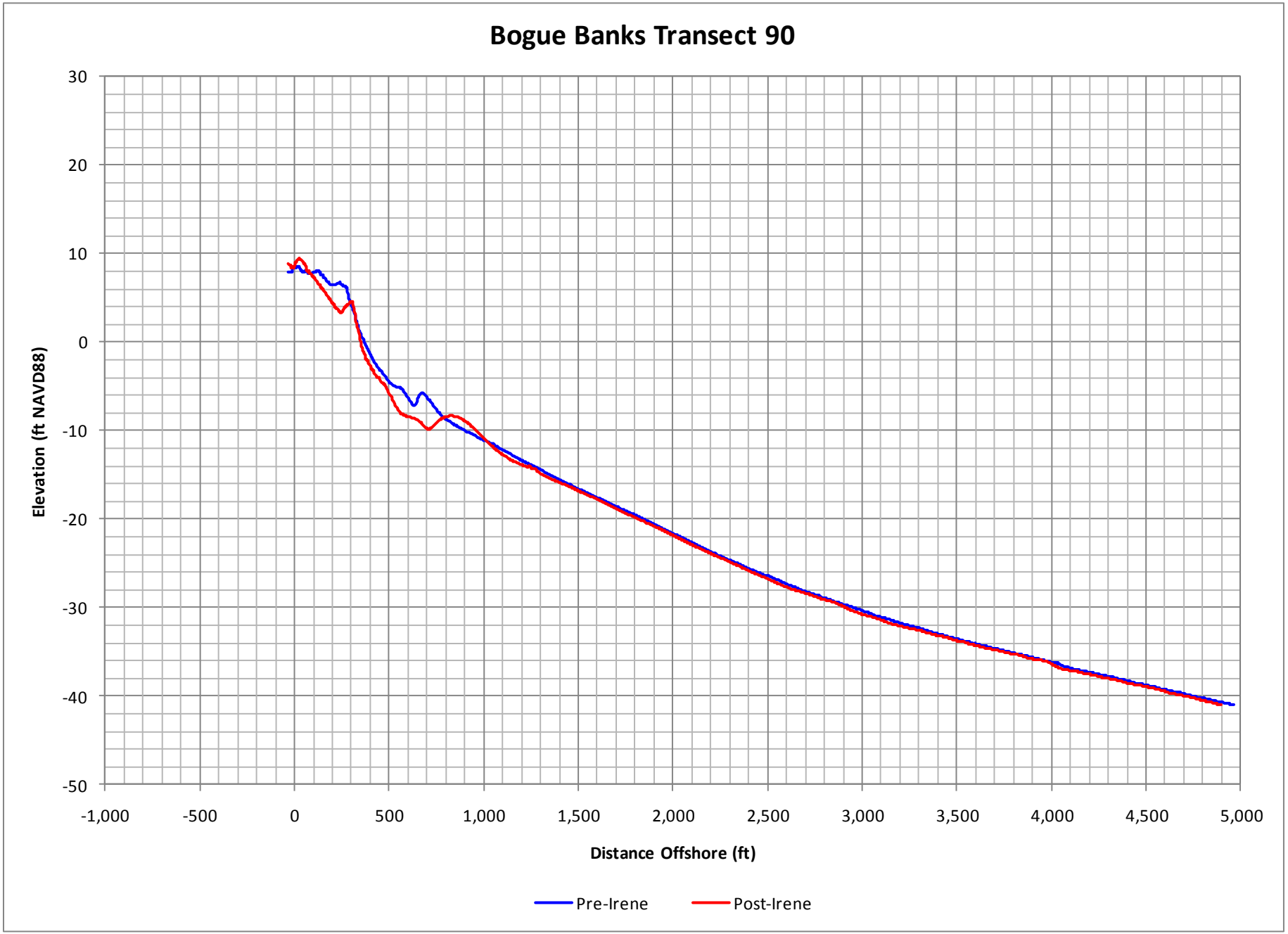

Figure B-79. Bogue Banks Profile Comparison

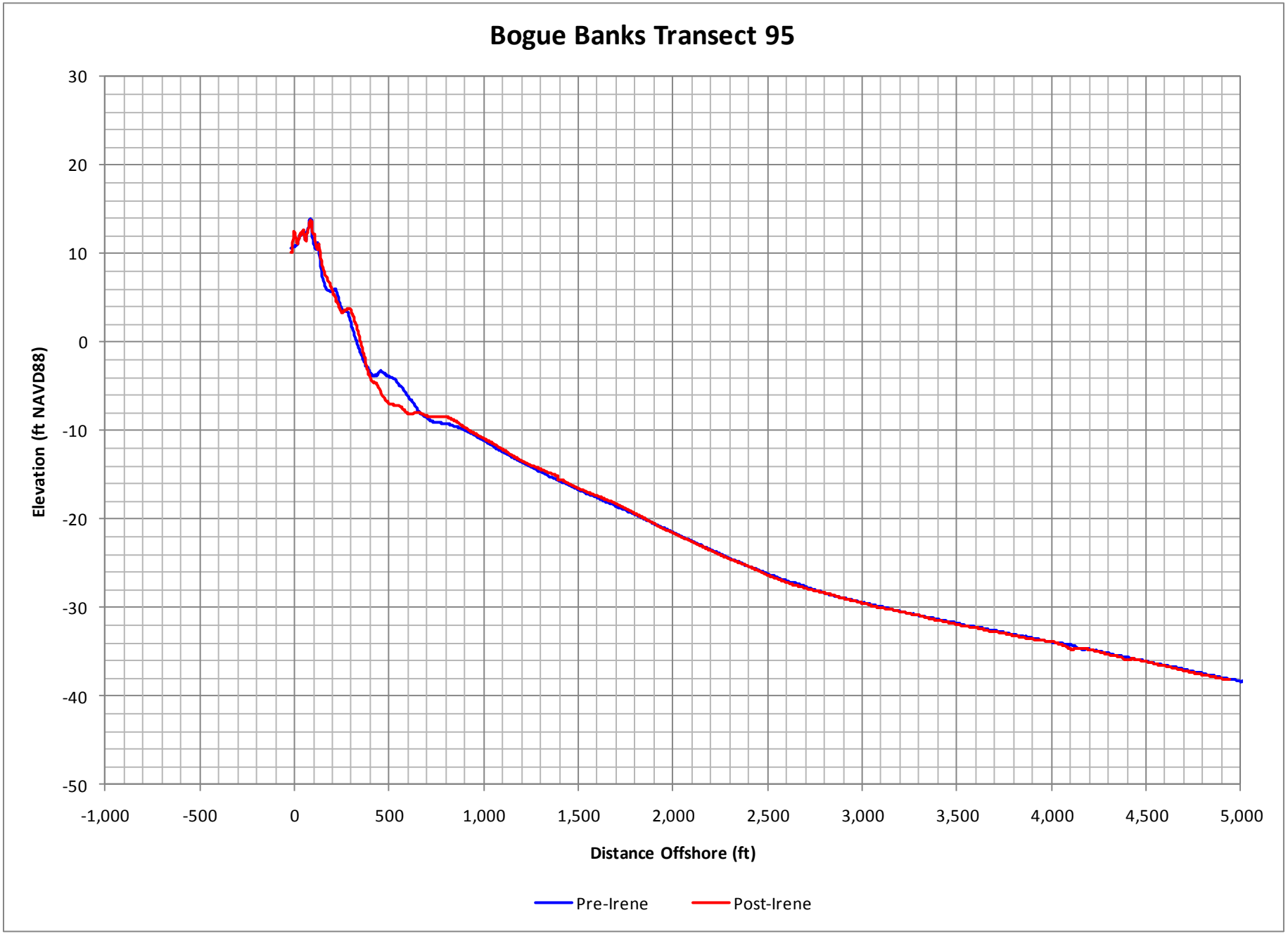

Figure B-80. Bogue Banks Profile Comparison

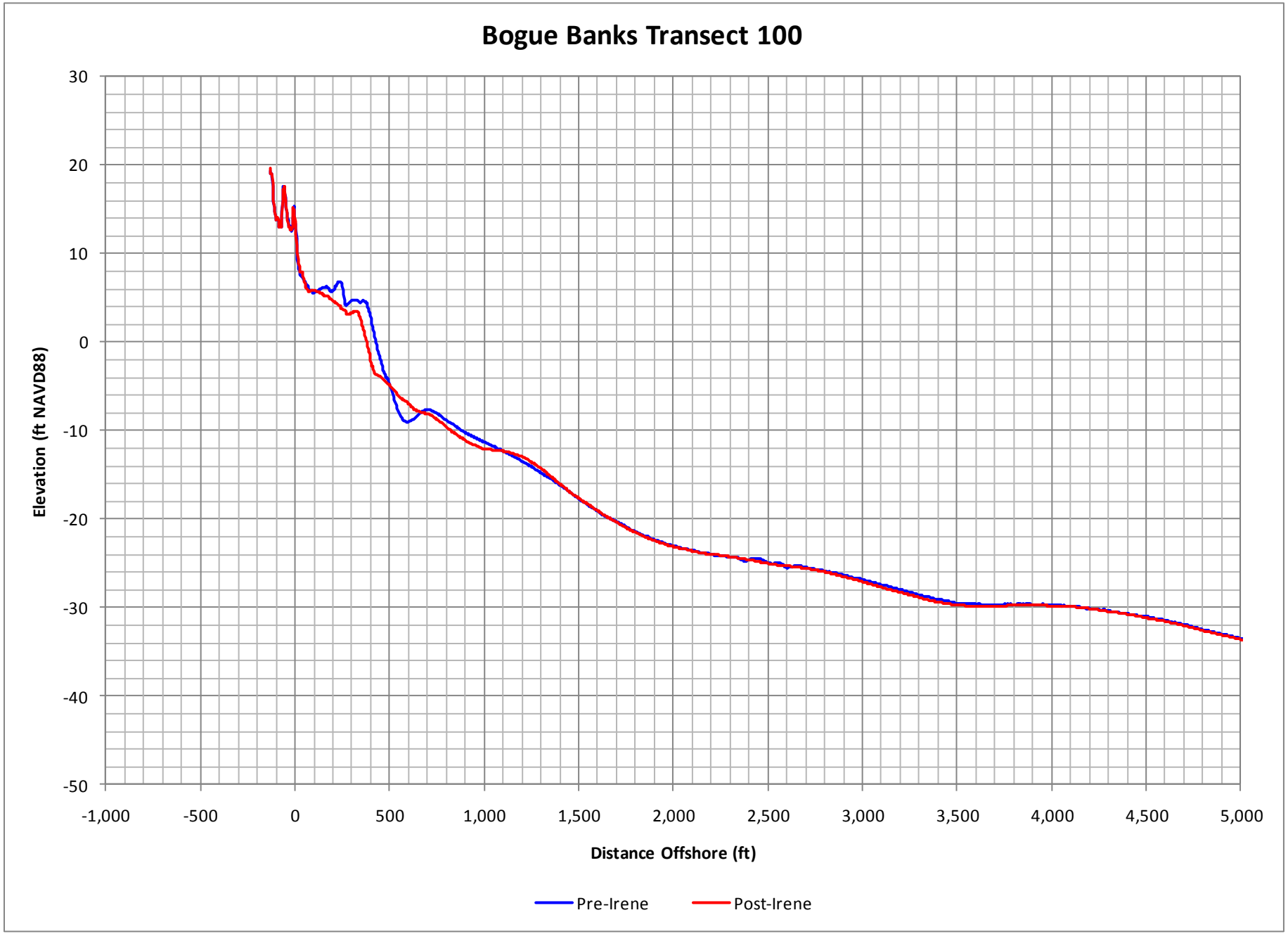

Figure B-81. Bogue Banks Profile Comparison

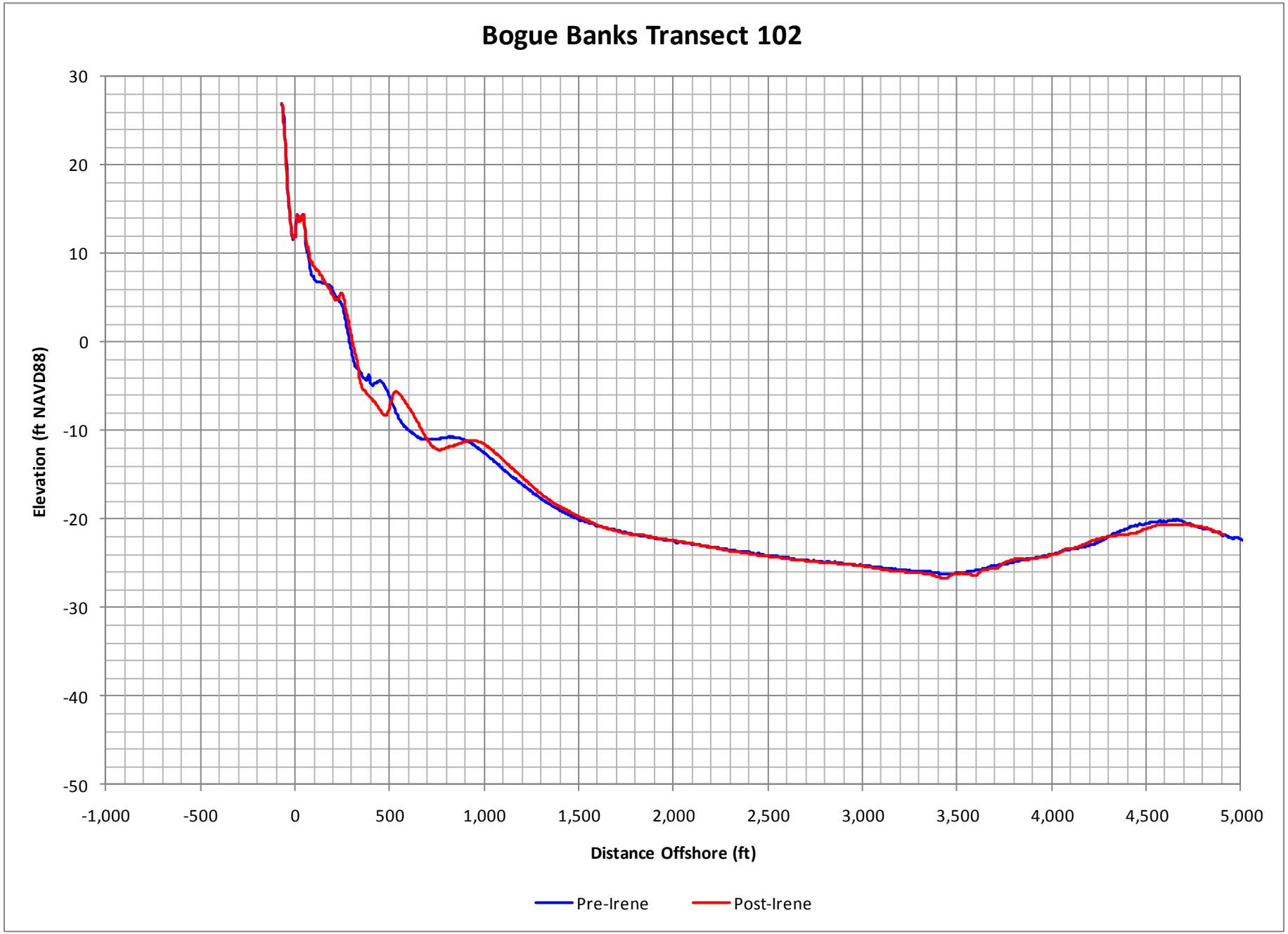

Figure B-82. Bogue Banks Profile Comparison

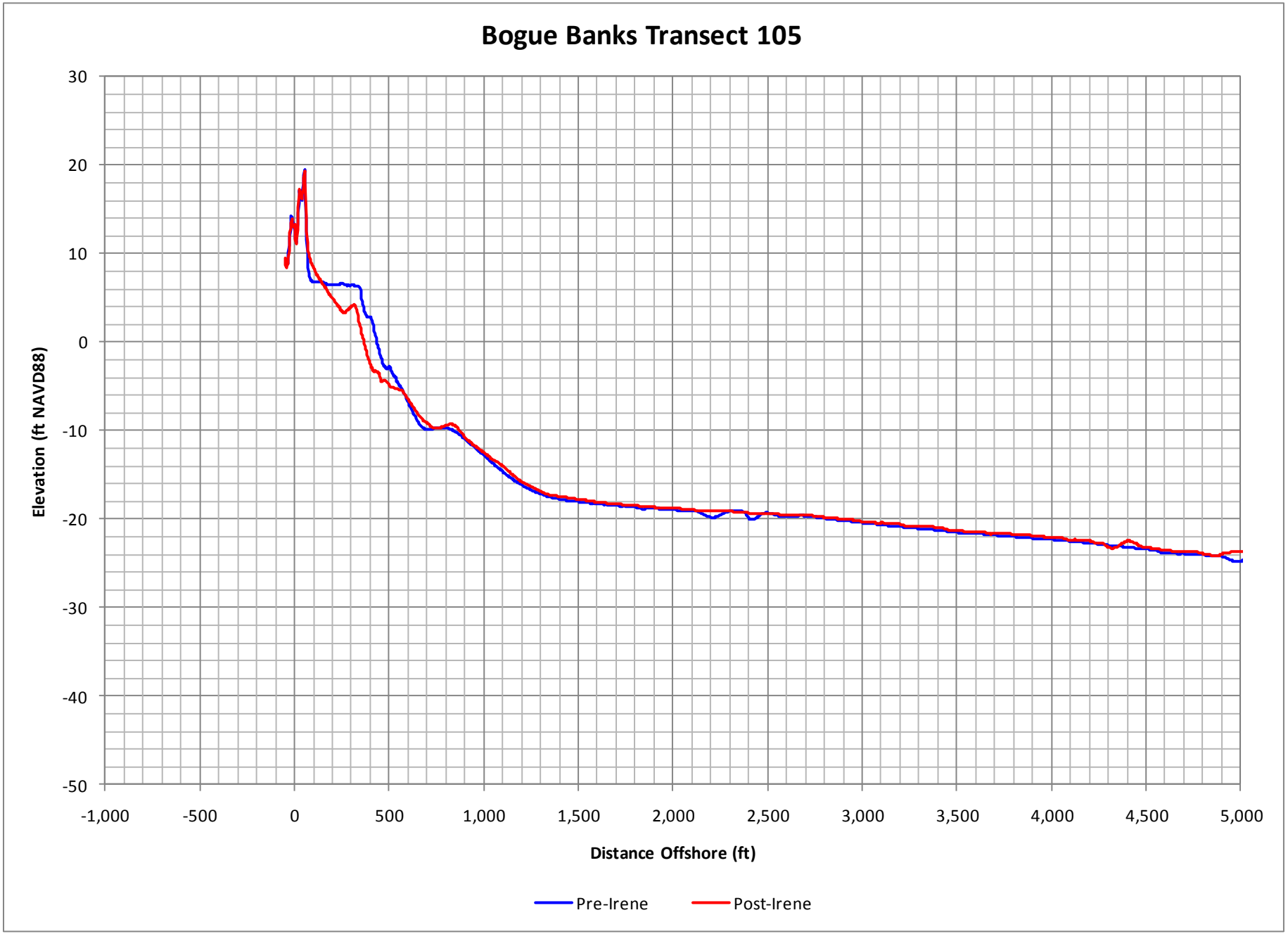

Figure B-83. Bogue Banks Profile Comparison

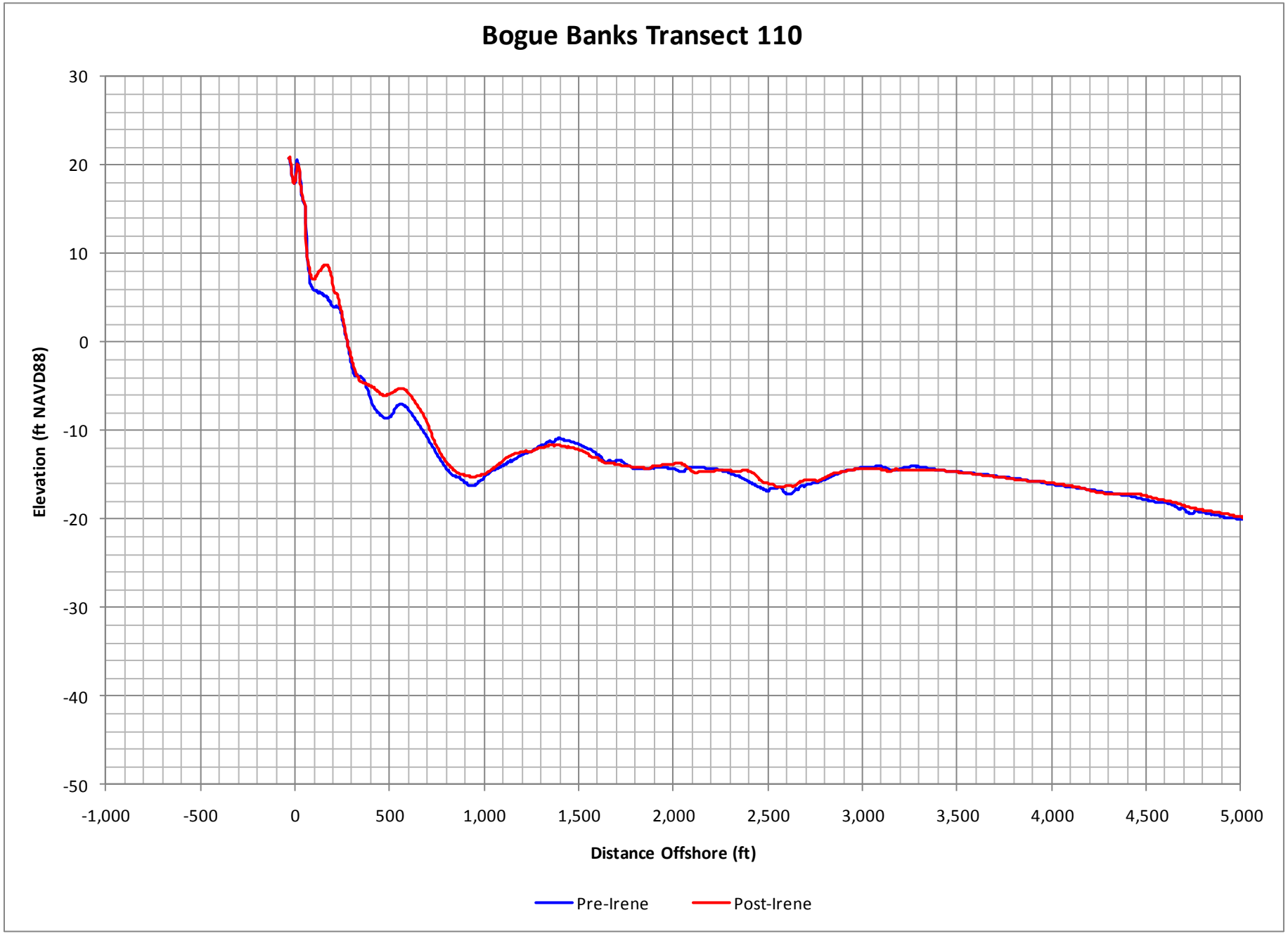

Figure B-84. Bogue Banks Profile Comparison

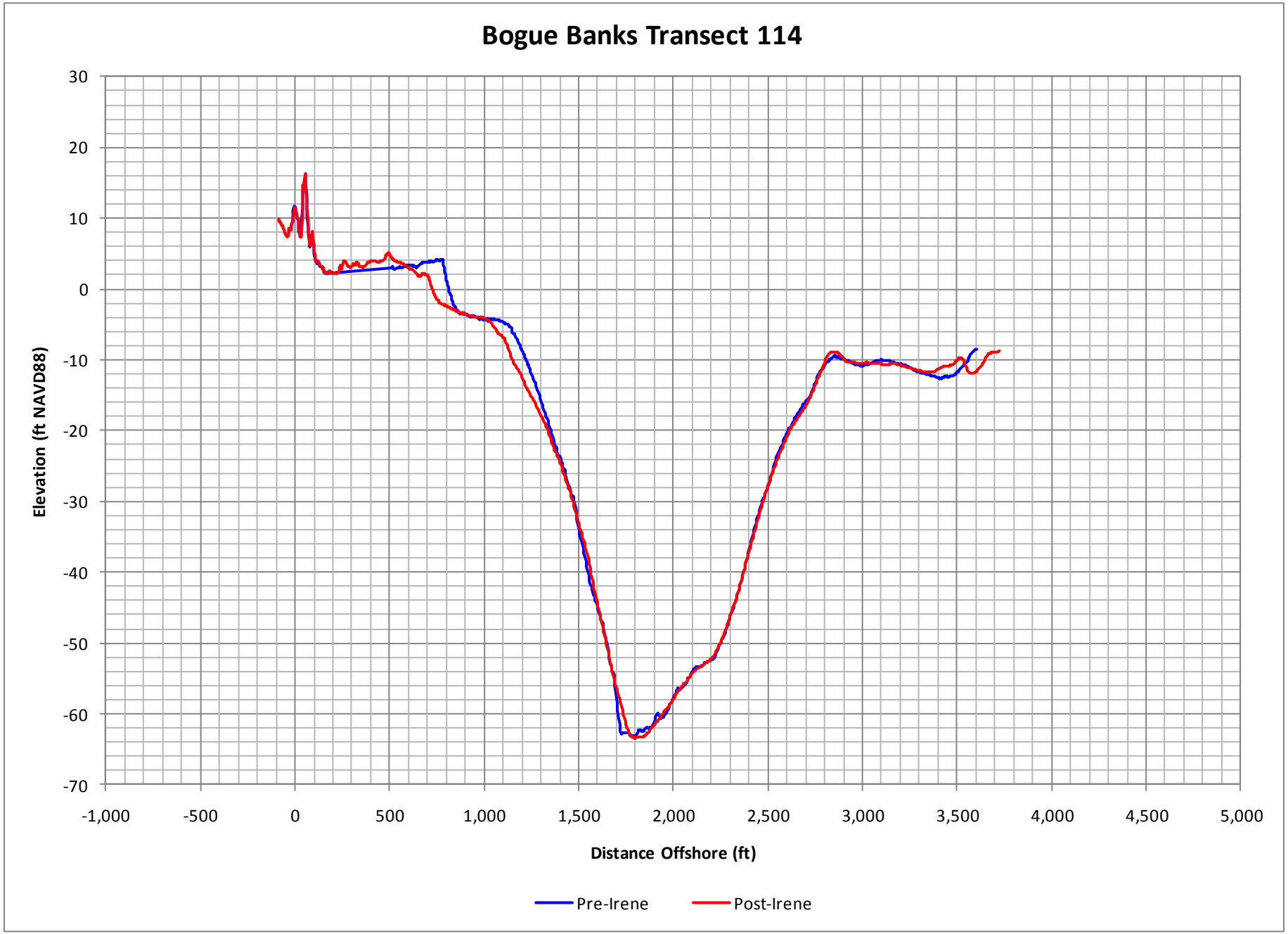

Figure B-85. Bogue Banks Profile Comparison

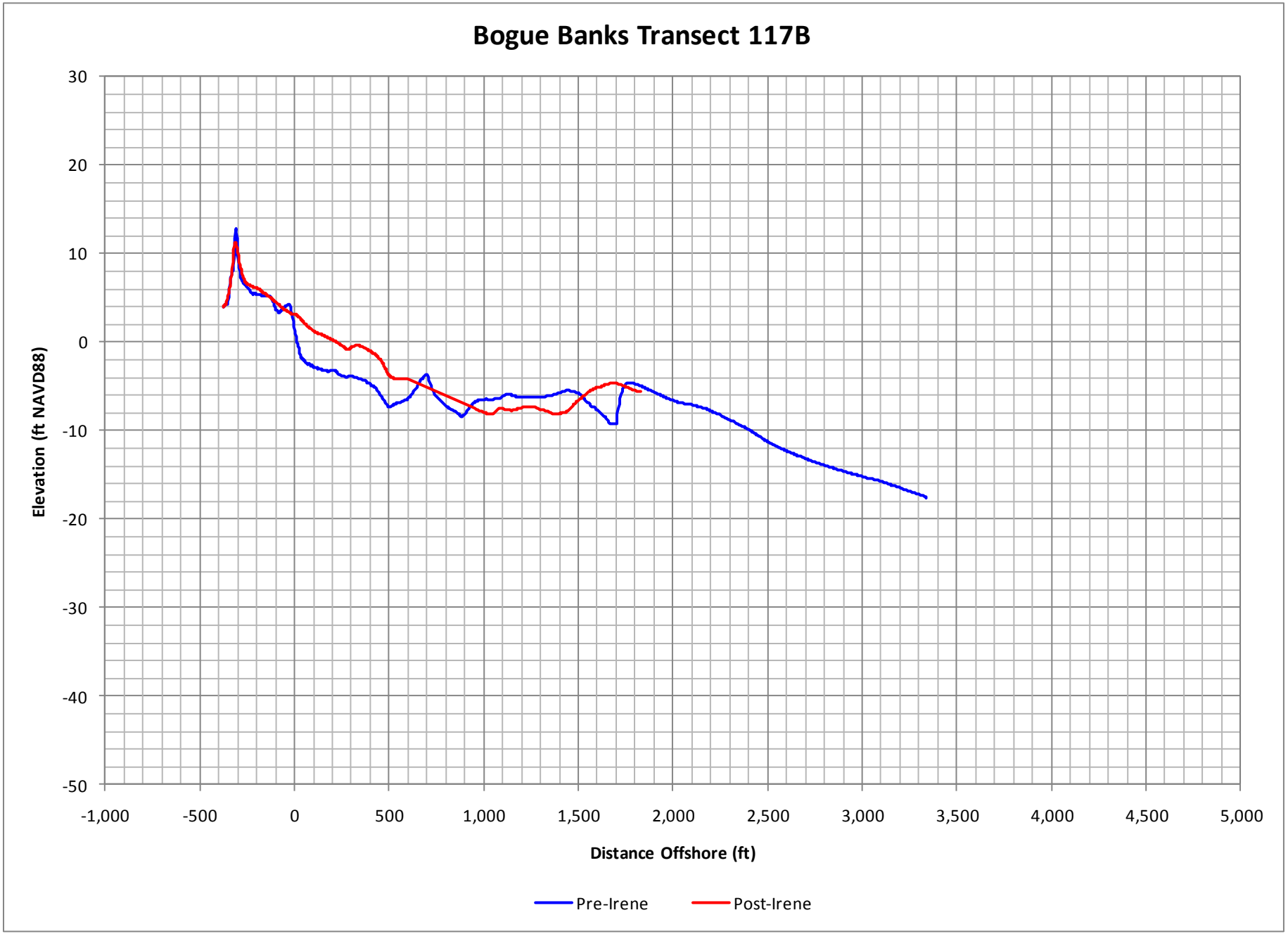

Figure B-86. Bogue Banks Profile Comparison

Figure B-87. Bogue Banks Profile Comparison

Figure B-88. Bogue Banks Profile Comparison

Figure B-89. Bogue Banks Profile Comparison

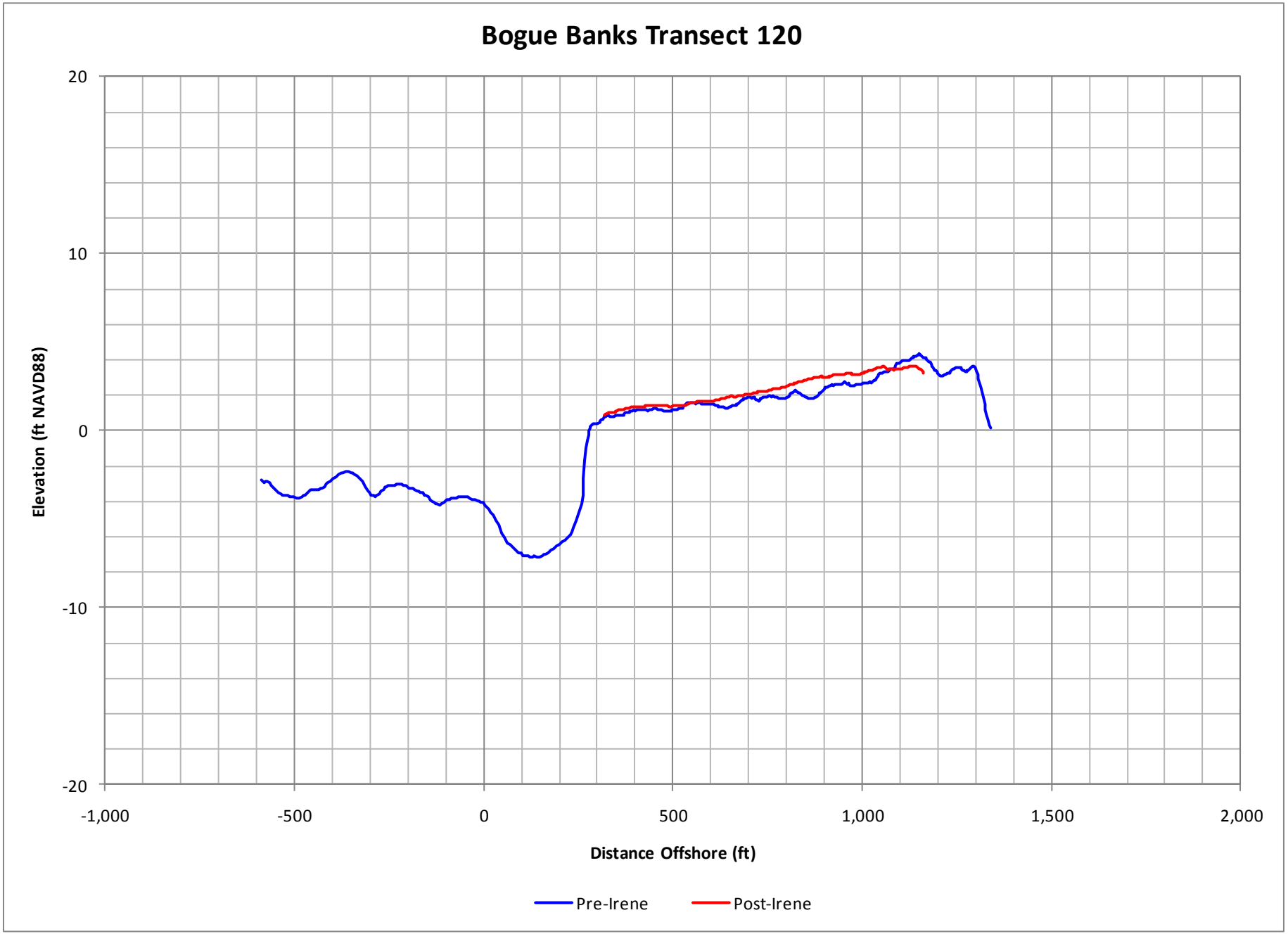

Figure B-90. Bogue Banks Profile Comparison

Appendix C
Results Tables

Table C-1. Summary of Shoreline Change and Volume Change Along Bogue Banks (June 2011 to September 2011)

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 June 1, 2011 to September 1, 2011.

Reach	Transect Number	Station	Shoreline Change @ MHW (+1.1 ft NAVD)	Above MHW (+1.1 ft NAVD)		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
				Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)	Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)	Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)	Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)	Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)
Bogue Inlet-Ocean	1	0+00	124.43	46.08	4.68	193.11	49.34	616.04	45.90	1462.00	41.28	2860.89	57.62
	2	5+59	43.40	57.81	8.78	199.33	7.08	531.67	12.12	1280.93	14.75	2561.74	21.13
	3	11+23	-82.17	41.22	-18.95	123.21	-30.36	365.38	-52.64	943.60	-48.15	1995.89	-46.76
	4	17+39	62.27	16.82	-5.72	87.88	-4.71	268.57	-29.73	749.58	-16.18	1674.52	5.33
	5	23+22	-6.97	50.36	-1.94	139.02	-0.41	333.72	-11.88	815.66	20.91	1721.00	50.83
	6	36+28	13.80	47.75	-4.56	115.15	-12.36	278.41	-10.05	681.31	5.44	1479.40	22.87
	7	53+10	-1.77	74.55	-4.92	149.04	-21.73	318.02	-33.21	710.40	-22.62	1460.76	-0.89
	8	67+74	2.60	67.96	-3.99	139.28	-13.87	297.78	-21.92	682.13	-9.11	1399.76	12.65
Emerald Isle West	9	80+91	-11.53	55.49	-4.00	121.46	-7.48	270.73	-20.28	640.62	-14.39	1334.86	1.30
	10	93+40	-12.72	54.43	-3.14	112.19	-9.27	243.36	-32.04	607.95	-16.07	1282.54	7.96
	11	108+58	-9.37	42.46	-2.73	96.42	-16.80	232.44	-32.82	585.39	-23.31	1246.50	-5.58
	12	121+18	-0.28	86.10	-1.48	151.72	-7.32	296.60	-18.02	657.94	-12.31	1333.43	11.67
	13	134+61	-14.01	70.26	-1.46	138.13	-14.26	289.98	-25.02	656.91	-18.72	1328.42	-2.42
	14	146+67	3.43	49.65	-6.50	113.01	-14.84	252.72	-30.44	600.84	-26.38	1256.07	-9.73
	15	160+16	-17.90	40.37	-8.35	98.47	-14.18	240.91	-28.62	582.94	-22.18	1232.57	-1.71
	16	174+79	-8.59	44.96	-6.75	98.98	-8.06	228.52	-32.64	571.36	-23.68	1226.01	-1.60
	17	189+23	0.08	66.79	0.52	132.34	-2.63	286.10	-14.52	664.00	8.61	1338.79	26.53
	18	203+53	0.10	65.63	-0.58	133.48	-12.80	284.64	-27.39	642.64	-22.92	1315.21	-2.46
	19	214+90	-11.47	52.73	-5.22	109.92	-10.13	251.43	-24.76	591.55	-24.03	1247.35	-9.81
	20	230+02	-7.39	90.50	-2.25	158.55	-5.44	311.39	-16.88	668.82	-17.69	1352.39	-0.86
	21	241+15	4.35	48.76	-14.02	105.97	-20.14	241.74	-41.83	589.33	-47.17	1260.45	-31.06
	22	252+19	1.35	75.20	-3.10	137.10	-4.53	277.73	-25.85	635.50	-21.95	1326.13	5.23
	23	263+24	0.36	46.66	-3.01	101.89	-7.52	234.91	-23.36	570.31	-30.89	1243.00	-5.71
	24	279+57	-9.56	109.99	-9.25	180.29	-11.17	325.61	-32.61	687.64	-44.09	1392.48	-24.48
	25	290+77	4.55	64.87	-4.30	132.45	-4.00	277.38	-14.77	633.23	-20.20	1324.88	0.78

Table C-1. Summary of Shoreline Change and Volume Change Along Bogue Banks (June 2011 to September 2011) Cont.

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 June 1, 2011 to September 1, 2011.

Reach	Transect Number	Station	Shoreline Change @ MHW (+1.1 ft NAVD)	Above MHW (+1.1 ft NAVD)		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
				Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)	Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)	Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)	Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)	Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)
Emerald Isle Central	26	304+77	-11.07	76.69	-4.54	142.92	-8.06	283.65	-24.34	647.74	-24.45	1346.73	1.43
	27	318+11	1.83	79.80	-3.70	150.56	-2.72	297.42	-17.65	668.49	-19.13	1366.36	-1.59
	28	329+10	-9.56	77.61	1.02	141.89	-5.21	286.65	-27.47	632.06	-49.64	1328.42	-23.68
	29	345+80	5.15	59.85	-3.46	121.84	-2.23	262.97	-16.18	621.61	-18.66	1308.18	5.43
	30	362+22	-33.68	45.23	-8.60	101.08	-22.62	242.44	-23.57	565.44	-52.13	1247.52	-24.52
	31	378+80	3.17	59.25	1.55	118.52	1.09	263.54	0.29	581.99	-36.62	1262.77	-21.13
	32	395+22	17.74	77.11	-2.02	142.17	-2.80	298.63	-0.21	644.89	-10.75	1332.76	7.98
	33	408+86	15.34	70.74	-1.26	133.33	0.04	274.22	-15.02	619.96	-24.84	1304.02	-5.78
	34	422+83	-10.90	64.86	-9.11	129.73	-9.26	268.35	-26.40	619.42	-33.92	1308.95	-13.00
	35	435+62	11.89	46.43	-1.82	97.95	1.90	236.09	5.51	569.72	-0.94	1235.21	11.56
	36	450+22	5.82	49.13	-5.40	98.99	-5.44	225.67	-7.43	552.62	-23.32	1229.57	-7.50
Emerald Isle East	37	461+34	-6.55	35.58	-3.23	80.51	-9.97	211.14	-14.39	541.02	-12.26	1197.19	4.55
	38	472+44	7.85	51.59	-0.17	108.27	-0.44	243.01	-5.81	599.40	-2.22	1275.37	17.91
	39	483+48	8.01	57.16	-2.98	114.06	-7.08	255.68	-10.27	606.14	-19.14	1300.94	-0.91
	40	494+44	-5.40	43.80	-1.84	94.66	-4.59	230.20	1.61	574.14	10.99	1238.17	32.90
	41	505+39	19.79	49.45	-4.62	103.81	-2.12	245.66	-0.51	585.53	-7.54	1257.28	10.10
	42	516+57	-19.74	34.39	-2.19	76.42	-13.79	192.43	-40.02	515.02	-40.47	1177.34	-14.69
	43	527+37	-3.86	38.72	-3.04	85.41	-5.90	219.72	-4.84	556.21	1.65	1222.53	28.30
	44	538+39	-10.33	57.56	-2.12	112.67	-9.16	250.19	-15.34	596.84	-27.20	1275.54	-7.87
	45	549+45	-2.09	51.61	-3.81	105.90	-12.41	250.79	-9.68	591.31	-27.43	1274.32	-6.36
	46	560+42	-7.23	50.33	-1.73	100.78	-7.52	239.40	-12.70	586.93	-29.78	1271.80	-7.54
	47	571+43	-10.22	53.48	-6.91	108.85	-17.55	265.04	-1.89	616.11	-18.48	1295.87	-2.29
	48	580+13	-15.50	52.83	-8.68	107.83	-20.29	250.81	-26.12	591.28	-50.65	1276.67	-34.61

Table C-1. Summary of Shoreline Change and Volume Change Along Bogue Banks (June 2011 to September 2011) Cont.

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 June 1, 2011 to September 1, 2011.

Reach	Transect Number	Station	Shoreline Change @ MHW (+1.1 ft NAVD)	Above MHW (+1.1 ft NAVD)		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
				Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)	Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)	Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)	Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)	Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)
Indian Beach/Salter Path	49	595+84	9.27	59.17	-7.89	116.79	-9.00	253.78	-22.46	602.46	-33.63	1298.80	-12.70
	50	608+06	6.92	77.60	-4.65	140.93	-4.26	282.83	-7.84	637.72	-19.31	1343.51	-2.68
	51	620+90	-15.10	60.48	-5.34	117.52	-9.26	248.54	-40.88	588.04	-48.14	1286.71	-19.83
	52	633+31	1.70	26.72	-4.17	67.18	-2.56	184.56	-11.37	513.42	-14.07	1187.18	10.46
	53	648+17	-12.10	83.31	-6.02	155.45	-14.03	312.71	-18.98	667.30	-39.41	1396.02	-20.15
	54	660+65	-1.21	113.30	-5.12	198.64	-16.77	371.53	-27.59	756.08	-37.45	1510.45	-12.38
	55	672+30	-24.27	54.90	-7.30	111.82	-22.81	260.97	-24.68	611.04	-33.55	1327.54	-6.14
	56	683+24	9.49	40.96	-7.59	95.77	-5.08	238.70	4.08	577.09	-11.00	1284.54	11.59
	57	693+79	2.46	57.75	-5.54	113.02	-13.66	253.62	-17.24	599.03	-28.40	1315.05	-2.48
	58	709+05	-2.46	53.87	-2.22	109.38	-8.29	253.97	-15.06	594.77	-35.31	1314.11	-9.33
Pine Knoll Shores West	59	723+93	11.44	49.89	-1.84	104.32	1.30	242.11	-19.15	575.72	-47.22	1294.61	-29.47
	60	736+01	2.04	42.99	-4.00	92.41	-3.03	225.66	-1.26	552.48	-30.40	1272.38	-15.25
	61	748+06	-1.01	62.34	-2.15	124.22	-9.32	274.60	-23.27	621.04	-49.50	1363.60	-32.41
	62	761+80	0.17	43.25	-8.42	95.34	-12.22	227.35	-20.72	565.45	-43.41	1299.42	-29.42
	63	774+77	22.52	49.78	-0.63	107.04	5.15	243.75	0.65	581.60	-18.16	1321.59	-2.15
	64	787+61	13.45	49.12	-2.13	108.26	-2.28	246.17	-12.13	586.63	-31.70	1335.83	-14.73
	65	800+91	-4.25	46.65	-5.71	100.91	-6.24	234.16	-1.67	581.21	-8.04	1335.24	11.06
Pine Knoll Shores East	66	813+33	15.48	45.87	-0.48	99.38	1.27	232.11	-0.46	574.28	-12.22	1332.37	8.75
	67	825+53	23.57	37.09	1.66	85.01	5.34	216.85	13.03	550.62	1.51	1298.20	21.67
	68	840+55	6.04	46.04	-1.17	99.77	0.81	237.58	2.11	589.45	-6.61	1348.36	10.12
	69	850+84	13.55	51.47	-1.97	108.30	1.07	231.60	-22.57	583.44	-30.18	1352.96	-11.63
	70	863+28	9.73	52.24	-5.76	112.86	-5.03	254.00	-18.79	612.66	-29.36	1391.08	-11.18
	71	882+23	11.77	49.69	-3.03	109.91	-1.58	242.27	-19.44	596.85	-38.70	1375.84	-27.54
	72	896+24	47.51	51.04	1.96	117.46	12.74	272.88	18.76	634.20	4.46	1424.69	20.74
	73	910+53	-0.59	42.26	-5.15	99.47	-11.35	221.84	-34.56	590.45	-52.38	1383.61	-38.29
	74	922+70	10.97	52.42	-2.21	118.44	1.10	269.12	-0.54	638.99	-13.92	1440.51	4.02
	75	937+70	35.04	54.99	0.31	121.98	4.59	282.99	5.32	659.17	-5.26	1463.96	2.08
	76	948+81	-5.01	37.08	-13.10	93.57	-15.27	227.81	-26.86	596.80	-41.96	1398.20	-34.68

Table C-1. Summary of Shoreline Change and Volume Change Along Bogue Banks (June 2011 to September 2011) Cont.

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 June 1, 2011 to September 1, 2011.

Reach	Transect Number	Station	Shoreline Change @ MHW (+1.1 ft NAVD)	Above MHW (+1.1 ft NAVD)		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
				Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)	Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)	Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)	Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)	Post-Irene Measured Volume (cy/ft)	Irene Volume Change (cy/ft)
Atlantic Beach	80	994+64	24.10	56.46	-7.50	132.57	-1.14	289.30	-7.26	679.33	-14.36	1494.97	-8.00
	85	1042+73	19.50	36.61	-3.41	99.17	-1.63	246.43	-1.20	638.34	-2.33	1448.91	-2.89
	90	1093+69	-7.88	52.27	-12.08	135.46	-19.13	320.02	-37.14	734.42	-46.45	1589.70	-56.63
	95	1141+97	24.17	71.18	4.27	149.38	0.31	333.67	-5.88	758.68	0.32	1633.30	-3.25
	100	1191+90	-49.41	122.70	-16.57	245.74	-26.26	467.58	-28.13	920.82	-23.95	1907.84	-36.79
	102	1211+94	13.91	115.55	3.36	204.20	2.04	378.35	0.57	769.38	12.86	2173.19	-0.13
Fort Macon	105	1241+79	-69.94	67.73	-19.89	153.02	-36.45	333.91	-31.69	751.04	-15.13	2449.18	6.39
	110	1271+73	1.00	70.85	9.78	136.73	8.93	306.39	28.66	1289.80	52.09	3161.36	50.30
Beaufort Inlet	114	10+00	-88.29	63.04	0.48	236.64	-11.51	514.51	-29.58	873.83	-40.30	1374.72	-43.03
Bogue Inlet	117B	0+00	-	-	-	-	-	-	-	-	-	-	-
	117	5+00	-	-	-	-	-	-	-	-	-	-	-
	118	10+00	-	-	-	-	-	-	-	-	-	-	-
	119	15+00	-	-	-	-	-	-	-	-	-	-	-
	120	20+00	-	-	-	-	-	-	-	-	-	-	-

moffatt & nichol

1616 East Millbrook Road, Suite 160
Raleigh, NC 27609
P 919. 781. 4626
F 919. 781. 4869
www.moffattnichol.com