APTIM

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December 21, 2018

Peter Rascoe
Town Manager
Town of Southern Shores
5375 N. Virginia Dare Trail
Southern Shores, NC 27949

Subject: **Town of Southern Shores, North Carolina – Vulnerability Assessment & Beach Management Plan**

Dear Mr. Rascoe:

Two (2) hardcopies and two (2) electronic copies of *the Town of Southern Shores, North Carolina Vulnerability Assessment & Beach Management Plan* are enclosed. The Vulnerability Assessment focusses on potential damage associated with a storm having similar characteristics as Hurricane Isabel, which impacted the Outer Banks in 2003. The Beach Management Plan provides a long-term vision for the Town of Southern Shores to sustain the beaches that support a significant portion of their local economy and maintains the tax base of the Town. The hardcopies and electronic copies include both the main report along with Appendices associated specifically with the vulnerability analysis.

The final version of the report addresses the comments we received from you on the draft document, which was submitted on November 20, 2018. I am planning to present the conclusions and recommendations of this report to Council during their planning session scheduled for Tuesday February 26, 2019. The presentation will specifically lay out the three proposed options included in the report for Council consideration. Cost and schedules for each option are provided in the report and will be discussed during the presentation. If Council decides to pursue one of the options, the Town could then immediately begin coordination with Dare County by providing estimated costs for the preferred option.

Please call me if you have any questions.

Sincerely,
Aptim Coastal Planning & Engineering of North Carolina, Inc.

Kenneth Willson
Vice President

TOWN OF SOUTHERN SHORES NORTH CAROLINA
VULNERABILITY ASSESSMENT
&
BEACH MANAGEMENT PLAN

SUBMITTED TO:

TOWN OF SOUTHERN SHORES

SUBMITTED BY:

APTIM COASTAL PLANNING & ENGINEERING OF NORTH CAROLINA, INC.

December 2018

EXECUTIVE SUMMARY

The Town of Southern Shores authorized Aptim Coastal Planning & Engineering of North Carolina, Inc. (APTIM) to conduct a Vulnerability Assessment and develop a Beach Management Plan that can be used by the Town for future planning. The Vulnerability Assessment focusses on potential damage associated with a storm having similar characteristics as Hurricane Isabel, which impacted the Outer Banks in 2003. The Beach Management Plan provides a long-term vision for the Town of Southern Shores to sustain the beaches that support a significant portion of their local economy and maintains the tax base of the Town. In order to sustain the beaches, the Beach Management Plan aims to maintain the Town's oceanfront beach and dune to a configuration that 1) provides a reasonable level of storm damage reduction to public and private development, 2) mitigates long-term erosion that could threaten public and private development, recreational opportunities, and biological resources, and 3) maintains a healthy beach that supports valuable shorebird and sea turtle nesting habitat.

Furthermore, the Beach Management Plan aims to coordinate the efforts of Southern Shores with neighboring communities in Dare County to achieve cost savings where possible. The 2017 beach nourishment project undertaken through a cooperative effort on the part of Dare County, and the Towns of Duck, Southern Shores, Kitty Hawk, and Kill Devil Hills, was implemented in a way that maximized cost savings and cost sharing. In this regard, the Southern Shores Beach Management Plan has been developed in such a way to align with other regional actions to achieve cost-sharing and cost savings. Furthermore, by developing a management plan before the beach reaches a critically eroded state, the Town may be able to maintain a greater level of storm damage reduction.

In addition to providing a higher level of storm damage reduction, implementation of a beach management plan establishes eligibility for the Town to recoup sand losses from coastal storms through FEMA's Public Assistance Program. Typically, coastal communities are eligible for public assistance funds for their beaches through Category B and Category G of the Public Assistance Program authorized by the Robert T. Stafford Disaster Relief and Emergency Assistance Act. While the Town is currently eligible for Category B assistance, this typically equates to a maximum of 6 cy/lf of sand to form temporary emergency dune structures, the purpose of which is to provide a minimal amount of protection until a more permanent solution is implemented. Through the implementation of the Beach Management Plan, the Town would be eligible for Category G funds, which allows for beaches to be considered eligible facilities under certain conditions. The options included in the Beach Management Plan were designed to meet these conditions, which may allow for reimbursement to replace sand lost from the beach as a result of a presidentially declared disaster.

Vulnerability Assessment

The vulnerability assessment employed the Storm Induced Beach Change Model (SBEACH). APTIM used the storm characteristics of Hurricane Isabel such as wave heights, wave period, water level, and duration to drive the model. Given this storm occurred over 15 years ago, APTIM simulated the storm using three (3) different sea level scenarios: 1) as it occurred in 2003; 2) the storm with water levels based on 15 years of sea level rise (2018 equivalent); and 3) the storm with 30 years of sea level rise from present day (2048 equivalent). Sea level rise rates were based on the North Carolina Sea Level Rise Assessment Report (NC CRC, 2015). The SBEACH results informed the development of the Beach Management Plan with regards to what sections of the Town may be vulnerable to impacts from the design storm, and what amount of additional volume would be required to reduce that vulnerability.

Beach Management Plan

The results of the vulnerability analysis, as well as the beach assessment conducted by APTIM in February 2018, were used in the development of a beach management plan for the Town of Southern Shores. The Beach Management Plan is aimed at sustaining the oceanfront beach along the entirety of the Town of Southern Shores. The Town's approximately 3.7 miles of shoreline varies in regards to the height and width of the primary dune, the distance structures are set back from the vegetation, and the rates of volume change that occur from station to station. Therefore, efforts first focused on understanding which portions of the Town require additional beach fill to achieve the goals of the overall plan. Both long-term erosion rates and storm impacts were analyzed to identify portions of the shoreline where structures are presently, or in the near future, may be vulnerable to the effects of chronic erosion and episodic storm events.

The extent of the Town's shoreline recommended for consideration for future beach nourishment is the southern 15,500 feet of shoreline from Station -155+00 (located approximately 200 ft. south of 5th Ave.) to the southern Town boundary with Kitty Hawk (Station 0+00). The area recommended for fill placement is more specifically described in terms of three (3) sub-sections. The "Main Placement Area" extends from Station -150+00 (located near 3rd Ave.) south to Station -50+00 (located approximately 450 feet south of Chicahauk Trl.). This area was identified based on the evaluation of the SBEACH storm damage vulnerability analysis and the beach volume analysis. The second sub-section is referred to as the "Transition Area". This area extends 5,000 feet from Station -50+00 (located approximately 450 feet south of Chicahauk Trl.) south to the Town boundary with Kitty Hawk at Station 0+00. The third sub-section extends approximately 500 feet north of 3rd Ave. and is referred to as the "Taper".

Once the linear extent of the proposed project was determined, three (3) design volume options were developed, which were aimed at optimizing the extent of storm damage reduction. The design volume options were based on an analysis that concluded that for SBEACH Storm Scenarios 3, 11, and 14, the average volume contained in the "volume envelope" of those profiles not impacted by the storm was 846 cy/lf, 858 cy/lf, and 872 cy/lf, respectively. In calculating these averages, Station 0+00 was considered to be an outlier. Therefore, Station 0+00 was not included in the calculation of average volumes. The average volumes within the "volume envelope" were used as a proxy for the targeted volume recommended to be present within the volume envelope on any given profile, to provide a reasonable level of storm damage reduction for each of the (3) three design volume options.

Options 1 and 2 are based on the results of Scenario 3, and therefore, are focused on providing a reasonable level of storm damage reduction based on a design storm similar to Hurricane Isabel with 2018 sea levels. This scenario also assumed the storm impacted the coast during a similar period in the lunar tidal cycle as when Hurricane Isabel impacted Dare County. Option 3 is based on the results of Scenario 11, and therefore, is focused on providing a reasonable level of storm damage reduction based on a design storm similar to Hurricane Isabel with 2048 sea levels.

Scenario 11 similarly assumed the storm impacted the coast during a similar period in the lunar tidal cycle as when Hurricane Isabel impacted Dare County. The 2048 sea levels are based on the RCP 8.5 greenhouse gas projections from the IPCC 5th Assessment Report (AR5). As a point of interest, the water levels in Scenario 11 were similar to water levels in Scenario 4. Scenario 4 was a design storm similar to Hurricane Isabel with 2018 sea levels; however in contrast to Scenario 3, Scenario 4 was formulated to impact the Town during spring tide as opposed to the actual period in the lunar tidal cycle that Hurricane Isabel impacted Dare County in September 2003.

Option 1 assumes a targeted volume density of 846 cy/lf to be maintained along the Southern Shores oceanfront based on the Scenario 3 analysis. The average density measured along the Town's oceanfront in the "Main Placement Area", which extends from Station -150+00 (located near 3rd Ave.) to -50+00 (located approximately 450 feet south of Chicahauk Trl.), was 801 cy/lf at the time of the December 2017 survey. Therefore, the fill density recommended for this option in the Main Placement Area is 45 cy/lf. At a density of 45 cy/lf, the Main Placement Area fill would require approximately 450,000 cy of sand. Placement of sand is also recommended south of the Main Placement Area to form a contiguous project with the Kitty Hawk/South Southern Shores project constructed in 2017 and scheduled for renourishment in 2022. This area is referred to as the Transition Area. Option 1 includes beach fill at 30 cy/lf between Stations -50+00 and 0+00, for an additional volume of 150,000 cy. Assuming a fill density at the northern end of the Main Placement Area of 45 cy/lf., a 500 ft. long taper would require approximately 11,250 cy, bringing the total design volume of Option 1 to 611,250 cy. Typically, beach nourishment projects include a design volume, and an advanced fill volume, which is determined based on spreading losses and annual erosion losses projected to occur between nourishment intervals. For the Options presented in this report, a nourishment interval of 5 years was assumed. The advanced fill volume recommended for Option 1 is 54,400 cy, bringing the total volume for Option 1 to 665,650 cy.

Similar to Option 1, Option 2 assumes a targeted volume density of 846 cy/lf, to be maintained along the Southern Shores oceanfront based on the Scenario 3 analysis. Option 2 volumes were based on evaluating the average density measured along the Town's oceanfront along both the "Main Placement Area" and the "Transition Area", which was 818 cy/lf at the time of the December 2017 survey. This average excludes Station 0+00 as it is considered an outlier. The deficiency in volume with an average of 818 cy/lf., and a target volume of 846 cy/lf., is 28 cy/lf. The fill density recommended for both the Main Placement Area and the Transition Area for Option 2 is 30 cy/lf. The number was increased from 28 cy/lf to 30 cy/lf to stay consistent with average fill densities proposed along Kitty Hawk, which in part was based on constructability limitations for the types of dredges anticipated to be used to construct the project. At a density of 30 cy/lf, the 15,000 foot long fill area would require approximately 450,000 cy of sand. Assuming a fill density at the northern end of the fill area of 30 cy/lf., a 500 foot-long taper would require approximately 7,500 cy, bringing the total design volume of Option 2 to 457,500 cy. The advanced fill volume recommended for Option 2 is 34,800 cy, bringing the total volume for Option 2 to 492,300 cy.

Option 3 assumes a targeted volume density of 858 cy/lf, to be maintained along the Southern Shores oceanfront based on the Scenario 11 analysis. As previously stated, the average density measured along the Town's oceanfront in the "Main Placement Area", which extends from Station -150+00 (located near 3rd Ave.) to -50+00 (located approximately 450 feet south of Chicahauk

Trl.), was 801 cy/lf at the time of the December 2017 survey. Therefore, the fill density recommended for Option 3 in the Main Placement Area is 57 cy/lf. At a density of 57 cy/lf, the Main Placement Area fill would require approximately 570,000 cy of sand. Similar to Option 1, Option 3 recommends placement of 30 cy/lf along the 5,000 foot-long Transition Area to form a contiguous project with Kitty Hawk, for an additional volume of 150,000 cy. Assuming a fill density at the northern end of the Main Placement Area of 57 cy/lf., a 500 ft. long taper would require approximately 14,250 cy, bringing the total design volume of Option 3 to 734,250 cy. The advanced fill volume recommended for Option 3 is 68,800 cy, bringing the total volume for Option 3 to 803,050 cy.

The scope of the development of this beach management plan was to determine a minimum cross sectional volume needed to provide an acceptable level of storm damage reduction. During the design and permitting of a proposed project, the design engineer will establish design parameters for the proposed beach fill that will include a dune fronted by a beach berm. Design parameters for both the dune and berm will include crest elevations, crest widths, and slopes that would provide the recommended cross-sectional volume. The detailed design process will also include an evaluation of ways to optimize the design of the fill that would achieve the design goals for the lowest cost.

Executive Summary Table 1 shows the design fill volume, advanced fill volume, taper fill volume, and total volume for each of the three options.

Executive Summary Table 1. Optional Design Summary

Design	Design Volume(1)	Transition Area Volume(2)	Advanced Fill Volume(3)	Taper Volume(4)	Total Volume	Avg. Fill Density(5)
Option 1	450,000	150,000	54,400	11,250	665,650	40
Option 2	300,000	150,000	34,800	7,500	492,300	30
Option 3	570,000	150,000	68,800	14,250	803,050	48

(1)Volume (CY) to construct the Main Placement Area excluding tapers, transition fill, and advanced fill (Stations -150+00 to -50+00).
(2)Volume (CY) to construct the Transition Area (Stations -50+00 to 0+00).
(3)Volume (CY) included to account for diffusion losses and background erosion. Re-nourishment interval assumed to be 5 years.
(4)Volume (CY) to construct a 500 foot taper on the northern end of the beach fill (Stations -155+00 to -150+00).
(5)Total Volume included in the Design Volume and Transition Area divided by 15,000 feet.

Estimated Schedule

A project schedule was developed to best coordinate the efforts of Southern Shores with neighboring communities in Dare County to achieve cost savings where possible. The 2017 beach nourishment projects undertaken through a cooperative effort on the part of Dare County, and the Towns of Duck, Kitty Hawk, and Kill Devil Hills, were designed with a 5-year maintenance cycle. The first maintenance event is scheduled for summer of 2022. The project schedule included in the Beach Management Plan was developed to align construction of a beach nourishment project for the Town of Southern Shores with the maintenance work scheduled for 2022.

The construction of a beach nourishment project for the Town of Southern Shores will require the completion of the following items:

- Financial Planning and Establishment of Revenue Streams
- Development/Refinement of Borrow Areas
- Final Design Work
- Environmental Documentation and Permitting (State and Federal)
- Obtaining Easements for Construction
- Development of Construction Plans and Specifications
- Solicitation of Construction Bids
- Awarding Construction Contract

The detailed project schedule included in the Beach Management Plan suggests that efforts associated with design and permitting the project should be initiated in February 2020 to allow for a 2022 construction timeframe. However, APTIM recommends that an updated beach profile survey be conducted in the Spring of 2019 to align with the annual beach profile surveys conducted by Duck, Kitty Hawk, and Kill Devil Hills. The reasons for this are discussed in the recommendations section of the report.

The overall schedule takes into consideration the time that was required to conduct similar tasks for the 2017 Multi-Town beach nourishment projects. APTIM consulted with state and federal agencies to re-calibrate the timeframe for permitting efforts. The majority of the items required to be completed in order to construct a project are items that can be coordinated and cost shared with other Dare County Towns.

Estimated Cost

Project cost estimates were developed for each of the three (3) options, to account for permitting/design, construction, pre-construction/construction administration, and environmental monitoring anticipated to be required during construction. The cost estimates also include a 10% contingency. Executive Summary Table 2 summarizes the associated costs for the three (3) options.

Executive Summary Table 2. Project Option Cost Estimates

Option	Volume (cy)	Permitting / Design Soft Cost	Construction Cost	Construction Soft Cost	Construction Env. Monitoring Costs	Contingency Cost (10%)	TOTAL COST
1	665,650	$435,000	$9,708,000	$219,500.00	$176,600.00	$1,053,900	$11,593,000
2	492,300	$435,000	$7,425,000	$201,500.00	$129,800.00	$819,100	$9,010,400
3	803,050	$435,000	$11,443,000	$233,500.00	$213,000.00	$1,232,500	$13,557,000

Recommendations
Based on the analysis and conclusions discussed in this report, APTIM is recommending the following:

1. **Determine Which Option To Pursue:** Given the information presented in this report, the Town of Southern Shores should first determine if it wishes to pursue any of the three beach fill options presented. If the Town determines that it wishes to pursue one of the three presented beach nourishment options, it must then decide which option provides the most cost effective approach. APTIM is prepared to support the Town with any of the three Options as a project we believe will achieve the Town's goals. More specifically, APTIM believes each option will maintain the oceanfront beach and dune to a configuration that 1) provides a reasonable level of storm damage reduction to public and private development, 2) mitigates long-term erosion that could threaten public and private development, recreational opportunities, and biological resources, and 3) maintains a healthy beach that supports valuable shorebird and sea turtle nesting habitat. The Town must determine which option is feasible given fiscal restraints.

2. **Begin Coordination with County and Neighboring Communities:** During the planning stages of the 2017 Multi-Town beach nourishment project, regular meetings were convened with Town and County representatives as well as the Town's Engineers and Financing Consultants. A similar meeting should be scheduled for the Spring of 2019 to begin the planning process for a potential 2022 project. During the meeting, the Towns and County should be provided updates on proposed volume and cost estimates, as well as a draft schedule of those efforts needed to be completed to go to construction in 2022. Discussions at this meeting should also focus on the need for additional sand sources for future projects. Furthermore, this meeting should aim to establish which Towns are planning to move forward with a 2022 project.

3. **Initiate Financial Planning:** A successful beach management program will require a stable revenue stream dedicated to the program. The Town of Southern Shores is in a favorable position to implement a beach management plan given the history of Dare County's willingness to partner with local communities on such programs. Furthermore, the opportunity to partner with neighboring local communities to cost share in some aspects of the project, has the potential to further reduce the Town's cost share to implement the overall program. Early and proper financial planning is vital to developing a revenue stream to support a beach management program. Other local communities in Dare County that have implemented similar programs, coordinated early on in the planning process with both Dare County and outside professional financial advisors. If the Town determines that it wishes to implement a beach management program, APTIM recommends the Town not only coordinate the initial plan with Dare County and its neighbors, but also seeks professional financial advice to properly budget and plan for the program.

4. **Continue Monitoring of the Beach Profiles:** As witnessed along the Town's southern shoreline between 2015 and 2017, the beach is a highly dynamic area. Sand movement due to storm events can cause considerable changes in the level of protection available by dunes and beach berms. For this reason, it is important to regularly monitor the beach profile. Based on observed trends and current beach densities, APTIM recommends that an updated beach profile survey be conducted in the Spring of 2019 to align with the annual beach profile surveys conducted by Duck, Kitty Hawk, and Kill Devil Hills.

   The analysis detailed in this report is based on beach profile surveys conducted along the Town's oceanfront in December 2017. If the Town of Southern Shores decides to pursue one of the recommended options, conducting beach profile surveys in the Spring of 2019 will serve several purposes. First, the surveys will allow engineers to determine whether the measured positive volume change reported in the 2018 Beach Assessment Report is continuing, or if that trend was being influenced by the construction of the 2017 Multi-Town Project. If negative volume changes are measured, these updated profile data would allow us to re-evaluate volume estimates, which directly correlates to cost estimates. Furthermore, collection of survey data in 2019 would ensure that the necessary engineering analysis could be performed starting in early 2020 rather than having to wait until new data are collected in Spring 2020, which may result in a slide in the schedule.

Through the implementation of these recommendations, the Town of Southern Shores will be establishing a beach management plan specifically aimed at achieving the shoreline management goals of the Town. The adoption of this beach management plan will allow for long-term financial planning which is key to implementing a successful program. This type of long-term planning and active coordination with neighboring Towns will leverage cost saving opportunities realized through multi-town cooperation. Furthermore, the implementation of a beach management program now, before the beaches reach a critically eroded state, allows the Town to provide a greater level of storm damage reduction at a lower cost.

TOWN OF SOUTHERN SHORES NORTH CAROLINA
VULNERABILITY ASSESSMENT
&
BEACH MANAGEMENT PLAN

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1 INTRODUCTION

The Town of Southern Shores authorized Aptim Coastal Planning & Engineering of North Carolina, Inc. (APTIM) to conduct a Vulnerability Assessment and develop a Beach Management Plan to be used by the Town for future planning. APTIM completed an evaluation of long-term and short-term shoreline and volumetric changes along the Town's oceanfront beaches in March 2018. The evaluation report recommended to the Town that a vulnerability assessment be conducted to gain additional information that would allow for the development of a Beach Management Plan.

The Vulnerability Assessment focusses on potential damage associated with a storm having similar characteristics as Hurricane Isabel, which impacted the Outer Banks in 2003. APTIM used the Storm Induced Beach Change Model, SBEACH, developed by Larson and Kraus (Larson and Kraus, 1989) for the US Army Corps of Engineers (USACE) to conduct the analysis. APTIM used the storm characteristics of Hurricane Isabel such as wave heights, wave period, water level, and duration to drive the model. Given this storm occurred over 15 years ago, APTIM simulated the storm using three (3) different sea level scenarios: 1) as it occurred in 2003; 2) the storm with water levels based on 15 years of sea level rise (2018 equivalent); and 3) the storm with 30 years of sea level rise from present day (2048 equivalent) based on the North Carolina Sea Level Rise Assessment Report (NC CRC, 2015). The SBEACH results inform the development of the Beach Management Plan with regards to what sections of the Town may be vulnerable to impacts from the design storm.

The Beach Management Plan included in this document, provides a long-term vision for the Town of Southern Shores to sustain the beaches that support a significant portion of their local economy and maintains the tax base of the Town. In order to sustain the beaches, the Beach Management Plan aims to maintain the Town's oceanfront beach and dune to a configuration that 1) provides a reasonable level of storm damage reduction to public and private development, 2) mitigates long-term erosion that could threaten public and private development, recreational opportunities, and biological resources, and 3) maintains a healthy beach that supports valuable shorebird and sea turtle nesting habitat.

Furthermore, this Beach Management Plan aims to coordinate the efforts of Southern Shores with neighboring communities in Dare County to achieve cost savings where possible. The 2017 beach nourishment project undertaken through a cooperative effort on the part of Dare County, and the Towns of Duck, Southern Shores, Kitty Hawk, and Kill Devil Hills, was specifically implemented in a way that maximized cost savings and cost sharing. In this regard, the Southern Shores Beach Management Plan has been developed in such a way to align with other regional actions to achieve cost-sharing and cost savings. Furthermore, by developing a management plan before the beach reaches a critically eroded state, the Town may be able to maintain a greater level of storm damage reduction.

2 PROJECT LOCATION

The Town of Southern Shores is located on the Outer Banks of North Carolina approximately 29 miles south-southeast of the North Carolina and Virginia border. The Town encompasses approximately 9.9 square miles extending along 3.7 miles of Atlantic Ocean shoreline from the Town of Duck south-southeast to the Town of Kitty Hawk. A location map is provided in Figure 1.

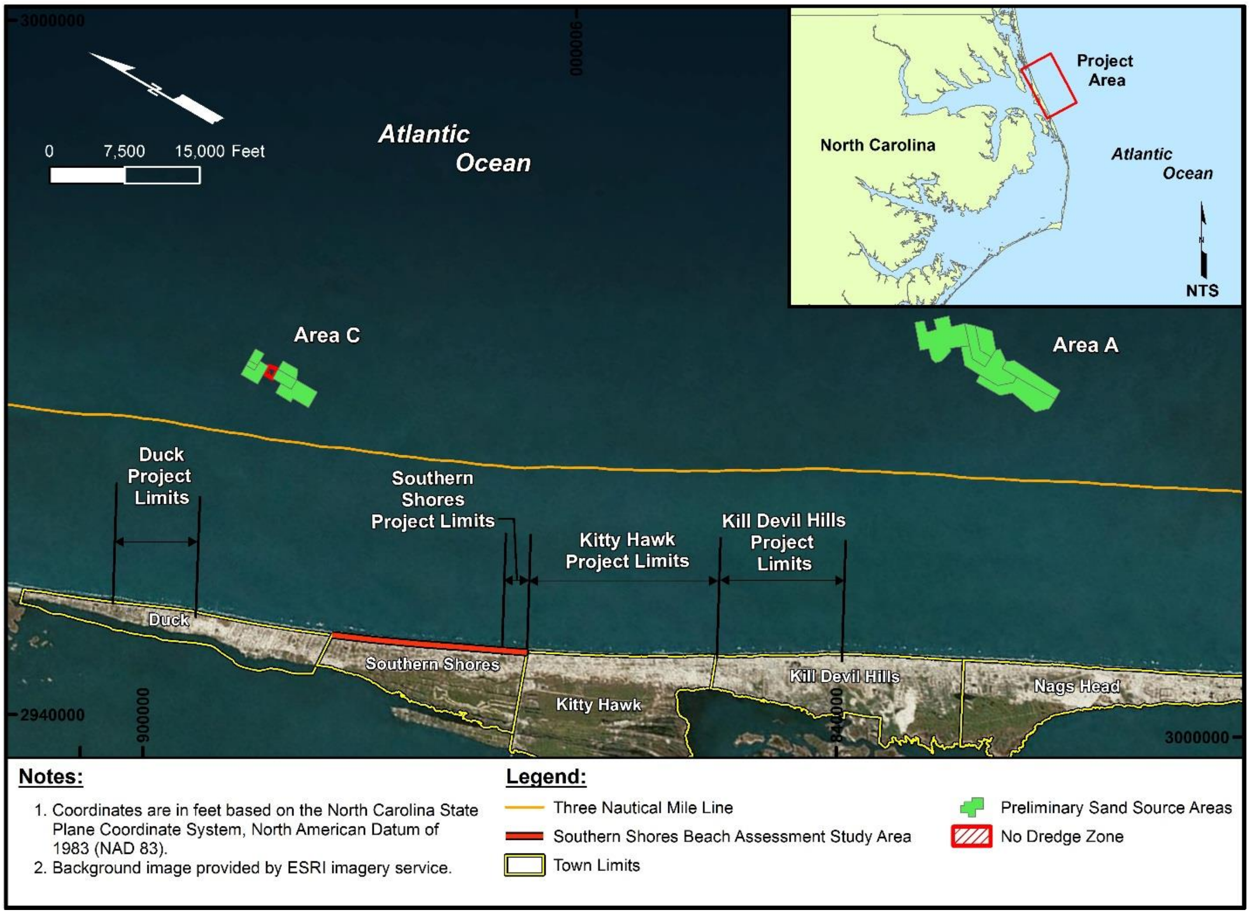

Figure 1. Project Location Map.

3 VULNERABILITY ANALYSIS

3.1 Methods

The vulnerability assessment employed a profile-based storm simulation model called SBEACH (Larson and Kraus, 1989). A similar assessment was conducted during the design phase of the Duck and Kill Devil Hills beach projects. The vulnerability assessment can both identify structures that may be vulnerable to a specific design storm and determine design requirements to avoid these impacts. Ideal minimum cross section volumes were defined based on the results of the vulnerability analysis, trends identified within the beach analysis (APTIM, 2018b), and the beach fill designs for the Towns of Duck and Kill Devil Hills.

3.2 Application

The SBEACH analysis conducted as a part of this study only identifies which structures could experience damage due to storm induced beach erosion caused by a storm having similar characteristics to Hurricane Isabel. The following basic assumptions underlie the SBEACH model:

- Breaking waves and variations in water level are the major causes of sand transport and profile response.
- The median sediment grain diameter along the profile is reasonably uniform across shore.
- The shoreline is straight (i.e. longshore effects are negligible during the simulation period).
- Linear wave theory is applicable everywhere along the beach profile.

Moreover, this study does not include an evaluation of damages to structures due to flooding, wave impacts, or wind nor does it quantify the economic impacts resulting from the damage or loss of these structures.

3.3 Data

Data sets employed in this analysis include oceanographic, meteorological, and bathymetric/topographical. Oceanographic and meteorological data collected during Hurricane Isabel were used to define the storm event simulated in the modeling analysis; storm data were obtained between August 30 and September 22, 2003. The December 2017 post-construction survey is the primary source of bathymetric/topographical data. This study was limited to available data as no field data collection was conducted in conjunction with the study. Details regarding each data set used in this analysis are discussed in the following sections. Where applicable, the location of the measurement devices (wave gauges, tide gauges, etc.) are referenced to the North Carolina State Plane Coordinate System.

3.3.1 Wave Data

Wave data used in this study were collected by a surface wave buoy (FRF630) operated and maintained by the USACE FRF Coastal and Hydraulics laboratory. Located roughly 10,000 feet (1.9 miles) from shore in nearly 60 feet of water, this directional waverider buoy has measured wave height, period, and direction since 1997. Considering it was originally installed as a non-directional wave buoy, wave height and period data collected between 1987 and 1996 are also available. The location of this wave gauge (Easting = 2969396.8, Northing = 907708.8, feet NAD83) is shown in Figure 2.

3.3.2 Water Level Data

Water level data used in this study were collected by the NOAA tide gauge (Station 8651370) located on the offshore end of the USACE FRF pier. Monthly mean and hourly water level data have been collected since June 1978, while verified high and low water levels have been recorded since November 1979. Six-minute data has been collected since October 1995. The location of this tide gauge (Easting = 2959975.4, Northing = 901370.2, feet NAD83) is shown in Figure 2.

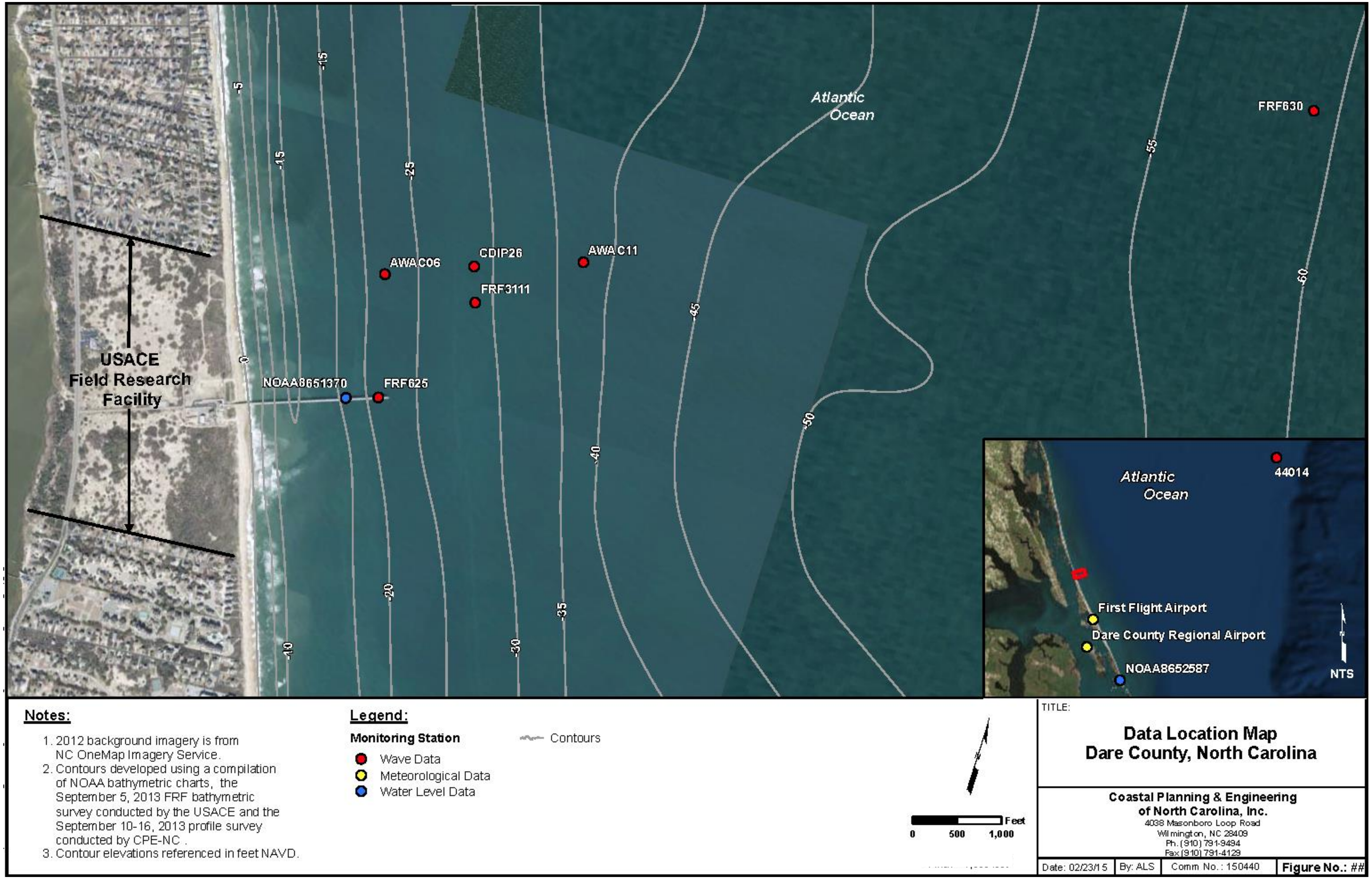

Figure 2. Location Map of wave and water level gauges used in the study.

3.3.3 Meteorological Data

Meteorological data used in this study (i.e. wind velocity) were collected at the NOAA tide gauge located on the offshore end of the USACE FRF pier. Although meteorological data has been collected since June 1991, wind velocity (i.e. speed and direction) data is only available after May 1996. The location of this meteorological gauge (Easting = 2959975.4, Northing = 901370.2, feet NAD83) is shown in Figure 2.

3.3.4 Topographic/Bathymetric Data

To clearly define existing conditions and better analyze vulnerability, a beach profile survey was conducted along the Town's shoreline. This survey consists of a total of 22 profiles with a spacing of approximately 1,000 feet. The 19,700 feet of shoreline was surveyed in December 2017. Survey data were collected along transects detailed in Table 1, which are referenced to the North Carolina State Plane coordinate system in feet NAD83 with a profile azimuth in degrees referenced to true north. Transects listed in Table 1 are shown graphically in Figure 3. The complete survey report was provided to the Town in March 2018 as an appendix to the *Town of Southern Shores Beach Assessment Report* (APTIM, 2018b).

The profile surveys extended landward until a structure was encountered or to a range 50 feet beyond the landward toe of dune, whichever is more seaward. Elevation measurements were also taken seaward along the profile to the -30 feet NAVD contour. Upland data collection includes all grade breaks and changes in topography to provide a representative description of the conditions at the time of the work. The maximum spacing between data records along individual profiles is 25 feet. The upland survey extends into wading depths sufficiently to overlap the offshore portion a minimum of 50 feet.

Additional beach profile surveys within the project area include those conducted by the US Army Corps of Engineers (USACE) Field Research Facility (FRF) in 2004, 2005, and 2006; limited beach profile surveys conducted by APTIM on the north and south end of the Town associated with projects for the Towns of Duck and Kitty Hawk in 2013, 2014, and 2015; a pre-construction survey conducted by Great Lakes Dredge & Dock in June 2017 along the south side of the Town associated with the beach fill. These surveys are described in greater detail in *Town of Southern Shores Beach Assessment Report* (APTIM, 2018b).

LIDAR surveys were conducted by the USACE following the impacts of Hurricane Matthew in October 2016. The surveys were conducted between October and December 2016. LIDAR is a remote sensing technology that uses light detection to map an area. It provides the most comprehensive data set for topography; however, the lack of water clarity restricts LIDAR from providing subaqueous data. The LIDAR data set extended alongshore beyond the project area extents. The cross-shore extent of the surveys was between the Mean High Water (MHW) shoreline and either the top or the landward toe of the dune.

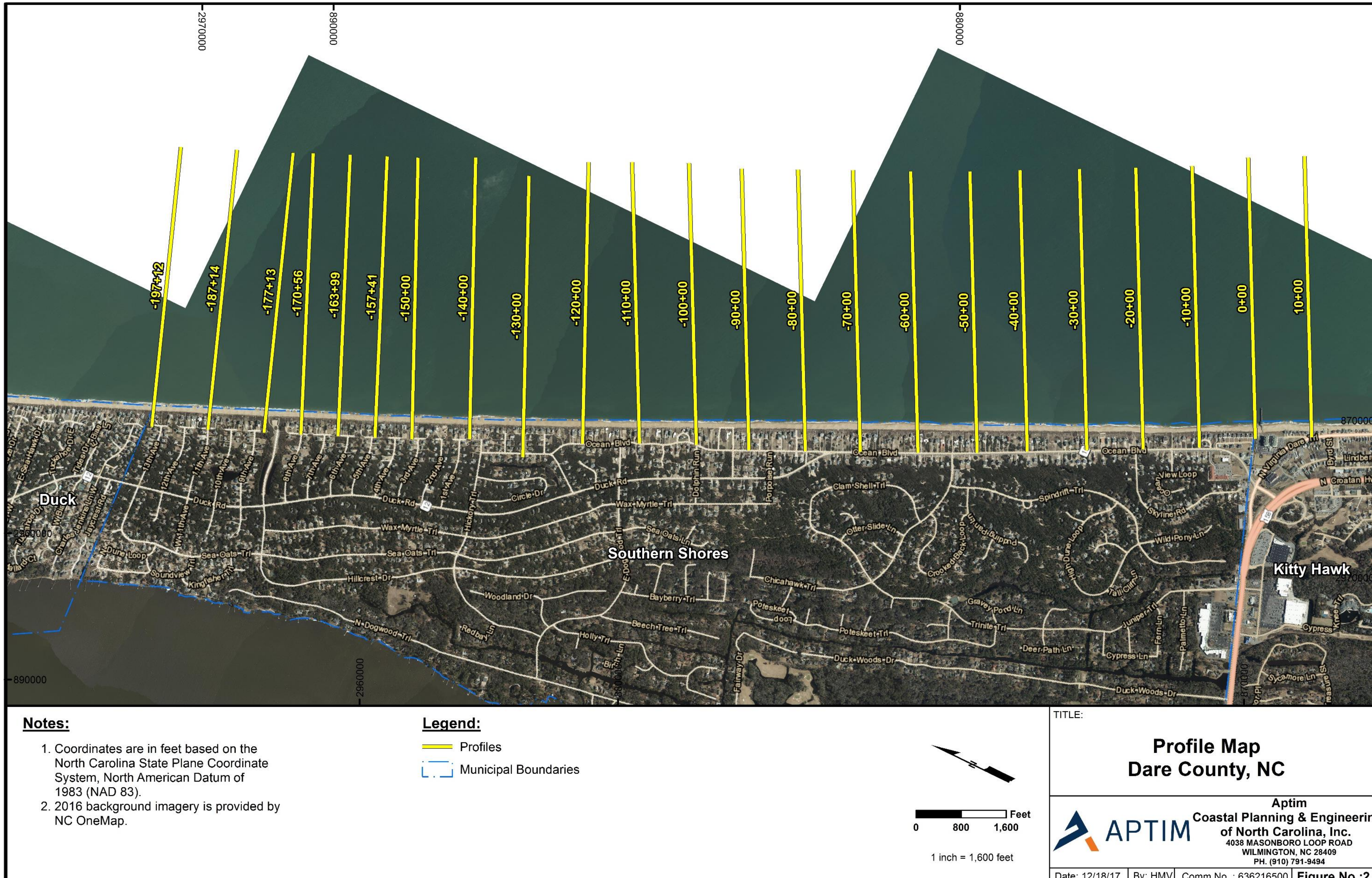

Figure 3. Location Map of beach profiles.

Table 1. Profile Survey Baseline and Azimuth

Profile	Easting	Northing	Azimuth
-197+12	2962840	889616.1	70
-187+14	2963230	888697.7	70
-177+13	2963619	887775.8	70
-170+56	2963880	887172.9	66.6
-163+99	2964142	886569.9	66.6
-157+41	2964403	885966.9	66.6
-150+00	2964665	885364.0	65.3
-140+00	2965116	884444.0	65.3
-130+00	2965239	883452.0	65.3
-120+00	2965920	882604.0	65.3
-110+00	2966366	881697.0	62.6
-100+00	2966790	880778.0	62.6
-90+00	2967110	879895.0	62.6
-80+00	2967533	878988.0	62.6
-70+00	2967951	878106.0	62.6
-60+00	2968381	877175.0	62.6
-50+00	2968838	876228.0	62.6
-40+00	2969249	875440.0	62.6
-30+00	2969732	874496.1	62.6
-20+00	2970190	873607.2	62.6
-10+00	2970653	872721.0	62.6
0+00	2971224	871890.8	62.6

Historic bathymetric data, extending from 1939 to present, is available within the NOAA Bathymetric Data Viewer (NOAA, 2018). The database includes data collected by both U.S. and non-U.S. oceanographic institutions, universities, and government agencies with worldwide data coverage.

The dates and techniques of these data sets within the project area are summarized in Table 2.

Table 2. Summary of Available Survey

Entity	Technique	Dates
USACE FRF	Topographic/ Bathymetric	Monthly between 1974 and 1977, 1994, 1995, 2001, 2003, 2004, 2006
APTIM	Topographic/ Bathymetric	2013, 2014, 2015 (Limited coverage on north and south end of Town)
APTIM	Topographic/ Bathymetric	2017 (Complete coverage of Town oceanfront)
GLDD	Topographic/ Bathymetric	2017 (Limited coverage on south end of Town)
USACE	LiDAR	2016
NOAA	Bathymetry	Various Charts from 1939 to Present

3.4 Model Configuration

Cross-shore performance evaluations utilized the Storm Induced Beach Change (SBEACH) model (Larson and Kraus, 1989). SBEACH is a two-dimensional model which simulates beach profile changes that result from varying storm waves and water levels. These profile changes include the formation and movement of morphological features such as longshore bars, troughs, berms, and dunes. SBEACH assumes that the simulated profile changes are produced only by cross-shore processes, while longshore sediment transport processes are neglected. This empirically based numerical model was formulated using both field data and the results of large-scale physical model tests. Input data required by SBEACH includes beach cross-sections, the median sediment grain size, several calibration parameters, and a temporally varying storm hydrograph (wave height, wave direction, wave period, and water surface elevation) and wind field (wind speed and direction). Simulated profile changes are driven by the cross-shore variation in wave height and wave setup calculated at discrete points along the profile from the offshore zone to the landward survey limit.

3.4.1 Grids

The beach profiles modeled were delineated along all project transects listed in Table 1. Modeled profiles were developed using a compilation of survey data sets to extend the profile from the landward extent of expected overwash offshore to a location beyond the depth of closure; extending the profiles beyond the December 2017 survey limits was necessary to ensure model stability. Surveys used to generate the model profiles, as detailed in Section 3.3.4, are provided below in the order in which they were compiled:

- December 2017 profile survey conducted by APTIM
- December 2016 LIDAR survey conducted by USACE
- May 2015 profile survey conducted by APTIM
- October 2006 profile survey conducted by USACE
- May 2005 profile survey conducted by USACE
- October 2004 profile survey conducted by USACE
- NOAA bathymetric charts

A typical profile compiled using the above surveys to represent the existing conditions within the SBEACH model is shown in Figure 4. Considering that profiles are gridded within the SBEAH model, a variable grid was used to provide fine resolution to adequately detail topographic and nearshore features in the model simulation while less variable offshore bathymetry was gridded using a coarser resolution to improve model efficiency. An example of typical profile grid spacing and associated limits used within the SBEACH model is provided in Table 3.

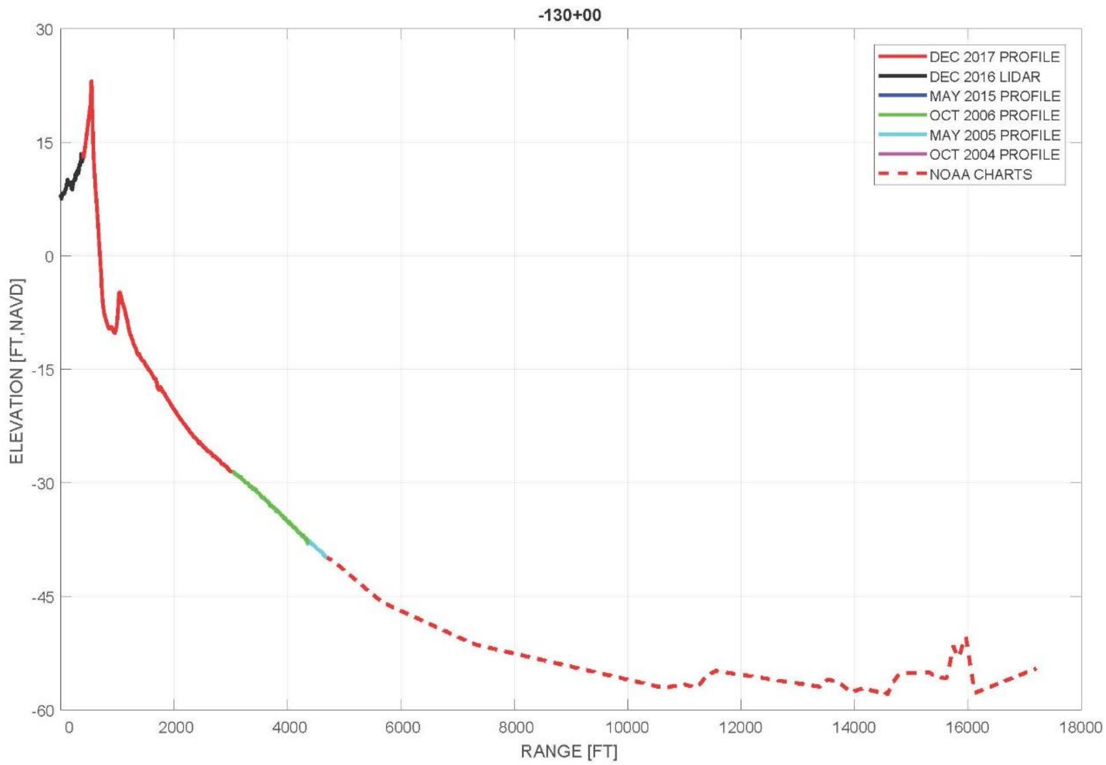

Figure 4. Typical SBEACH Profile

Table 3. Typical SBEACH Grid

Cell		Range Limits (ft)		Elevation Limits (ft, NAVD)	
Width (ft)	Number	Nearshore	Offshore	Nearshore	Offshore
5	500	0	2,500	Subaerial	-25
10	200	2,500	4,500	-25	-40
20	100	4,500	6,500	-40	-50
50	50	6,500	9,000	-50	-55
100	80	9,000	17,000	-55	-60

3.4.2 Parameters

Considering SBEACH is an empirical model, the user must define beach and sediment transport parameters. To define these parameters, the model was calibrated using surveys collected at the nearby USACE FRF prior to and following Hurricane Isabel. Model calibration was completed by adjusting the beach and sediment transport parameters until the post-storm beach profiles generated by SBEACH were similar to surveyed post-storm profiles. The calibrated model was then validated using surveys collected at the nearby USACE FRF prior to and following the 1991 Perfect Storm. Calibration and verification details are provided in the Duck Erosion and Shoreline Management Feasibility Study (CPE, 2013). Similar to the process employed for the Town of Kill Devil Hills (CPE, 2015b), the SBEACH model calibrated for the Town of Duck was used to define model parameters for the Town of Southern Shores. The beach and sediment transport parameters used in all SBEACH production runs are summarized in Table 4.

Table 4. SBEACH Model Parameters

Parameter	Units	Value
Landward Surf Zone Depth	ft	1
Effective Grain Size	mm	0.59
Maximum Slope Prior to Avalanching	deg	45
Transport Rate Coefficient	m^4/N	2.50E-06
Overwash Transport Parameter	m^2/s	5.00E-03
Coefficient of Slope Dependent Term	-	2.50E-03
Transport Decay Coefficient Multiplier	-	0.5
Water Temperature	°C	20

3.5 Model Application

The nature of this storm vulnerability analysis is comparable to the vulnerability analysis employed by APTIM in the formulation of the Town of Duck (CPE, 2015a) and the Town of Kill Devil Hills (CPE, 2015b) beach nourishment projects. The approach focuses on potential damage associated with a storm having similar characteristics as Hurricane Isabel, which impacted the Outer Banks in 2003. Moreover, additional analyses were completed using higher water levels associated with the design storm event occurring during spring tide and in the future considering various sea level rise scenarios. This facilitated an improved evaluation of vulnerability and identification of recommendations for a higher level of storm damage reduction.

3.6 Setup

Design storms were developed using oceanographic and meteorological data sets presented in Section 3.3. Hourly wave, wind, and water level data measured between August 30 and September 22, 2003 were used to define the model boundary conditions. Wave data used to create the storm hydrograph were collected at USACE wave gauge FRF630, while water surface elevation and meteorological data used to complete the storm hydrograph and create the storm wind field were collected at the Duck tide gauge. Considering the location of the FRF630 wave gauge, the water depth at the offshore boundary was set to 57 feet. Wave height randomization, using model default values, was included in the model. The model utilized a 1 minute time step for all simulations.

In an effort to identify recommendations for a higher level of storm damage protection, simulations were conducted to evaluate model sensitivity to the various forcing conditions (i.e. wave height, wave period, wind speed and direction, and water level). Following initial simulations of the Hurricane Isabel conditions in 2003 and the scaling of the various storm parameters to a 50-year storm, twenty-four (24) additional scenarios were considered for additional model simulations. Considering tide level variability and projected sea level rise (North Carolina Coastal Resources Commission Science Panel, 2015), it was determined that water level was the most appropriate boundary condition to vary. For example, the peak water level only increased 0.06 feet when scaling Hurricane Isabel to a 50-year storm, whereas the peak water level increased 0.86 feet when the peak surge of Hurricane Isabel occurred during an average spring tide event vs the measured tide during the storm. Furthermore, increasing sea level rise from 2018 levels to 2048 levels with the RCP 8.5 carbon emission increased the peak water level 0.78 feet.

The water level boundary conditions were varied for both tide cycle and relative sea level rise (RSLR). The tide cycle variation considered measured tides, average spring tides, and peak tide while the RSLR variation considered measured (i.e. Tide Gauge Projections) and variable degrees of greenhouse gas concentration trajectories adopted by the IPCC for the 5th Assessment Report (AR5). The IPCC AR5 evaluated four different trajectories referred to as Representative Concentration Pathways (RCP). The *North Carolina Sea Level Rise Assessment Report* evaluated two of the four trajectories referred to as RCP 2.5 and RCP 8.5 (North Carolina Coastal Resources Commission Science Panel, 2015).

Ultimately, only a select number of the scenarios considered were simulated using SBEACH. The various peak water levels for those scenarios simulated are detailed in Table 5. The sea level rise component of the elevated water levels assumed a constant rise rate since 2003 that varied from 0.015 feet/year (i.e. 5.4 inches of RLSR in 30 years) to 0.023 feet/year (i.e. 8.1 inches of RSLR in 30 years). The tide cycle component of the elevated water levels assumed a spring tide elevation of 2.04 feet NAVD, which was the average spring tide measured during hurricane season since 2003; the predicted tide elevation that occurred during Hurricane Isabel's peak surge was 1.18 feet NAVD. In an effort to develop realistic storm scenarios that could occur during an average spring tide, the storm peak was adjusted to occur during the August 10, 2003 spring tide with an associated elevation of 2.04 feet NAVD.

Table 5. Peak Water Levels Modeled

Scenario	Tide	SLR Rate	Year	Surge (ft)	Tide (ft, NAVD)	Stage (ft, NAVD)
1	Measured	N/A	2003	4.44	1.18	5.62
3	Measured	Measured	2018	4.44	1.41	5.85
4	Spring	Measured	2018	4.44	2.27	6.71
11	Measured	RCP 8.5	2048	4.44	2.19	6.63
14	Spring	RCP 8.5	2048	4.44	3.05	7.49

3.7 Results

SBEACH was used to identify structures impacted during storm events. A one (1) foot change in profile elevation has been identified as a reasonable threshold for estimating when structures become vulnerable to wave damage, including undermining and/or inundation (USACE, 1985). Therefore, a structure was considered damaged if any part of the structure was seaward of the landward most location where the profile was lowered by 1 foot. For this study, the landward most location where the profile was lowered by 1 foot was extracted from model results along profiles to identify *impact points*. These *impact points* were then connected to create an *impact line* that was used to identify structures damaged between profiles.

Impact lines were generated for all five (5) scenarios listed in Table 5. However, the position of the impact lines for Scenario 4 and Scenario 11, were nearly identical, which is primarily due to the similar stage elevations, which differ by only 0.08 ft. as shown in Table 5. Maps that delineate the *impact line* for simulation Scenarios 1, 3, 11, and 14 given December 2017 initial conditions can be found in Appendix A. For display purposes, the impact line for Scenario 4 was not included in the maps.

Considering the inexact nature of the SBEACH analysis, structures located within 15 feet of the impact lines shown on the maps included in Appendix A were considered vulnerable. This is consistent with the analysis performed for the Town of Duck (CPE-NC, 2015a). Using the 1-foot erosion criteria and the 15-foot buffer, the Scenario 1 simulation identified four (4) single family structures that are at risk of damage due to a storm similar to Hurricane Isabel. These structures are located between Stations -120+00 (southern boundary of the property at 226 Ocean Blvd.) and -90+00 (located approximately 300 feet south of Trout Run). The Scenario 3 simulation identified six (6) single family structures that are at risk of damage due to a storm similar to Hurricane Isabel. All six (6) of these structures were also located between Stations -120+00 and -90+00. The Scenario 11 simulation identified ten (10) single family structures that are at risk of damage due to a storm similar to Hurricane Isabel with associated sea level values for 2048. These structures are located between Stations -140+00 (located approximately 200 feet south of 1st Ave.) and -90+00 (located approximately 300 feet south of Trout Run). The Scenario 14 simulation identified twenty-seven (27) single family structures that are at risk of damage due to a storm similar to Hurricane Isabel with associated sea level values for 2048 and impacting the area during a spring tide. These structures are located between Stations -140+00 (located approximately 200 feet south of 1st Ave.) and -60+00 (located approximately 600 feet north of Chicahauk Trl.).

Other than identifying which buildings are vulnerable to storm damage, the analysis does not include other potential damages that are associated with storm surge (flooding), wave impacts, or wind. This storm damage risk assessment was conducted using the December 2017 position of the shoreline and profile condition.

The risk of a storm comparable to the design storm (Hurricane Isabel) impacting the area over the next 30 years was evaluated to provide guidance for planning purposes. In this regard, assuming Hurricane Isabel has a 4% (25-year storm) to 5% (20-year storm) chance of occurring any given year, the risk of a similar storm impacting the Town of Southern Shores within the next 5 years would be between 18% and 23%. Over the next 15 years, the risk would increase to be between 46% and 54%. The risk of several return period events (design storms) occurring within various time periods is provided in Table 6.

Table 6. Design Storm Risk

Time Period	Return Period Event					
(years)	1-Year	5-Year	10-Year	20-Year	25-Year	50-Year
1	100%	20%	10%	5%	4%	2%
2	100%	36%	19%	10%	8%	4%
3	100%	49%	27%	14%	12%	6%
4	100%	59%	34%	19%	15%	8%
5	100%	67%	41%	23%	18%	10%
10	100%	89%	65%	40%	34%	18%
15	100%	96%	79%	54%	46%	26%
20	100%	99%	88%	64%	56%	33%
25	100%	100%	93%	72%	64%	40%
30	100%	100%	96%	79%	71%	45%

4 BEACH MANAGEMENT PLAN DEVELOPMENT

The results of the vulnerability analysis described in Section 3, as well as the beach assessment conducted by APTIM in February 2018, were used in the development of a beach management plan for the Town of Southern Shores. The Beach Management Plan aims to provide a long-term plan to be implemented by the Town of Southern Shores that will sustain the beaches that support a significant portion of their local economy and maintains the tax base of the Town. The plan has been designed to maintain the Town's oceanfront beach and dune to a configuration that 1) provides a reasonable level of storm damage reduction to public and private development, 2) mitigates long-term erosion that could threaten public and private development, recreational opportunities, and biological resources, and 3) maintains a healthy beach that supports valuable shorebird and sea turtle nesting habitat.

The existing shoreline management initiatives within the Town of Southern Shores have been limited to beach bulldozing or scraping, sand fencing, dune vegetation, and truck haul to build and/or repair dunes. Essentially all of the shoreline management efforts are presently carried out by individuals or groups of individual property owners. The exception to this was the 2017 beach nourishment project, which placed sand along the southern 2,500 feet of the Town's ocean shoreline. This project was constructed as part of a multi-Town project that included Kitty Hawk, Kill Devil Hills, and the Town of Duck. The Southern Shores portion of the project was funded through a cooperative agreement between Dare County, Kitty Hawk, the Town of Southern Shores, and individual property owners in the area in which sand was placed.

4.1 Project Extent

The Beach Management Plan is aimed at sustaining the beach along the entirety of the Town of Southern Shores oceanfront. The Town's approximately 3.7 miles of shoreline varies in regards to the height and width of the primary dune, the distance structures are set back from the vegetation, and the rates of volume change that occur from station to station. Therefore, it is first necessary to understand which portions of the Town's oceanfront shoreline require additional beach fill to achieve the goals of the overall plan and which portions may, at present, provide a reasonable level of storm damage reduction. As part of the plan development, both long-term erosion rates and storm impacts were analyzed to identify portions of the shoreline where structures are presently, or may in the near future, be vulnerable to the effects of chronic erosion and episodic storm events.

4.1.1 Long-Term Erosion Threat

Volume change rates determined from the volume change analysis conducted as part of *Town of Southern Shores Beach Assessment Report* (APTIM, 2018b) were used to evaluate long-term erosion threats. The December 2017 beach profile survey conducted by APTIM was the first known survey to collect beach profiles along the entire length of the Town's oceanfront shoreline. The US Army Corps of Engineers (USACE) Field Research Facility (FRF) conducted several surveys between 2004 and 2006 that covered approximately 15,000 feet of the Town's southern oceanfront. These profiles were spaced approximately 1,000-feet apart from approximately 3rd Ave. (Station -150+00) to the Kitty Hawk border (Station 0+00). Furthermore, APTIM conducted several surveys between 2013 and 2015 along the northern and southern sections of the Town associated with studies they were conducting for the Towns of Duck and Kitty Hawk, respectively.

Based on USACE FRF surveys conducted along the southern 15,000 feet of the Town's oceanfront between October 2004 and October 2006, the average volumetric change rate measured along the profiles from Station -150+00 (approximately 3rd Ave.) to Station 0+00 (Southern Shores / Kitty Hawk border) above the -24 ft. contour was -0.4 cy/lf./yr. Although the average volume change rate was less than 1 cy/lf./yr. during this period, considerable variability in the volume change rate was measured from profile to profile as shown in Figure 5. The area from Station -140+00 (approximately 200 feet south of 1st Ave.) to Station -40+00 (northern boundary of property at 72 Ocean Blvd.) experienced a volume change rate of approximately -5 cy/lf./yr between October 2004 and October 2006.

Volume changes along the portion of beach from Stations -150+00 to 0+00 were also measured between October 2006 and December 2017 using the data collected by the USACE FRF and APTIM, respectively. The average volumetric change rate measured over the approximately 11-year period along the profiles from Station -150+00 to Station 0+00 above the -24 ft. contour was 3.2 cy/lf./yr. Figure 5 shows the profile by profile comparison. It is notable that every profile saw positive volume change between October 2006 and December 2017; however, the southern 2,500 feet of the Town shoreline was directly benefited by the beach nourishment project constructed in summer 2017.

As mentioned previously, APTIM is not aware of any historical beach profile survey data available north of Station -150+00 in Southern Shores, with the exception of three (3) profiles that were surveyed in 2013 and 2015 as part of a monitoring initiative conducted by the Town of Duck. The average volume change measured between September 2013 and December 2017 along Stations -197+12 (northern Town Limit), -187+14 (11^{th} Ave.) and -177+13 (approximately 200 feet south of 9^{th} Ave.) was -1.6 cy/lf. (erosion). This equates to an average volume change rate of -0.4 cy/lf./yr.

One additional factor to consider with regards to volume change trends along the Town's oceanfront is the dramatic change that occurred along the southern portion of the Town that led to the need for sand to be placed in this section. In the approximate 8.5-year period between October 2006 and May 2015, the profile located at Station 0+00, which is at the border of Southern Shores and Kitty Hawk, gained approximately 92 cubic yards of sand. However, over the following 2-year period between May 2015 and June 2017, that same profile lost approximately 187 cubic yards of sand. Figure 6 shows comparative photographs of this portion of the beach demonstrating the dramatic change that occurred between May 2015 and January 2017. These large fluctuations may be due to bathymetric features present in the nearshore and offshore regions adjacent to Southern Shores. Such features have been observed offshore of Kitty Hawk and Kill Devil Hills and have been attributed to anomalous volume change trends along certain portions of the beach.

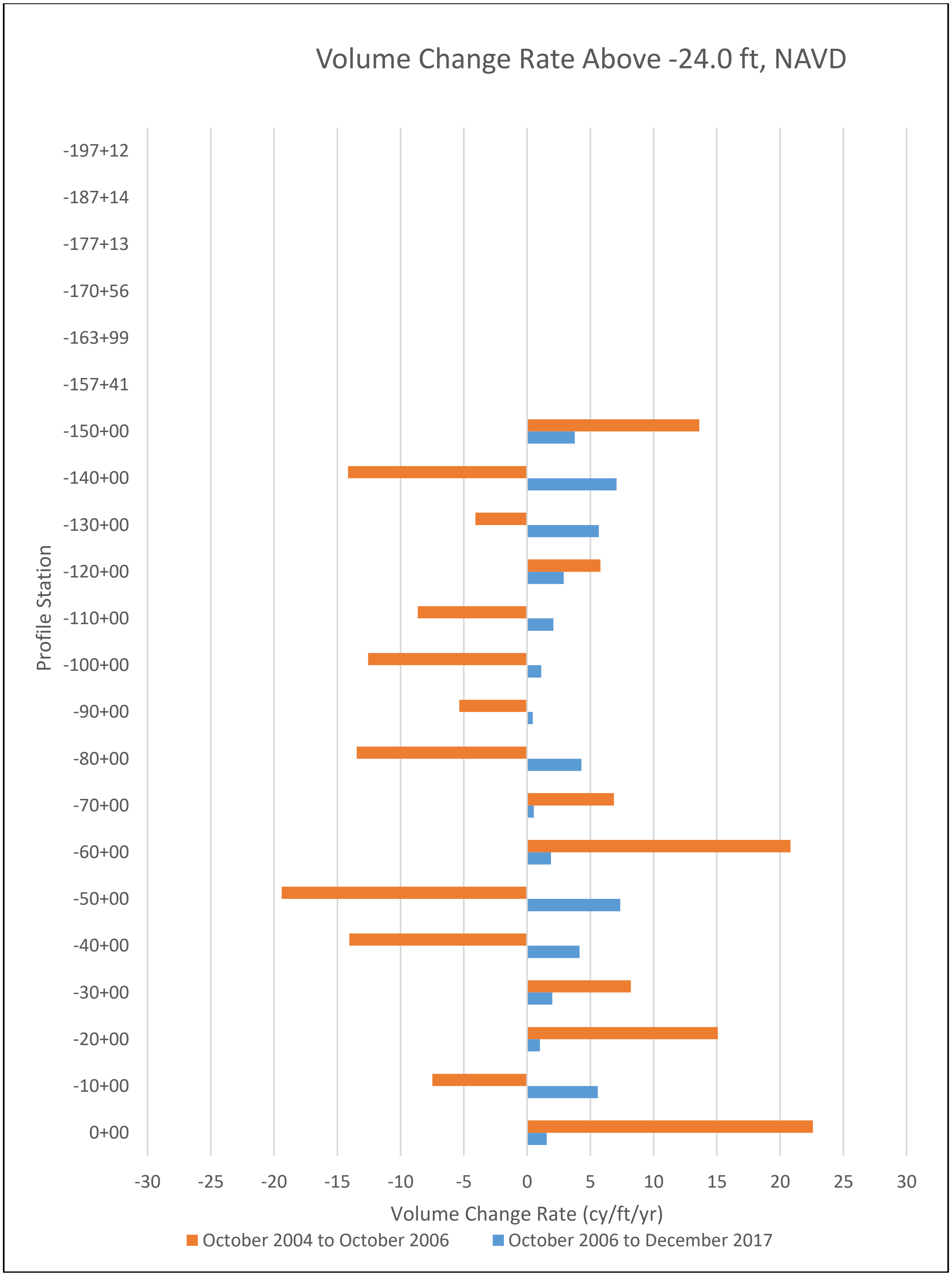

Figure 5. Annual Volumetric Change Rate above -24 FT NAVD (CY/LF/YR) between October 2004 and October 2006, and between October 2006 and December 2017.

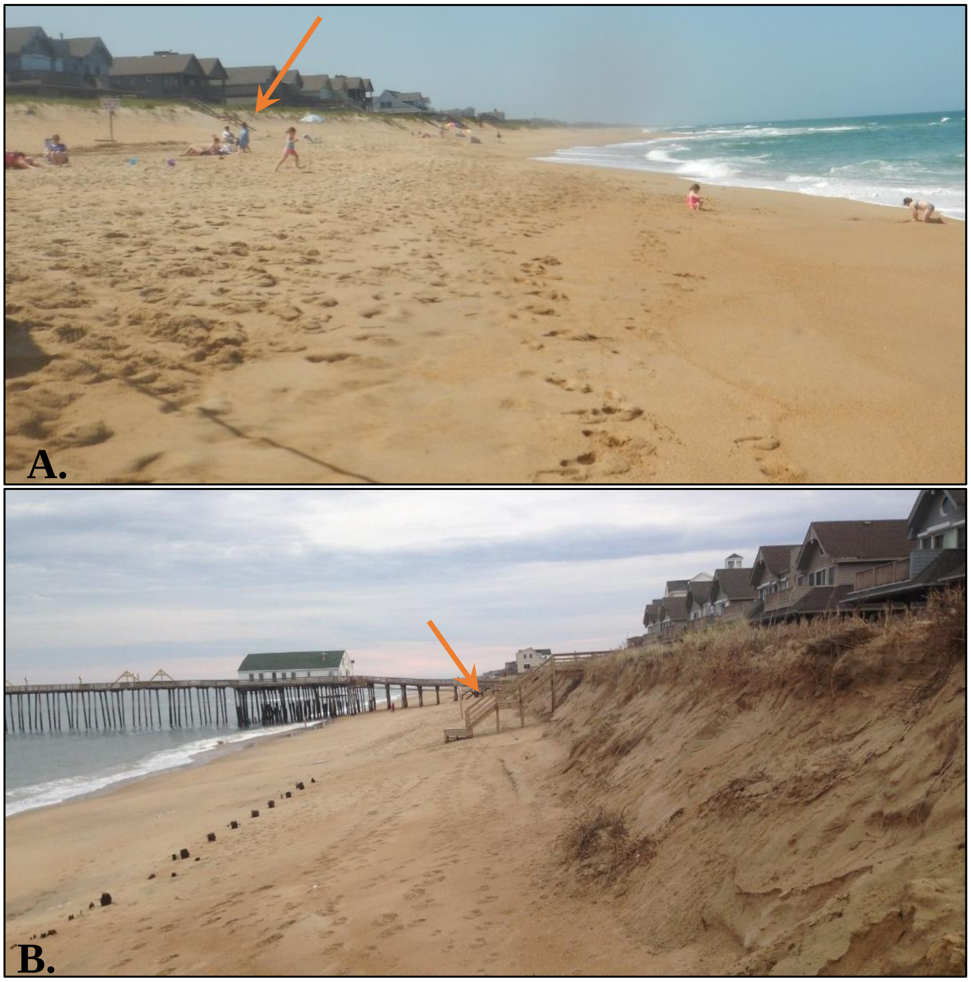

Figure 6. Photos comparing the south end of the Town's beach in May 2015 (A) and January 2017 (B). Note the orange arrows which indicate the location of the same set of stairs in both pictures.

4.1.2 Storm Damage Risk

The SBEACH model discussed in Section 3 was primarily used to identify structures vulnerable to storm damage and to evaluate the ideal volume density required on any given profile to provide an acceptable level of storm damage reduction. Initial conditions represent profile data collected by APTIM in December 2017, while model boundary conditions were defined using oceanographic and meteorological data as discussed in Section 3.3. In following the methodology used in the design of the Town of Duck (CPE-NC, 2015a) and Town of Kill Devil Hills (CPE-NC, 2015b) beach nourishment projects, APTIM utilized conditions observed during Hurricane Isabel in 2003 to generate the design storm (Scenario 1).

As discussed in Section 3.7, the Scenario 1 and Scenario 3 simulations identified four (4) and six (6) single-family structures, respectively, that are at risk of damage due to a storm similar to

Hurricane Isabel. These structures are located between -120+00 (southern boundary of the property at 226 Ocean Blvd.) and -90+00 (located approximately 300 feet south of Trout Run). The Scenario 11 simulation identified ten (10) single-family structures that are at risk of damage. The impacts observed under Scenario 11, which reflects sea level rise projected to 2048 under the RCP 8.5 greenhouse gas trajectory and measured tide levels observed during Hurricane Isabel, were similar to those observed under Scenario 4, which reflects the 2018 sea level and Hurricane Isabel impacting the coast during a typical spring tide. These structures are located between Station -140+00 (located approximately 200 feet south of 1st Ave.) and -90+00 (located approximately 300 feet south of Trout Run). The Scenario 14 simulation identified twenty-seven (27) single-family structures that are at risk of damage. Scenario 14 reflects a storm similar to Hurricane Isabel impacting the beach under projected 2048 sea level using the RCP 8.5 greenhouse gas trajectory and spring tide levels. These structures are located between Stations -140+00 (located approximately 200 feet south of 1st Ave.) and -60+00 (located approximately 600 feet north of Chicahauk Trl.).

4.1.3 Beach Volumes

As part of *Town of Southern Shores Beach Assessment Report* (APTIM, 2018b), the total volume measured along each profile above the -24 ft. NAVD88 contour was calculated. The landward extent of the volume calculation was established along each profile as the horizontal location of the landward +20.0 ft. NAVD88 contour, thus the entire active profile from the landward extent of the dune seaward to the depth of closure was included in the calculations. This area of the profile was referred to as the volume envelope. Figure 7 shows a cross section of the profile along Station -10+00, which graphically depicts the volume envelope. Comparing the volume measured in the volume envelope along the Town's oceanfront allowed for a relative comparison of the volume of sand that makes up the beach along the Town's oceanfront. However, the dune elevation on Station 0+00 did not reach an elevation of +20.0 ft. NAVD88 in December 2017, and therefore, the landward limit of the volume envelope for Station 0+00 was the location of the December 2017 dune crest.

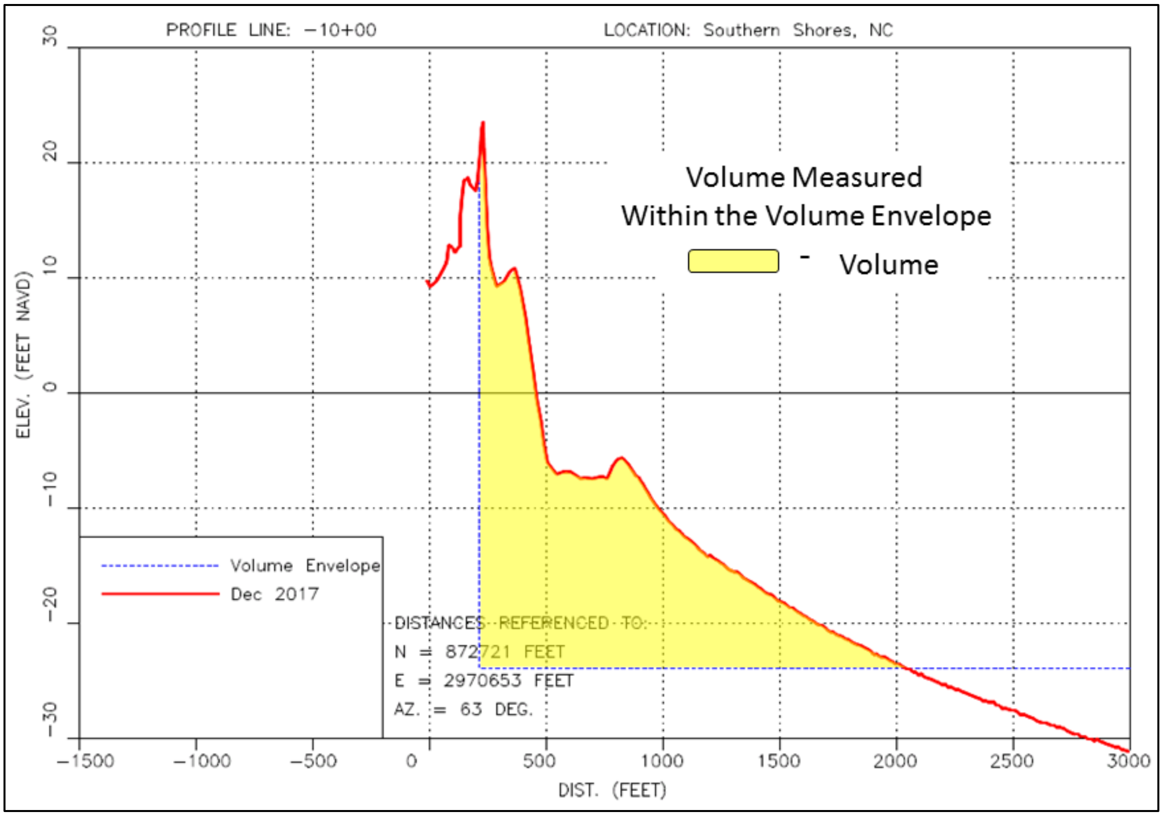

Figure 7. Beach profile cross section illustrating the volume envelope.

Figure 8 shows the volume measured within the volume envelope along each of the 22 Southern Shores profiles surveyed in December 2017. The red vertical line represents the average volume of 830.2 cy/lf measured within the envelope along all 22 profiles. Table 7 shows the calculated volume within the volume envelope for each station along the Towns Shoreline. The data represented in Figure 8 and Table 7 suggests that the area from Station -150+00 (located near 3rd Ave.) to Station -70+00 (located approximately 500 ft. south of where Ocean Blvd. and Duck Rd. meet), falls below the average volume.

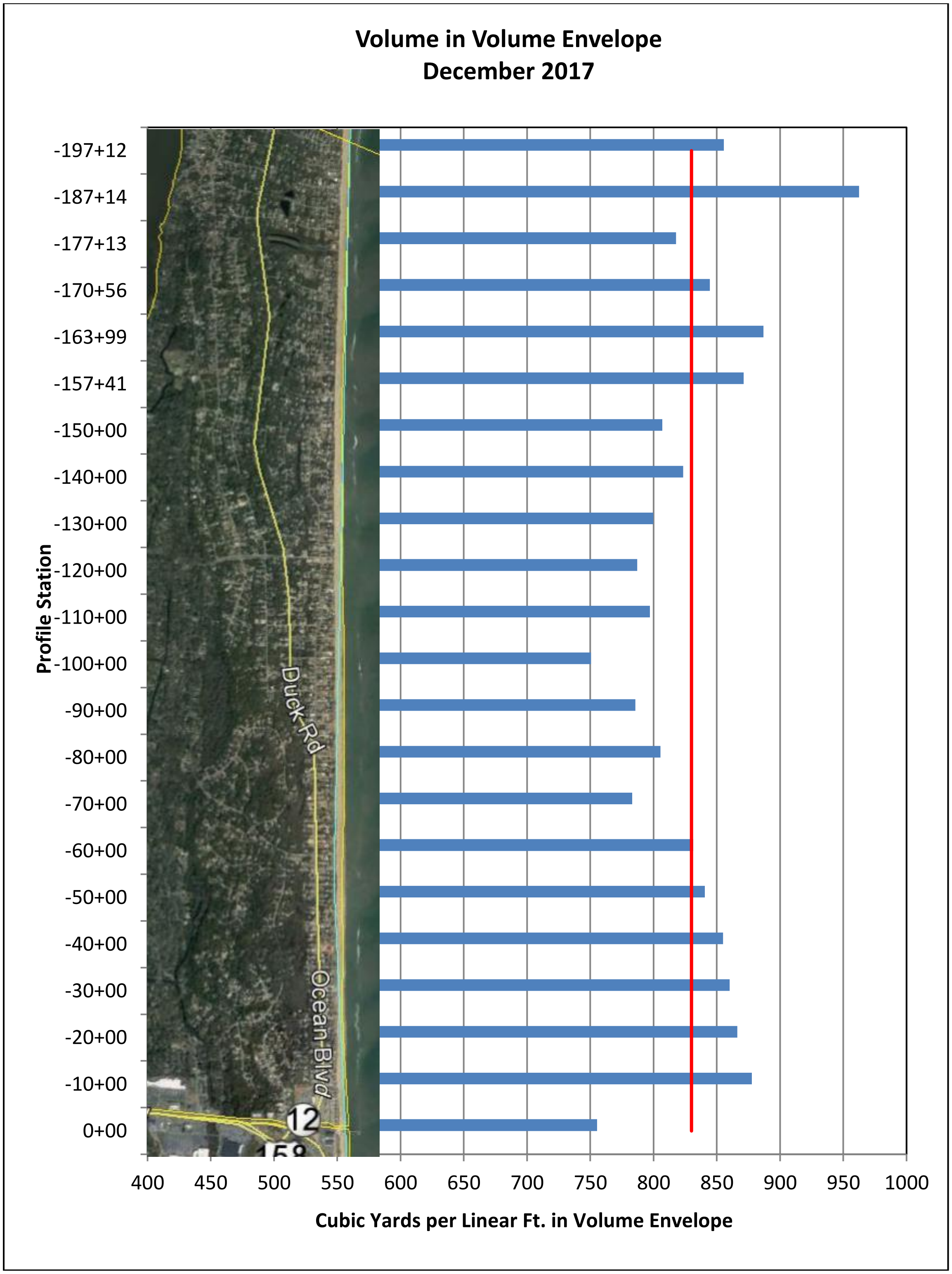

Figure 8. Measured volume density within the volume envelope at each Station.

Table 7. Density measured within the volume envelope shown on Figure 7 at each Station based on December 2017 Survey.

	Volume Density in Volume Envelope & Deviation from Average Volume measured in December 2017	
Station	Density (cy/lf.)	Deviation from Average (cy/lf)
-197+12	855.6	25.4
-187+14	962.4	132.2
-177+13	817.7	-12.5
-170+56	844.6	14.4
-163+99	886.8	56.6
-157+41	871.2	41.0
-150+00	807.0	-23.2
-140+00	823.4	-6.8
-130+00	799.8	-30.4
-120+00	787.0	-43.2
-110+00	797.1	-33.1
-100+00	750.6	-79.6
-90+00	785.7	-44.5
-80+00	805.6	-24.6
-70+00	783.1	-47.1
-60+00	831.3	1.1
-50+00	840.5	10.3
-40+00	855.0	24.8
-30+00	860.2	30.0
-20+00	866.1	35.9
-10+00	877.8	47.6
0+00	755.4	-74.8

The SBEACH model was used to evaluate the ideal volume density required on any given profile to provide an acceptable level of storm damage reduction. A profile-by-profile evaluation of the SBEACH generated post-storm profiles for Scenarios 3, 11, and 14 was conducted. The SBEACH simulations for Scenario 3 showed the dune along the Town of Southern Shores remained relatively well intact with the exception of the four profiles located from Stations -100+00 (Dolphin Run) to -70+00 (approximately 500 feet south of the Ocean Blvd./Duck Road split). SBEACH simulations for Scenario 11 showed a wider array of profiles at which the dune crest was impacted. Those profiles that showed impacts to the dune crest included Stations -197+12, -177+13, and each of the Stations from -120+00 through -60+00. SBEACH simulations for Scenario 14 showed impacts to the dune crest included Stations -197+12, -177+13, -150+00, and each of the Stations from -130+00 through -50+00.

Using the SBEACH results as a proxy for identifying beach conditions that provide adequate storm damage reduction given the design storm characteristics, the average volume of sand within the volume envelope was calculated for those profiles for which the crest of the primary dune was not significantly compromised for Scenarios 3, 11, and 14. Station 0+00 was considered to be an outlier, given its relatively low volume within the volume envelope and no impacts of the various simulations, as well as the fact that the landward limit of the volume envelope is slightly different from other profiles as explained previously, due to a relatively lower dune profile on this station. Therefore, Station 0+00 was not included in the calculation of average volumes. The resulting average volumes are provided in Table 8. These densities were used as the recommended density within the volume envelope to provide adequate storm damage reduction given the conditions associated with Scenarios 3, 11, and 14.

Table 8. Average density within volume envelope

Scenario	Average Volume Envelope Density of Profiles Not Impacted (cy/lf)
3	846
11	858
14	872

An examination of the volume measured within the volume envelope, which are listed in Table 7, show that the profiles between Stations -150+00 and -50+00 all have densities less than the average volume envelope densities of those profiles not impacted by the Scenario 3 and 11 simulations (Table 8). In other words, if the minimum density target to provide a level of storm damage reduction is 846 cy/lf based on the results of Scenario 3 or 858 cy/lf. based on Scenario 11, the portion of the beach between Stations -150+00 and -50+00 would need additional fill to achieve that minimum density. Similarly, if the minimum density target to provide a level of storm damage reduction is 872 cy/lf (Scenario 14), the portion of the beach between Stations -157+41 and -20+00 would need additional fill to achieve that minimum density.

4.1.4 End Losses and Taper Section

Based on both the location of vulnerable structures identified in Section 4.1.2 and the results of the volume envelope analysis discussed in Section 4.1.3, the area between Stations -150+00 (located near 3rd Ave.) and -50+00 (located approximately 450 feet south of Chicahauk Trl.) is recommended for placement of beach fill. This portion of the Town's oceanfront extends approximately 10,000 feet. This portion of the recommended project is referred to as the "Main Placement Area".

In order to reduce end losses that occur following the initial construction of a beach nourishment project, taper sections on each end of the main fill section are normally included in the beach fill design. Based on an analysis conducted for the Town of Duck (CPE, 2015a), 500-foot tapers should be included on the north and south ends of the project. This would extend the fill area from approximately Stations -155+00 to -45+00, a linear distance of approximately 11,000 feet.

The development of the proposed beach management plan assumes that the southernmost 1,500-foot portion of the Town's shoreline that received fill in 2017 will continue to be maintained. Assuming that area receives fill and the same taper is constructed from Stations -15+00 to -25+00, a gap between the two projects would exist between -25+00 and -45+00. Such a gap could result in a localized focus of wave energy at Stations -25+00 and -45+00 which would hasten the diffusion or spreading losses from the main fill. There is also the possibility that higher levels of wave energy and/or water levels could impact the backshore within the gap. Therefore, a minimal amount of fill should be placed in the gap to create a contiguous project.

4.1.5 Summary of Project Extent Analysis

The extent of the Town's shoreline recommended for consideration for future beach nourishment is the southern 15,500 feet of shoreline from Station -155+00 (located approximately 200 ft. south of 5th Ave.) to the southern Town boundary with Kitty Hawk (Station 0+00). The area recommended for fill placement is more specifically described in terms of 3 sub-sections. The "Main Placement Area" extends from Station -150+00 (located near 3rd Ave.) south to Station -50+00 (located approximately 450 feet south of Chicahauk Trl.). This area was identified based on the evaluation of the SBEACH storm damage vulnerability analysis and the beach volume analysis described in Section 4.1.3. The "Transition Area" extends 5,000 feet from Station -50+00 south to the Town boundary with Kitty Hawk at Station 0+00. The third sub-section extends 500 feet from Stations -155+00 to -150+00 and is referred to as the "Taper". Figure 9 shows a location map of the recommended project limits including these three sub-sections.

4.2 Project Volume

The results of the SBEACH model combined with the beach envelope analysis discussed in Section 4.1.3 were used to determine several design volume options aimed at optimizing the extent of storm damage reduction.

4.2.1 Storm Damage Reduction Design Volume

Section 4.1.3 discussed the analysis conducted for three (3) Scenarios simulated using SBEACH, to determine which profiles exhibited impacts to the dune crest for each scenario. This analysis concluded that for Scenarios 3, 11, and 14, the average volume contained in the volume envelope for those profiles along the Town's oceanfront, not impacted was 846 cy/lf, 858 cy/lf, and 872 cy/lf, respectively (Table 8). These volumes are used as a proxy for the targeted volume recommended to be present within the volume envelope in order to provide storm damage reduction for each of the 3 Options.

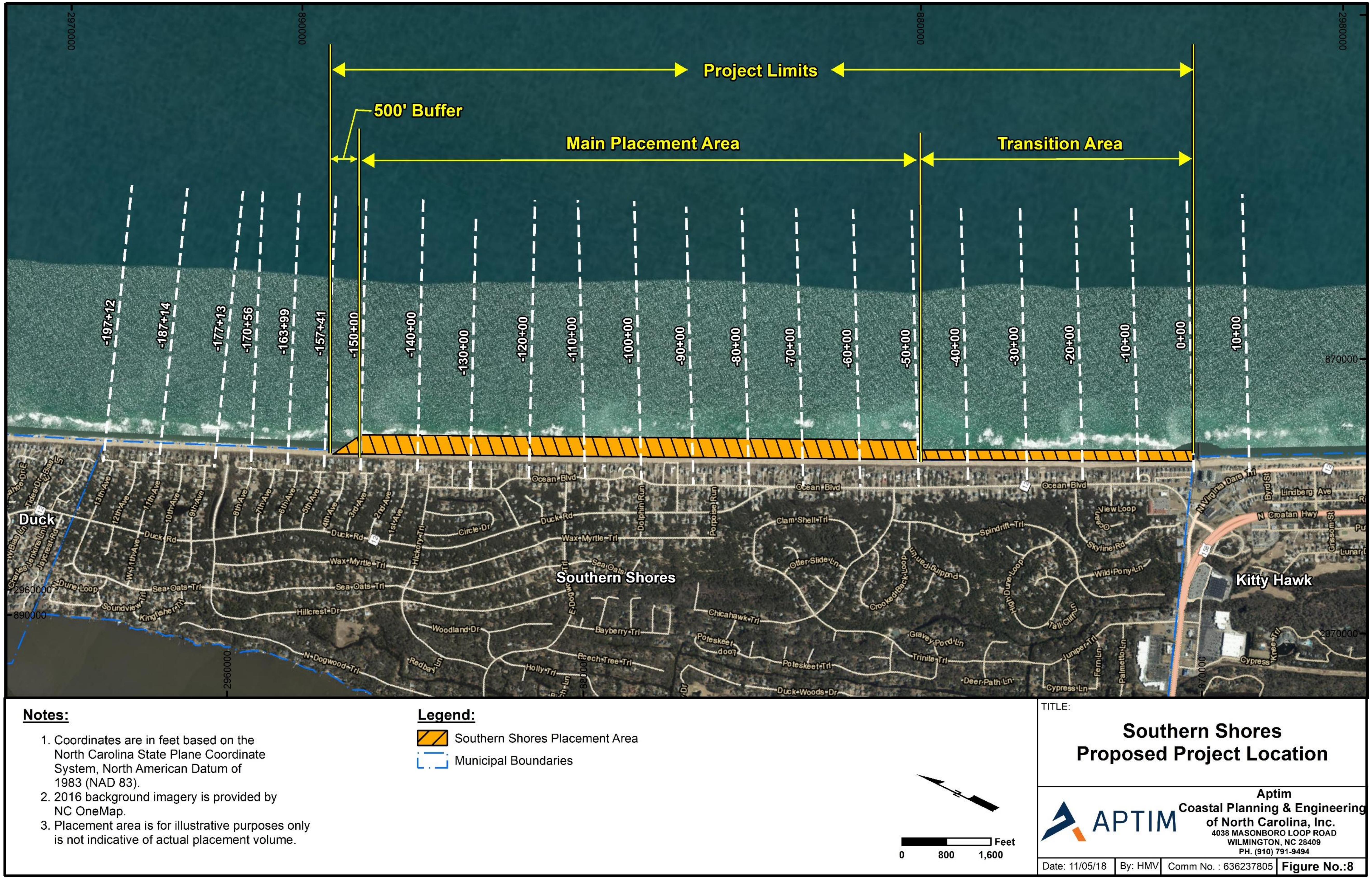

Figure 9. Location Map showing the recommended project extent.

The beach fill options presented in this report are intended to be used for future planning of a beach maintenance program. Options 1 and 2 are based on results of Scenario 3, and therefore, are focused on providing a reasonable level of storm damage reduction based on a design storm similar to Hurricane Isabel with 2018 sea levels. This scenario also assumed the storm impacted the coast during a similar period in the lunar tidal cycle as when Hurricane Isabel impacted Dare County. Option 3 is based on the results of Scenario 11, and therefore, is focused on providing a reasonable level of storm damage reduction based on a design storm similar to Hurricane Isabel with 2048 sea levels. Scenario 11 assumed the storm impacted the coast during a similar period in the lunar tidal cycle as when Hurricane Isabel impacted Dare County. The 2048 sea levels are based on the RCP 8.5 greenhouse gas projections from AR5. As previously mentioned, Scenario 11 is similar to Scenario 4, which is a design storm similar to Hurricane Isabel with 2018 sea levels; however in contrast to Scenario 3, Scenario 4 would impact during spring tide as opposed to the actual measured tides recorded during the storm in September 2003.

<u>Option 1:</u> The targeted volume density to be maintained along the Southern Shores oceanfront based on the Scenario 3 analysis discussed in Section 4.1.3 is 846 cy/lf. The average density measured along the Town's oceanfront in the "Main Placement Area", which extends from Stations -150+00 (located near 3rd Ave.) to -50+00 (located approximately 450 feet south of Chicahauk Trl.), was 801 cy/lf at the time of the December 2017 survey. Therefore, the fill density needed in this section to achieve a target envelope density of 841 cy/lf is 45 cy/lf. At a fill density of 45 cy/lf, the Main Placement Area fill would require approximately 450,000 cy of sand.

As stated in Section 4.1.4, placement of sand is recommended south of the Main Placement Area to form a contiguous project with the Kitty Hawk/South Southern Shores project constructed in 2017 and scheduled for renourishment in 2022. This area is referred to as the Transition Area. In that regard, Option 1 includes beach fill at 30 cy/lf. between Stations -50+00 and 0+00, or an additional volume of 150,000 cy within the transition area. The 30 cy/lf. density is based on the anticipated fill density for the Kitty Hawk Project that the Southern Shores fill would tie into at the southern limit.

The total volume placed along the 15,000-foot section from Stations -150+00 through 0+00 would be 600,000 cy of sand, which equates to an average fill density of approximately 40 cy/lf. As mentioned above, beach fills also need taper sections to minimize the loss of fill off the ends of the main fill. Since Option 1 would tie into the Kitty Hawk Project on the south end, no taper would be required. However; a taper is recommended for the northern end of the fill. Assuming a fill density at the northern end of the fill of 45 cy/lf., a 500 ft. long taper would require approximately 11,250 cy, bringing the total design volume of Option 1 to 611,250 cy.

<u>Option 2:</u> Option 2 proposes an average fill density of 30 cy/lf along the entire 15,000-foot section of beach between Stations -150+00 and 0+00 (Main Placement Area and Transition Area). The 30 cy/lf density proposed for Option 2 was derived by first determining the average volume in the volume envelope between Stations -150+00 and -10+00. The average volume in the volume envelope along this section is 818 cy/lf. Comparing this average to the targeted volume density of 846 cy/lf, suggests an average fill volume of 28 cy/lf. is required to achieve the 846 cy/lf target. This number was increased to 30 cy/lf to stay consistent with average fill densities proposed along

Kitty Hawk, which in part was based on constructability limitations for the types of dredges anticipated to be used to construct the project.

At an average density of 30 cy/lf, along both the Main Placement Area and the Transition Area, the total volume placed along the 15,000-foot section from Stations -150+00 through 0+00 would be 450,000 cy of sand. Similar to Option 1, a taper is recommended for the northern end of the fill for Option 2. Assuming a fill density at the northern end of the fill of 30 cy/lf., a 500 ft. long taper would require approximately 7,500 cy, bringing the total design volume of Option 2 to 457,500 cy.

Option 3: Option 3 is focused on providing a reasonable level of storm damage reduction taking into consideration 2048 sea levels. In this regard, the targeted volume density to be maintained along the Southern Shores oceanfront for Option 3 is based on the Scenario 11 analysis, which is 858 cy/lf (See Table 8). As discussed under Option 1, the average density measured along the Town's oceanfront in the "Main Placement Area", was 801 cy/lf at the time of the December 2017 survey. Therefore, the fill density needed in this section to achieve a fill density of 858 cy/lf is 57 cy/lf. At a density of 57 cy/lf, the Main Placement Area fill would require approximately 570,000 cy of sand.

Similar to Option 1, Option 3 includes beach fill at a density of 30 cy/lf. in the Transition Area between Stations -50+00 and 0+00, or an additional volume of 150,000 cy. The total volume placed along the 15,000 foot section from Stations -150+00 through 0+00 would be 720,000 cy of sand, which equates to an average fill density of approximately 48 cy/lf. Like Options 1 and 2, a taper is recommended for the northern end of the fill for Option 3. Assuming a fill density at the northern end of the fill of 57 cy/lf., a 500 ft. long taper would require approximately 14,250 cy, bringing the total design volume of Option 3 to 734,250 cy.

The scope of the development of this beach management plan was to determine a minimum cross-sectional volume needed to provide an acceptable level of storm damage reduction. During the design and permitting of a proposed project, the design engineer will establish design parameters for the proposed beach fill that will include a dune fronted by a beach berm. Design parameters for both the dune and berm will include crest elevations, crest widths, and slopes that would provide the recommended cross-sectional volume. The detailed design process will also include an evaluation of ways to optimize the design of the fill template that would achieve the design goals for the lowest cost.

4.2.2 Diffusion Losses

Any beach fill placed along a shoreline is subject to diffusion losses. Diffusion or spreading will occur with any sand placement activity as the nourished beach evolves into an equilibrium planform comparable to the adjacent shorelines (Dean, 2002). Diffusion losses are the result of the fill template spreading alongshore and occurs when the fill material spreads outside the fill placement or project area.

The Duck Feasibility Study (CPE, 2013) included preliminary estimates of diffusion losses by employing a simple diffusion model. This estimate was later improved in the design study (CPE, 2015a) by using the GENESIS model to obtain a better estimate of how the project would perform; GENESIS simulates the long-term planform evolution of the beach in response to wave conditions, coastal structures, and other engineering activity including beach nourishment. Unlike the simple diffusion model used in the Duck feasibility study (CPE, 2013), which was based on a single representative wave condition, diffusion in GENESIS is driven by actual wave data.

Diffusion loss estimates for the three (3) options proposed in Section 4.2.1 for Southern Shores were computed using Dean's simplified method (Houston, 1996) and a breaking wave height calibrated based on the GENESIS analysis for the Duck shoreline (CPE, 2015a). Dean's simplified method is a function of the fill segment length, berm width (or shoreline advance), active profile height, fill sediment grain size, and the breaking wave height. A summary of the input parameters for the three options proposed in Section 4.2.1 is provided in Table 9.

As previously stated, the proposed fill segment in the Main Placement Area is 10,000 feet in length. This length was used to conservatively estimate diffusion losses for Options 1 and 3, as the fill density and associated shoreline perturbation in the Main Placement Area are greater than those in the Transition Area; moreover, the Transition Area shoreline is uniform throughout Kitty Hawk, which significantly reduces diffusion in this area considering the longer extent of the less pronounced shoreline perturbation. In Option 2, a fill length of 15,000 feet was used as the fill density in the Main Placement Area and the Transition Area are the same. The shoreline advance is a function of the fill density being recommended and the height of the active profile. The height of the active profile for each option was assumed to be 30 feet based on a berm height of +6.0 ft. NAVD88 and a depth of closure of -24 ft. NAVD88, which is consistent with the adjacent projects. The value used for the fill sediment grain size is based on the average grain size of the material contained in Borrow Area A (CPE-NC, 2015c).

Table 9. Diffusion Model Input

	Diffusion Model Input		
Input Parameter	**Option 1**	**Option 2**	**Option 3**
Fill Segment Length (ft)	10,000	15,000	10,000
Shoreline Advance (ft)	40.5	27	51.3
Active Profile (ft)	30	30	30
Fill Sediment Grain Size (mm)	0.36	0.36	0.36
Breaking Wave Height (ft)	0.55	0.55	0.55

The results of the diffusion model analysis are provided in Table 10. The losses listed for Options 1 and 3 reflect losses that would occur from the 10,000-foot section of the Main Placement Area between Stations -150+00 and -50+00. The losses listed for Option 2 reflect losses that would occur from the 15,000-foot section of the Main Placement Area plus the Transition Area between Stations -150+00 and 0+00.

Table 10. Diffusion Model Results

Years	Diffusion Model Results Option 1 Diffusion Loss (cy)	Option 2 Diffusion Loss (cy)	Option 3 Diffusion Loss (cy)
1	22,780	14,940	28,860
2	32,910	21,420	41,690
3	40,980	26,520	51,910
4	48,000	30,900	60,800
5	54,400	34,800	68,800

4.2.3 Background Erosion Losses

Typically, a beach nourishment project incorporates both diffusion losses and background erosion into the construction template to account for expected losses that occur during the interim period between nourishment events. Section 4.1.1 details the volume change measured along the Town of Southern Shores between 2004 and 2018. Although surveys conducted along the proposed project limits between October 2004 and October 2006 indicated an average volumetric loss above the -24 ft. contour of approximately 0.4 cy/lf./yr., the average volumetric change measured between October 2006 and December 2017 above the -24 ft. contour was a positive 3.2 cy/lf./yr. Every profile saw positive volume change between October 2006 and December 2017; however, the southern 2,500 feet of the Town shoreline was directly benefited by the beach nourishment project constructed in summer 2017.

Based on this analysis, no additional fill is being recommended to account for background erosion losses. APTIM recommends that the Town continue to monitor the shoreline over the next 2 years and modify the design as warranted based on the results of this monitoring.

4.2.4 Project Volume Summary

The evaluation of the three optional beach fill designs was based on the assumption that the full beach fill design profile will be in place when the design storm impacts the project area. Losses that may occur between nourishment intervals were accounted for based on calculated diffusion losses only, as volume change calculations based on historic profile data did not result in a net loss. Table 11 shows the design fill volume, advanced fill volume, taper fill volume, and total volume for each of the three options presented. The advanced fill volume assumes a five-year nourishment interval. The taper volume is based on a taper length on the north end of 500 feet and no taper on the south where the project is proposed to tie into the Kitty Hawk project.

Table 11. Optional Design Summary

Design	Design Volume(1)	Transition Area Volume(2)	Advanced Fill Volume(3)	Taper Volume(4)	Total Volume	Avg. Fill Density(5)
Option 1	450,000	150,000	54,400	11,250	665,650	40
Option 2	300,000	150,000	34,800	7,500	492,300	30
Option 3	570,000	150,000	68,800	14,250	803,050	48

(1)Volume (CY) to construct the Main Placement Area excluding tapers, transition fill, and advanced fill (Stations -150+00 to -50+00).
(2)Volume (CY) to construct the Transition Area (Stations -50+00 to 0+00).

(3)Volume (CY) included to account for diffusion losses and background erosion. Re-nourishment interval assumed to be 5 years.
(4)Volume (CY) to construct a 500 foot taper on the northern end of the beach fill (Stations -155+00 to -150+00).
(5)Total Volume included in the Design Volume and Transition Area divided by 15,000 feet.

4.2.5 Sand Sources (Borrow Areas)

The 2017 Multi-Town beach nourishment project used sand from two (2) offshore borrow areas shown in Figure 1. All the sand used to construct the Southern Shores portion of the project came from Borrow Area A. Borrow Area A is located on the Outer Continental Shelf between 5.0 and 6.5 miles offshore of the Towns of Kill Devil Hills and Nags Head in water depths between 50 and 60 ft. (NAVD88). The proposed borrow area covers 1,173 acres (CPE-NC, 2015c). Surveys conducted following completion of the 2017 project indicated approximately 12.8 million cubic yards of sand is available for future projects (APTIM, 2018a).

Although a sufficient volume of beach quality sand is available in Borrow Area A, the unit cost for sand is highly dependent on the proximity of the sand source to the project. In that regard, the identification of a sand source closer to the Southern Shores project area would reduce the cost of a future project. A desktop assessment of potential sand resources that may be available to Southern Shores in the future indicates four (4) potential sources in addition to Borrow Area A. Two (2) potential sources are located in proximity to Borrow Area C, which provided a portion of the sand used to construct the Town of Duck project in 2017 (Figure 10). Two (2) additional potential sand sources are located between two (2) and five (5) miles directly offshore of the Town of Southern Shores (Figure 11).

Preliminary estimates for the development of these borrow sources have been developed as part of this analysis and are included in Section 4.4. If these borrow sources were confirmed to contain sufficient volumes of beach compatible material, a reduction in construction cost could be realized by not only Southern Shores, but also the other three northern Dare County Towns of Duck, Kitty Hawk and Kill Devil Hills. For this reason, it would be in the interest of these other communities to share in the cost of future sand source investigations.

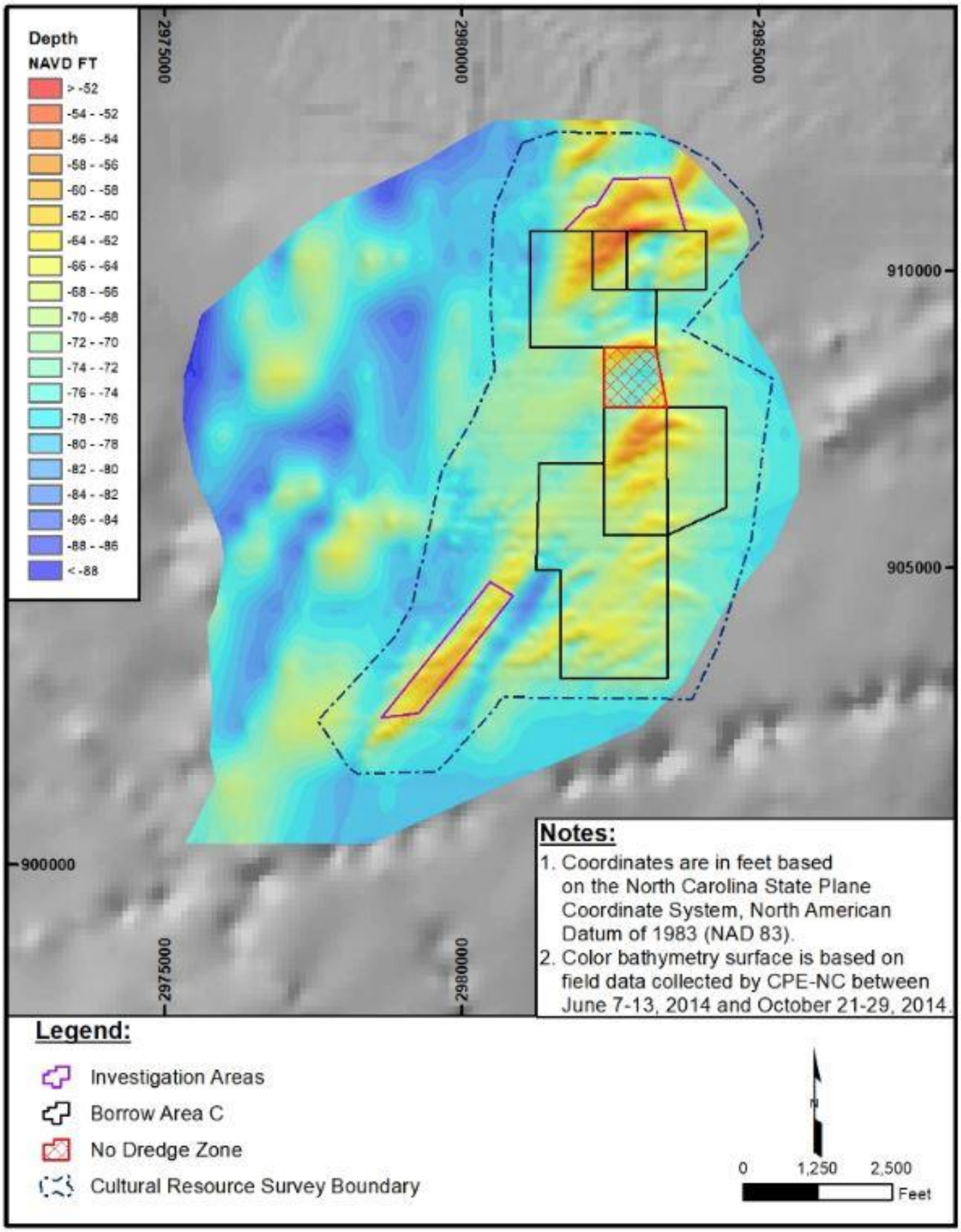

Figure 10. Potential sand sources located in the vicinity of Borrow Area C.

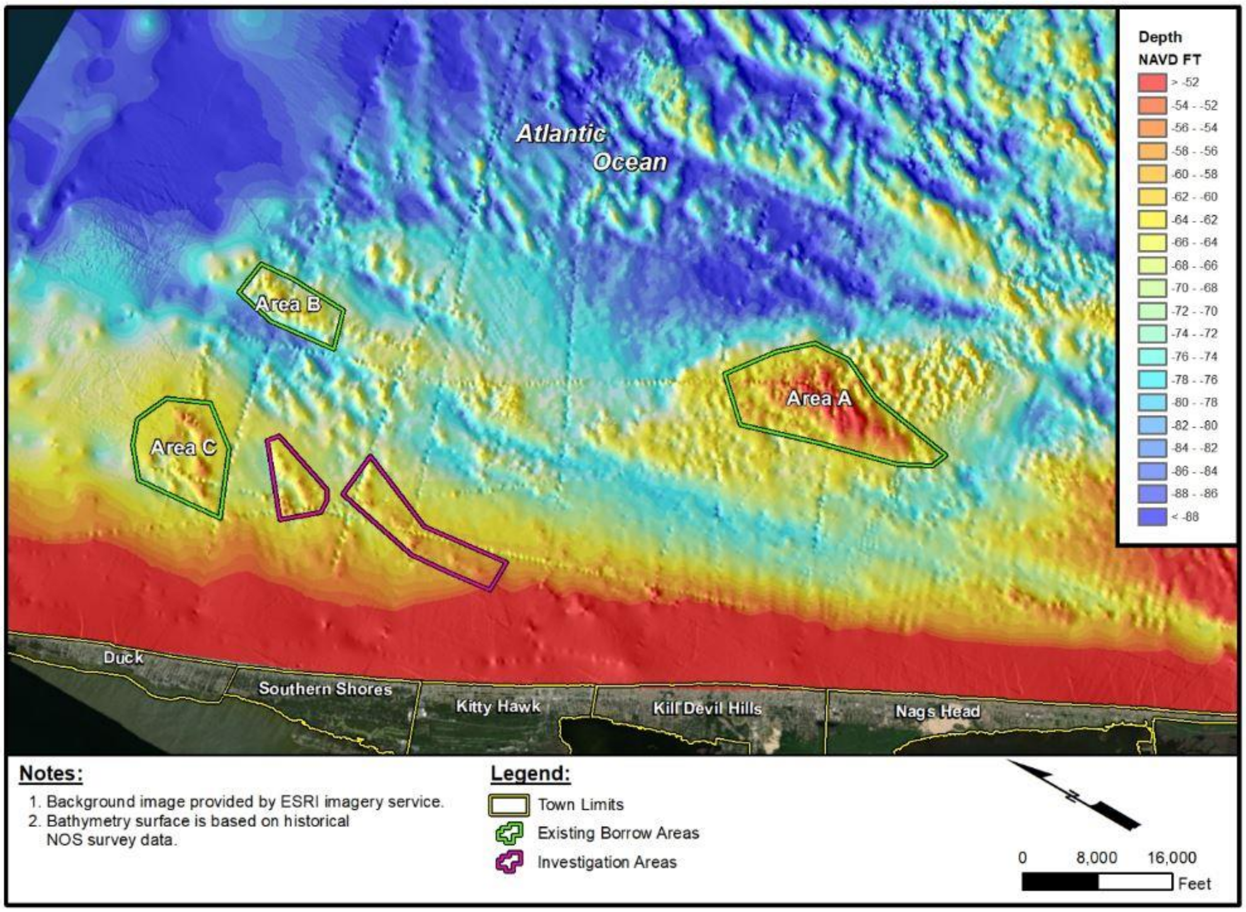

Figure 11. Potential sand sources located directly offshore of Southern Shores.

4.3 Project Schedule

One of the primary focusses of this beach management plan is to coordinate the efforts of Southern Shores with neighboring communities in Dare County to achieve cost savings where possible. The Town of Nags Head is scheduled to construct a renourishment project in the summer of 2019. The efforts required to permit and design a project for Southern Shores could not be completed in a time frame that would allow Southern Shores to coordinate efforts with the Town of Nags Head in 2019.

The 2017 beach nourishment projects undertaken through a cooperative effort on the part of Dare County, and the Towns of Duck, Kitty Hawk, and Kill Devil Hills, were designed with a 5-year maintenance cycle. The first maintenance event is scheduled for summer of 2022. The following schedule has been developed to align the construction of a beach nourishment project for the Town of Southern Shores, with the maintenance work scheduled for 2022.

The construction of a beach nourishment project for the Town of Southern Shores will require the completion of the following items:

- Financial Planning and Establishment of Revenue Streams
- Development/Refinement of Borrow Areas
- Final Design Work
- Environmental Documentation and Permitting (State and Federal)
- Obtaining Easements for Construction
- Development of Construction Plans and Specifications
- Solicitation of Construction Bids
- Awarding Construction Contract

The majority of the items required to be completed in order to construct a project are items that can be coordinated and cost shared with Dare County and the other Dare County Towns. In fact, only the efforts associated with financial planning and obtaining easements for construction will be solely the responsibility of Southern Shores. Even the development of final design work, which will require updated beach profiles surveys, may allow some cost savings due to joint mobilization of field crews to conduct the surveys.

A detailed schedule of the required tasks was developed by APTIM, which suggests that efforts should be initiated in February 2020 to allow for a 2022 construction timeframe. However, APTIM recommends that an updated beach profile survey be conducted in the Spring of 2019 to align with the annual beach profile surveys conducted by Duck, Kitty Hawk, and Kill Devil Hills. The reasons for this are discussed in the recommendations section of the report. If the Town of Southern Shores decides to pursue one of the recommended options, conducting beach profile surveys in the Spring of 2019 will allow engineers to determine whether the measured positive volume change reported in the 2018 Beach Assessment Report is continuing, or if that trend was being influenced by the construction of the 2017 Multi-Town Project. If negative volume changes are measured, these updated profile data would allow us to re-evaluate volume estimates, which directly correlates to cost estimates. Furthermore, collection of survey data in 2019 would ensure that the necessary engineering analysis could be performed starting in early 2020 rather than having to wait until new data are collected in Spring 2020, which may result in a slide in the schedule.

The schedule, detailed in Table 12, takes into consideration the time that was required to conduct similar tasks for the 2017 Multi-Town beach nourishment projects and APTIM's consultation with state and federal agencies to re-calibrate the time frame for state and federal permitting efforts.

Construction of the 2022 project was assumed to take 5 months, between May and October, which is based on the actual construction period of the 2017 project. Although the volume required to construct the Southern Shore portion of the 2022 project would be greater than the volume placed along Southern Shores during the 2017 project, the volumes proposed for the other three (3) Towns are significantly less than the initial construction of the 2017 project. Therefore, the 5-month period should allow sufficient time to complete all four (4) Towns.

Table 12. Proposed Project Schedule for Southern Shores Beach Nourishment Project

Milestone	Start Date	Completion Date	Number of Months
Project Initiations (Interagency Kickoff Meeting)	February-2020	February-2020	1
Borrow Area Development/Refinement	April-2020	February-2021	10
Final Design Work	July-2020	January-21	6
Federal Permitting	February-2020	June-2021	16
State Permitting	November-2020	June-2021	7
Obtaining Easements for Construction	January-2021	January-2022	12
Development of Construction Plans and Specifications	December-2020	June-2021	6
Solicitation of Bids	June-2021	August-2021	1.5
Award Construction Contract	August-2021	September-2021	1.5
Construction	May-2022	October-2022	5

The 2017 Multi-Town beach nourishment project was originally scheduled for the summer of 2016. However, at the time bids were received in mid-January 2016, the contractors indicated that they could not build the project for the estimated cost during the summer of 2016. However, during the pre-bid meeting held December 15, 2015, contractors inferred they had capacity to construct the project in 2016. Following the unsuccessful bid opening in January 2016, the project specifications were modified to allow for construction in 2017 and the project was re-bid in March 2016. The second solicitation of bids resulted in a favorable bid for construction of the project in 2017. The proposed project schedule in Table 12 assumes a bid opening of August 8, 2021. This date is expected to result in favorable bids for construction in 2022, however, dredge capacity from year to year is highly variable.

4.4 Project Cost Estimate

Project cost estimates have been developed to account for permitting/design, construction, pre-construction/construction administration, and environmental monitoring anticipated to be required during construction. The total estimated cost includes a 10% contingency. The estimated cost does not include annual monitoring costs or costs associated with vegetation or sand fencing. Table 13 summarizes each of the associated costs for the three options as well as the Total Project cost. A detailed description of the estimated cost is provided in the following sections.

Table 13. Project Option Cost Estimates

Option	Volume (cy)	Permitting / Design Soft Cost	Construction Cost	Pre-Construction/ Construction Admin.	Construction Env. Monitoring Costs	Contingency Cost (10%)	TOTAL COST

1	665,650	$435,000	$9,708,000	$219,500.00	$176,600.00	$1,053,900	$11,593,000
2	492,300	$435,000	$7,425,000	$201,500.00	$129,800.00	$819,100	$9,010,400
3	803,050	$435,000	$11,443,000	$233,500.00	$213,000.00	$1,232,500	$13,557,000

4.4.1 Permitting/Design

The estimated cost for permitting and design is the same for the three options discussed. The total estimated cost to obtain permits and authorizations, finalize the project design, and conduct offshore sand resource investigations for borrow sources, from which to obtain the sand for the project is $420,000. The associated costs for obtaining permits and finalizing the project design were based in part on the level of effort required to permit the Duck, Kitty Hawk, and Kill Devil Hills project. Some efficiencies in the process required for Southern Shores, as well as the analysis conducted during the development of this Beach Management Plan were factored into this estimate.

Construction costs discussed in Section 4.4.2, assumed the sand for the project would come from Borrow Area A, located offshore Kill Devil Hills and Nags Head. Section 4.2.5 describes additional potential borrow sources located closer to some of the projects, including Southern Shores. The costs to investigate these additional sources were included in the estimated cost for "Permitting/Design". The total cost of sand resource investigations was developed and the cost was split four (4) ways, assuming these costs would be split between the Towns of Duck, Southern Shores, Kitty Hawk, and Kill Devil Hills. This is consistent with how sand resources were identified for the 2017 project. Successful identification of additional compatible sand would likely drive costs of a 2022 project down for all Towns participating.

4.4.2 Construction Costs

Construction cost estimates for the Southern Shores project assumed the project would be constructed in a similar fashion as the 2017 beach nourishment project, which used hopper dredges. A hopper dredge is a self-propelled, maneuverable vessel that can independently load, transport, and unload dredged material. The hopper dredge has a trailer suction pipe with a draghead that strips layers of sediment and hydraulically suctions the material into the hopper. For the proposed project, material would be off loaded by direct pump-out through a submerged pipeline while the vessel is moored offshore. For the Town of Duck project, which was approximately 8,500 feet long, three (3) pump-outs were used to construct the project.

Once the material is discharged from the pipe onto the beach, onshore construction crews will shape the material into the desired construction template. The material will be managed in a way that reduces turbidity, which at times, includes constructing shore parallel dikes along which water from the slurry flows, allowing additional time for material to settle out of suspension before the seawater returns to the ocean. Equipment such as bulldozers and front-end-loaders are used to shape sand on the beach and move pipes as necessary.

In order to determine costs for the construction of the Town of Southern Shores proposed project, a cost estimate was developed for a 2022 Multi-Town project to include Duck, Southern Shores, Kitty Hawk, and Kill Devil Hills. From that estimate, individual costs for Southern Shores were extracted. The cost estimates for the Multi-Town project proposed for construction in 2022, was based on projecting the cost experienced for the 2017 initial construction of the Dare County projects to 2022 levels.

The primary factor used to project the cost from 2017 to 2022 was the marine equipment index published by the USACE in Appendix E of EP 1110-1-8 for Region 3 (USACE, 2016). The economic indexes are provided for the years 1982 to 2015. The 2022 cost projections were made based on the trend in increased cost from 1982 to 2015. The measured trend suggested the 2017 costs would increase by a factor of 1.093 by 2022.

In order to estimate projected 2022 costs for mobilization/demobilization, performance and payment bonds, and borrow area surveys, the respective actual costs of the 2017 project were multiplied by 1.093. The projected 2022 costs however, did not include increased costs associated with the addition of the proposed Southern Shores project. Therefore, a separate cost estimate was made to determine the additional cost of mobilizing the dredge pipe necessary for the Southern Shores project as well as providing for additional pump-out stations. The total additional mobilization and demobilization cost for Southern Shores was estimated to be $837,000. The total cost for mobilization/demobilization, performance and payment bonds, and borrow area surveys were then combined and pro-rated between the four (4) Town's based on the percent of the combined project volume of sand proposed for each individual Town's project.

The 2017 construction of the Duck project included material from Borrow Areas A and C as shown in Figure 1. Initial construction of the Duck project depleted the volume available in Borrow Area C, therefore, unless additional borrow sources can be identified, nourishment of the Duck project in 2022 as well as a project for Southern Shores, will have to rely on material form Borrow Area A. In house cost estimates for constructing the projects along Duck, Kill Devil Hills, and Kitty Hawk, which were prepared prior to the construction of the 2017 projects, were used as a proxy to determine the cost of nourishing Duck and Southern Shores with material from Borrow Area A. Once incremental costs for Duck and Southern Shores were calculated, the unit costs for all four (4) projects were projected from 2017 costs to 2022 costs using the 1.093 multiplier.

4.4.3 Pre-Construction/Construction Administration

Costs were estimated for professional services associated with both pre-construction and construction administration. Pre-construction services are associated with conducting design surveys, preparation of construction plans and specifications, development of the bidding document, assisting the owner during the bid solicitation process, responding to technical questions from bidders, evaluation of bids, and contract negotiations. Construction administration services includes serving as the owner's agent during construction. The responsibilities of the agent typically include: observing contractors work and recommending if it is compliant with permits and contract documents; participating in regular public meetings; providing daily project updates to the owner; providing recommendations for final payment and project closeout; and notifying the owner and regulatory agencies of any observed non-compliant item of work as required by permit or contract documents. Costs associated with performing a post-construction survey and producing a post-construction report were also included in the estimate.

The differences in costs for this item, observed when comparing the cost for each option in Table 13, is driven by the difference in the estimated time to construct each option. The costs associated with Pre-Construction/Construction Administration assumes that all four (4) projects will be bid out as one contract to a construction contractor.

4.4.4 Construction Environmental Monitoring Costs

The total project costs represented in Table 13 include costs associated with anticipated environmental monitoring that will be required during project construction. This assumption is based on past interactions with regulatory agencies and permit conditions attached to the permits that allowed for construction of the 2017 project. The costs assume that both sea turtle relocation trawling and sea turtle nest monitoring and relocation will be required. A daily rate for both monitoring types was estimated based on actual costs accrued for the service during the 2017 project. This daily cost was applied to the anticipated number of days required to construct each of the three options.

5 CONCLUSIONS

An evaluation of long-term volume changes, storm vulnerability, and beach volume density were conducted in order to determine if portions of the Town of Southern Shores should be considered for future beach nourishment projects. The determination of whether beach nourishment should be considered by the Town was based on an understanding that the Town generally desires to sustain the beaches that support a significant portion of their local economy and maintains the tax base of the Town. More specifically, the Town is focused on maintaining the oceanfront beach and dune to a configuration that 1) provides a reasonable level of storm damage reduction to public and private development, 2) mitigates long-term erosion that could threaten public and private development, recreational opportunities, and biological resources, and 3) maintains a healthy beach that supports valuable shorebird and sea turtle nesting habitat.

The evaluation of long-term volume changes, storm vulnerability, and beach volume density lead to a recommendation that the Town should consider beach nourishment, or the placement of beach quality sand, along the southern 15,500 feet of shoreline from Station -155+00 (located approximately 200 ft. south of 5th Ave.) to the southern Town boundary with Kitty Hawk (Station 0+00). The area recommended for sand placement is more specifically described in terms of three (3) sub-sections. The “Main Placement Area” extends from Station -150+00 (located near 3rd Ave.) south to Station -50+00 (located approximately 450 feet south of Chicahauk Trl.). This is the primary area identified based on the evaluation of the SBEACH storm damage vulnerability analysis and the beach volume analysis described in Section 4.1.3. The “Transition Area” extends from Station -50+00 (located approximately 450 feet south of Chicahauk Trl.) south to the Town boundary with Kitty Hawk at Station 0+00. Placement of sand along this 5,000 foot portion of the beach is primarily focused on tying in the project to the Kitty Hawk project. The third sub-section extends approximately 500 feet north of 3rd Ave. and is referred to as the "Taper".

Upon establishing the recommended areas to conduct beach nourishment, the analysis focused on recommended volume densities to place sand. Three (3) beach fill options were developed, which provide different levels of protection. Options 1 and 2 are based on results of Scenario 3 and therefore are focused on providing a reasonable level of storm damage reduction based on a design storm similar to Hurricane Isabel with 2018 sea levels during the same tide range as that experienced in September 2003 when Isabel impacted Dare County. Option 3 is based on the results of Scenario 11, which was focused on providing a reasonable level of storm damage reduction based on a design storm similar to Hurricane Isabel with 2048 sea levels during the same tide range as that experienced in September 2003, which are similar to sea levels experienced today during an average spring tide.

Total volume required for each option considered the recommended beach fill in the Main Placement Area, the Transition Area, the taper, as well as sand expected to be lost during a projected 5-year nourishment interval. The total volume required for Option 1 is 665,650 cubic yards of sand. Options 2 and 3 would require 492,300 cubic yards and 803,050 cubic yards, respectively. Sufficient volumes of sand to construct any of the three options are available from the previously designed borrow area, Borrow Area A, located offshore of Kill Devil Hills.

The detailed project schedule, developed as part of this Beach Management Plan, aims at aligning efforts required by the Town of Southern Shores with neighboring communities in Dare County to achieve cost savings where possible. In that regard, the schedule developed for the Southern Shores project looks to align construction with the anticipated first re-nourishment of the Duck, Kitty Hawk, and Kill Devil Hills projects in 2022. The project schedule suggests that efforts should be initiated in February 2020 to allow for a 2022 construction timeframe. The schedule considered the time required to conduct similar tasks for the 2017 Multi-Town beach nourishment and was re-calibrated based on consultations with state and federal agencies.

Project cost estimates were developed for each of the three (3) beach fill options. These estimates consider costs associated with permitting/design, construction, pre-construction/construction administration, and environmental monitoring anticipated to be required during construction. The total estimated cost also includes a 10% contingency. The total estimated cost for Option 1 is $11,593,000. Options 2 and 3 are estimated to cost $9,010,400 and $13,557,000, respectively. The estimated costs do not include annual monitoring costs or costs associated with vegetation or sand fencing.

6 RECOMMENDATIONS

Based on the analysis and conclusions discussed in this report, APTIM is recommending the following:

1. **Determine Which Option To Pursue:** Given the information presented in this report, the Town of Southern Shores should first determine if it wishes to pursue any of the three

beach fill options presented. If the Town determines that it wishes to pursue one of the three presented beach nourishment options, it must then decide which option provides the most cost-effective approach. APTIM is prepared to support the Town with any of the three Options as a project we believe will achieve the Town's goals. More specifically, APTIM believes each option will maintain the oceanfront beach and dune to a configuration that 1) provides a reasonable level of storm damage reduction to public and private development, 2) mitigates long-term erosion that could threaten public and private development, recreational opportunities, and biological resources, and 3) maintains a healthy beach that supports valuable shorebird and sea turtle nesting habitat. The Town must determine which option is feasible given fiscal restraints.

2. **Begin Coordination with County and Neighboring Communities:** During the planning stages of the 2017 Multi-Town beach nourishment project, regular meetings were convened of Town and County representatives as well as the Town's Engineers and Financing Consultants. A similar meeting should be scheduled for Spring of 2019 to begin the planning process for a potential 2022 project. During the meeting, the Towns and County should be provided updates on proposed volume and cost estimates, as well as a draft schedule of those efforts needed to be completed to go to construction in 2022. Discussions at this meeting should also focus on the need for additional sand sources for future projects. Furthermore, this meeting should aim to establish which Towns are planning to move forward with a 2022 project.

3. **Initiate Financial Planning:** A successful beach management program will require a stable revenue stream dedicated to the program. The Town of Southern Shores is in a favorable position to implement a beach management plan given the history of Dare County's willingness to partner with local communities on such programs. Furthermore, the opportunity to partner with neighboring local communities to cost share in some aspects of the project, has the potential to further reduce the Town's cost share to implement the overall program. Early and proper financial planning is vital to developing a revenue stream to support a beach management program. Other local communities in Dare County that have implemented similar programs, coordinated early on in the planning process with both Dare County and outside professional financial advisors. If the Town determines that it wishes to implement a beach management program, APTIM recommends the Town not only coordinate the initial plan with Dare County and its neighbors, but also seeks professional financial advice to properly budget and plan for the program.

4. **Continue Monitoring of the Beach Profiles:** As witnessed along the Town's southern shoreline between 2015 and 2017, the beach is a highly dynamic area. Sand movement due to storm events can cause considerable changes in the level of protection available by dunes and beach berms. For this reason, it is important to regularly monitor the beach profile. Based on observed trends and current beach densities, APTIM recommends that

an updated beach profile survey be conducted in the Spring of 2019 to align with the annual beach profile surveys conducted by Duck, Kitty Hawk, and Kill Devil Hills.

The analysis detailed in this report is based on beach profile surveys conducted along the Town's oceanfront in December 2017. If the Town of Southern Shores decides to pursue one of the recommended options, conducting beach profile surveys in the Spring of 2019 will serve several purposes. First, the surveys will allow engineers to determine whether the measured positive volume change reported in the 2018 Beach Assessment Report is continuing, or if that trend was being influenced by the construction of the 2017 Multi-Town Project. If negative volume changes are measured, these updated profile data would allow us to re-evaluate volume estimates, which directly correlates to cost estimates. Furthermore, collection of survey data in 2019 would ensure that the necessary engineering analysis could be performed starting in early 2020 rather than having to wait until new data are collected in Spring 2020, which may result in a slide in the schedule.

Through the implementation of these recommendations, the Town of Southern Shores will be establishing a beach management plan specifically aimed at achieving the shoreline management goals of the Town. The adoption of this beach management plan will allow for long-term financial planning which is key to implementing a successful program. This type of long-term planning and active coordination with neighboring Towns will leverage cost saving opportunities realized through multi-town cooperation. Furthermore, the implementation of a beach management program now, before the beach reaches a critical state of erosion, allows the Town to provide a greater level of storm damage reduction at a lower cost.

In addition to providing a higher level of storm damage reduction, implementation of a beach management plan establishes eligibility for the Town to recoup sand losses from coastal storms through FEMA's Public Assistance Program. Typically, coastal communities are eligible for public assistance funds for their beaches through Category B and Category G of the Public Assistance Program authorized by the Robert T. Stafford Disaster Relief and Emergency Assistance Act. Category B stipulates that if a natural or engineered beach has eroded to a point where a 5-year flood could damage improved property, cost-effective emergency protective measures on the beach that protect against damage from that flood are eligible. Currently, the Town of Southern Shores is available for this type of PA funding, however, eligible measures typically include the construction of emergency sand berms to protect against additional damage from a 5-year flood. This typically equates to approximately 6 cy/lf of sand to form temporary emergency dune structures, with the purpose of providing a minimal amount of protection until a more permanent solution is implemented.

Through the implementation of the Beach Management Plan, the Town would be eligible for Category G funds, which allows for beaches to be considered eligible facilities under certain conditions. Each of the three proposed options would meet those conditions, which include: the beach is not a federally constructed shoreline under the specific authority of USACE; the beach was constructed by the placement of imported sand—of proper grain size—to a designed elevation, width, and slope; and the Applicant has established and adhered to a maintenance program involving periodic renourishment with imported sand to preserve the original design.

7 REFERENCES

APTIM, 2018a. Aptim Coastal Planning & Engineering of North Carolina, Inc., *2017 Dare County Beach Nourishment Project, Project Completion Report*, Wilmington, NC.

APTIM, 2018b. Aptim Coastal Planning & Engineering of North Carolina, Inc., *Town of Southern Shores Beach Assessment Report*, Wilmington, NC.

CPE-NC, 2013. Coastal Planning & Engineering of North Carolina, Inc., *Erosion and Shoreline Management Feasibility Study*, Wilmington, NC.

CPE, 2015a – Coastal Planning & Engineering of North Carolina, Inc., *Town of Duck North Carolina Erosion & Shoreline Management Design Report*, Wilmington, NC.

CPE, 2015b – Coastal Planning & Engineering of North Carolina, Inc., *Town of Kill Devil Hills North Carolina Erosion & Shoreline Management Design Report*, Wilmington, NC.

CPE, 2015c – Coastal Planning & Engineering of North Carolina, Inc., *Comprehensive Marine Sand Search and Borrow Area Design Report: Towns of Duck, Kitty Hawk, and Kill Devil Hills, Dare County, North Carolina*, Wilmington, NC.

Dean, Robert G., 2002 – Beach Nourishment Theory and Practice. Singapore: World Scientific.

Houston, James R., 1996. "Simplified Dean's Method for Beach-Fill Design." Journal of Waterway, Port, Coastal, and Ocean Engineering. American Society of Civil Engineers, 122(3), 143-146.

Larson, Magnus and Kraus, Nicholas C., 1998. SBEACH: Numerical Model for Simulating Storm-Induced Beach Changes, Report 1, Empirical Formulation and Model Development, U.S. Army Corps of Engineers, Vicksburg, MS.

National Oceanic and Atmospheric Administration (NOAA), 2018. National Centers for Environmental Information, Bathymetric Data Viewer: https://maps.ngdc.noaa.gov/viewers/bathymetry/

North Carolina Coastal Resources Commission Science Panel (NC CRC), 2015. North Carolina Sea Level Rise Assessment Report, 34 pgs (with appendices).

U.S. Army Corps of Engineers, 2016. Construction Equipment Ownership and Operating Expense Schedule, Region III. Engineering Pamphlet EP 1110-1-8, Appendix E – Economic Indexes for Construction Equipment, pp. E1-E2.

U.S. Army Corps of Engineers, 1985. Estimates of hurricane winds for the east and gulf coasts of the United States. Technical Note CETN-1-36, pp. 1-7.

APPENDIX A

STORM DAMAGE VULNERABILITY MAPS SOUTHERN SHORES, NORTH CAROLINA

G:\Enterprise\Dare\636216500\Mxd\Storm_Damage_Risk_Map1.mxd

Notes:

1. 2016 background imagery is from NC OneMap.

Legend:

- Profiles
- Storm Scenario 1 Impact Line (2003 Sea Level)
- Storm Scenario 3 Impact Line (2018 Sea Level)
- Storm Scenario 11 Impact Line (2048 Sea Level – Assumes Highest Greenhouse Gas Concentration Trajectory Used by IPCC for AR5 – RCP 8.5)
- Storm Scenario 14 Impact Line (2048 Sea Level – Assumes Highest Greenhouse Gas Concentration Trajectory Used by IPCC for AR5 – RCP 8.5 during a Spring Tide)

Feet
0 100 200
1 inch = 200 feet

TITLE:

Appendix A - Storm Damage Vulnerability Maps Southern Shores, North Carolina

APTIM
Coastal Planning & Engineering of North Carolina, Inc.
4038 Masonboto Loop Road
Wilmington, NC 28409
Ph. (910)791-9494
Fax (910) 791-4129

Date: 10/26/18	By: HMV	Comm No. : 636216500	Figure No.: 01

Notes:

1. 2016 background imagery is from NC OneMap.

Legend:

- Profiles
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- Storm Scenario 3 Impact Line (2018 Sea Level)
- Storm Scenario 11 Impact Line (2048 Sea Level – Assumes Highest Greenhouse Gas Concentration Trajectory Used by IPCC for AR5 – RCP 8.5)
- Storm Scenario 14 Impact Line (2048 Sea Level – Assumes Highest Greenhouse Gas Concentration Trajectory Used by IPCC for AR5 – RCP 8.5 during a Spring Tide)

Feet
0 100 200
1 inch = 200 feet

TITLE:

Appendix A - Storm Damage Vulnerability Maps Southern Shores, North Carolina

APTIM
Coastal Planning & Engineering of North Carolina, Inc.
4038 Masonboto Loop Road
Wilmington, NC 28409
Ph. (910)791-9494
Fax (910) 791-4129

Date: 10/26/18	By: HMV	Comm No. : 636216500	Figure No.: 02

G:\Enterprise\Dare\636216500\Mxd\Storm_Damage_Risk_Map2.mxd

Notes:

1. 2016 background imagery is from NC OneMap.

Legend:

- Profiles
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- Storm Scenario 3 Impact Line (2018 Sea Level)
- Storm Scenario 11 Impact Line (2048 Sea Level – Assumes Highest Greenhouse Gas Concentration Trajectory Used by IPCC for AR5 – RCP 8.5)
- Storm Scenario 14 Impact Line (2048 Sea Level – Assumes Highest Greenhouse Gas Concentration Trajectory Used by IPCC for AR5 – RCP 8.5 during a Spring Tide)

Feet
0 100 200
1 inch = 200 feet

TITLE:

Appendix A - Storm Damage Vulnerability Maps Southern Shores, North Carolina

APTIM
Coastal Planning & Engineering of North Carolina, Inc.
4038 Masonboro Loop Road
Wilmington, NC 28409
Ph. (910)791-9494
Fax (910) 791-4129

Date: 10/26/18	By: HMV	Comm No. : 636216500	Figure No.: 03

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G:\Enterprise\Dare\636216500\Mxd\Storm_Damage_Risk_Map4.mxd

Notes:

1. 2016 background imagery is from NC OneMap.

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- Storm Scenario 3 Impact Line (2018 Sea Level)
- Storm Scenario 11 Impact Line (2048 Sea Level – Assumes Highest Greenhouse Gas Concentration Trajectory Used by IPCC for AR5 – RCP 8.5)
- Storm Scenario 14 Impact Line (2048 Sea Level – Assumes Highest Greenhouse Gas Concentration Trajectory Used by IPCC for AR5 – RCP 8.5 during a Spring Tide)

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Feet
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1 inch = 200 feet

TITLE:

Appendix A - Storm Damage Vulnerability Maps Southern Shores, North Carolina

APTIM
Coastal Planning & Engineering of North Carolina, Inc.
4038 Masonboro Loop Road
Wilmington, NC 28409
Ph. (910)791-9494
Fax (910) 791-4129

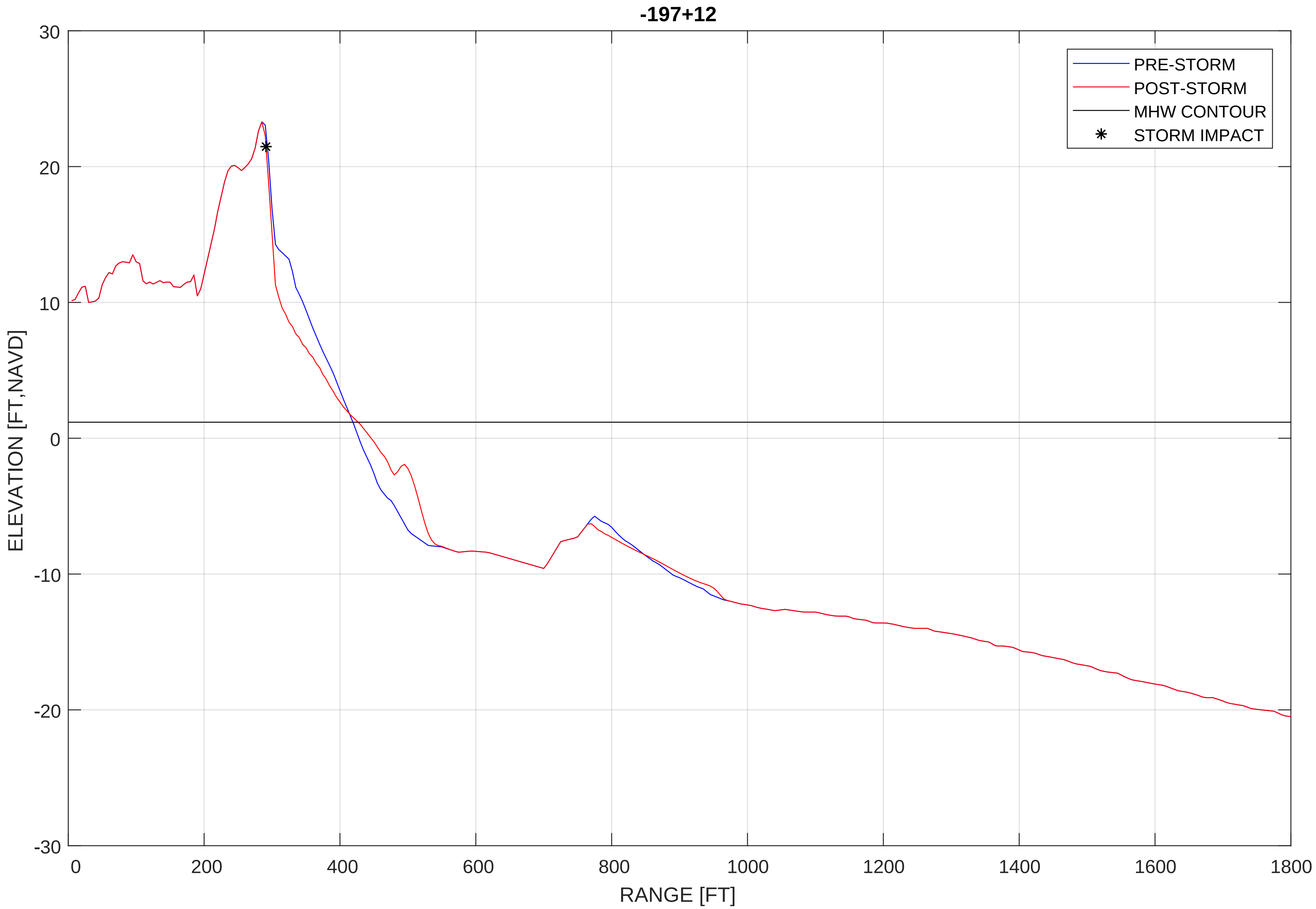
Date: 10/26/18 | By: HMV | Comm No. : 636216500 | Figure No.: 04

APPENDIX B

PRE-STORM AND POST-STORM SBEACH PROFILE CROSS SECTIONS

Scenario 1 (Isabel Storm with 2003 Sea Level)
Scenario 3 (Isabel Storm with 2018 Sea Level)
Scenario 11 (Isabel Storm with 2048 Sea Level – Assumes highest greenhouse gas concentrations trajectory used by IPCC for AR5 – RCP 8.5 and measured tides)
Scenario 14 (Isabel Storm with 2048 Sea Level – Assumes highest greenhouse gas concentrations trajectory used by IPCC for AR5 – RCP 8.5 and spring tides)

PRE-STORM AND POST-STORM SBEACH PROFILE CROSS SECTIONS
Scenario 1 (Isabel Storm with 2003 Sea Level)



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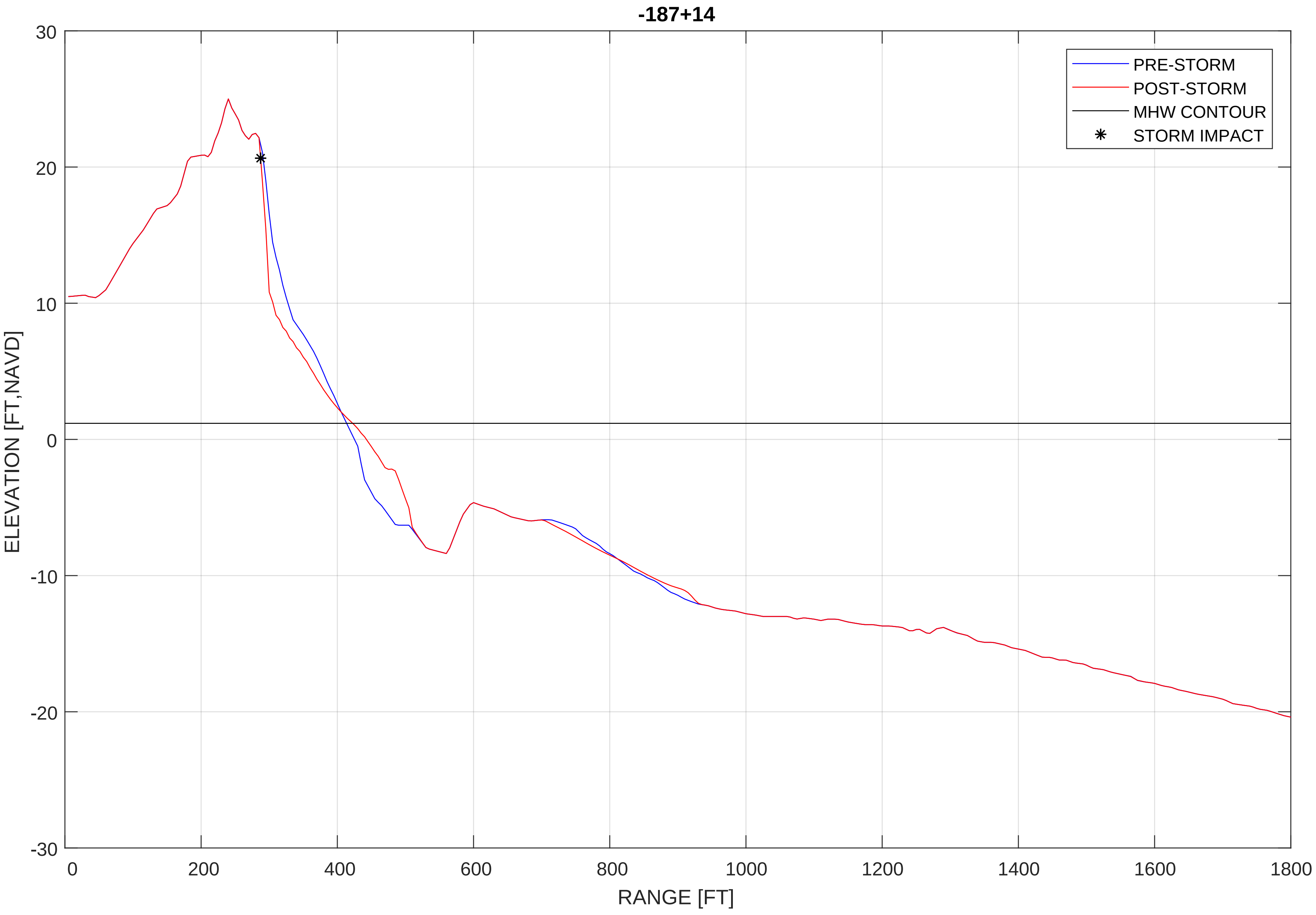

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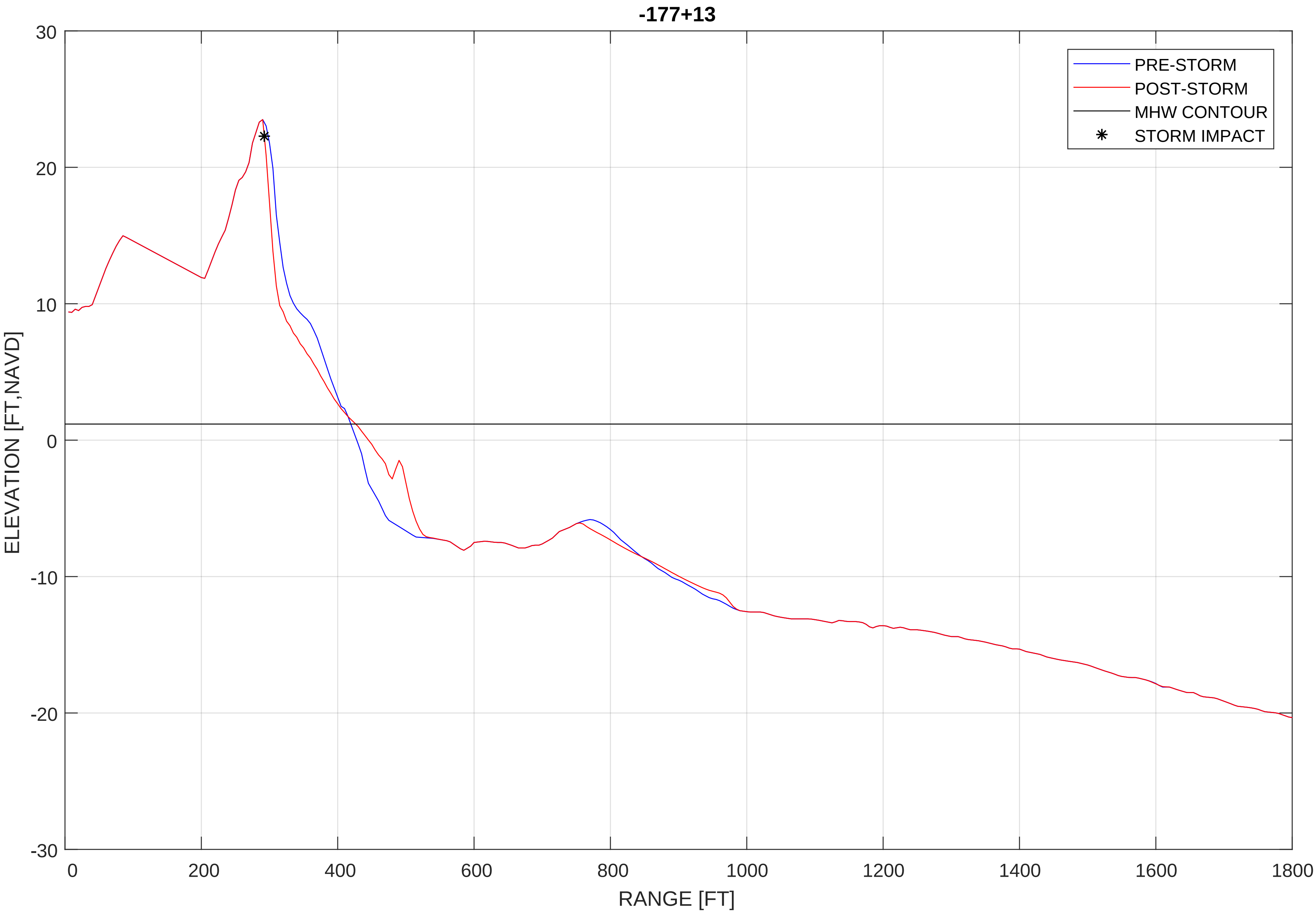

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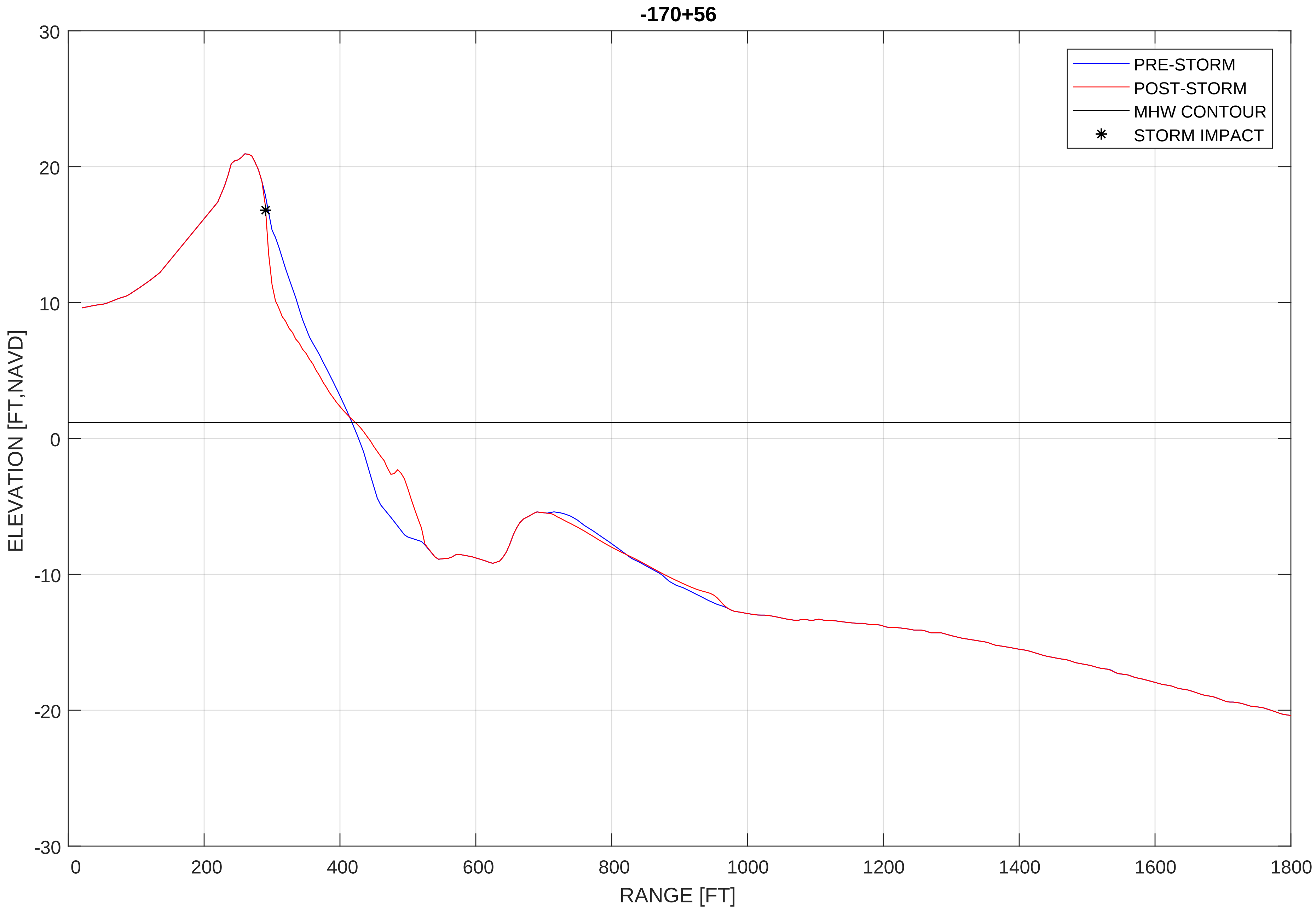
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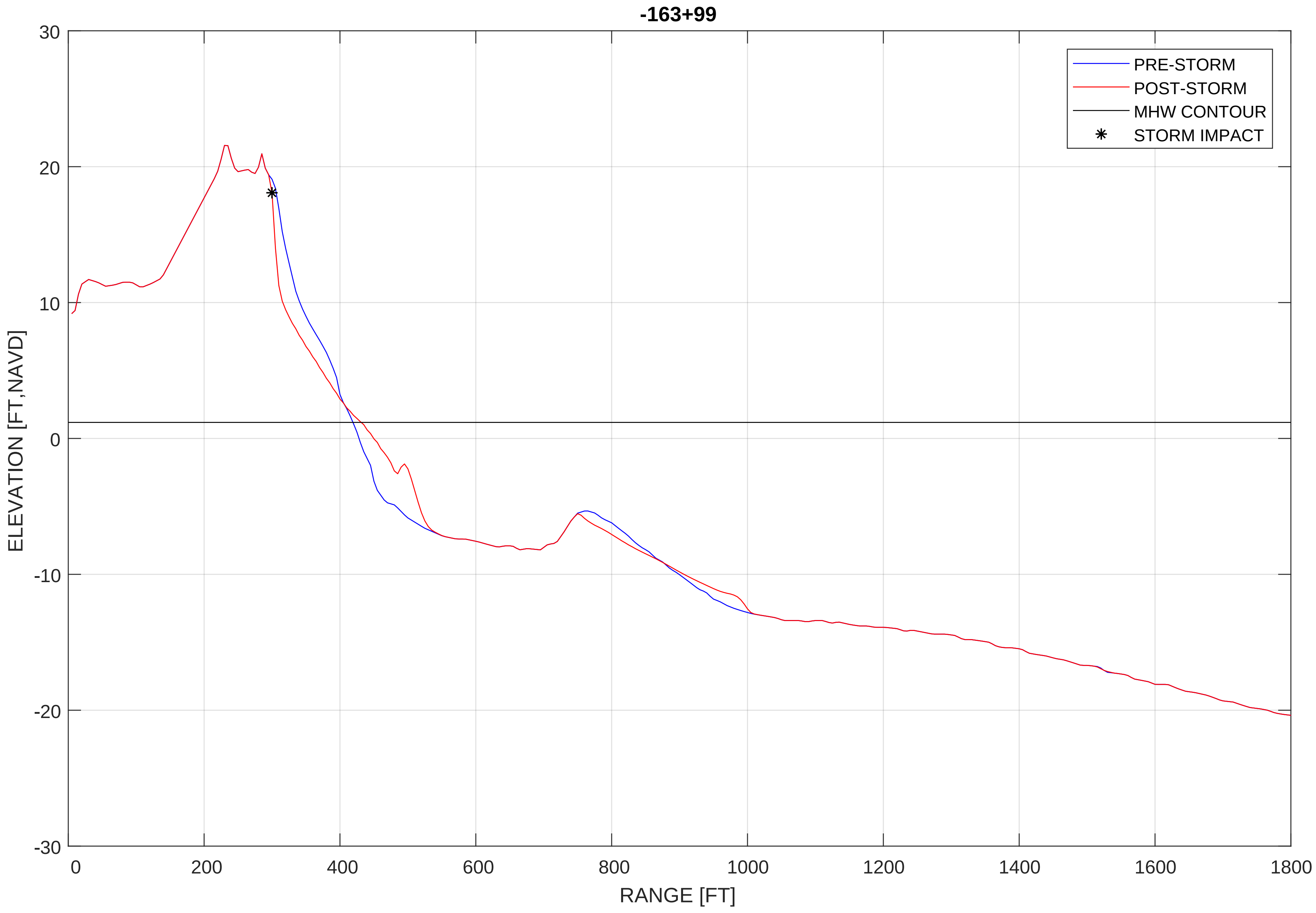
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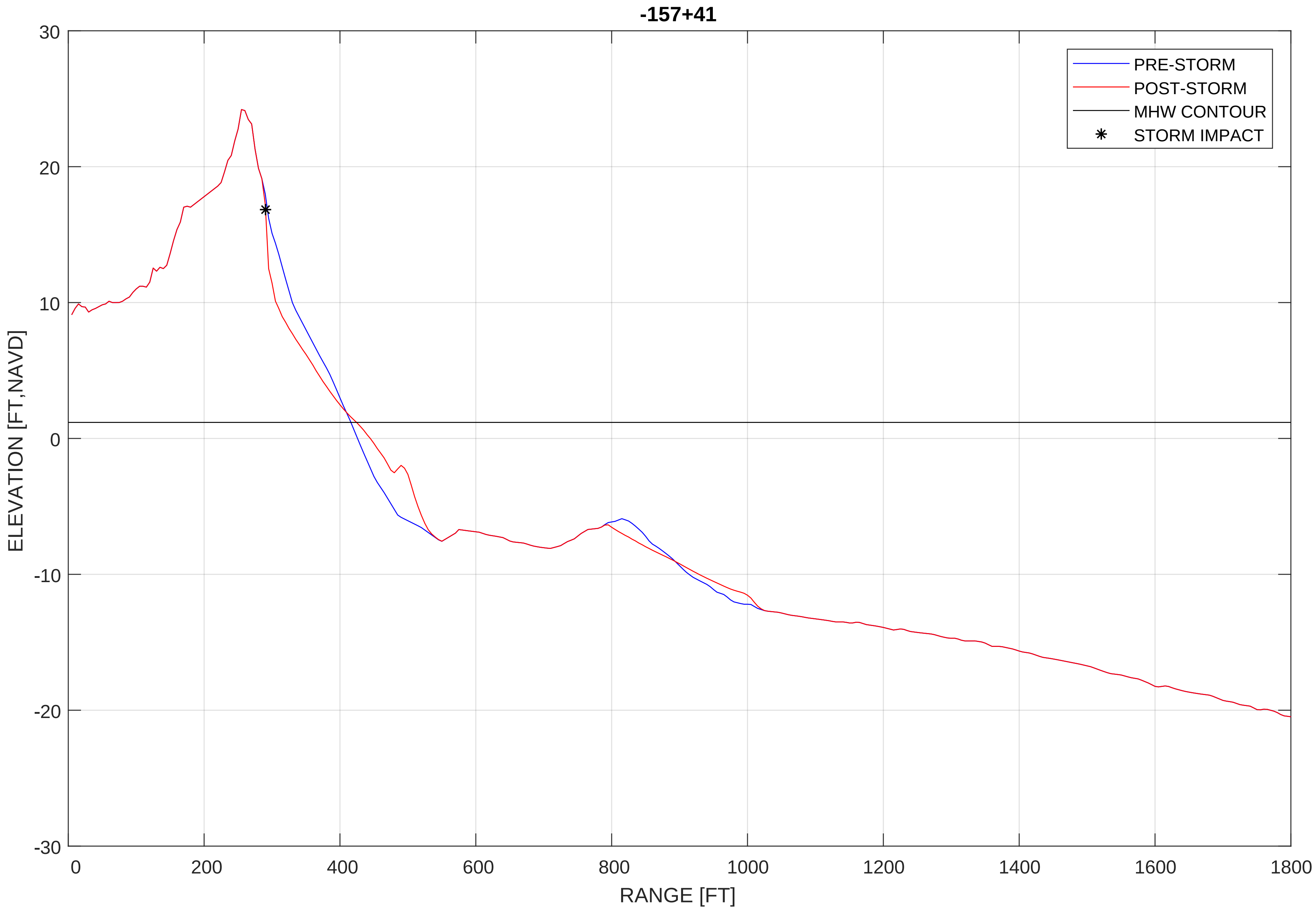
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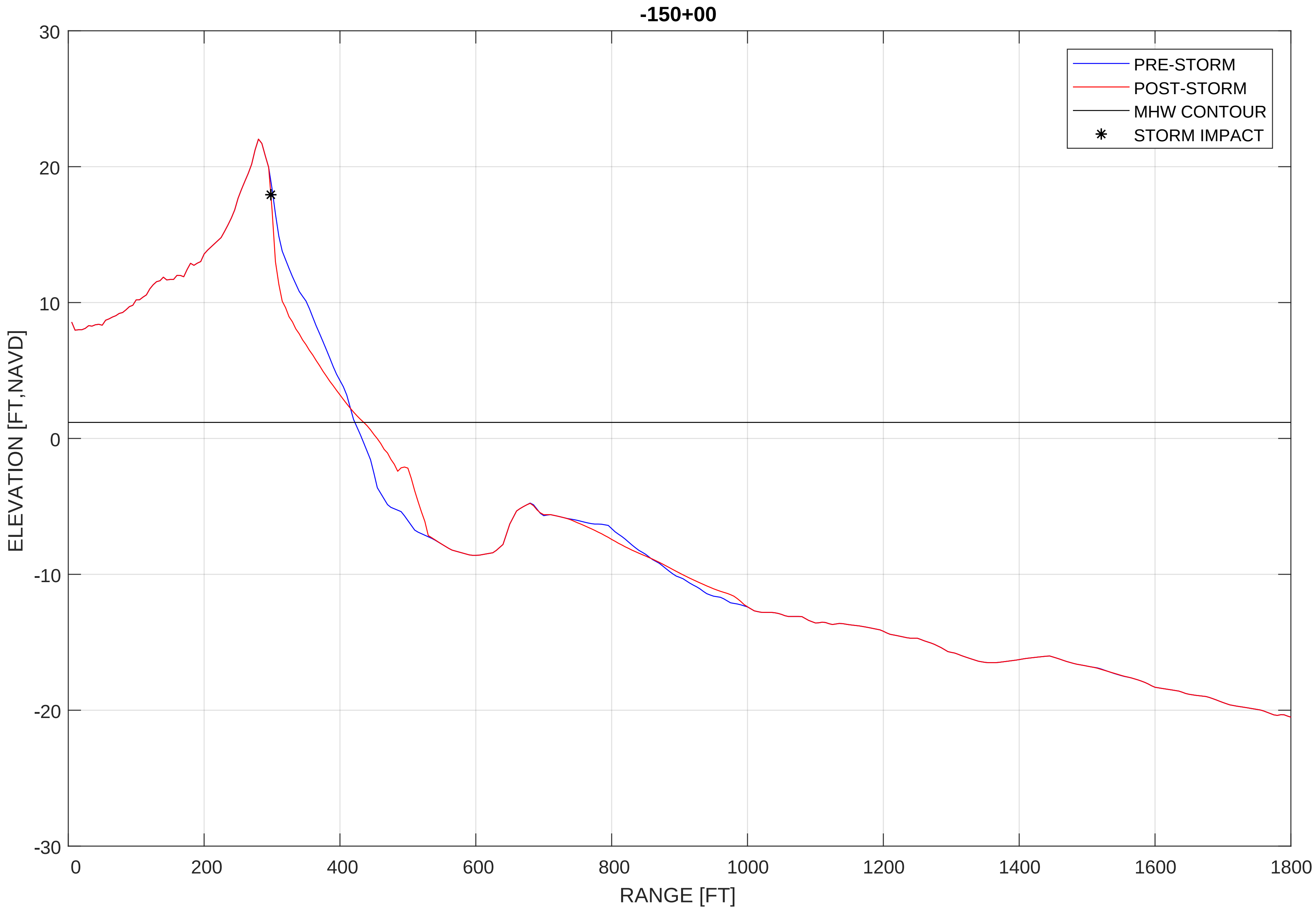

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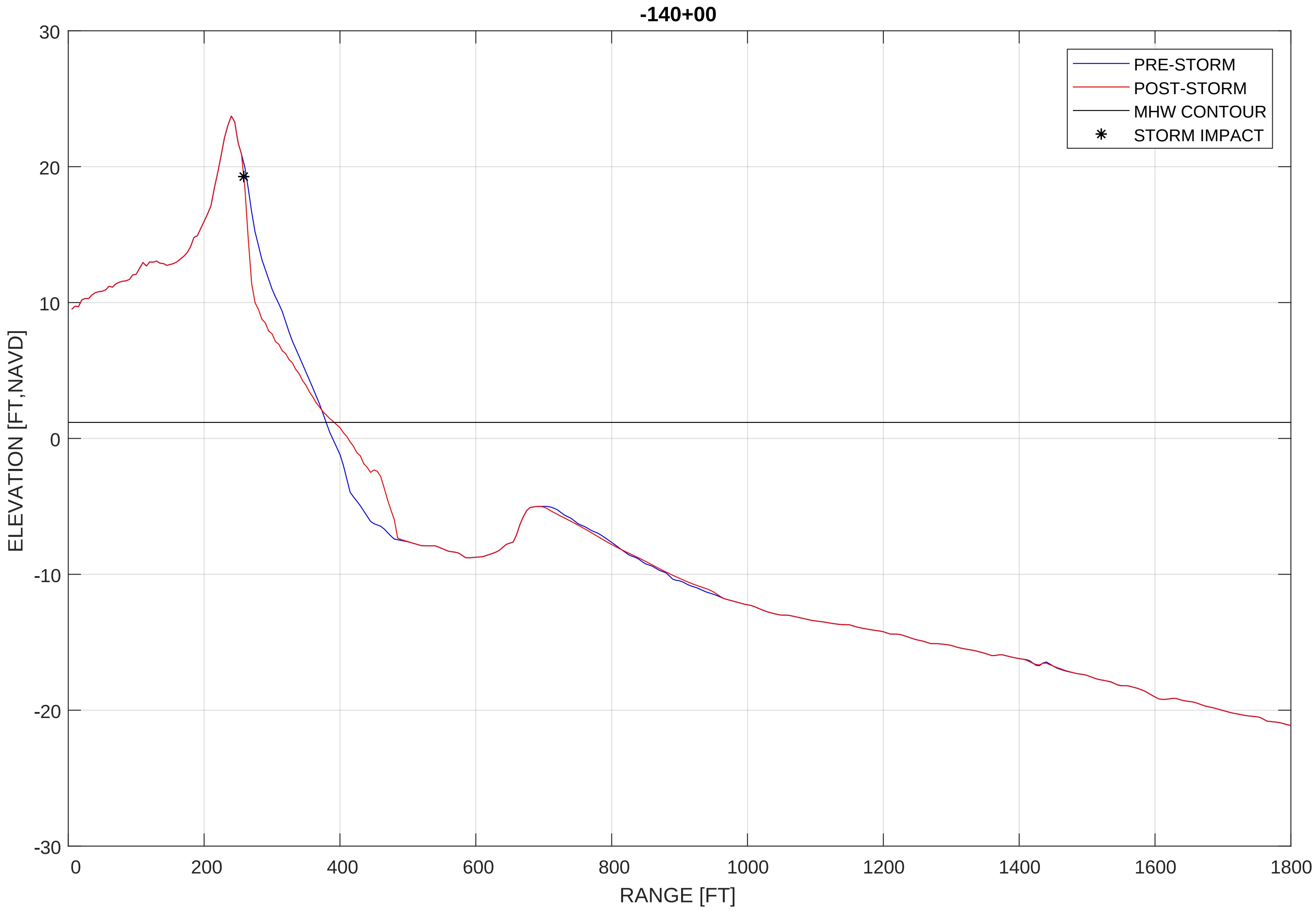

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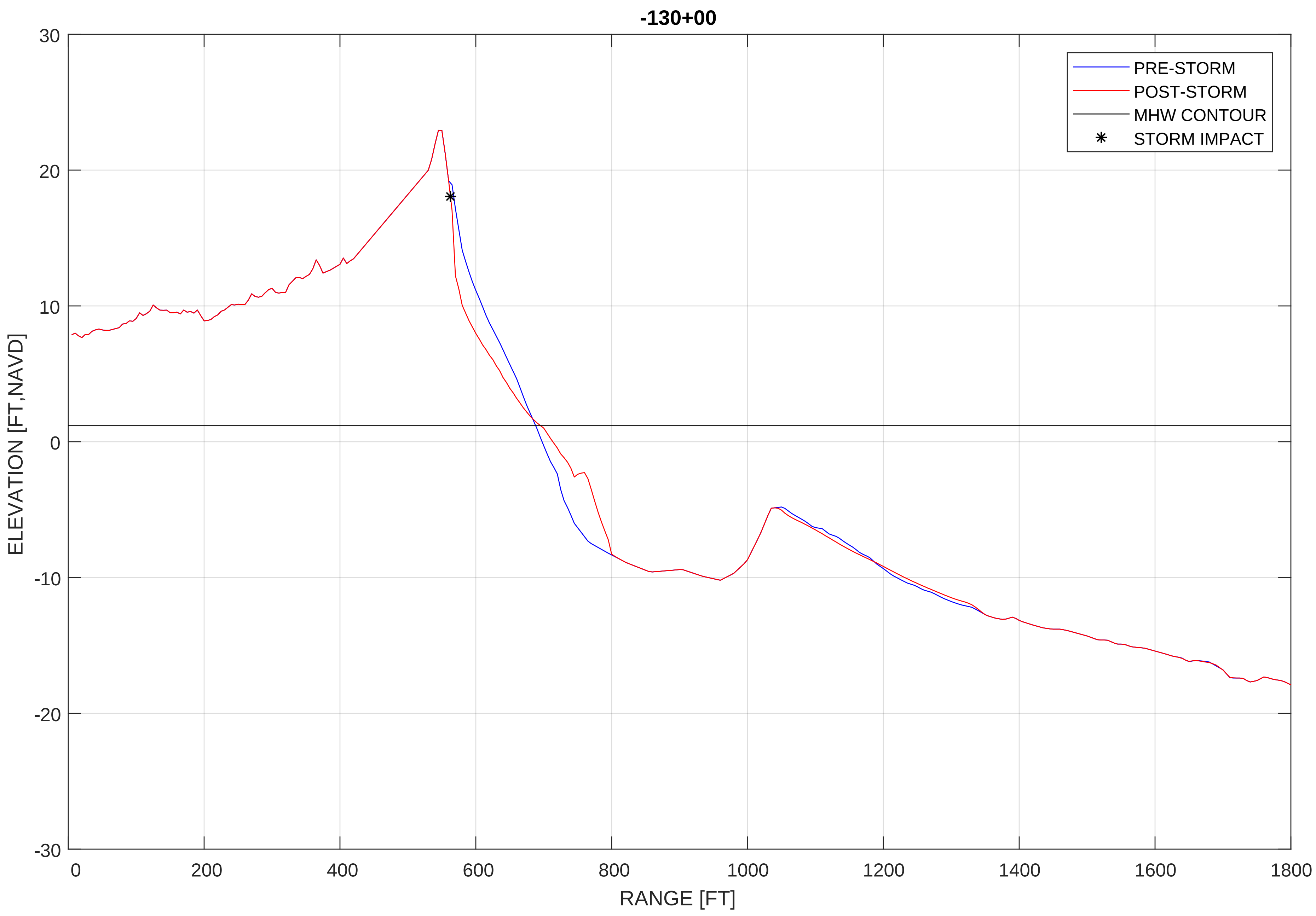

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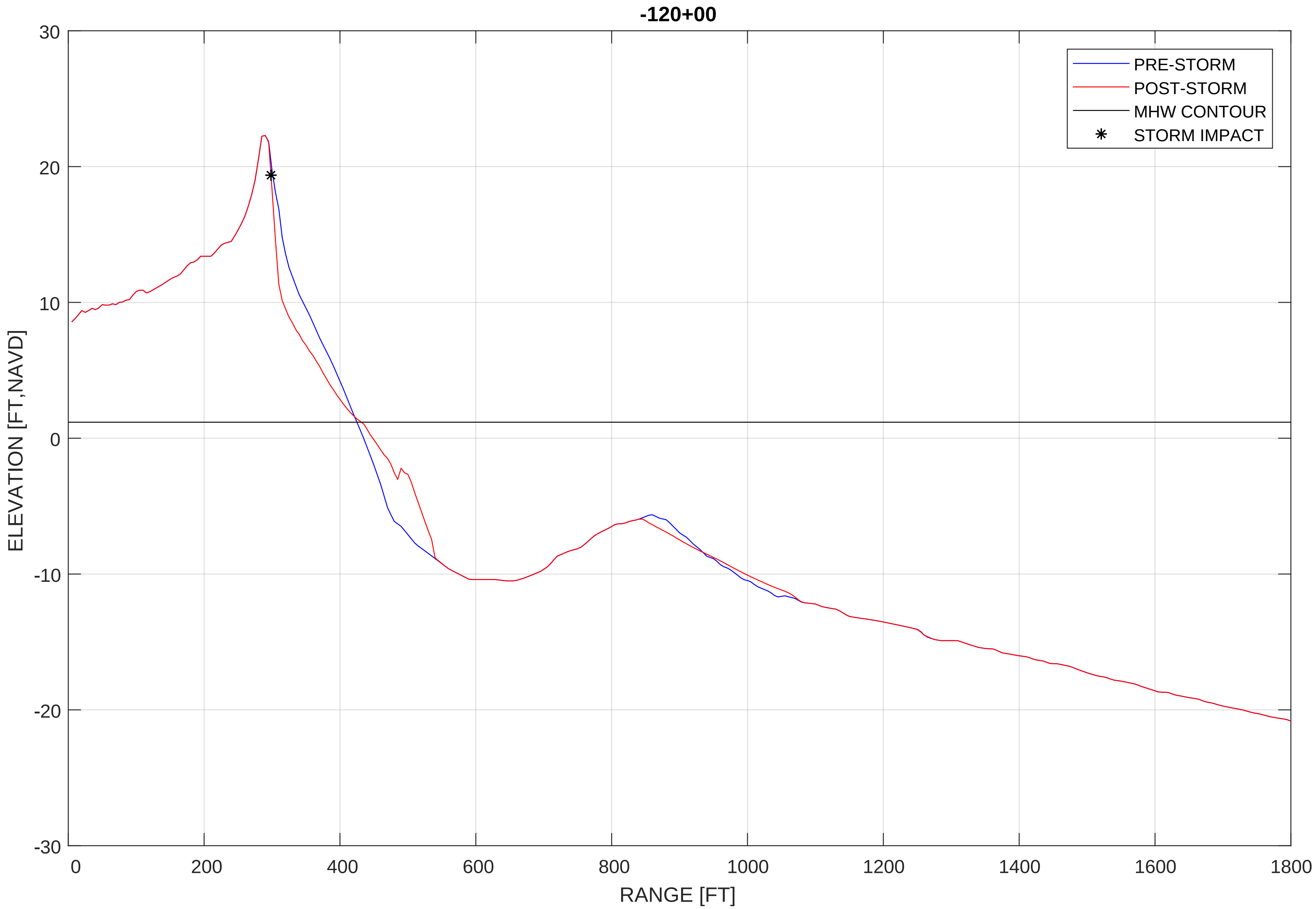
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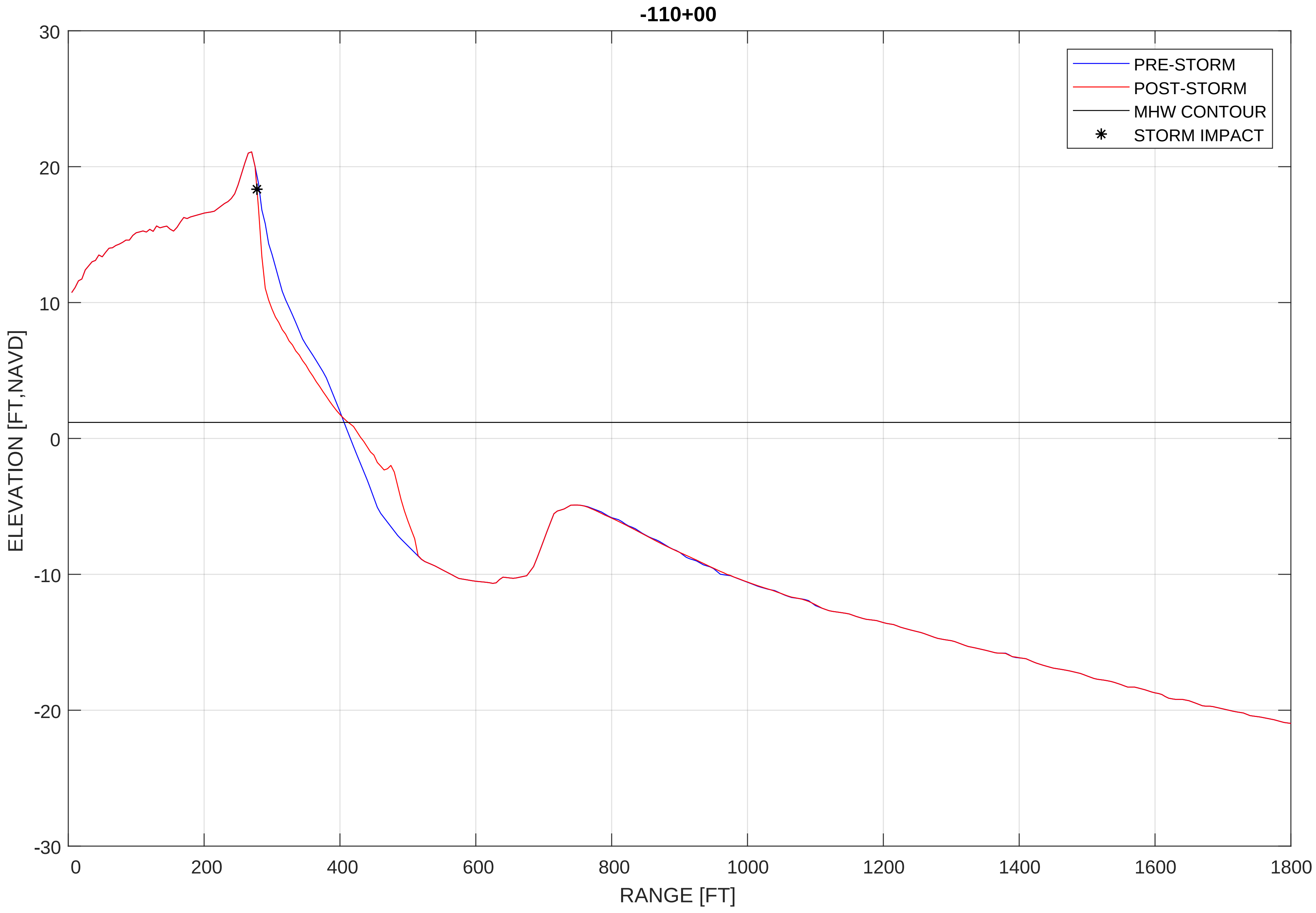

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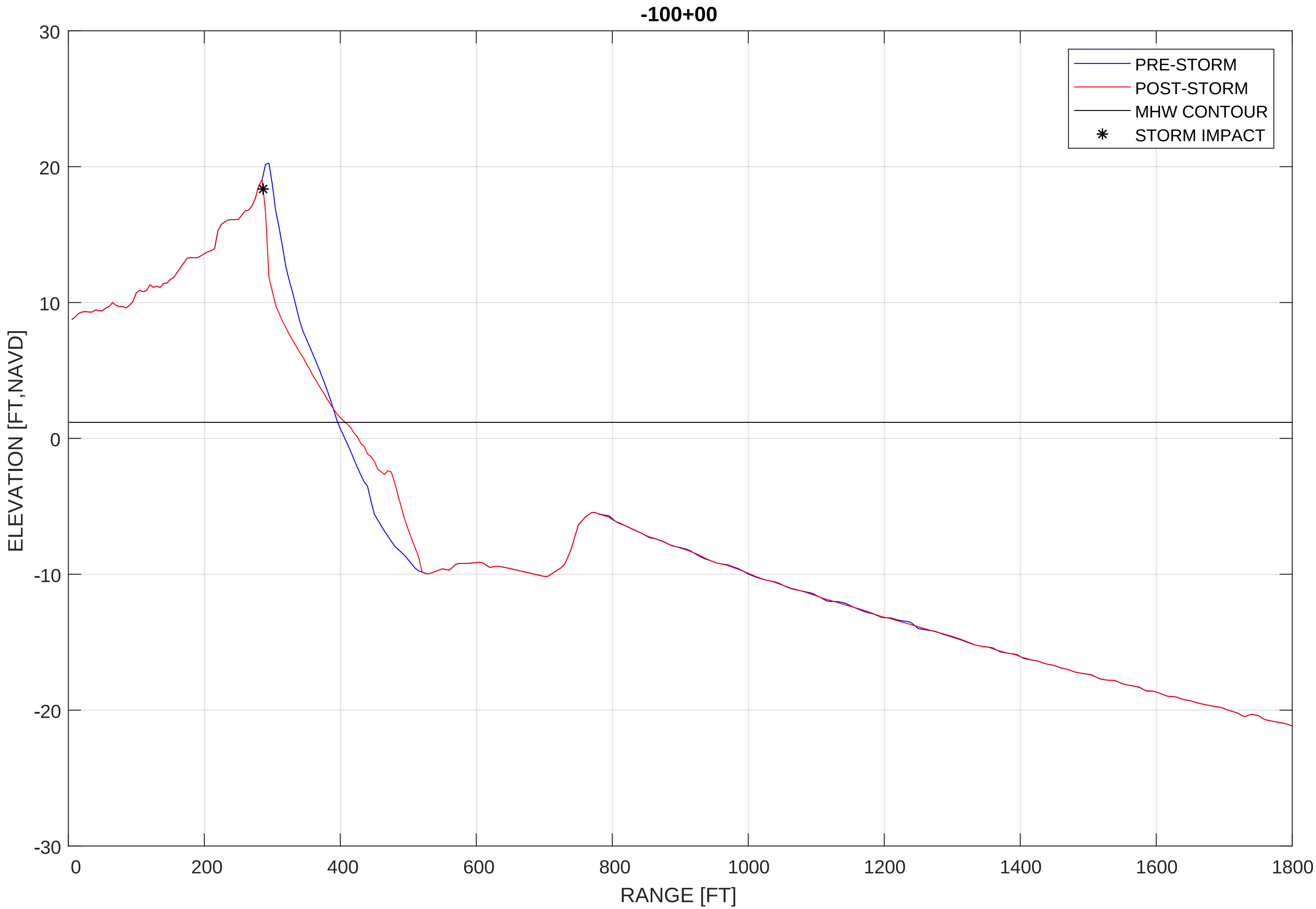

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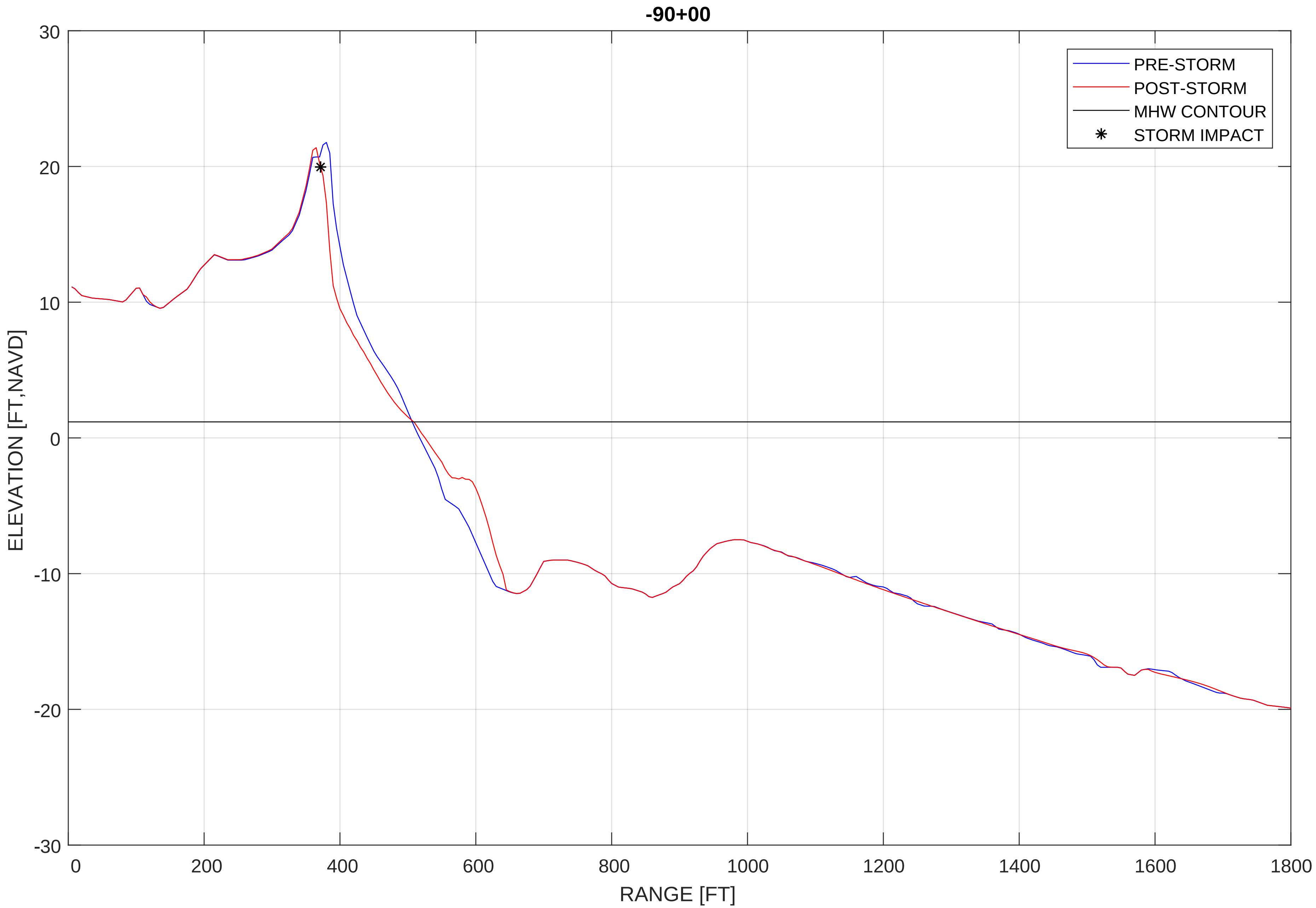

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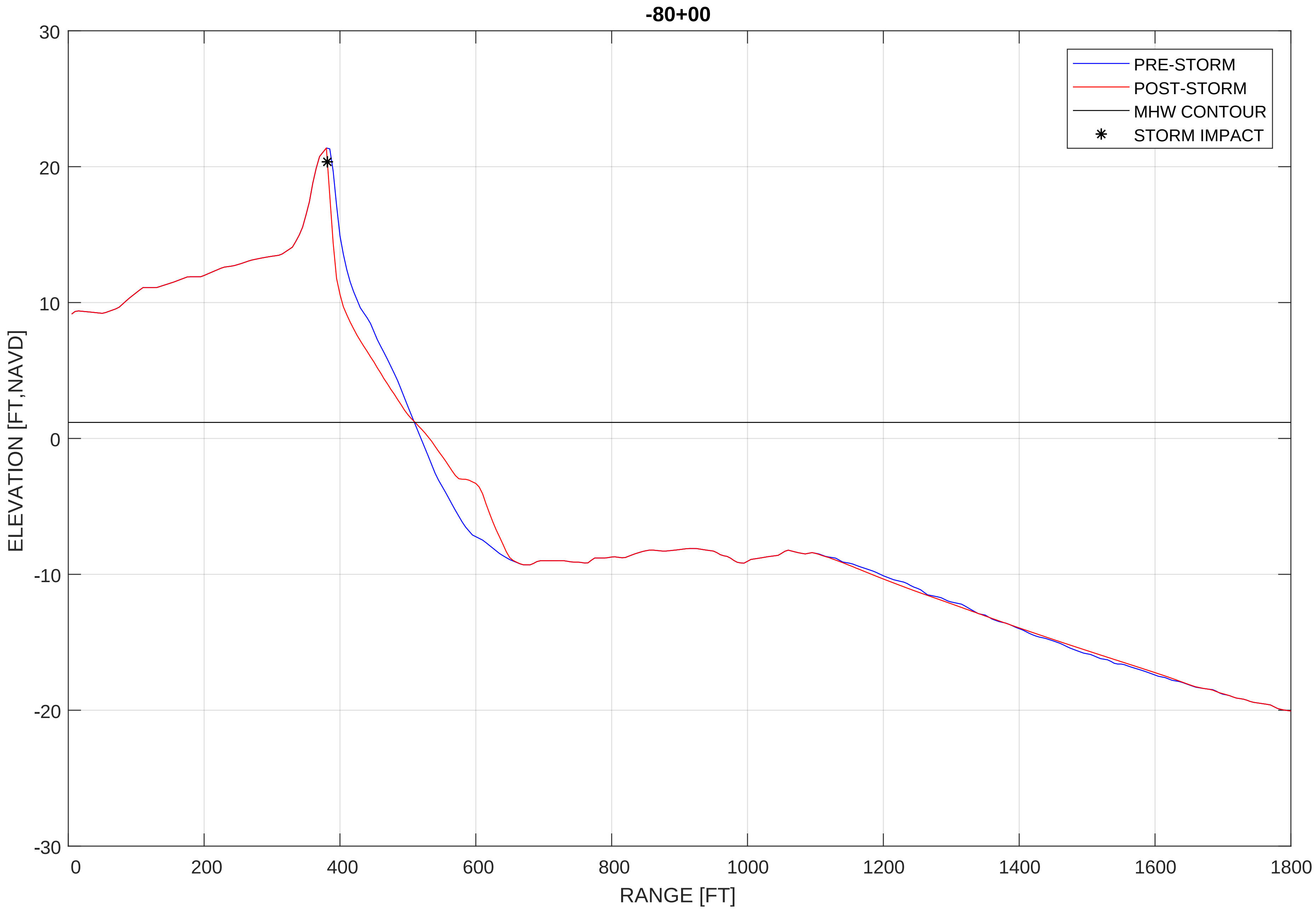
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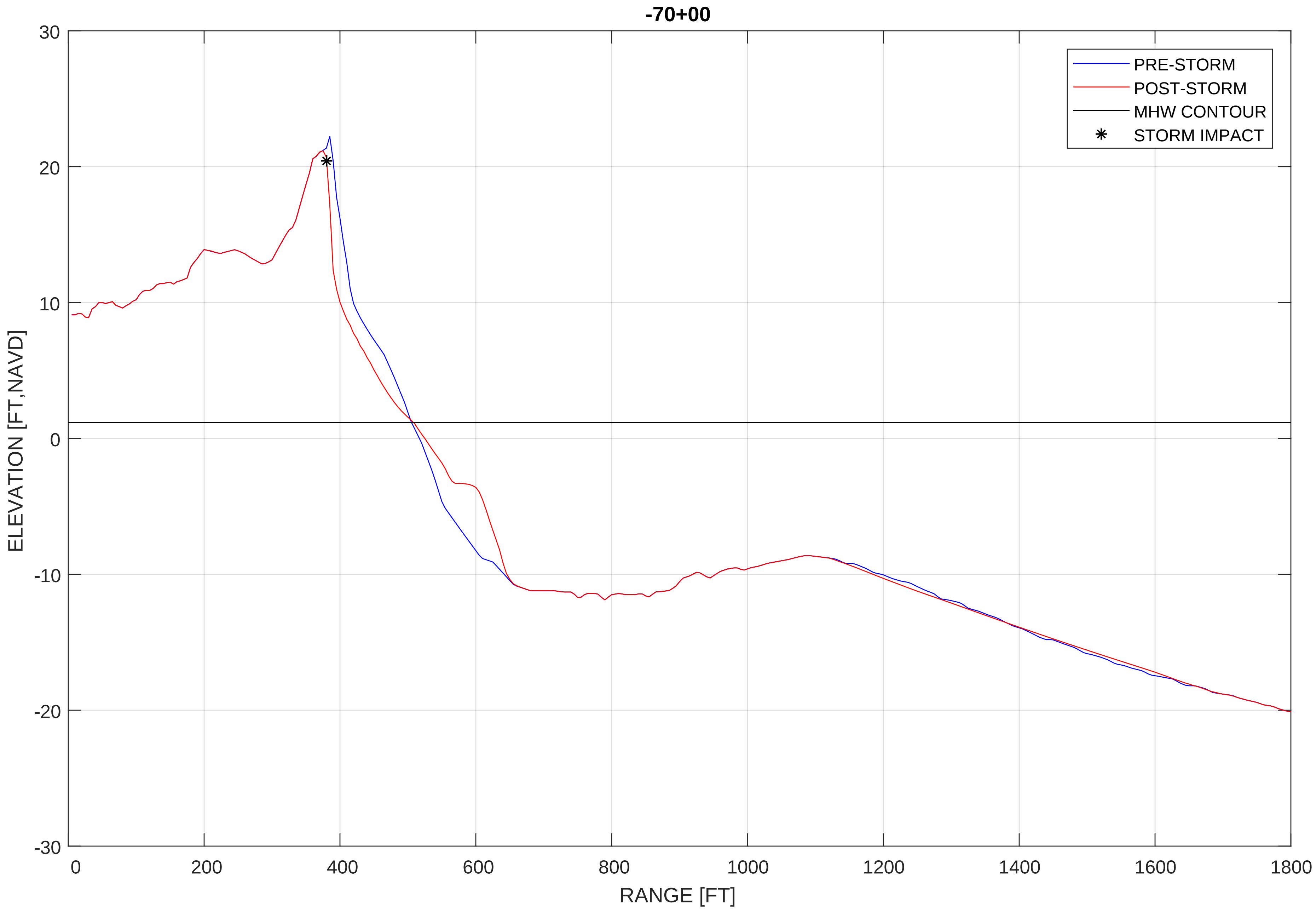

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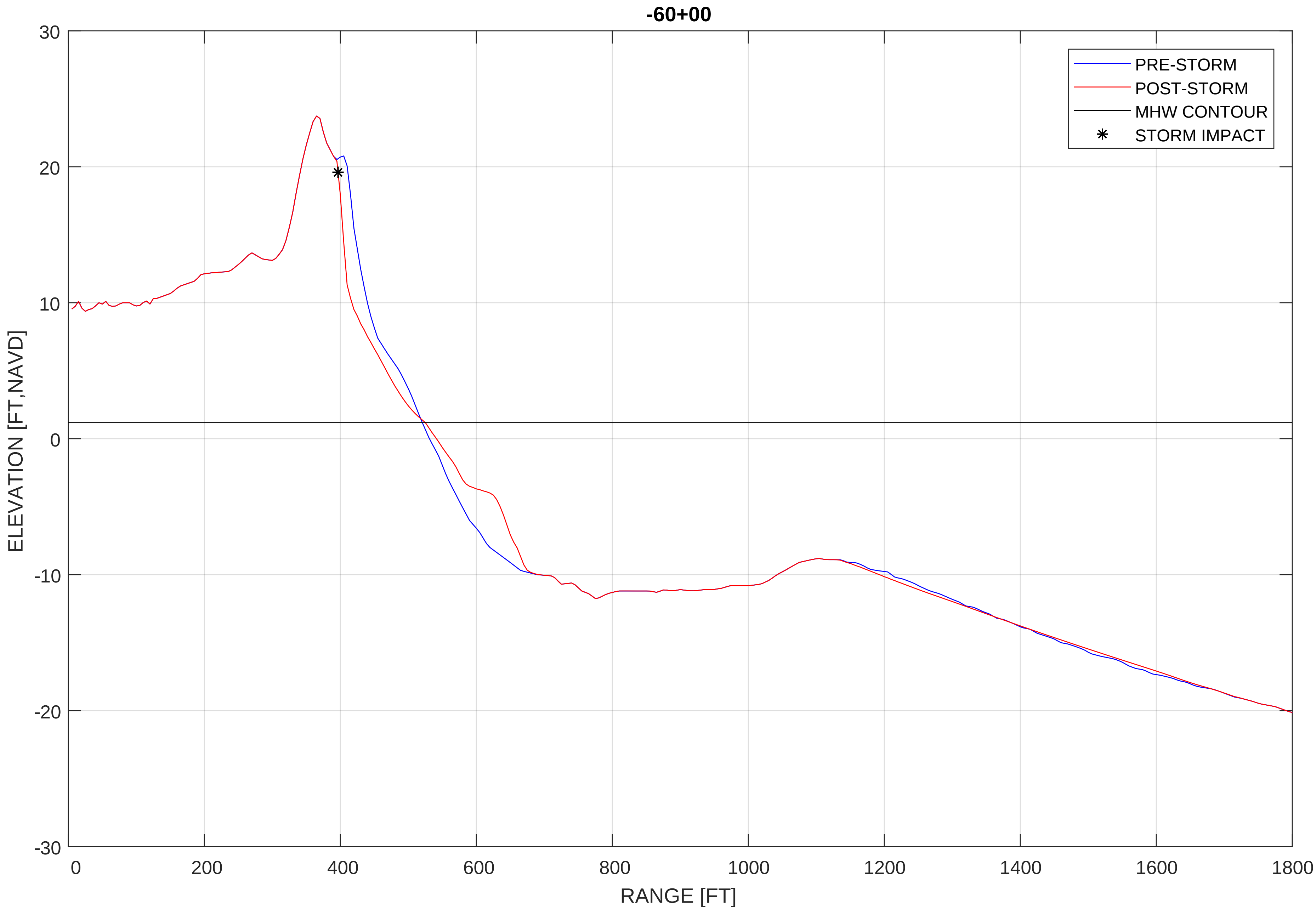

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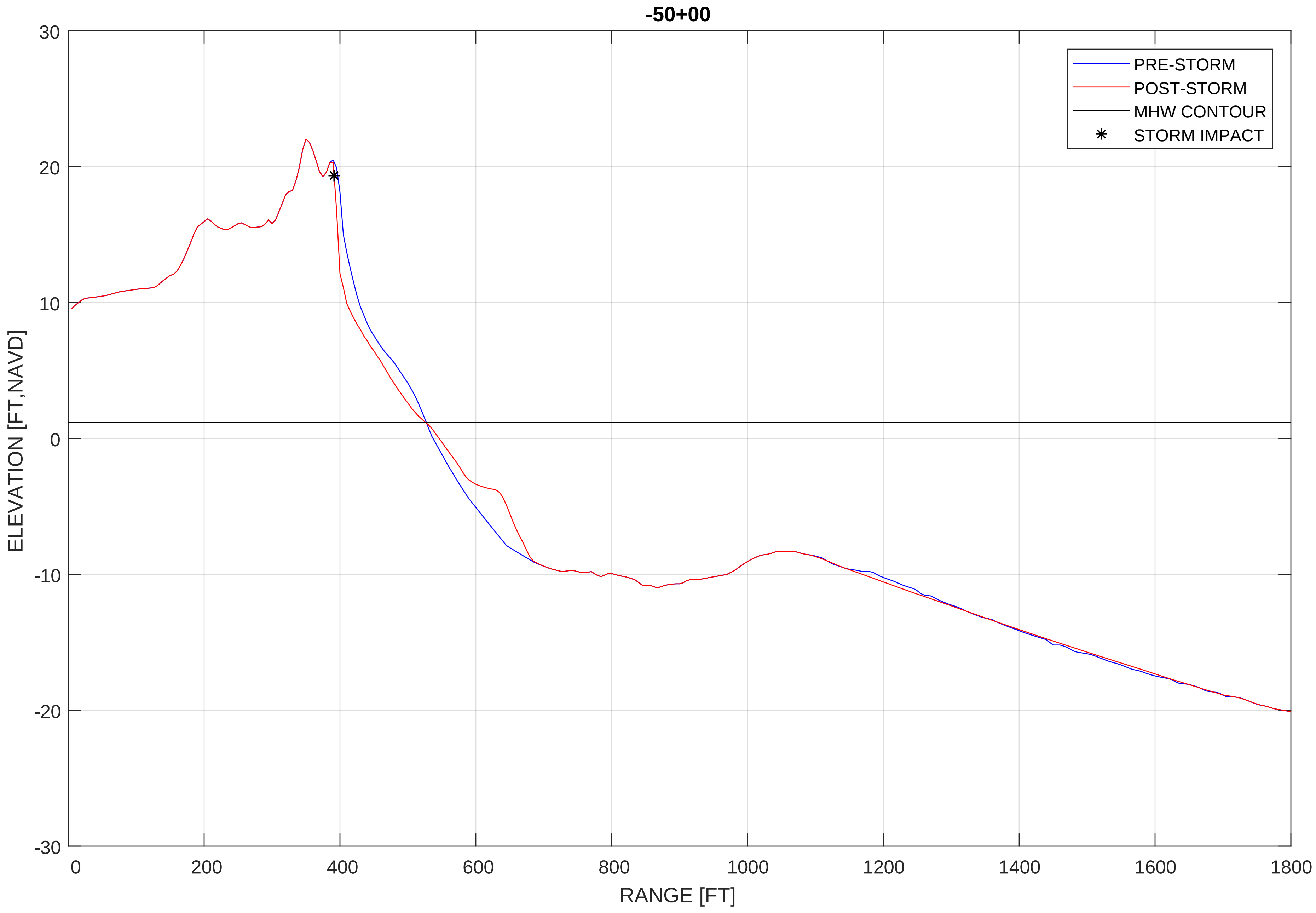

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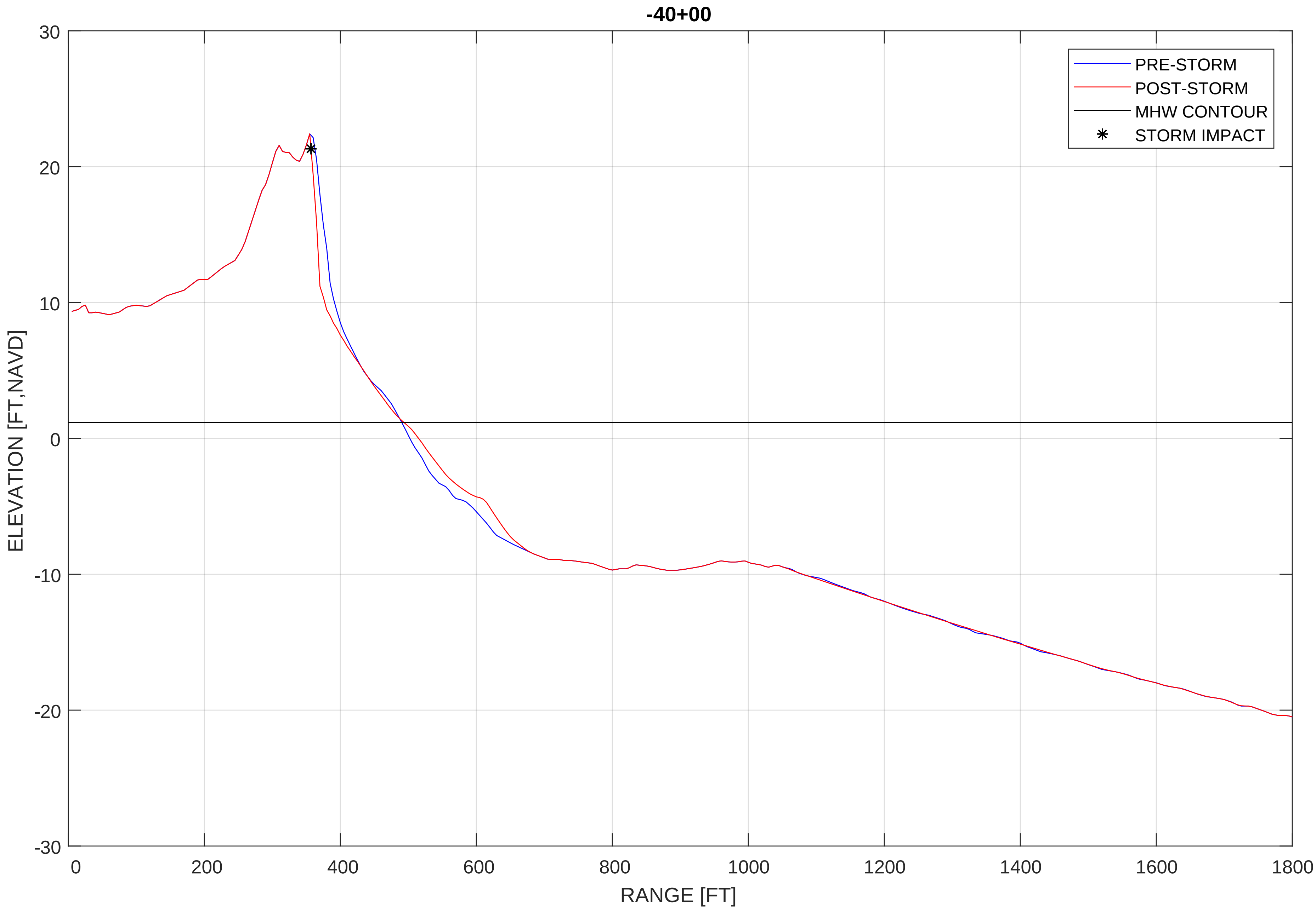

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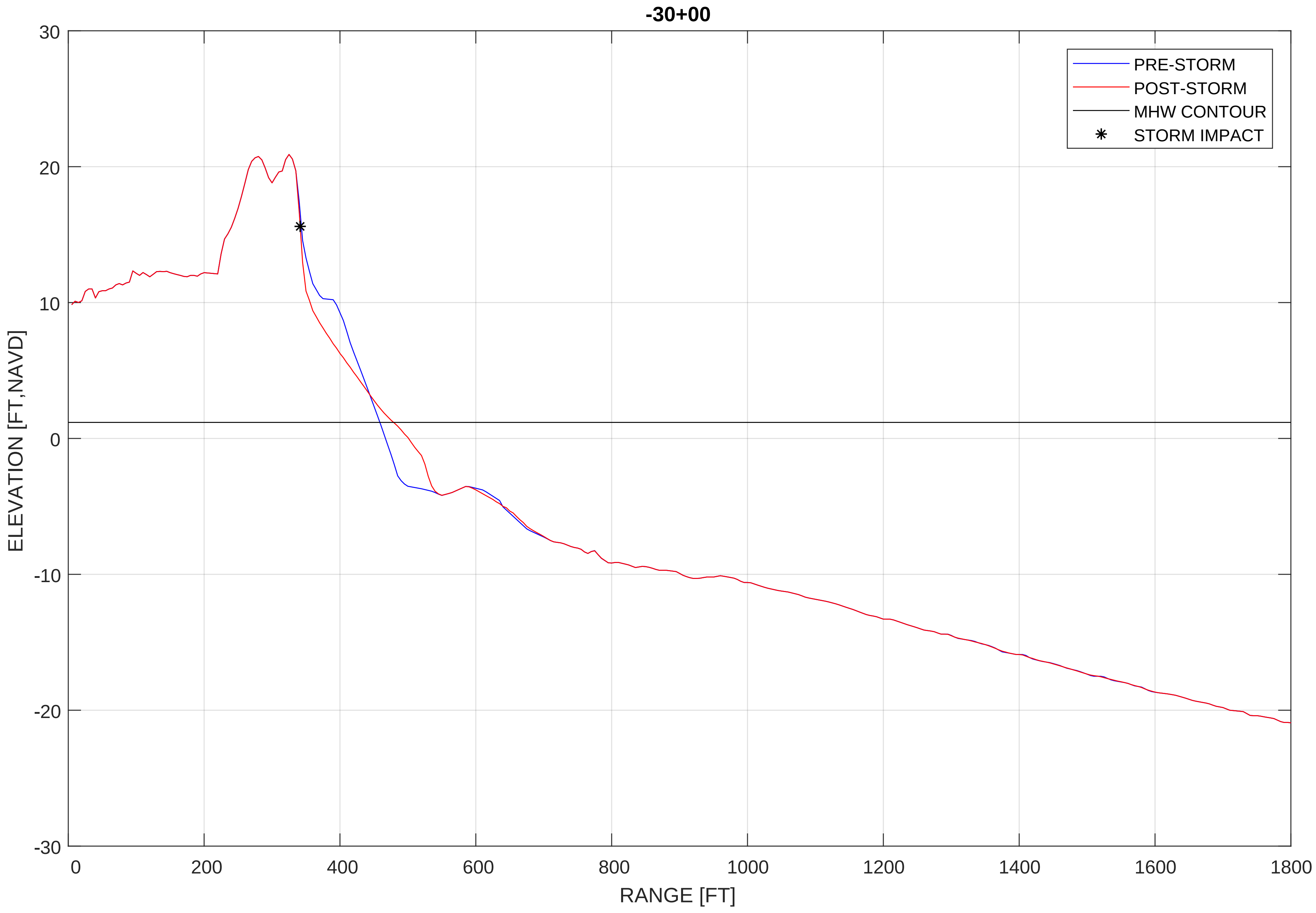
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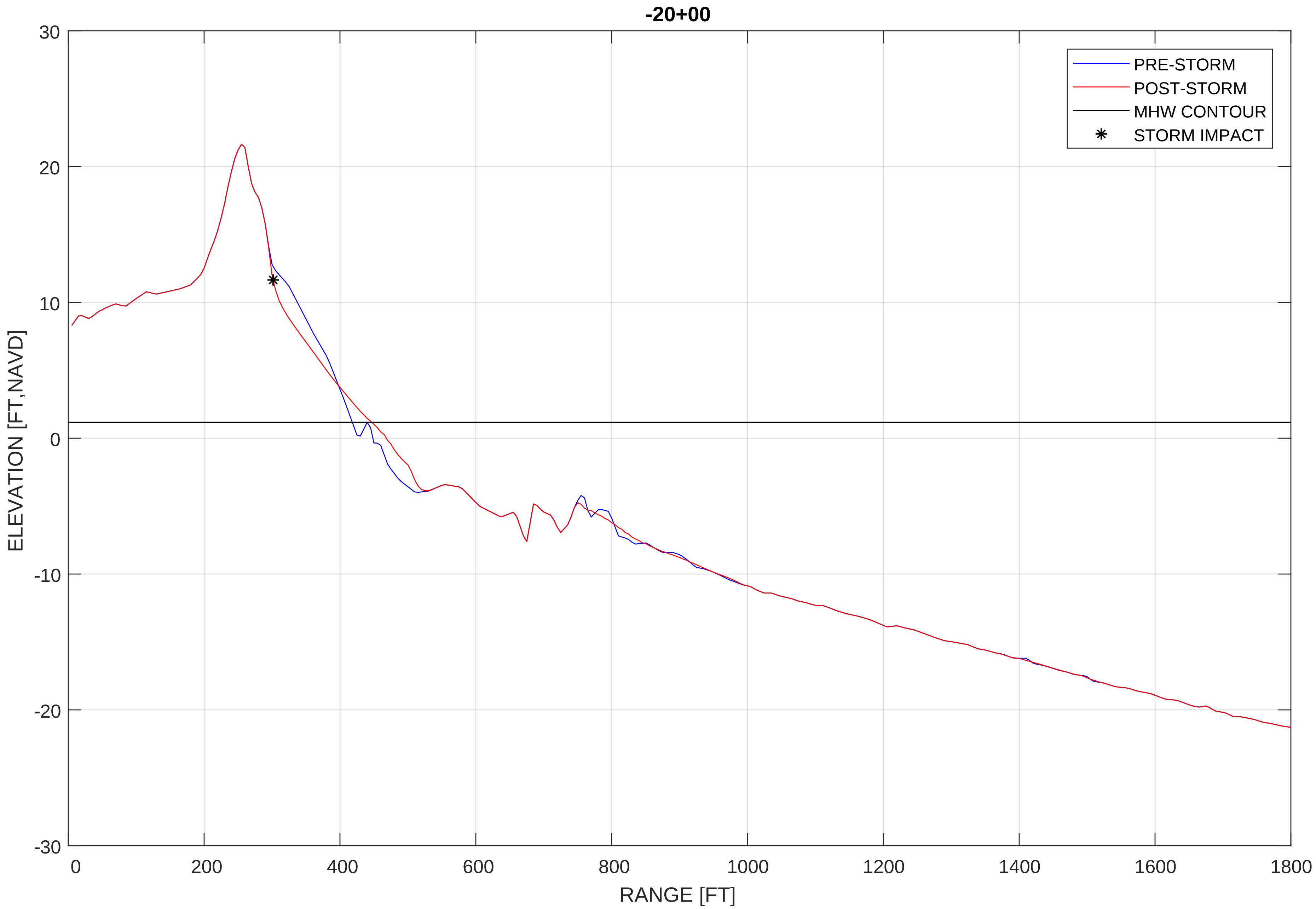
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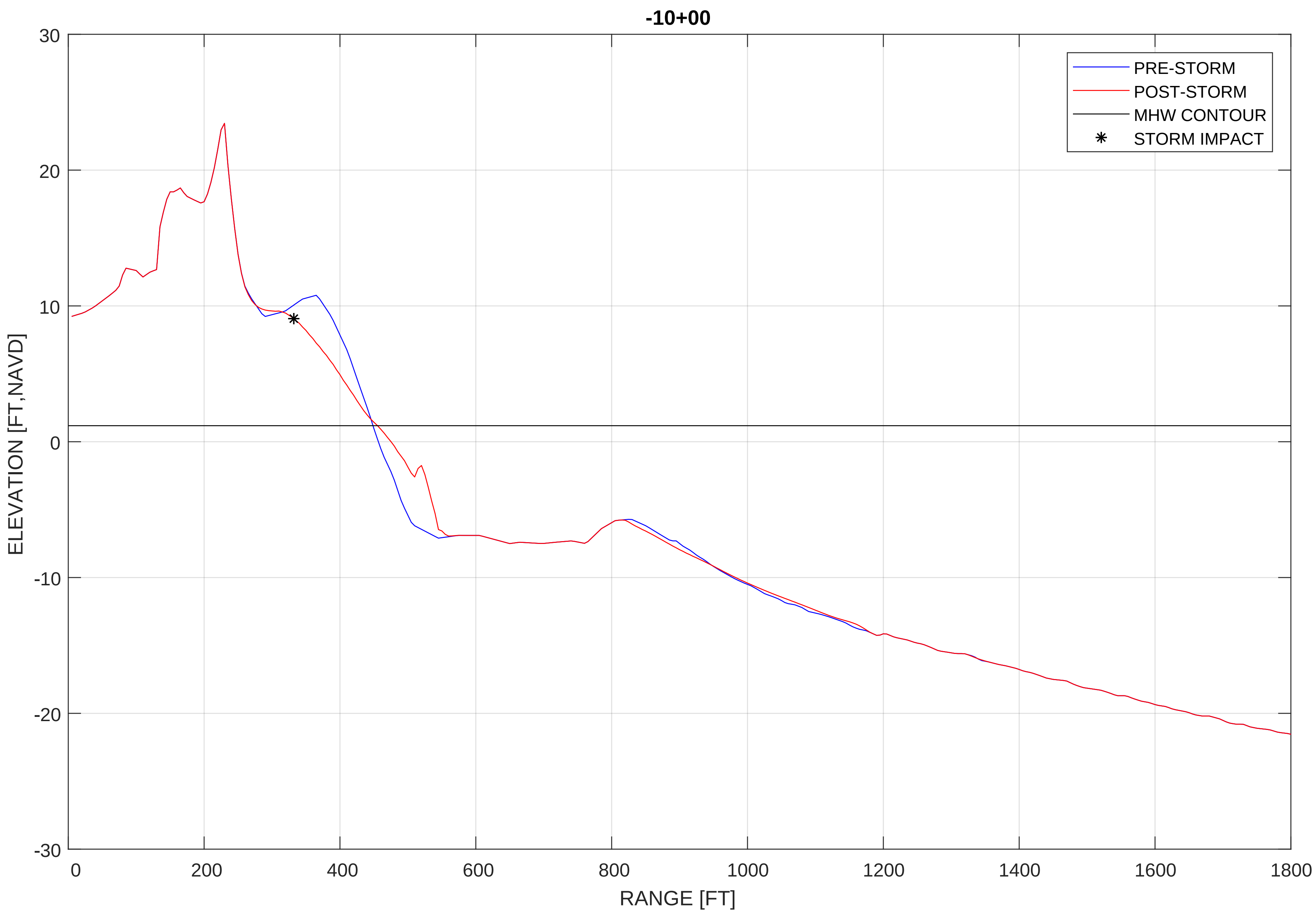

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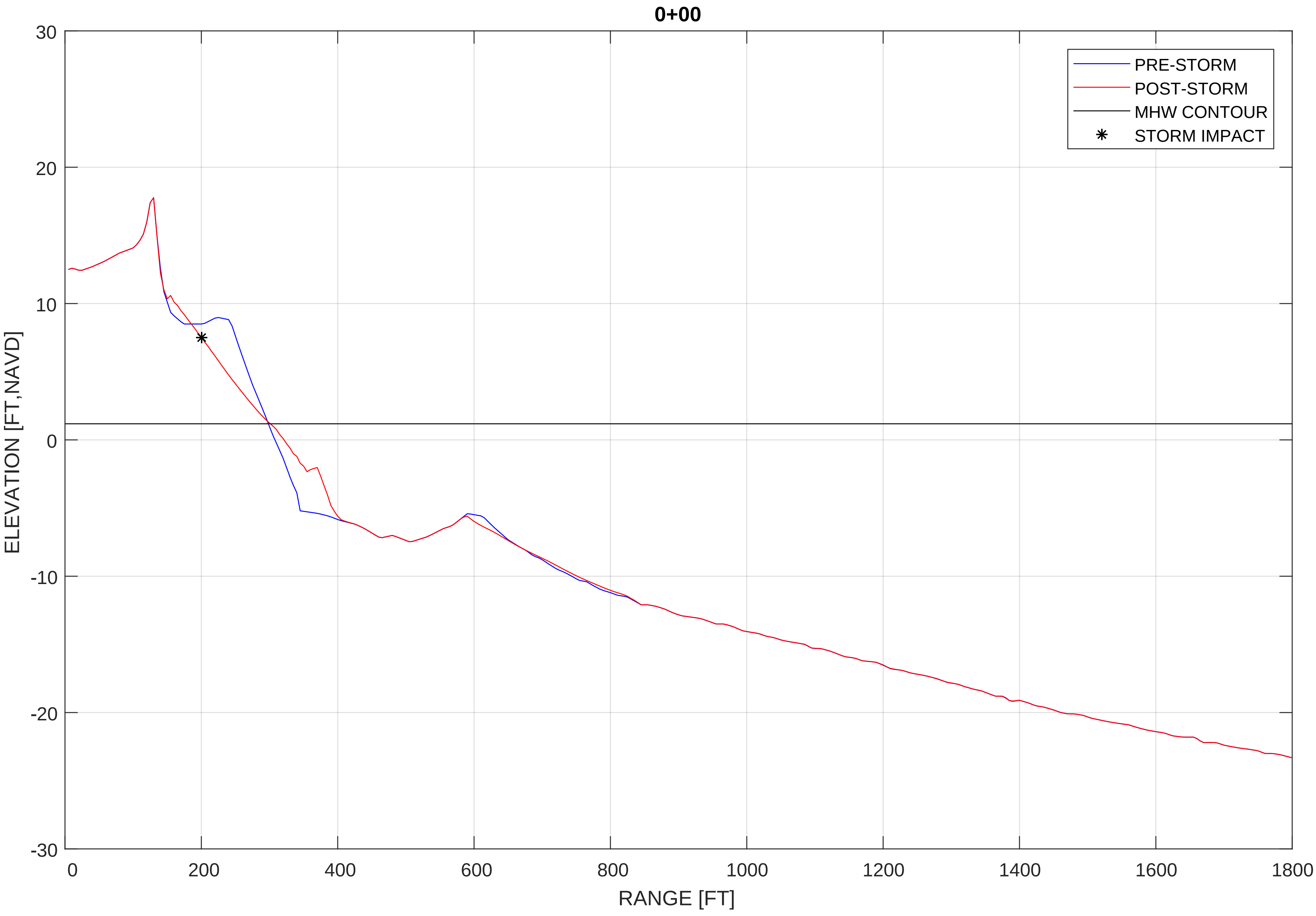

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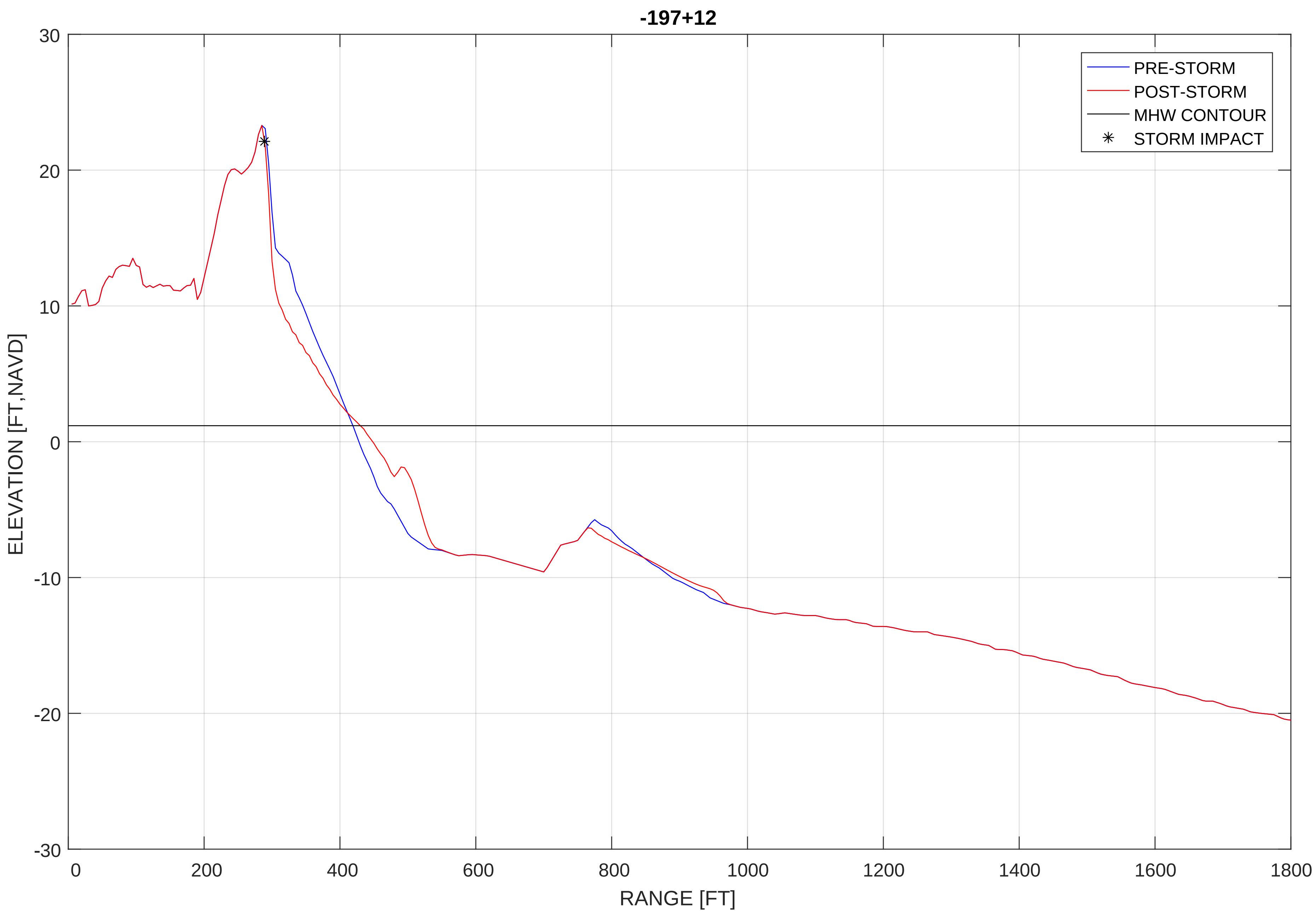
PRE-STORM AND POST-STORM SBEACH PROFILE CROSS SECTIONS
Scenario 3 (Isabel Storm with 2018 Sea Level)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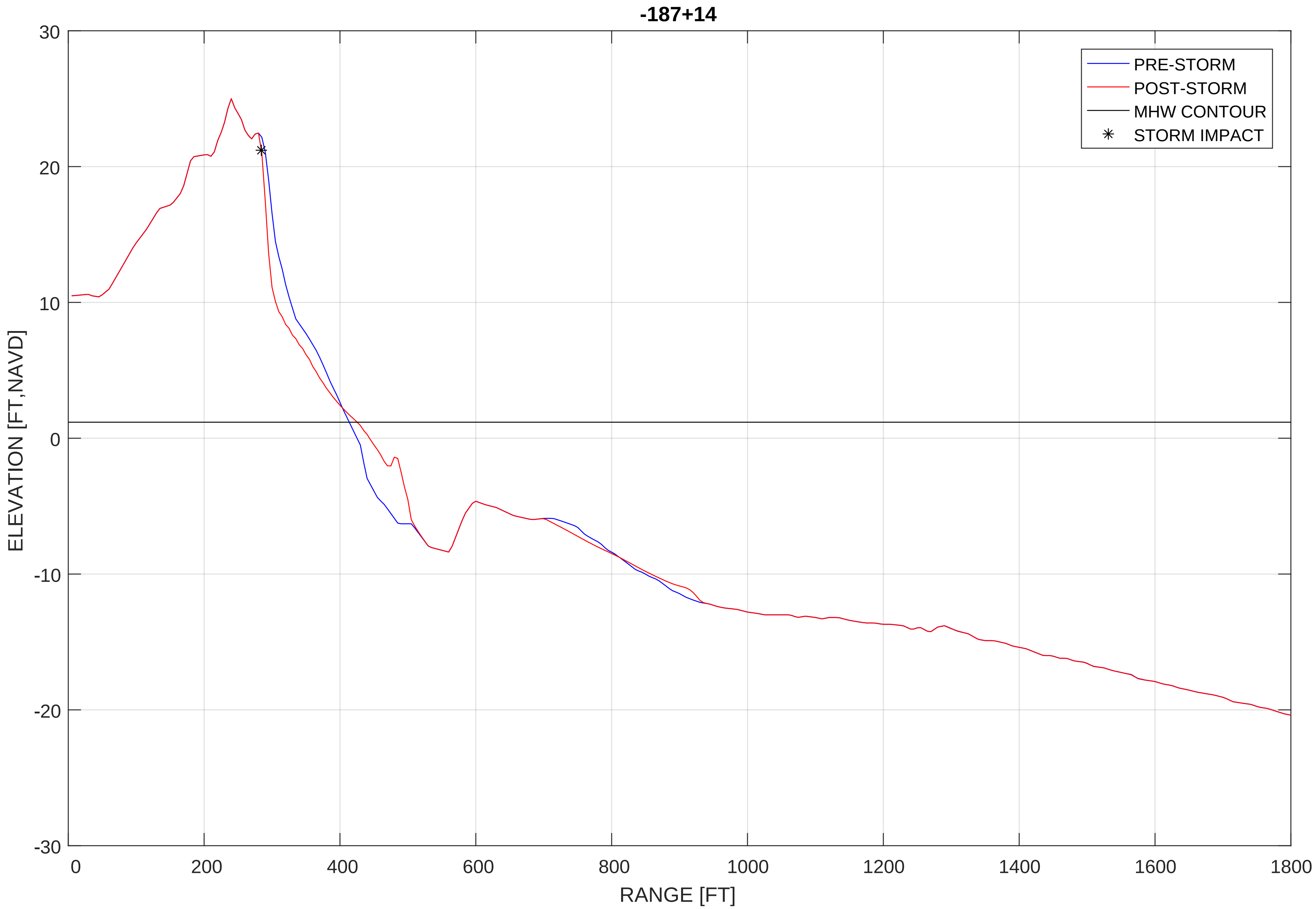

-187+14
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
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-20
-30
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1000
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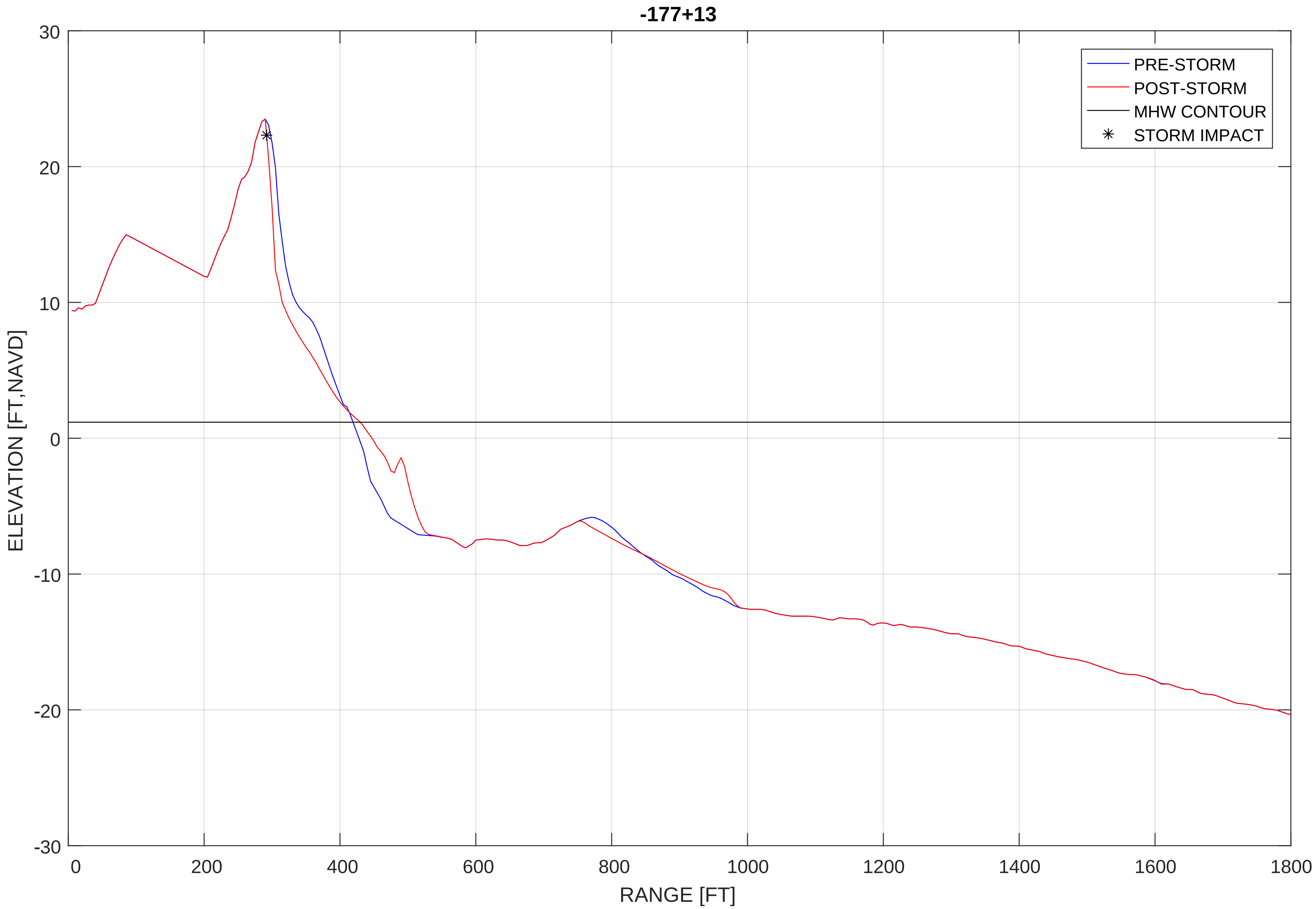
1400
1600
1800
RANGE [FT]


-177+13
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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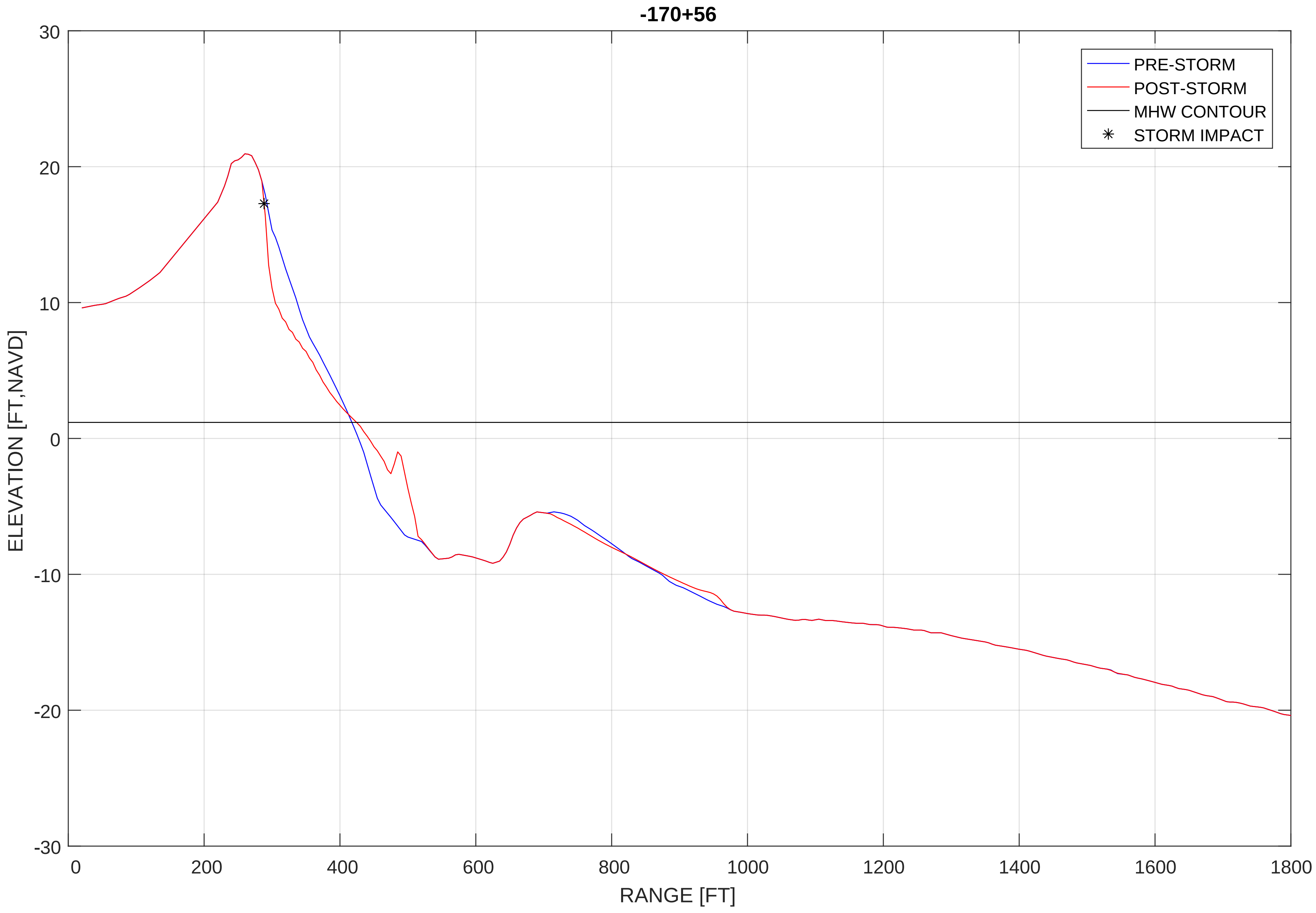
-170+56
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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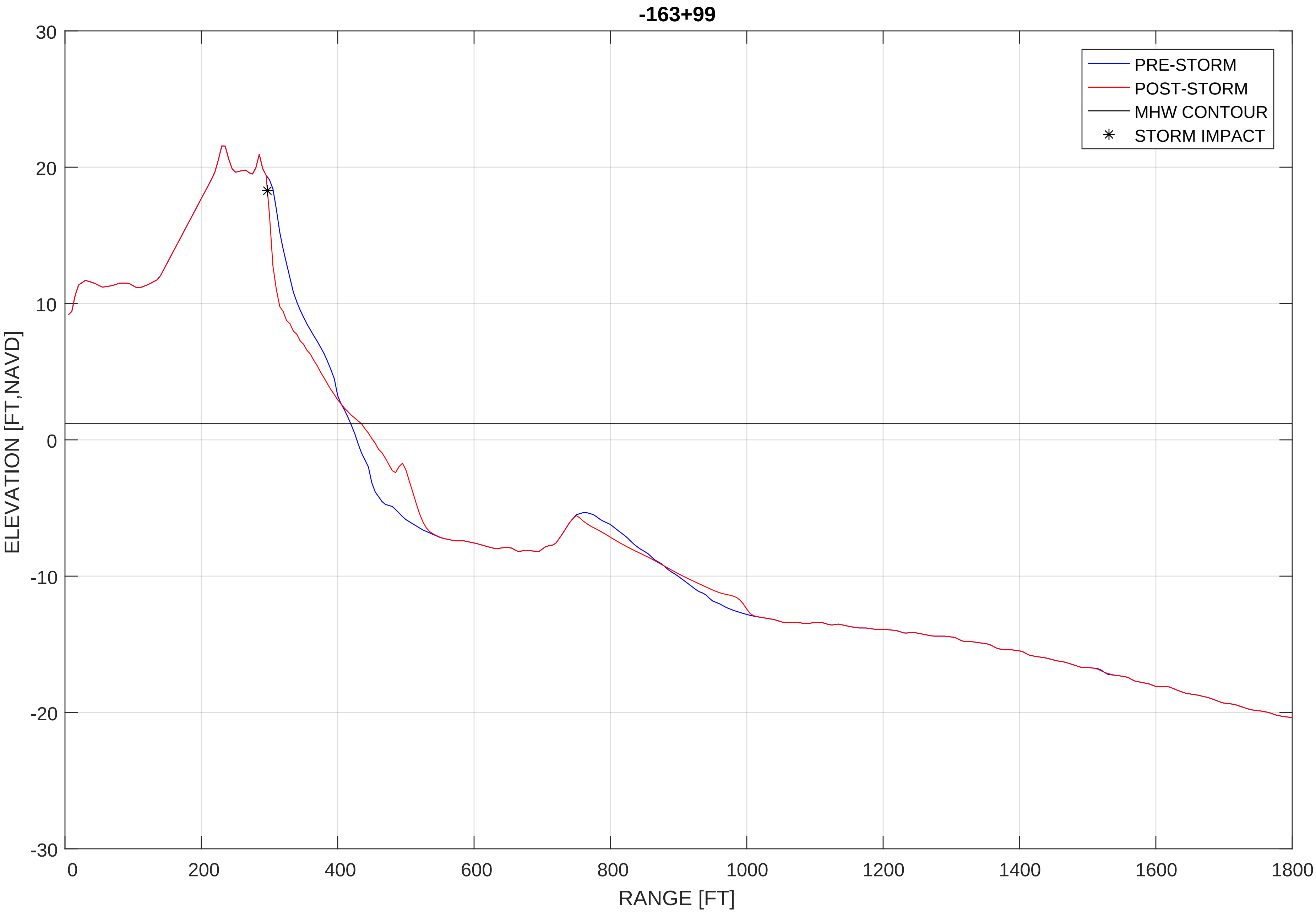

-163+99
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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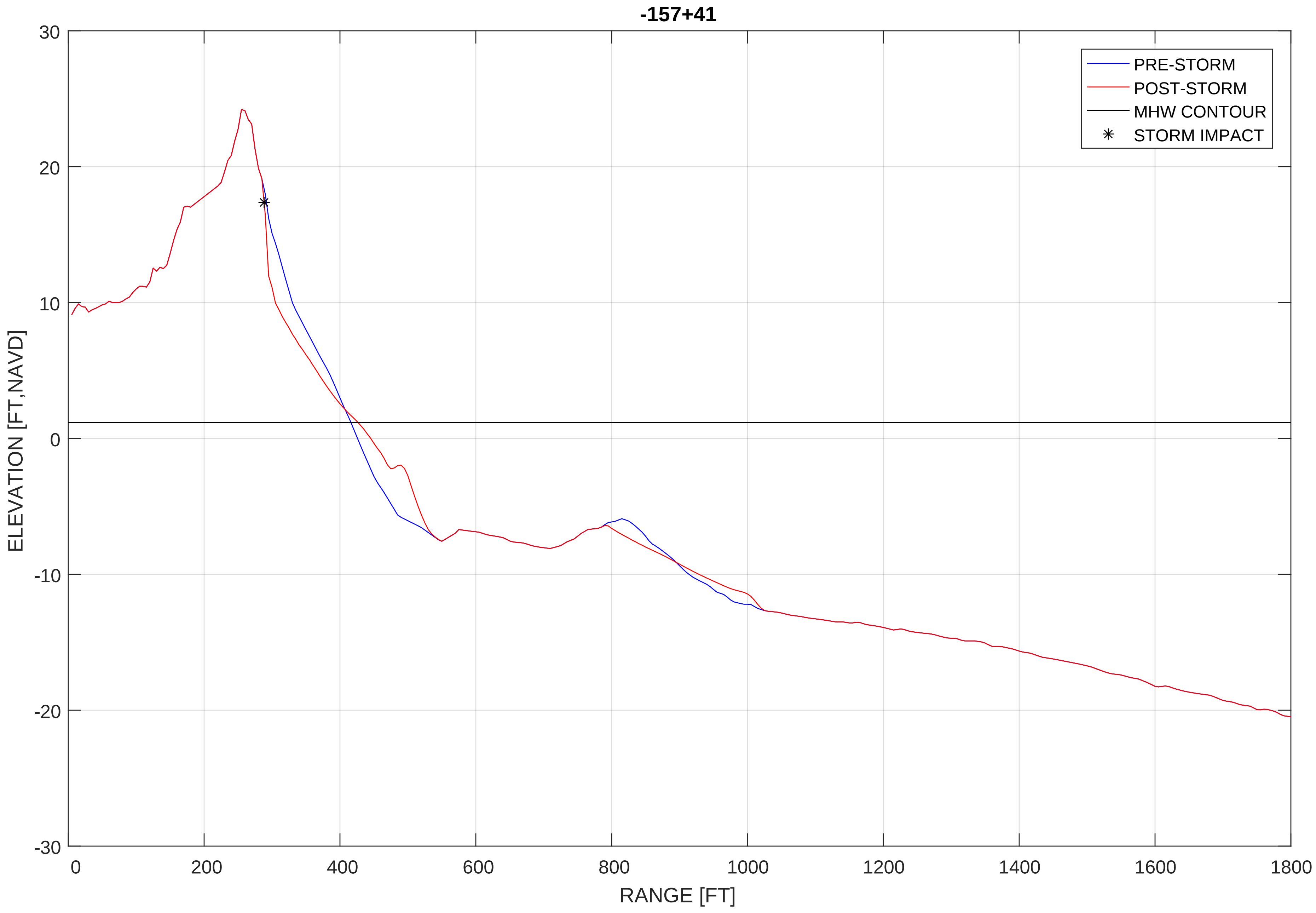

-157+41
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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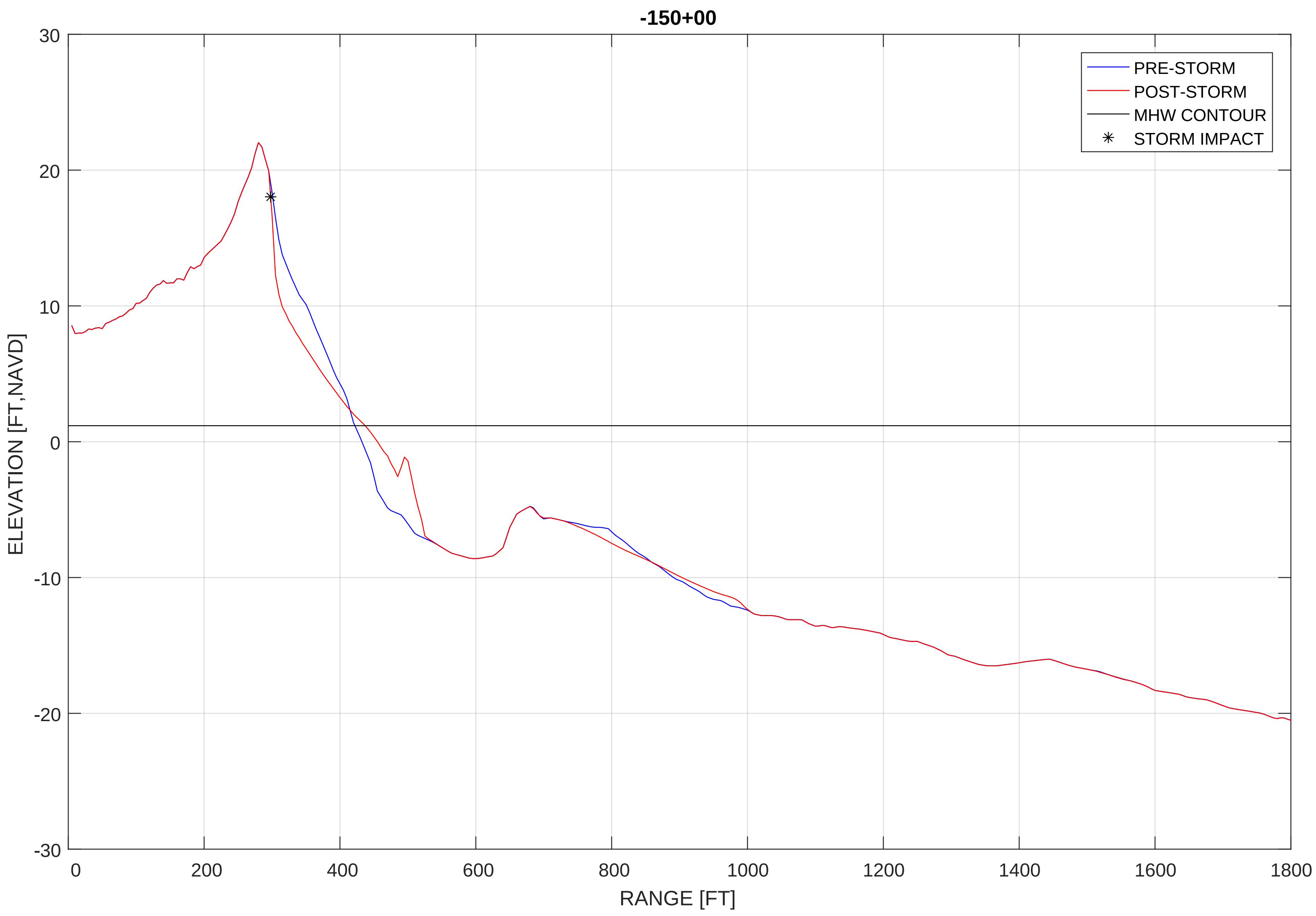

-150+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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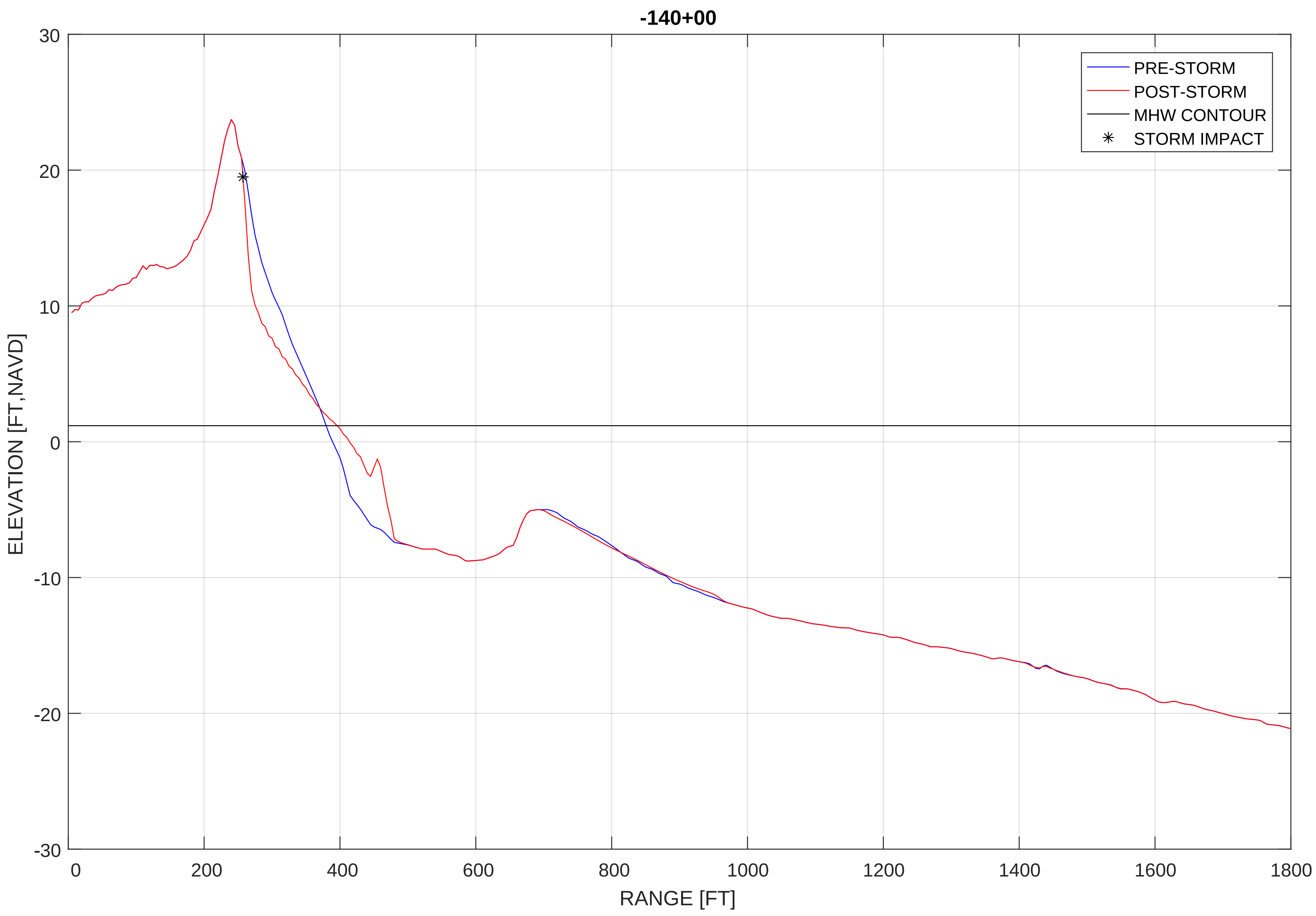

-140+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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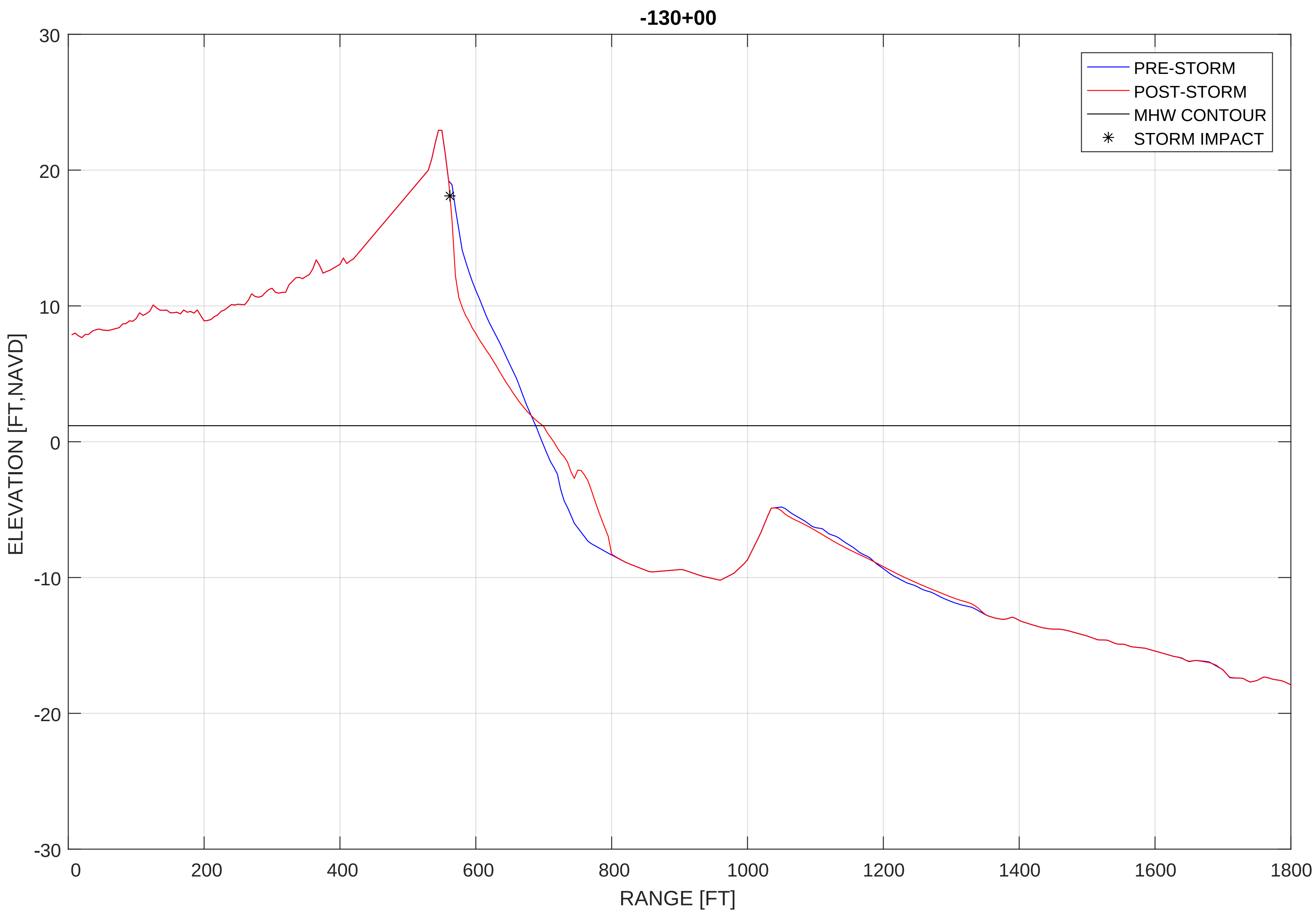

-130+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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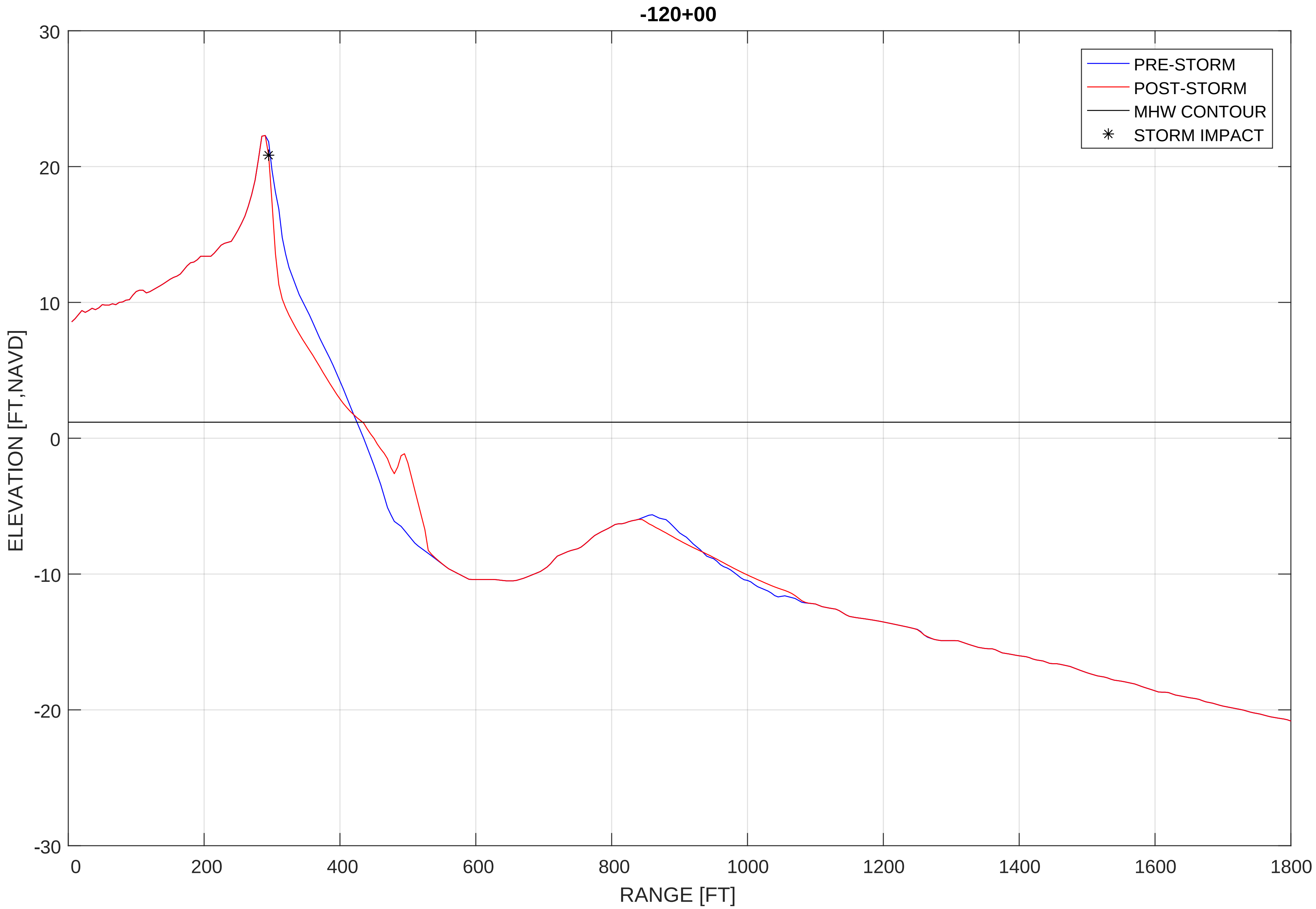

-120+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
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ELEVATION [FT,NAVD]
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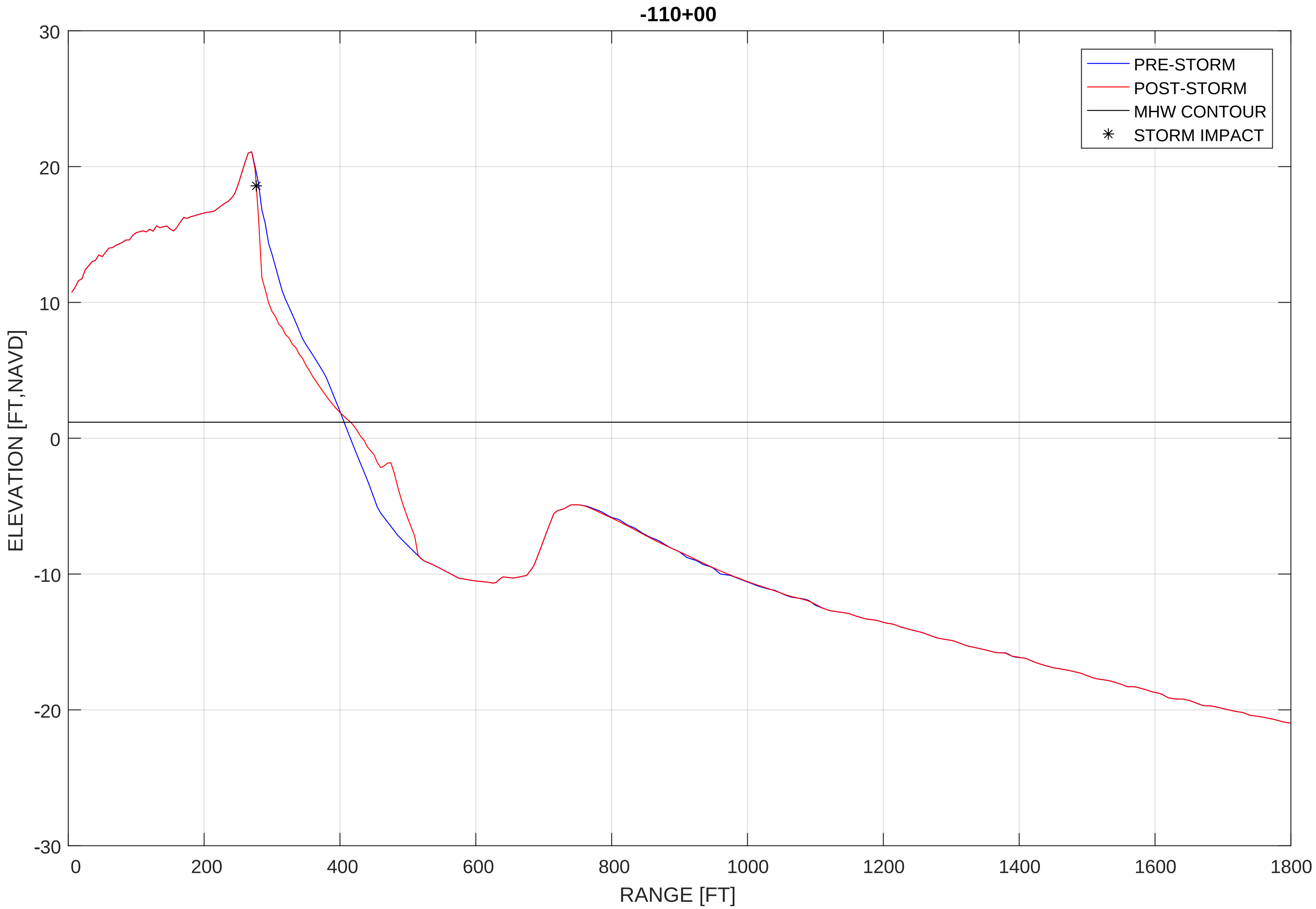
RANGE [FT]


-110+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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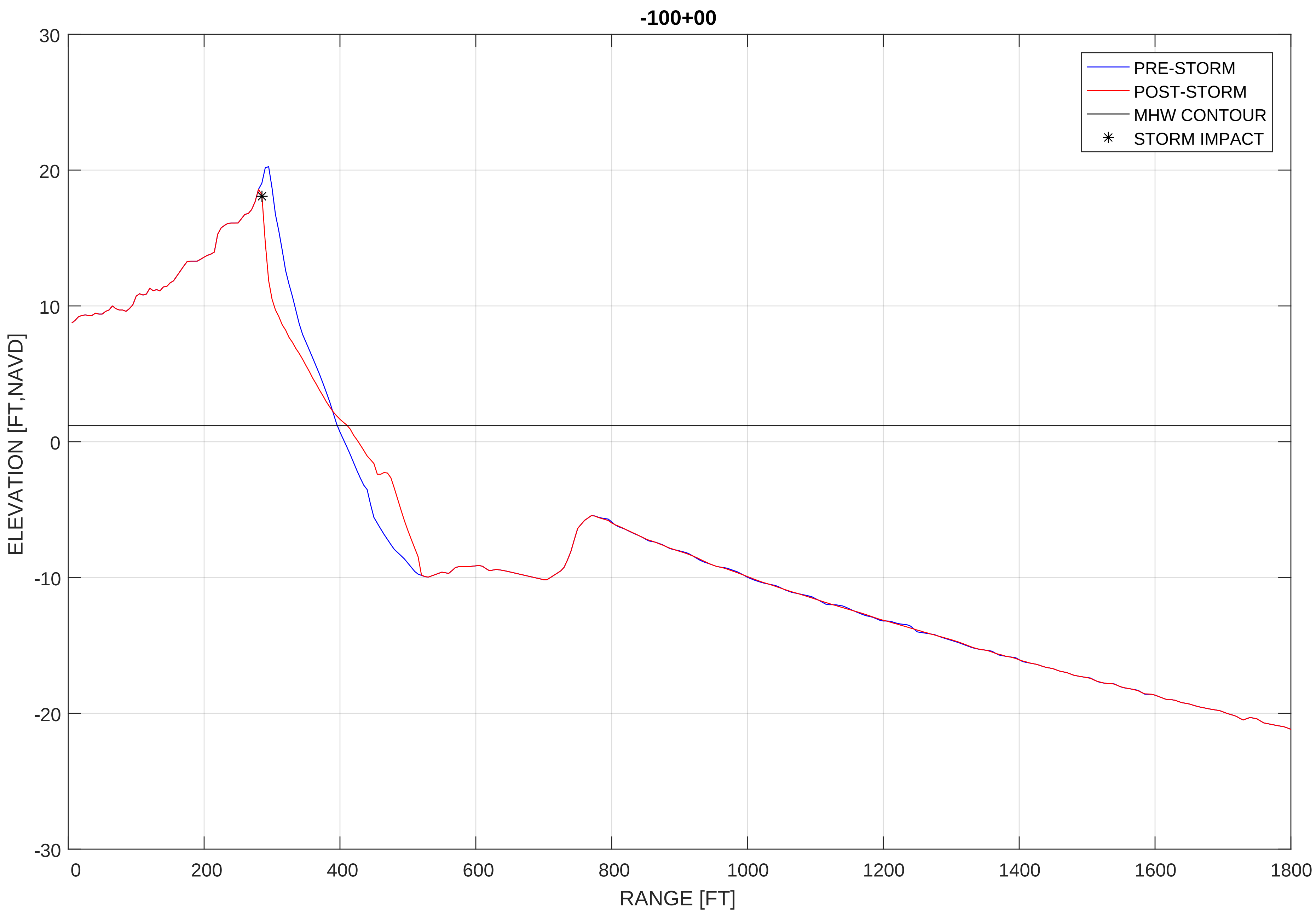
-100+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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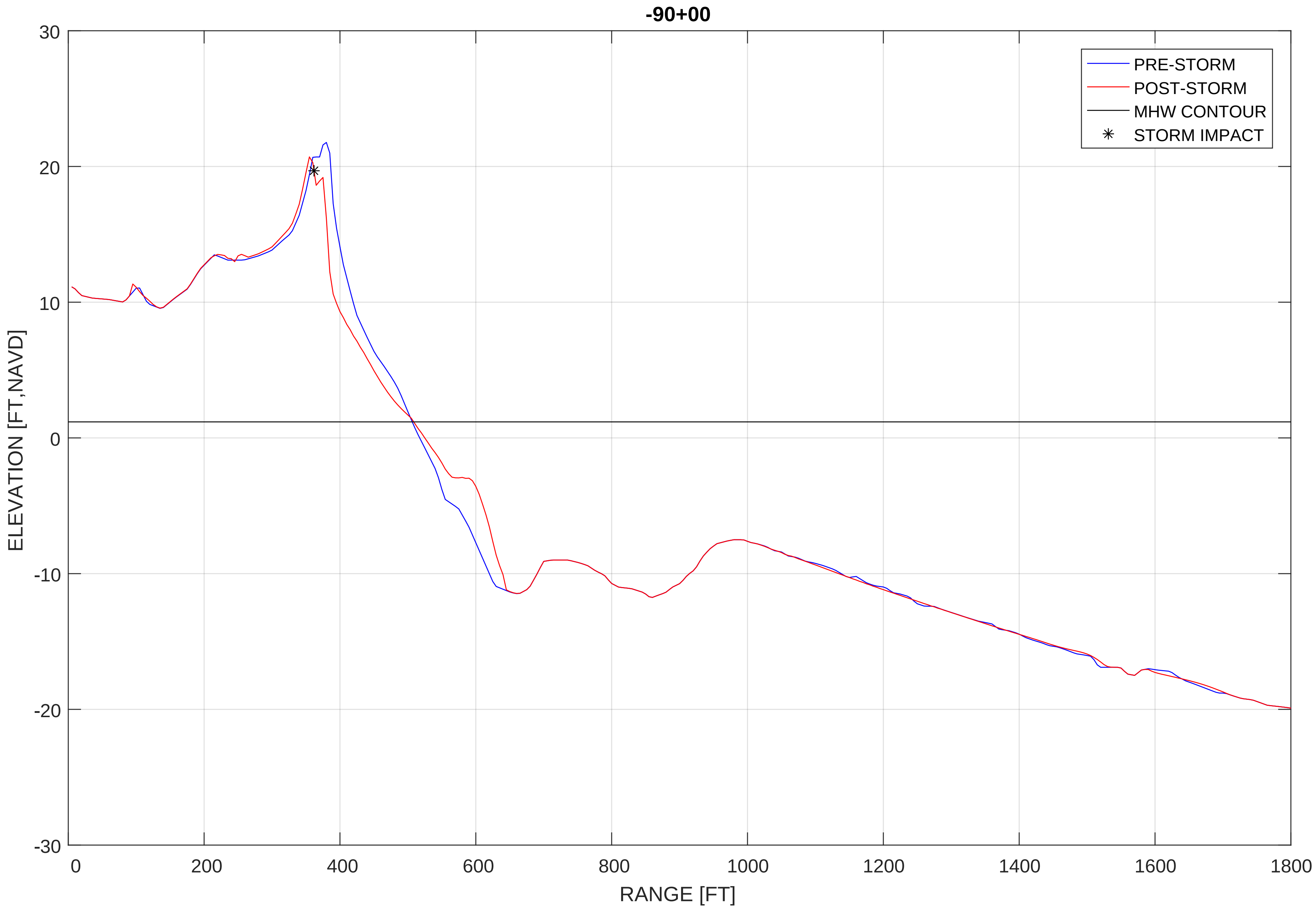
-90+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
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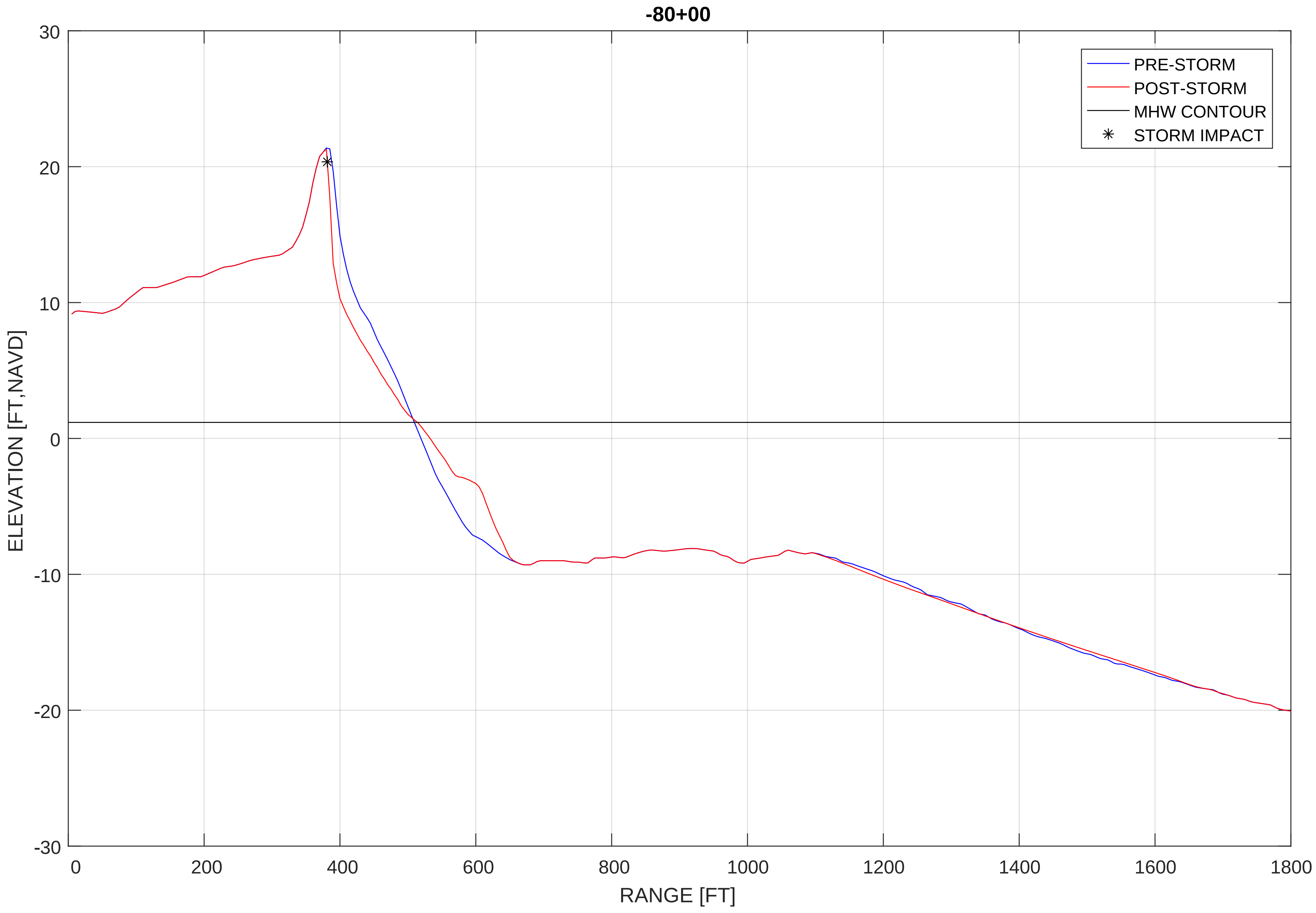
RANGE [FT]



-80+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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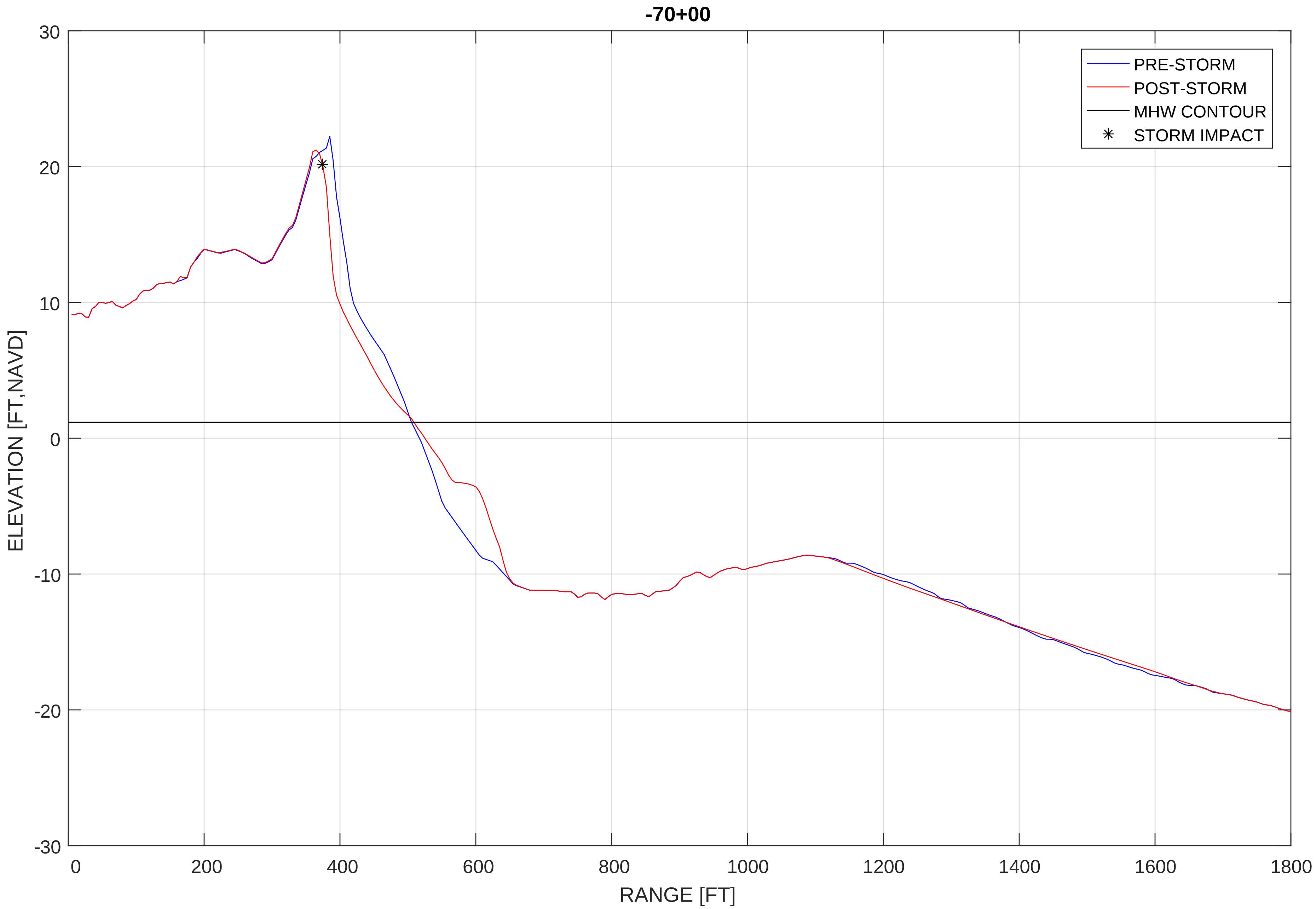

-70+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
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ELEVATION [FT,NAVD]
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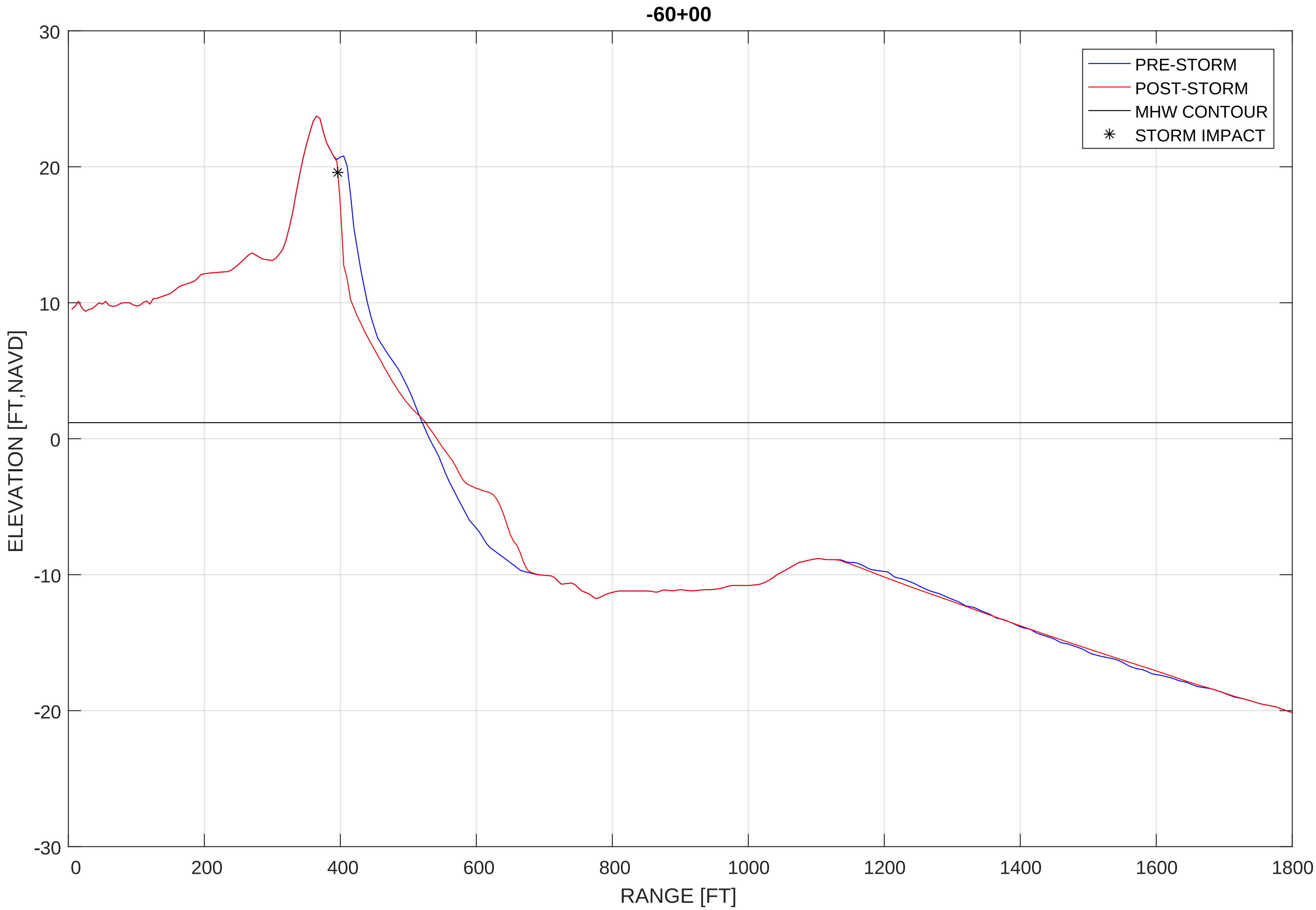
RANGE [FT]


-60+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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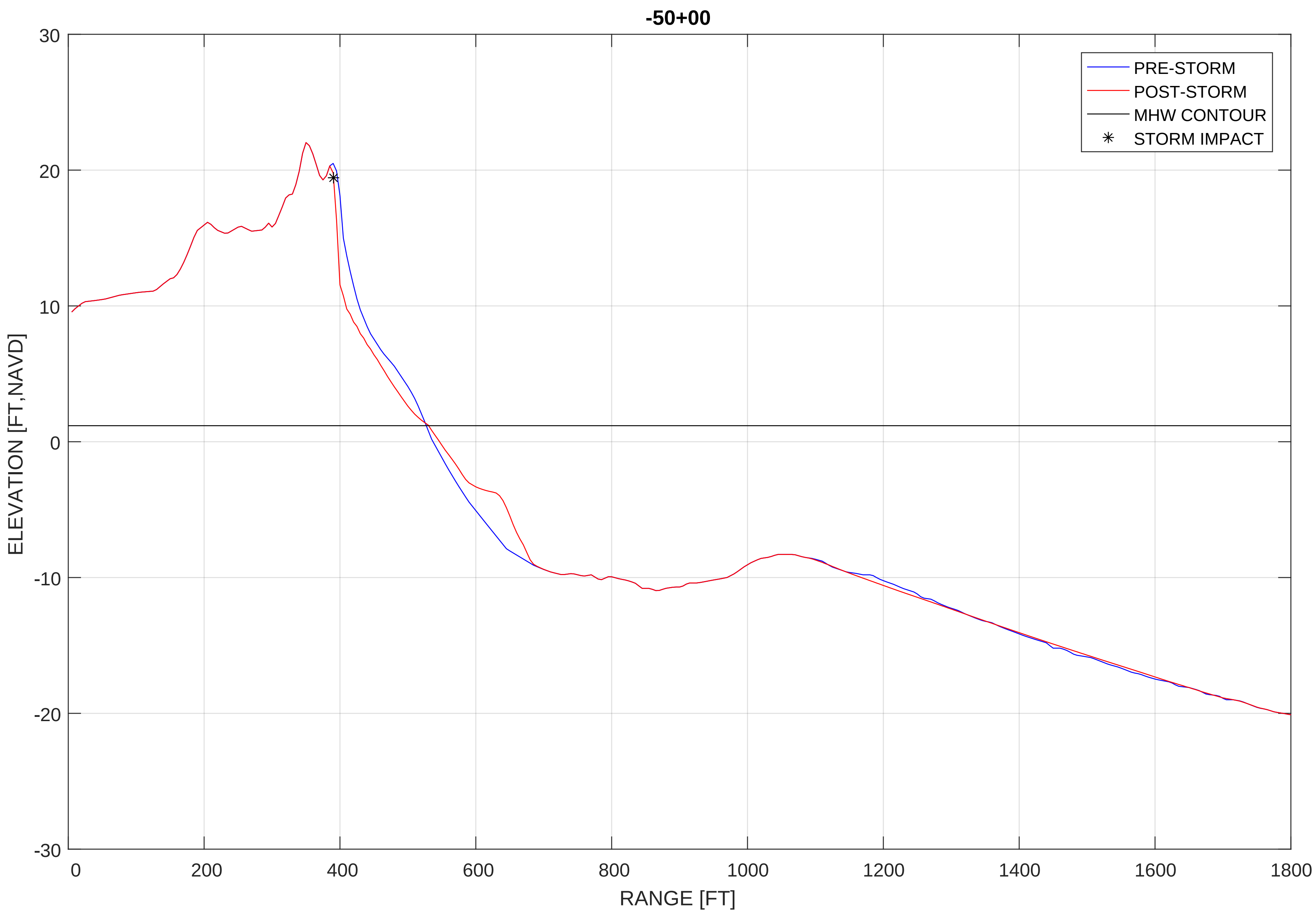
-50+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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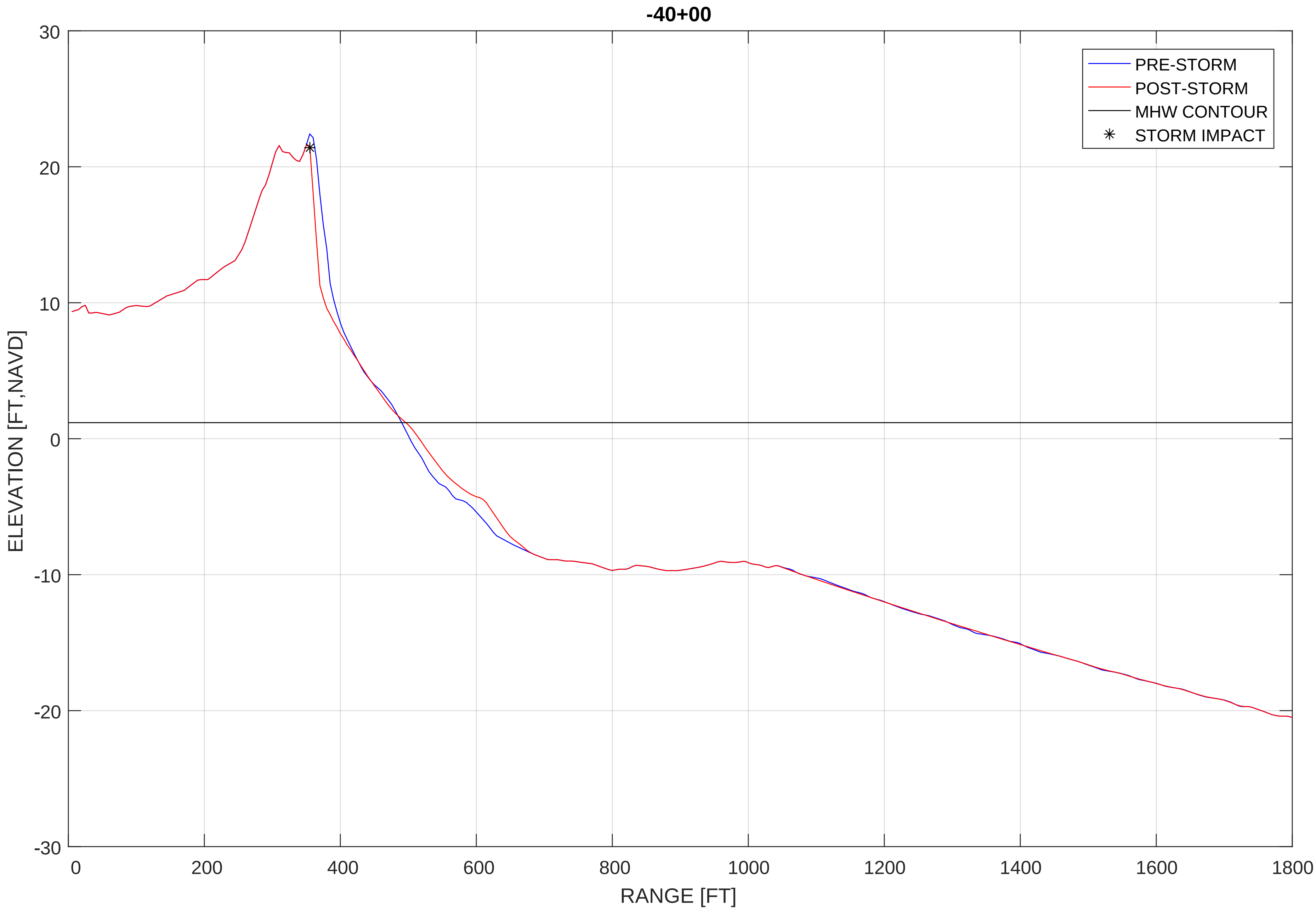

-40+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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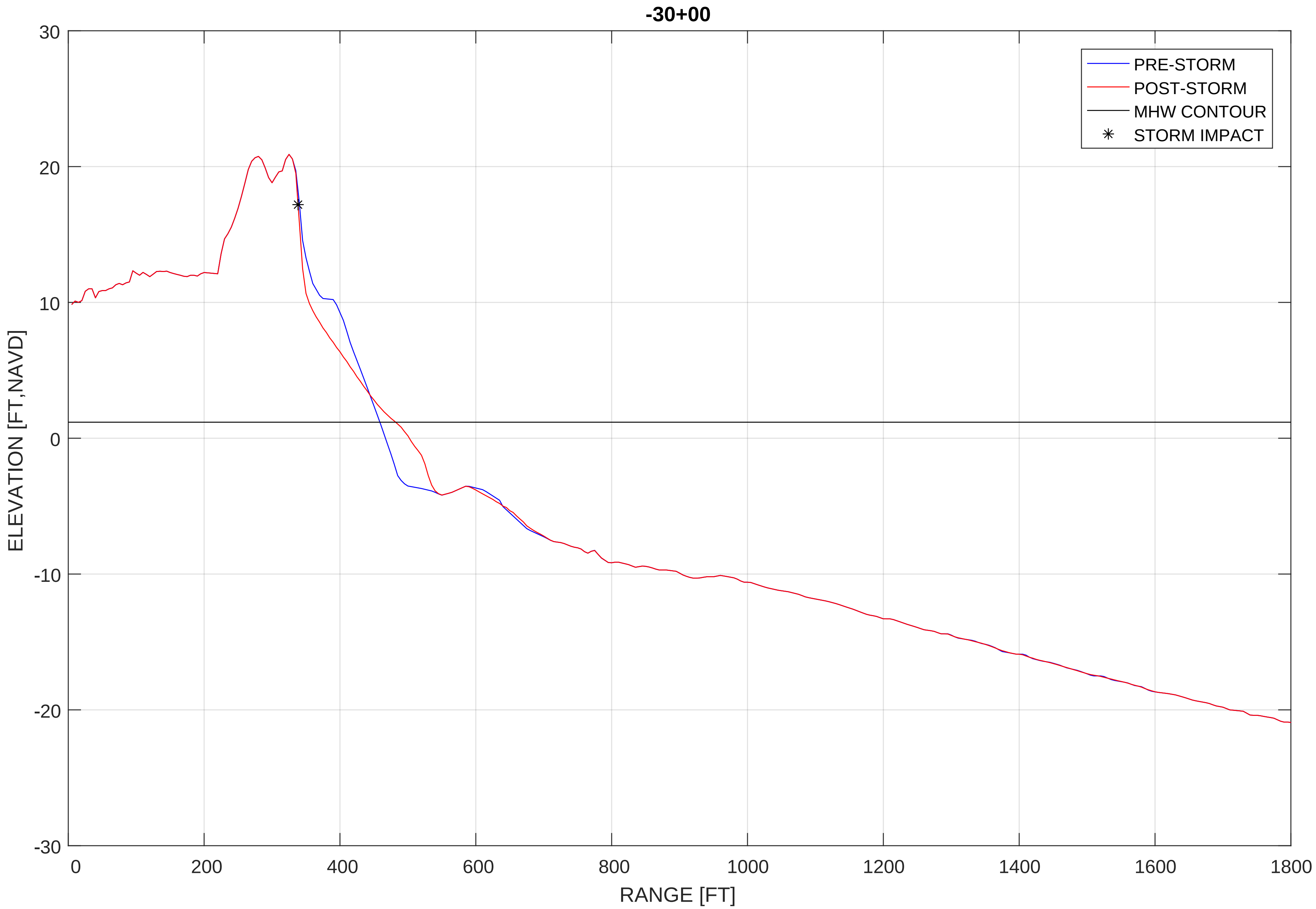

-30+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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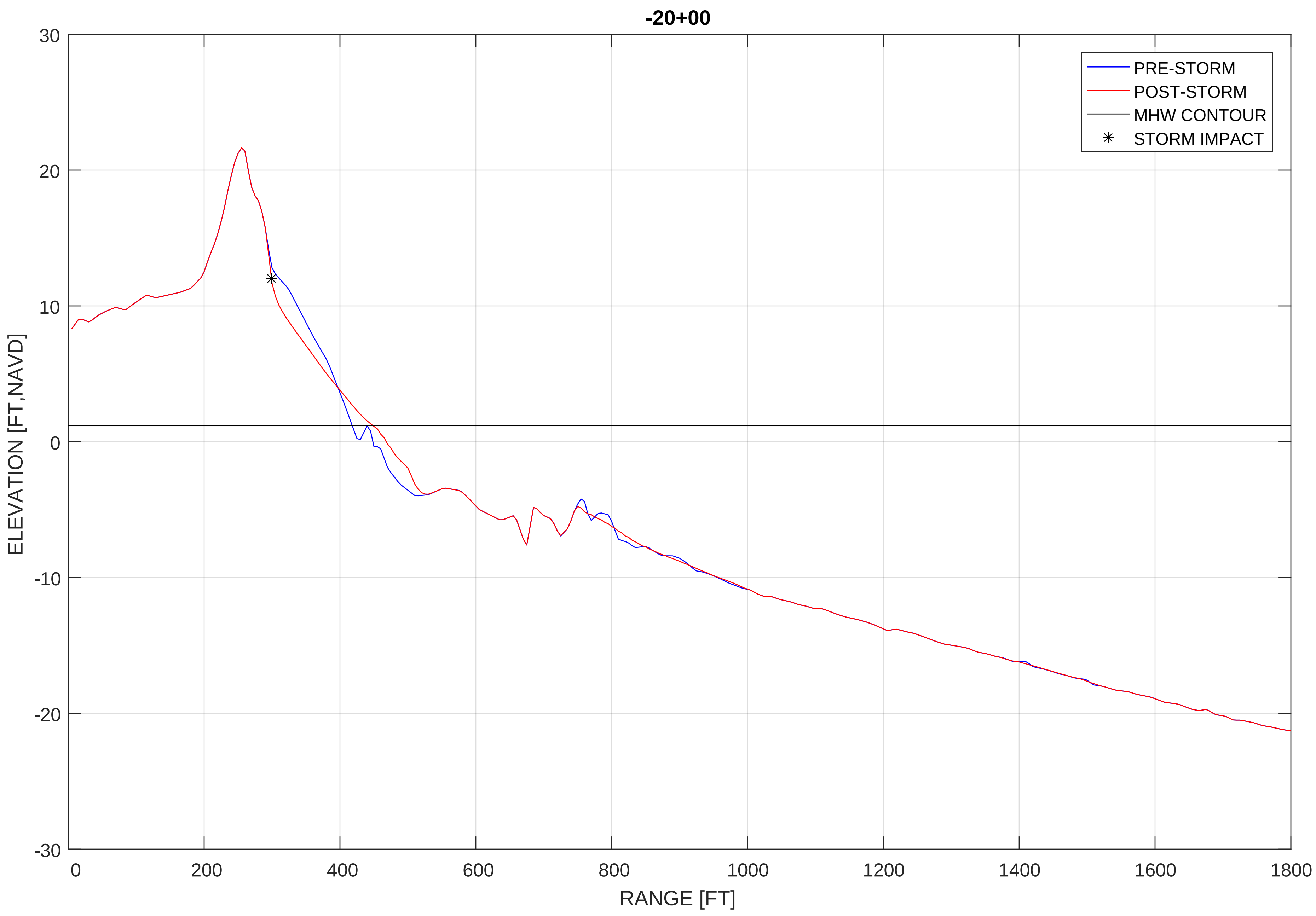

-20+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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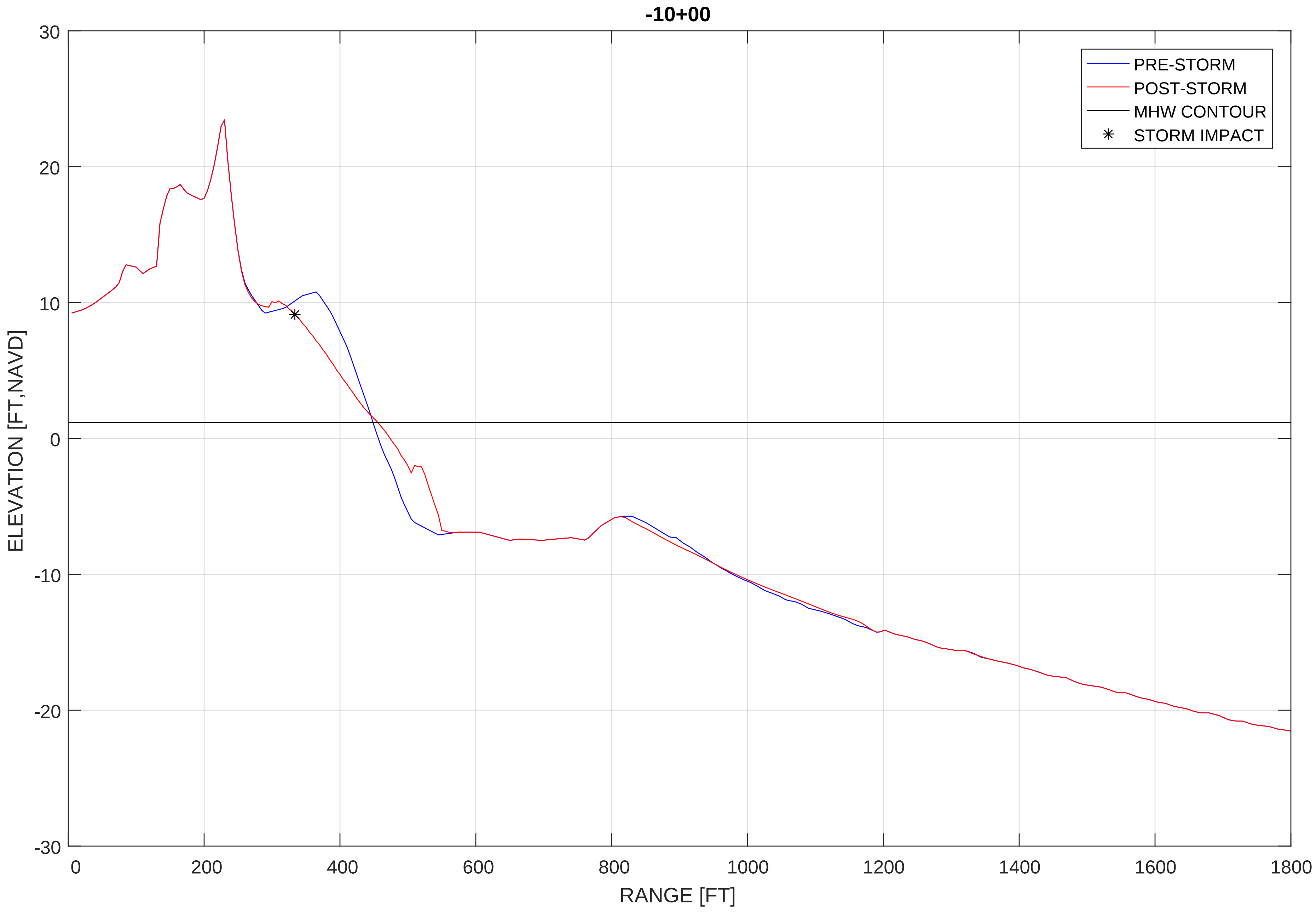
-10+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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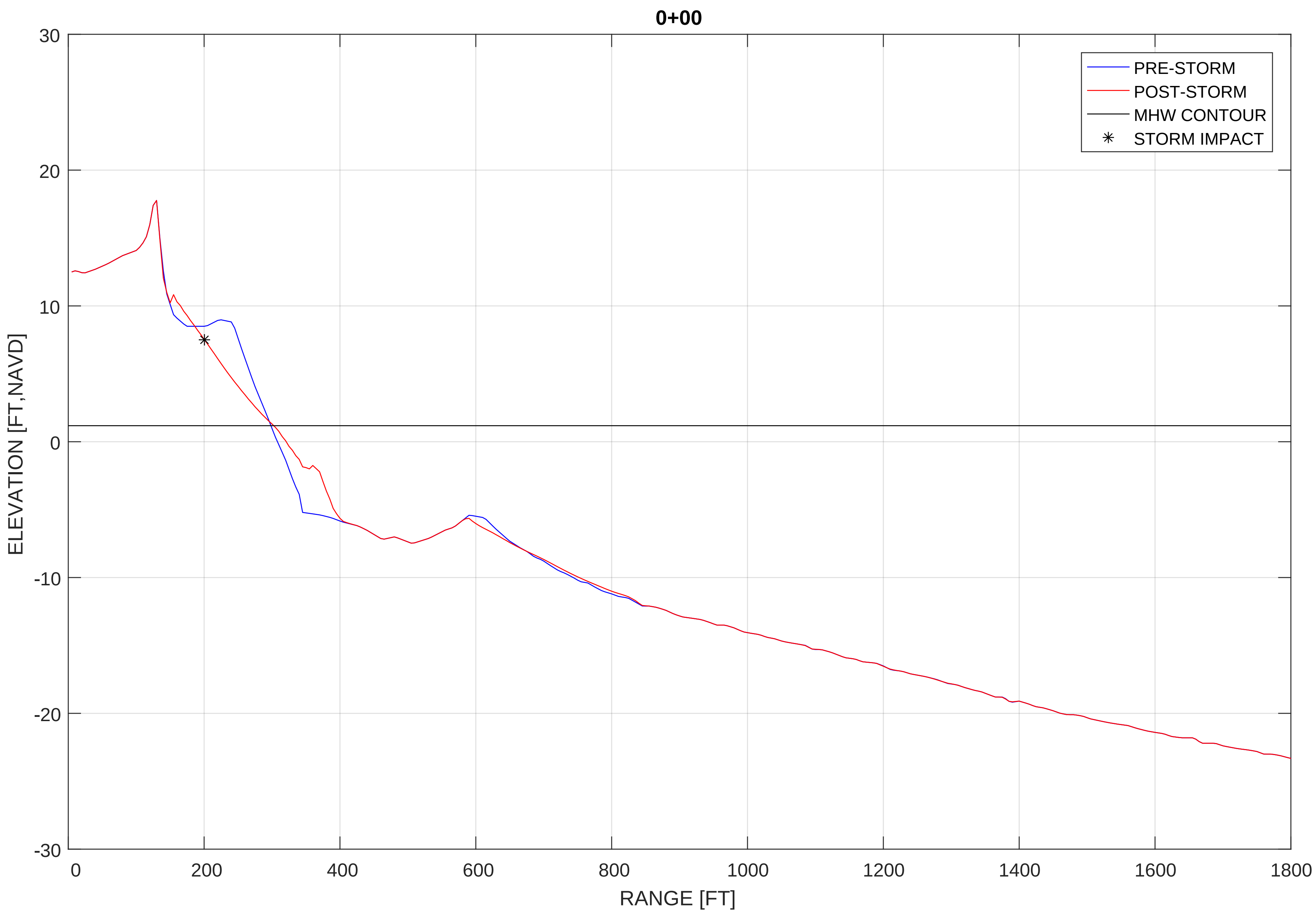

0+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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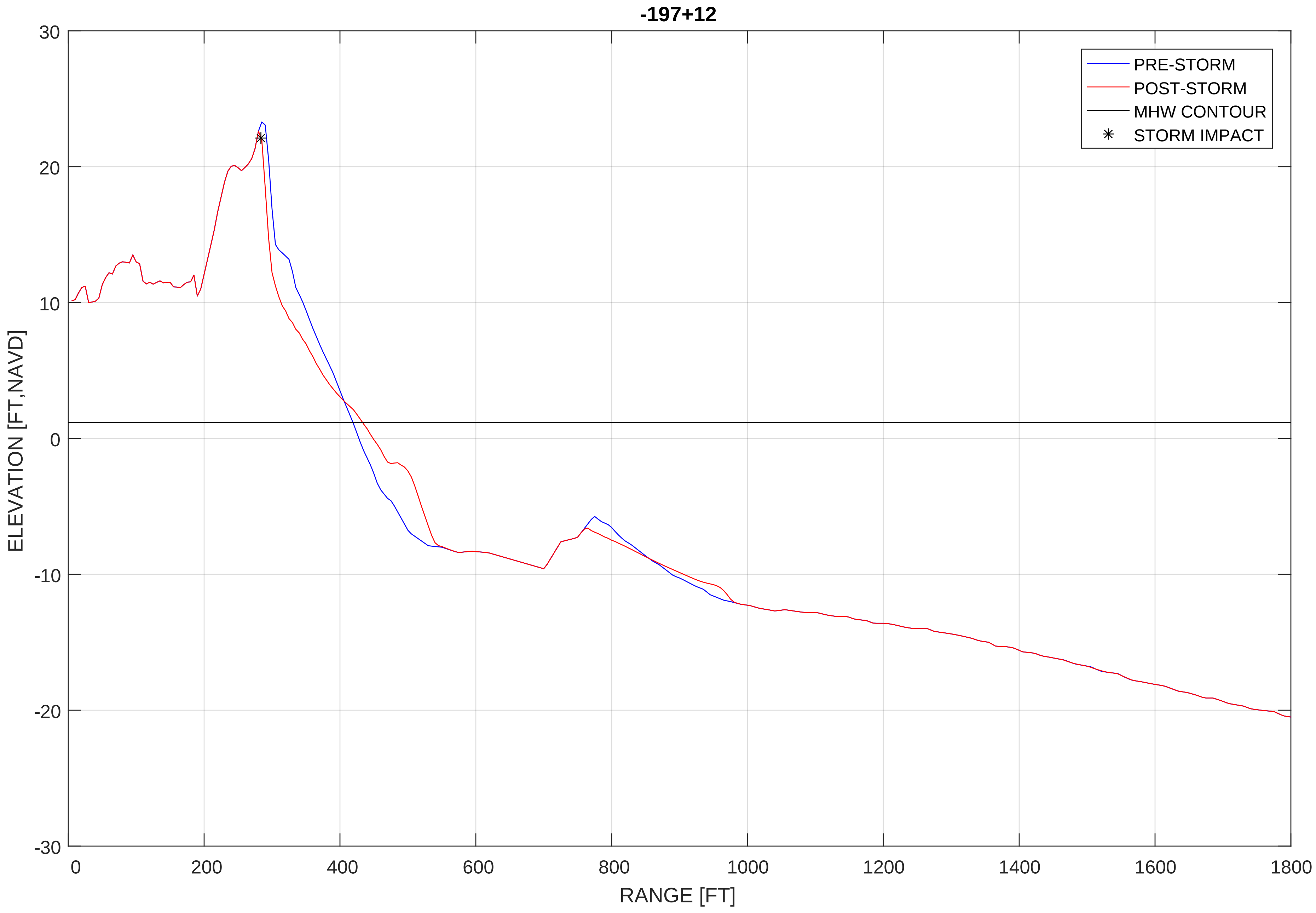
PRE-STORM AND POST-STORM SBEACH PROFILE CROSS SECTIONS
Scenario 11 (Isabel Storm with 2048 Sea Level – Assumes highest greenhouse gas concentrations trajectory used by IPCC for AR5 – RCP 8.5 and measured tides)


-197+12
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
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ELEVATION [FT,NAVD]
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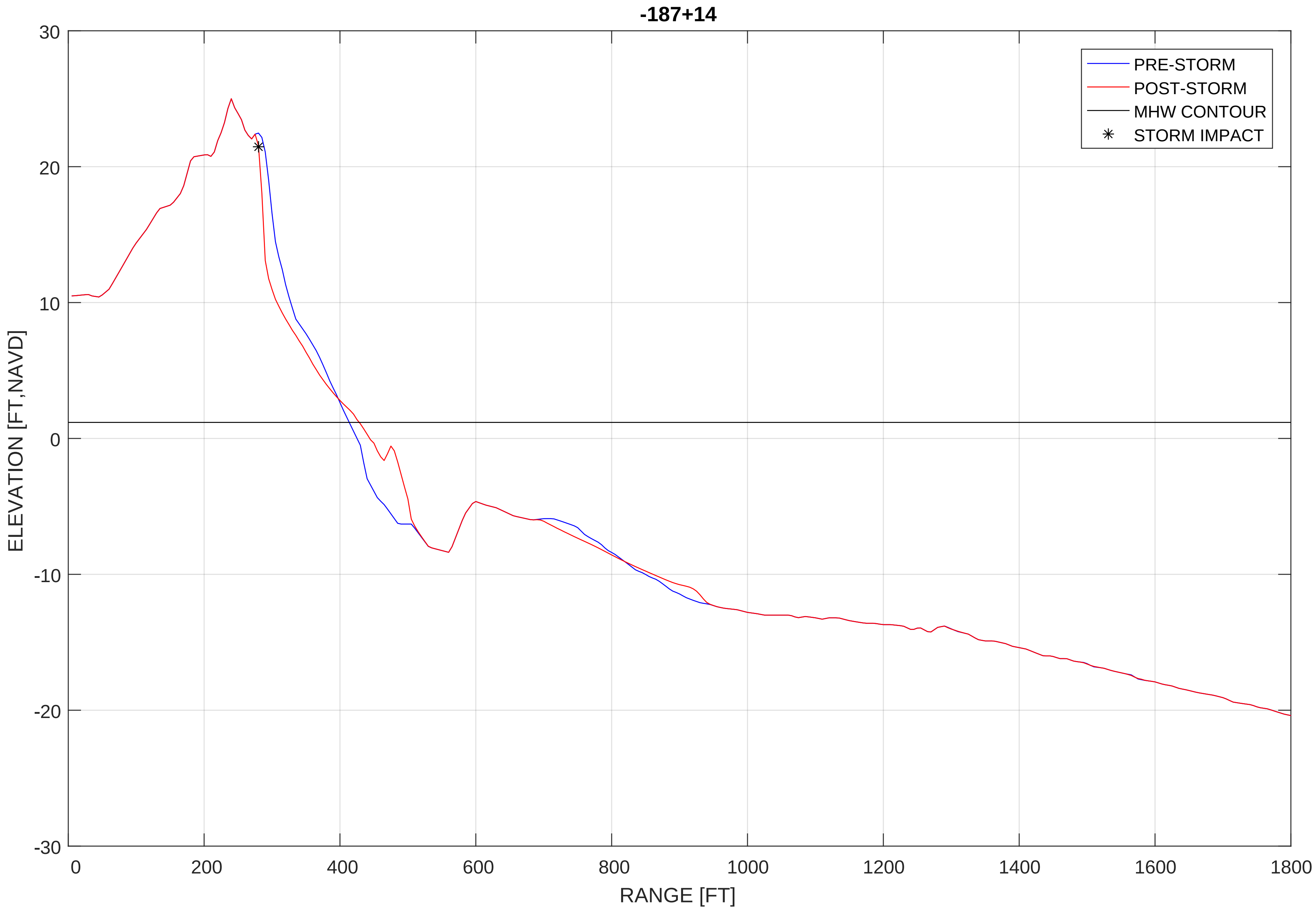
1800
RANGE [FT]



-187+14
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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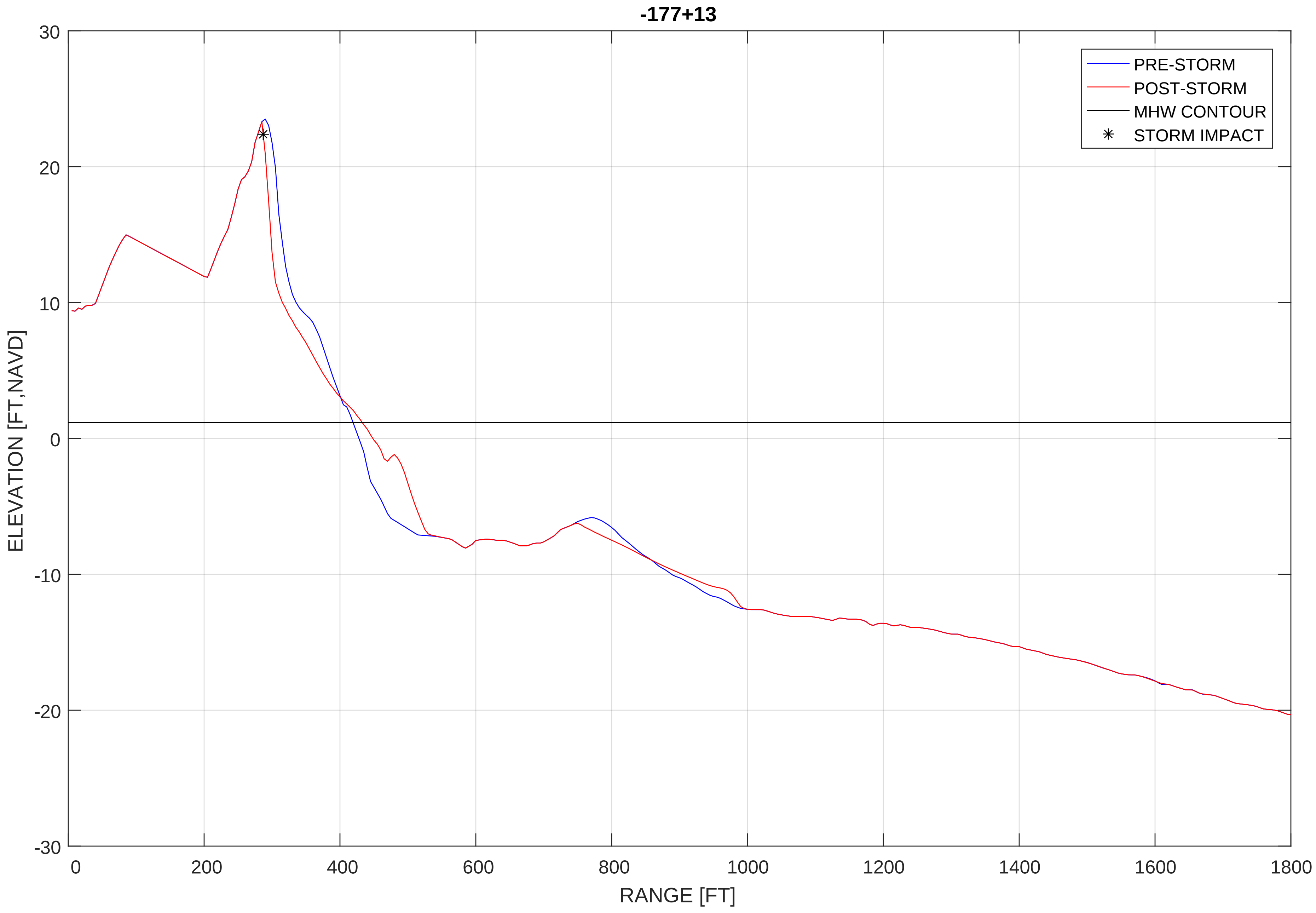

-177+13
ELEVATION [FT,NAVD]
RANGE [FT]
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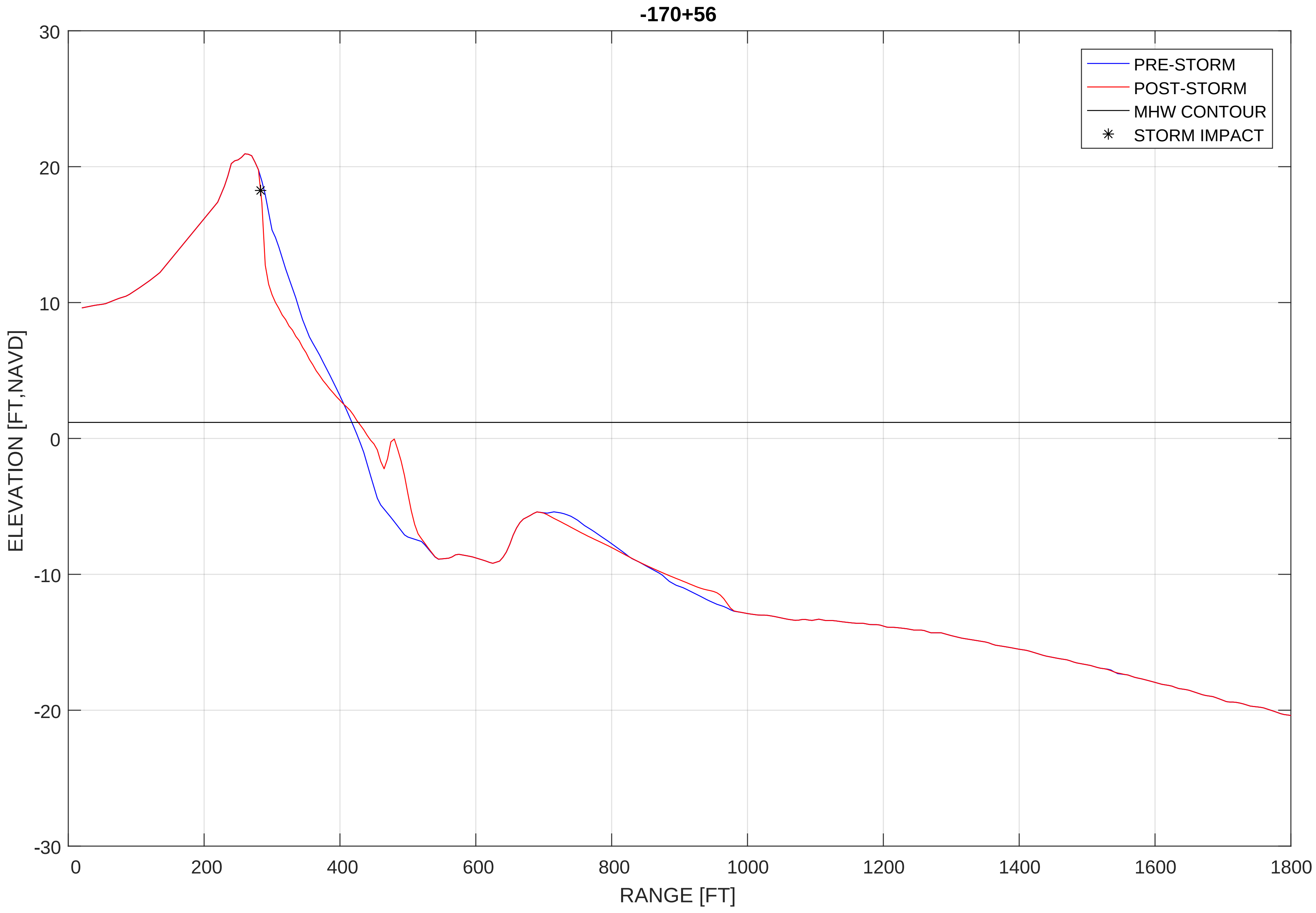
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT



-170+56
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
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ELEVATION [FT,NAVD]
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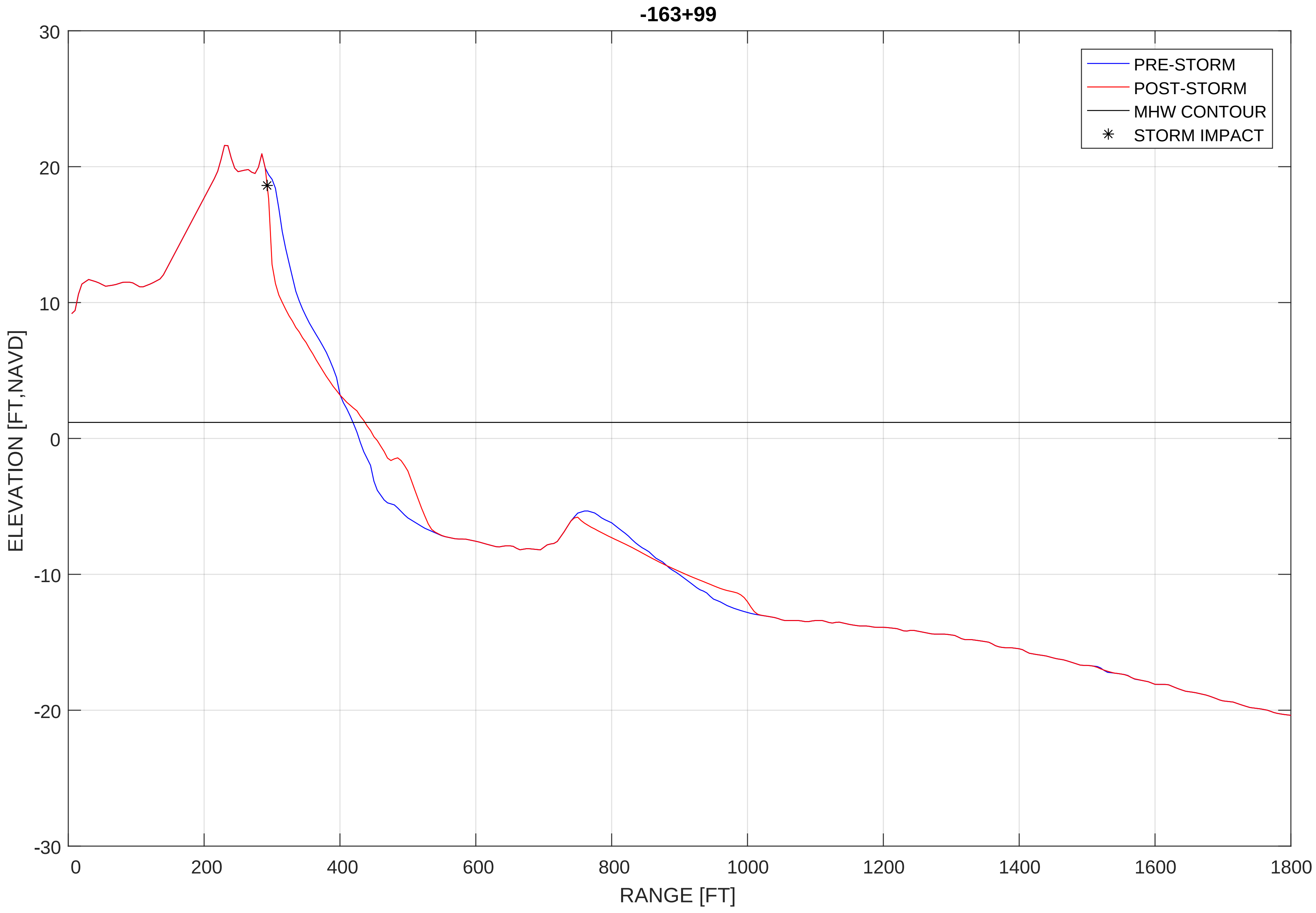
RANGE [FT]



-163+99
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ELEVATION [FT,NAVD]
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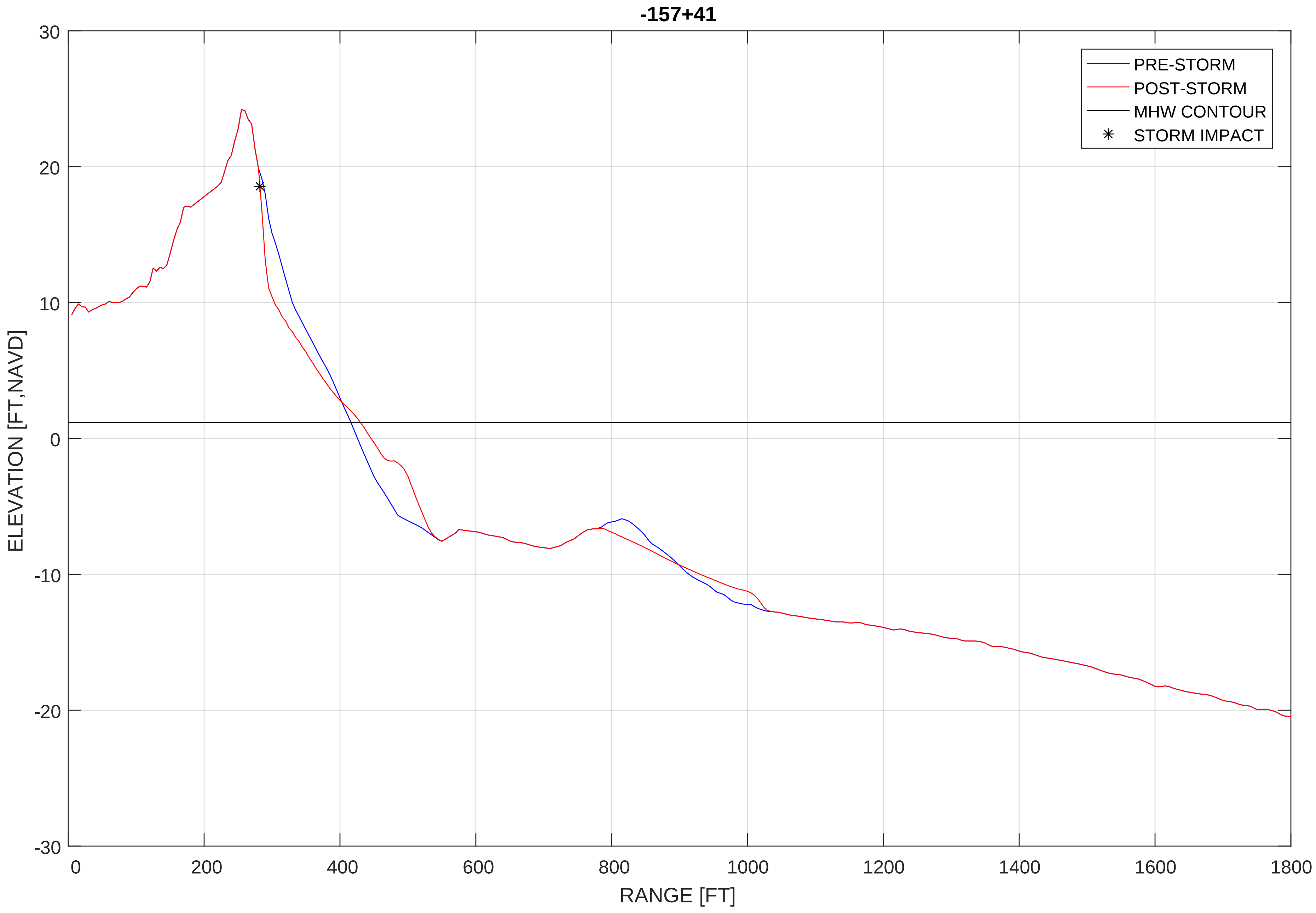
RANGE [FT]
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT



-157+41
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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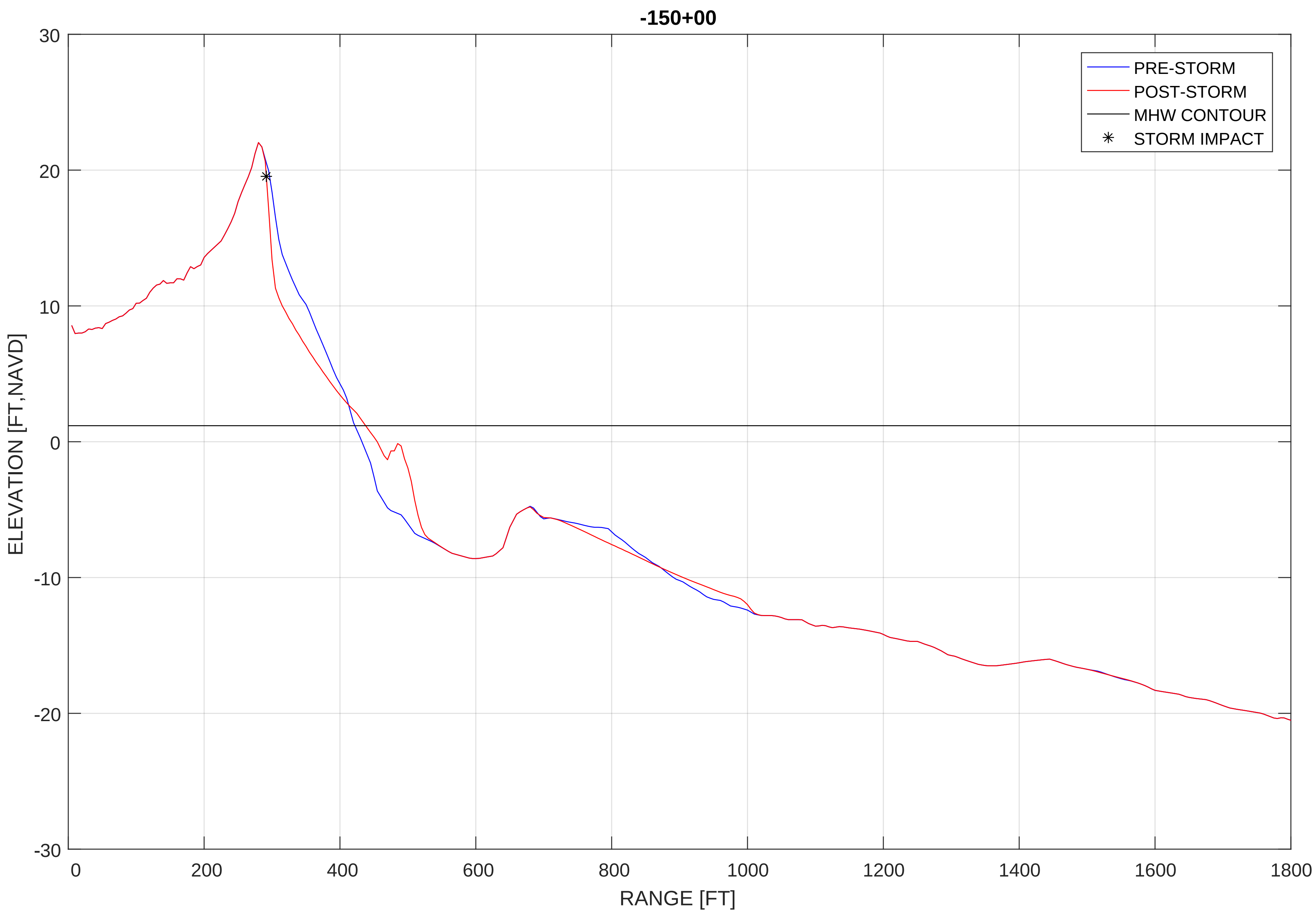
-150+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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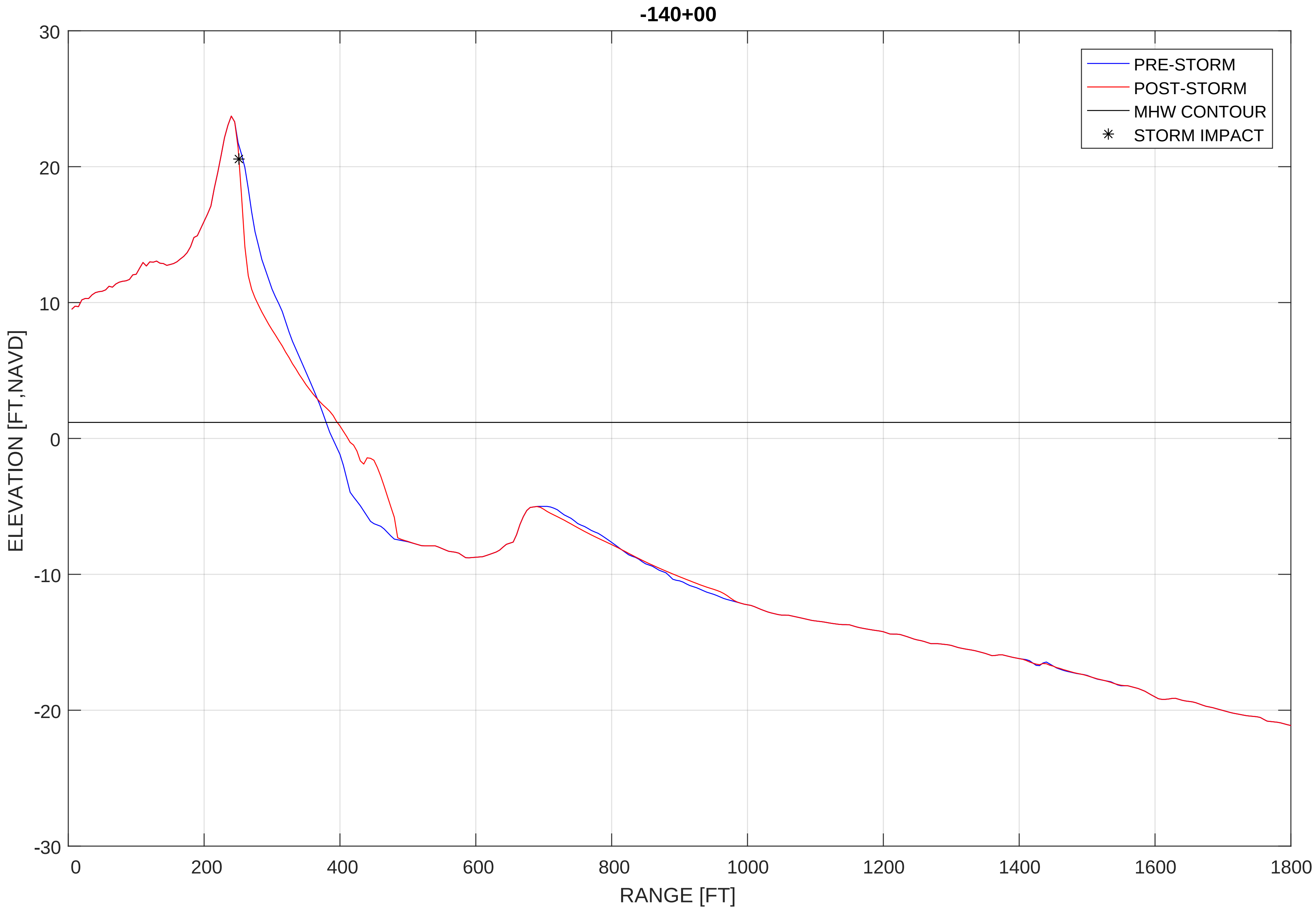

-140+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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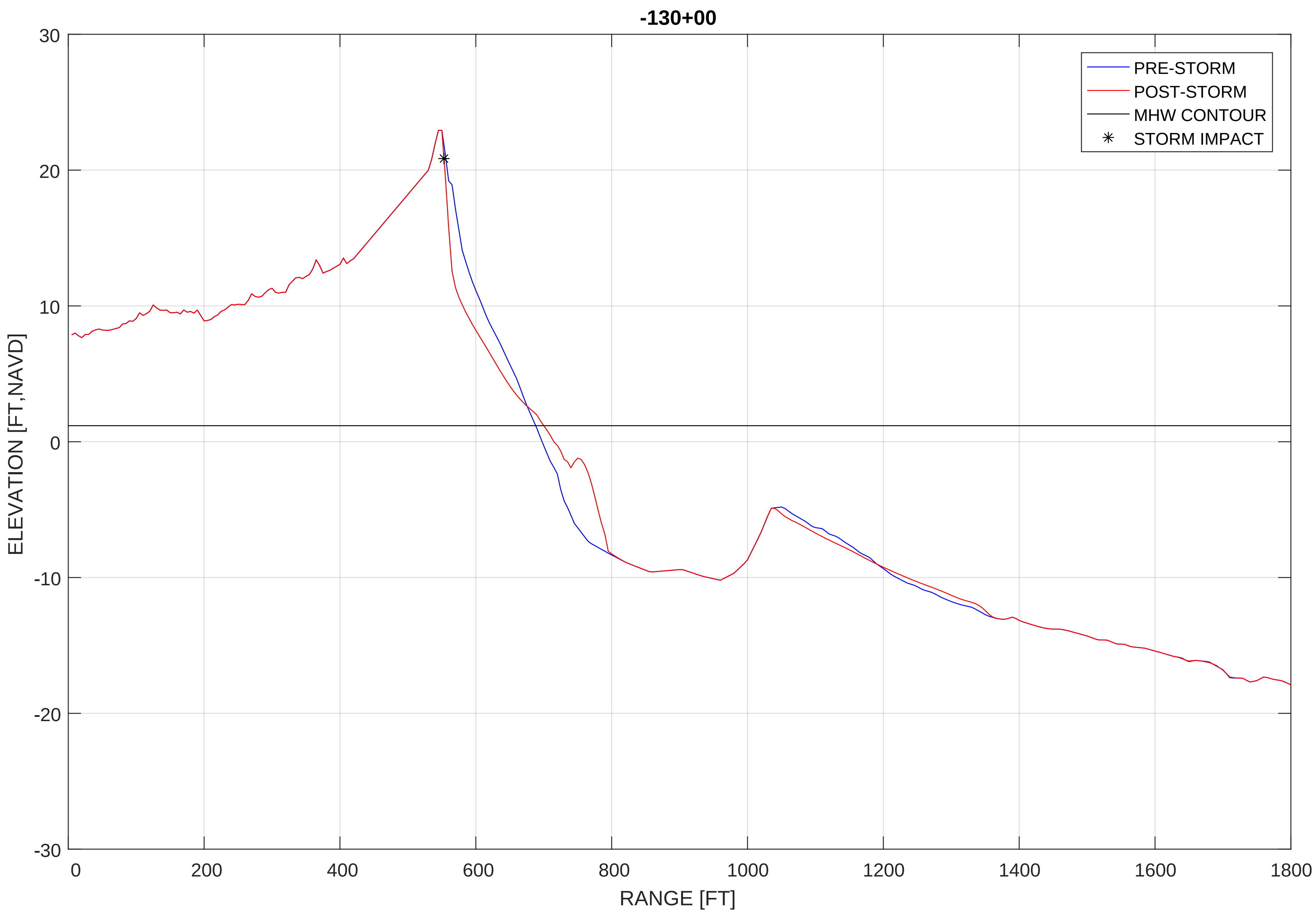

-130+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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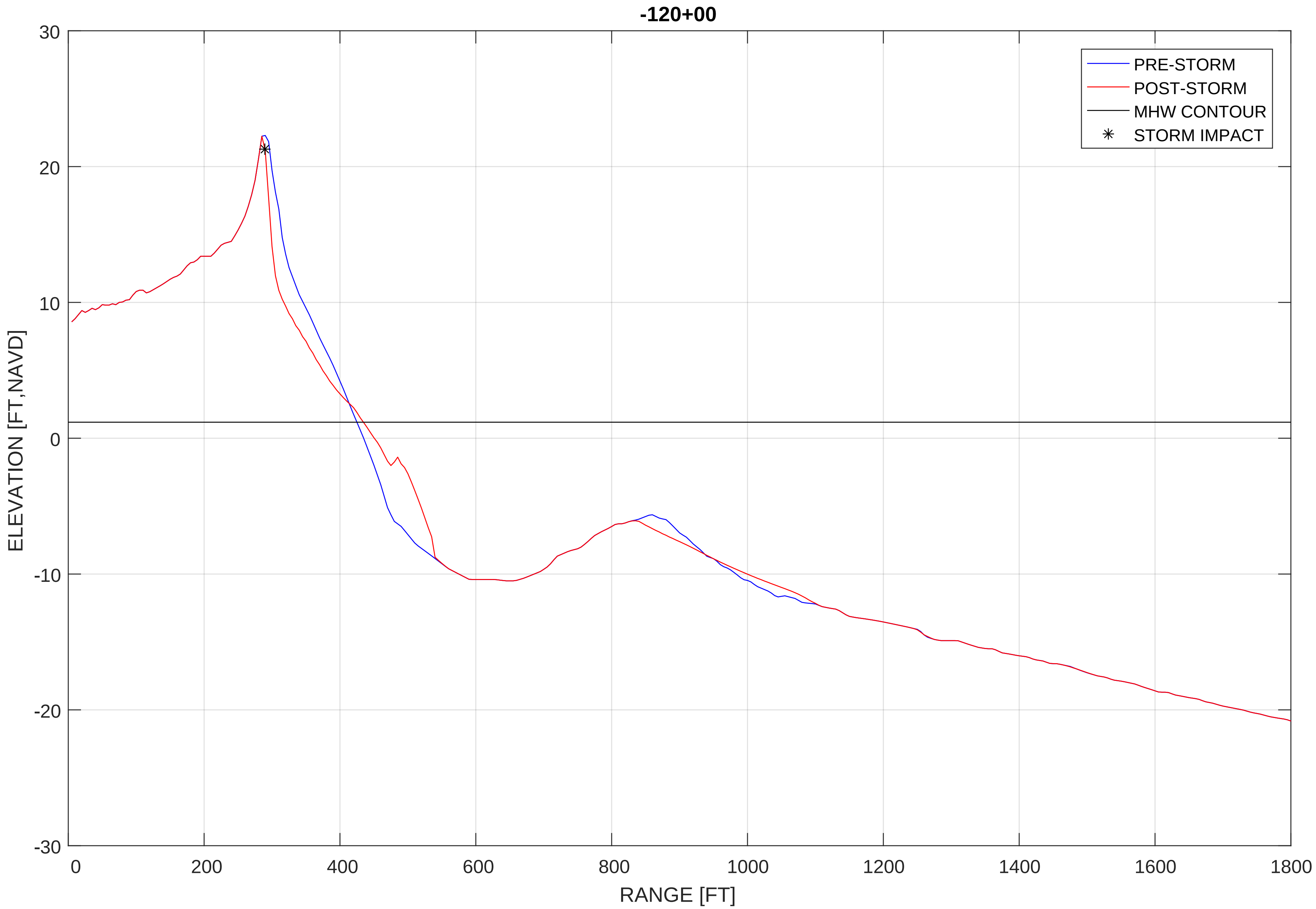
-120+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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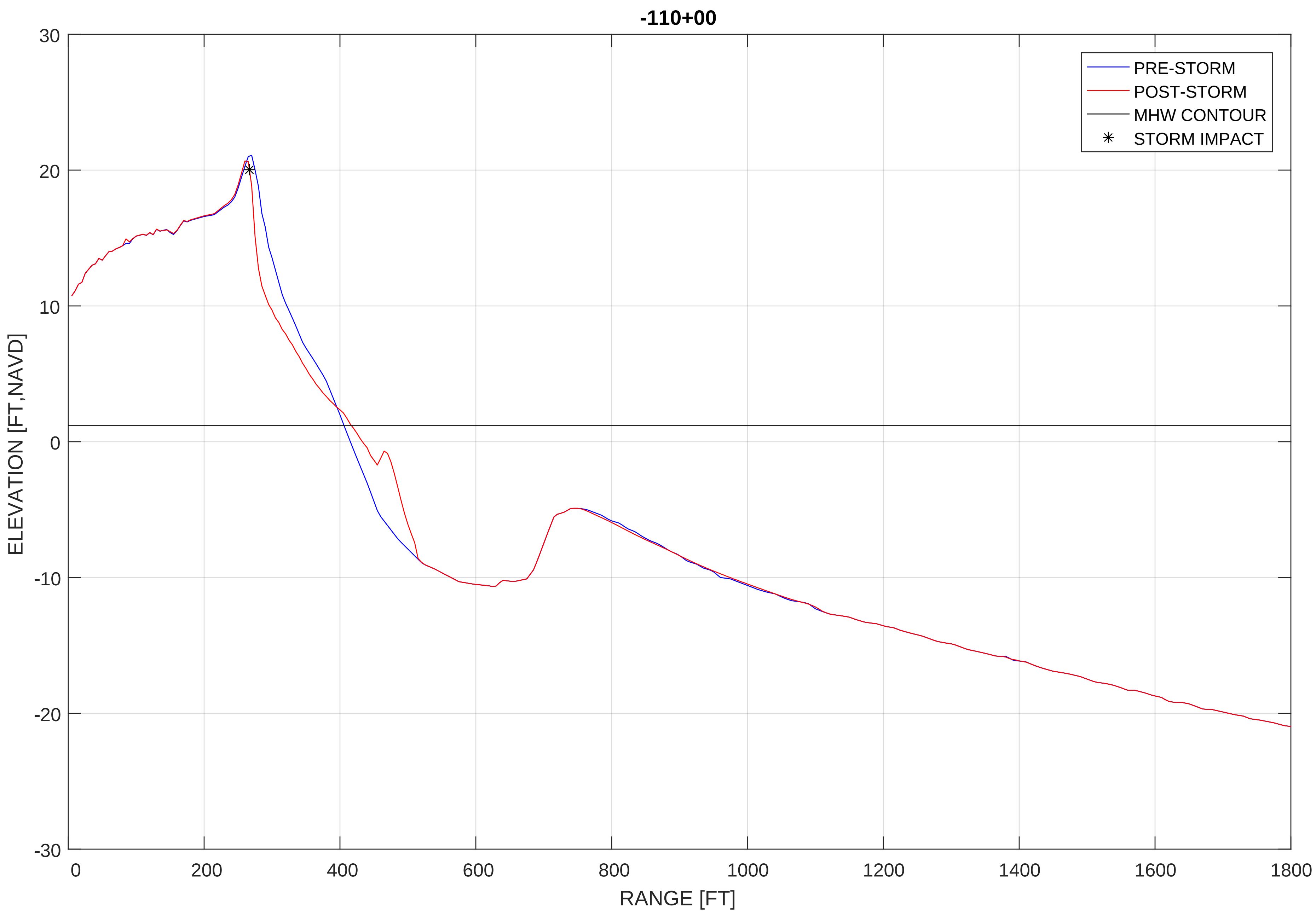
-110+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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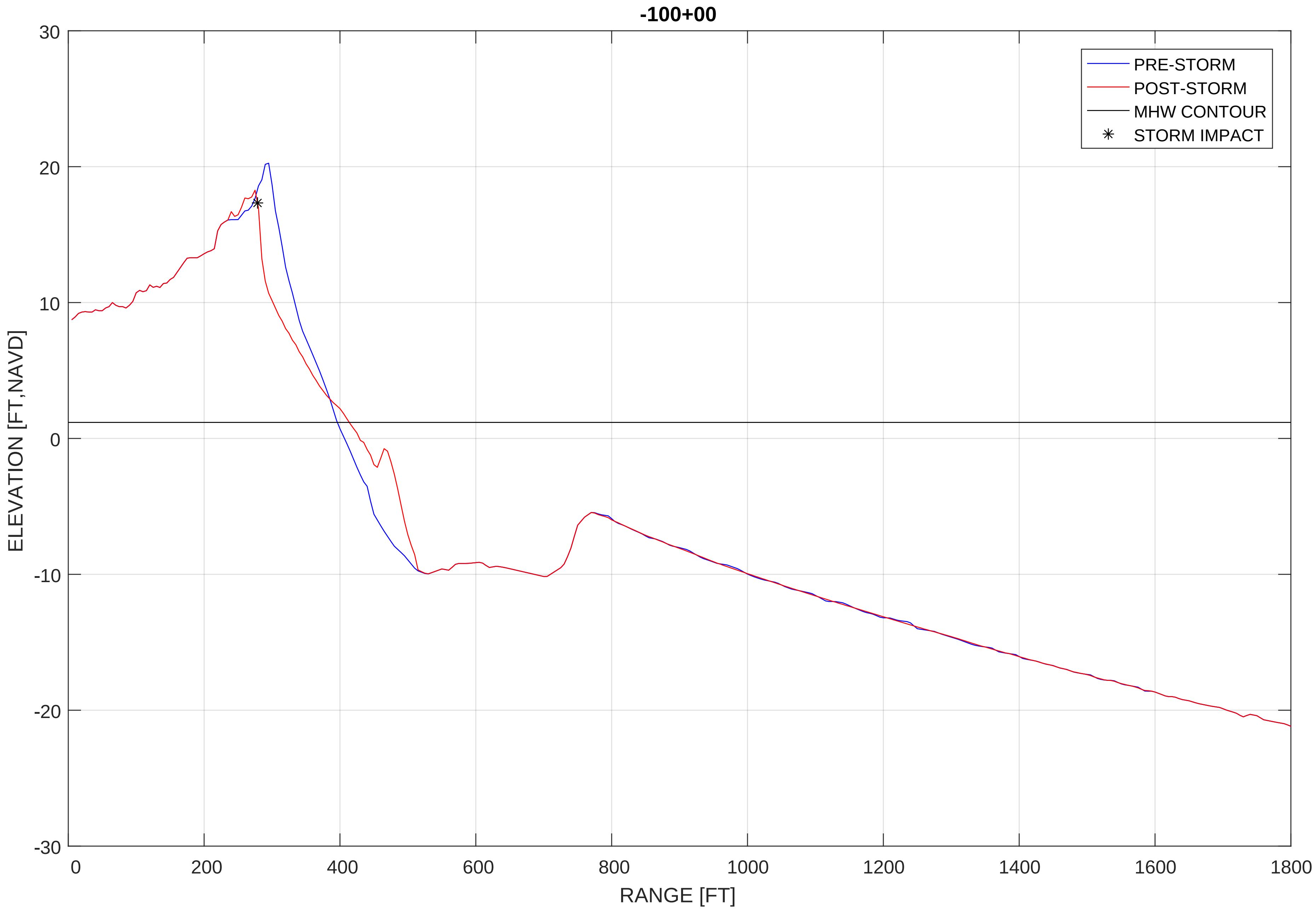

-100+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
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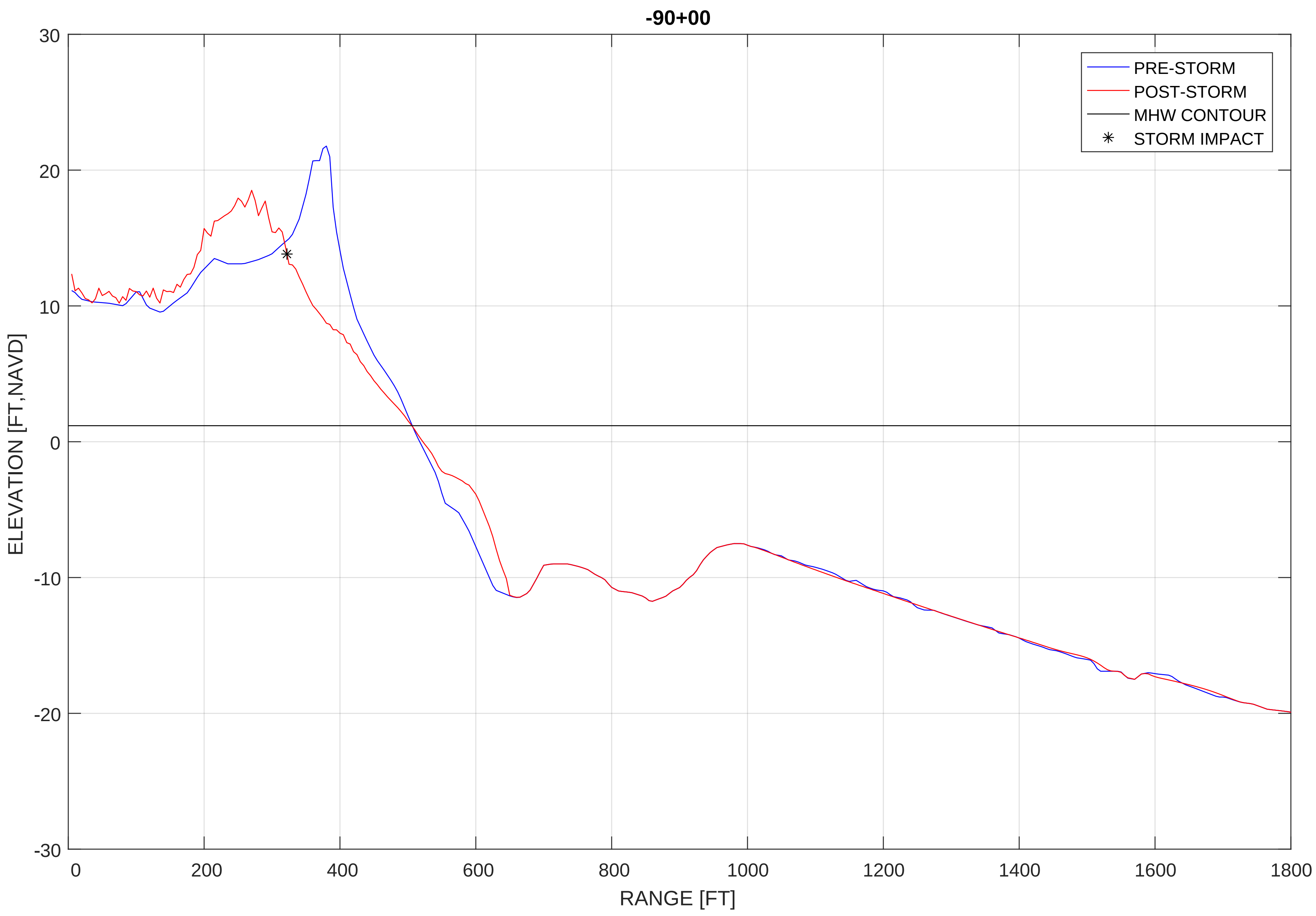
ELEVATION [FT,NAVD]
RANGE [FT]



-90+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
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ELEVATION [FT,NAVD]
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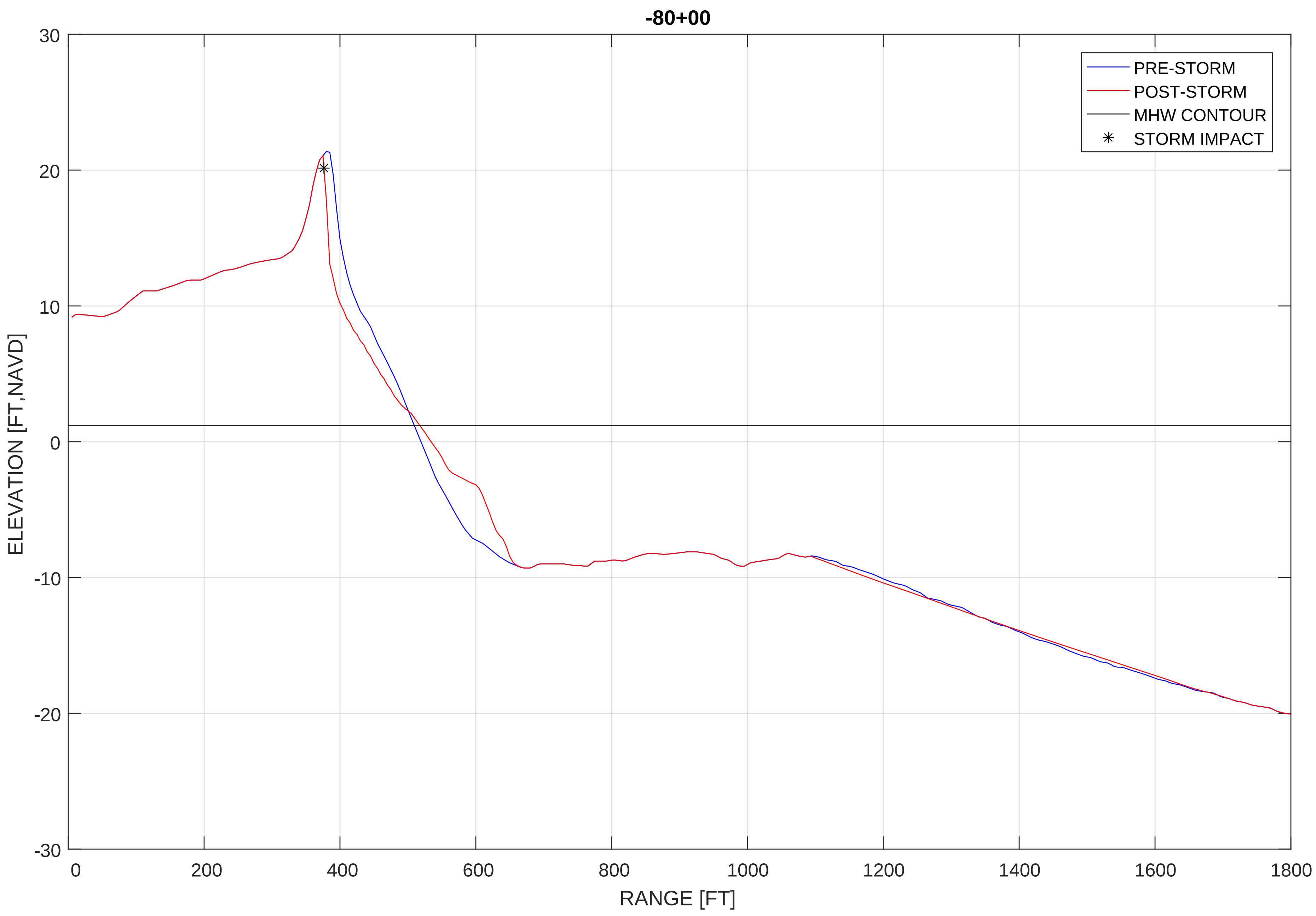
RANGE [FT]



-80+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
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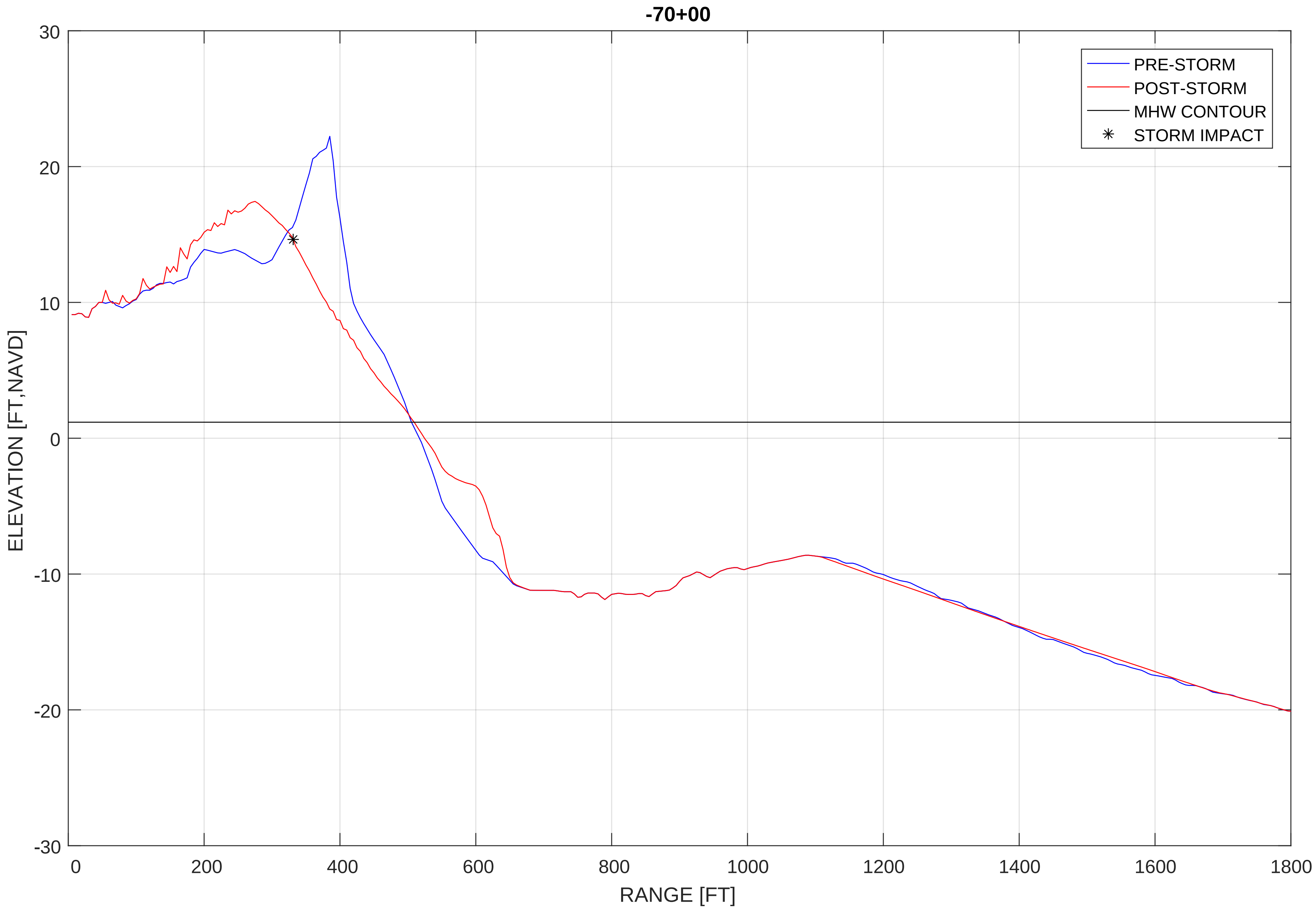
RANGE [FT]



-70+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
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ELEVATION [FT,NAVD]
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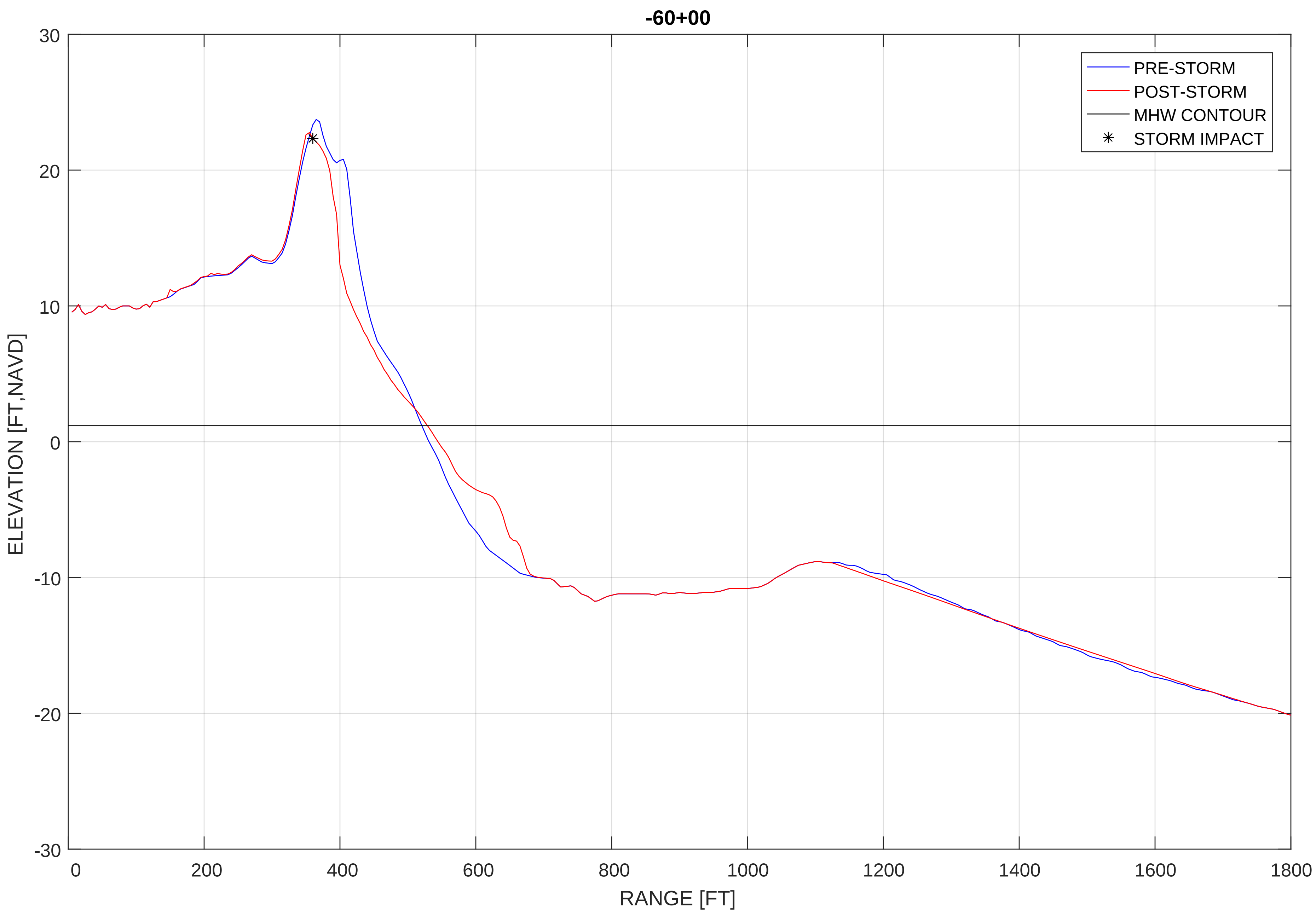
RANGE [FT]


-60+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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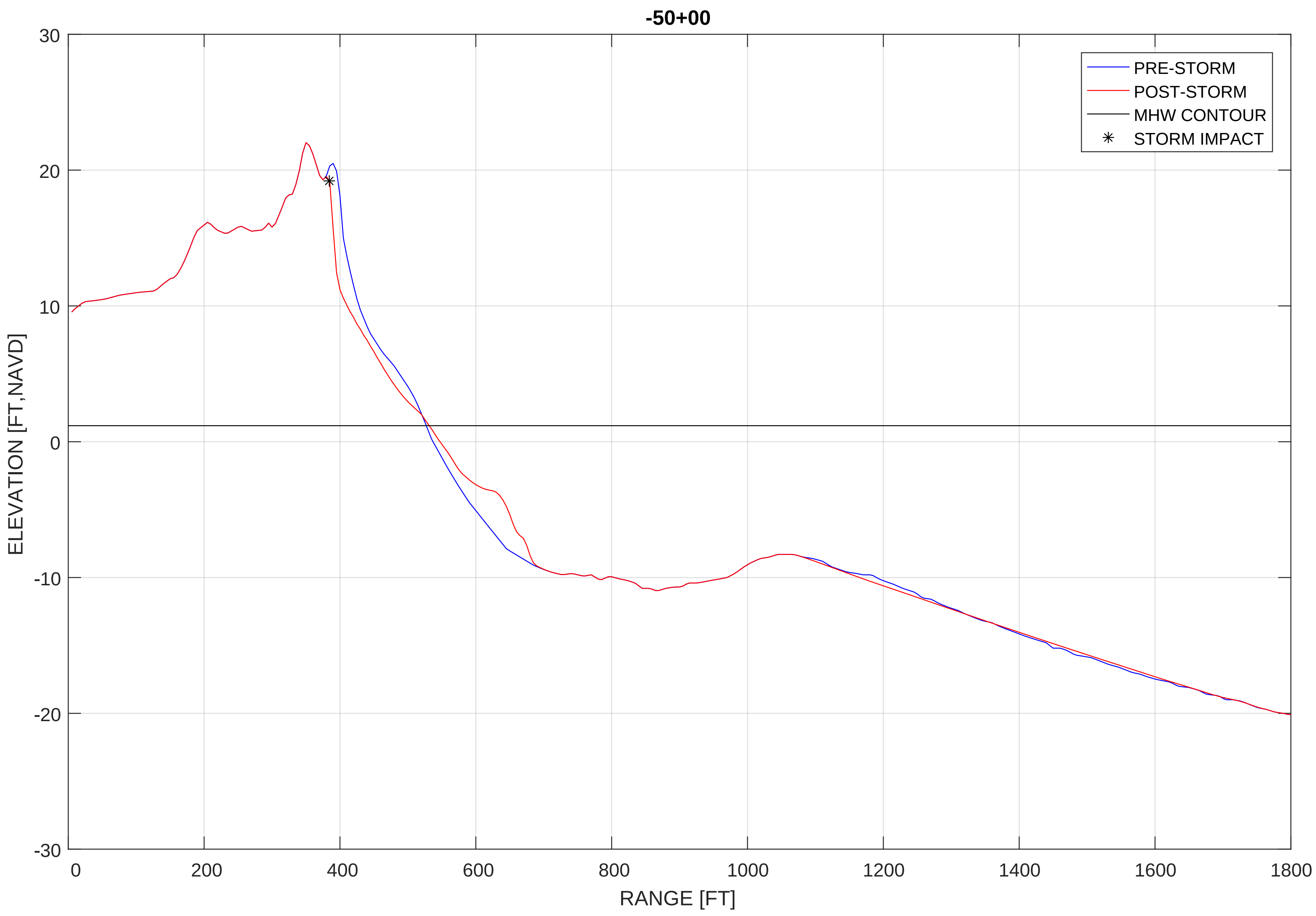
-50+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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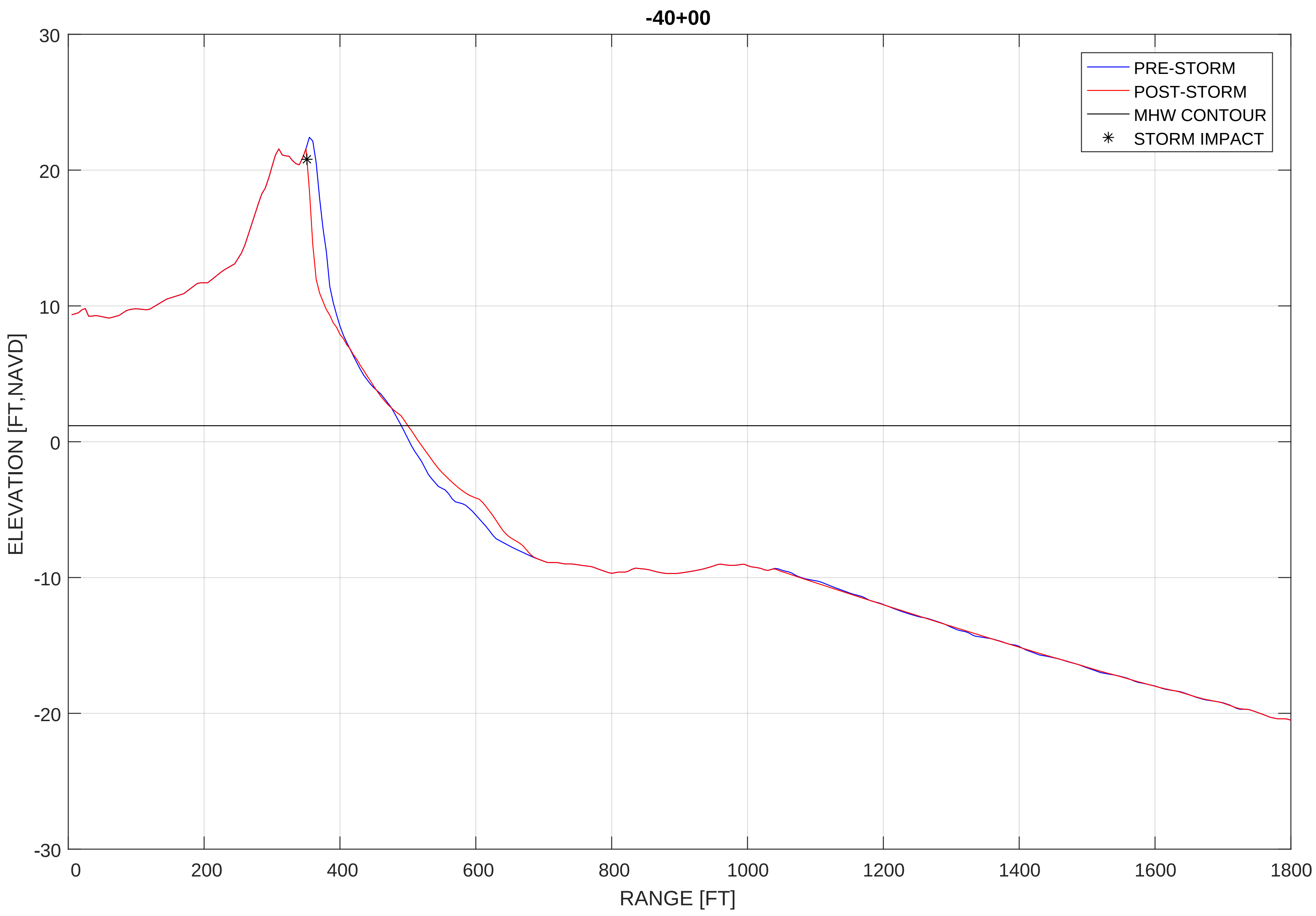

-40+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
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RANGE [FT]
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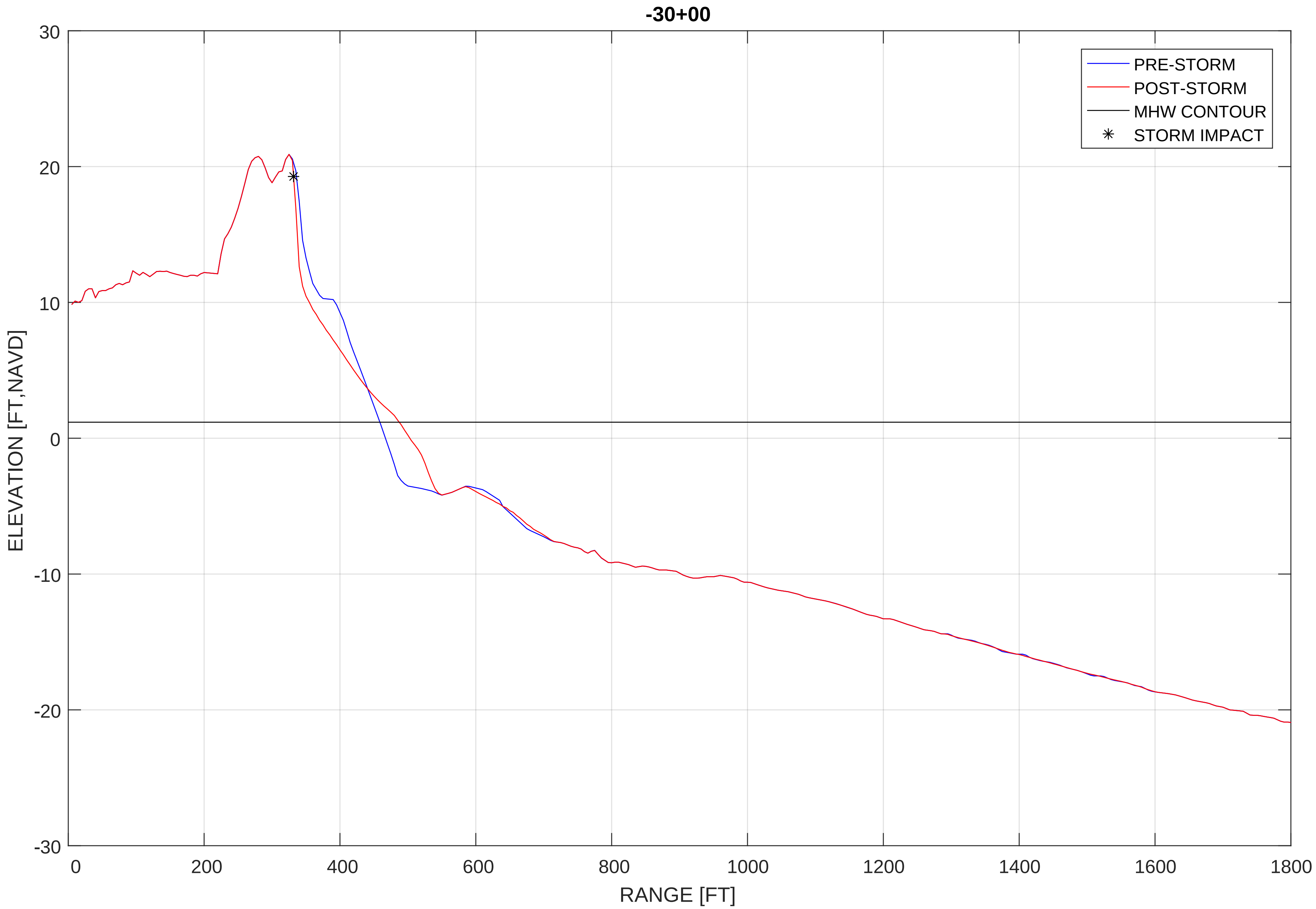

-30+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
30
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-30
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1200
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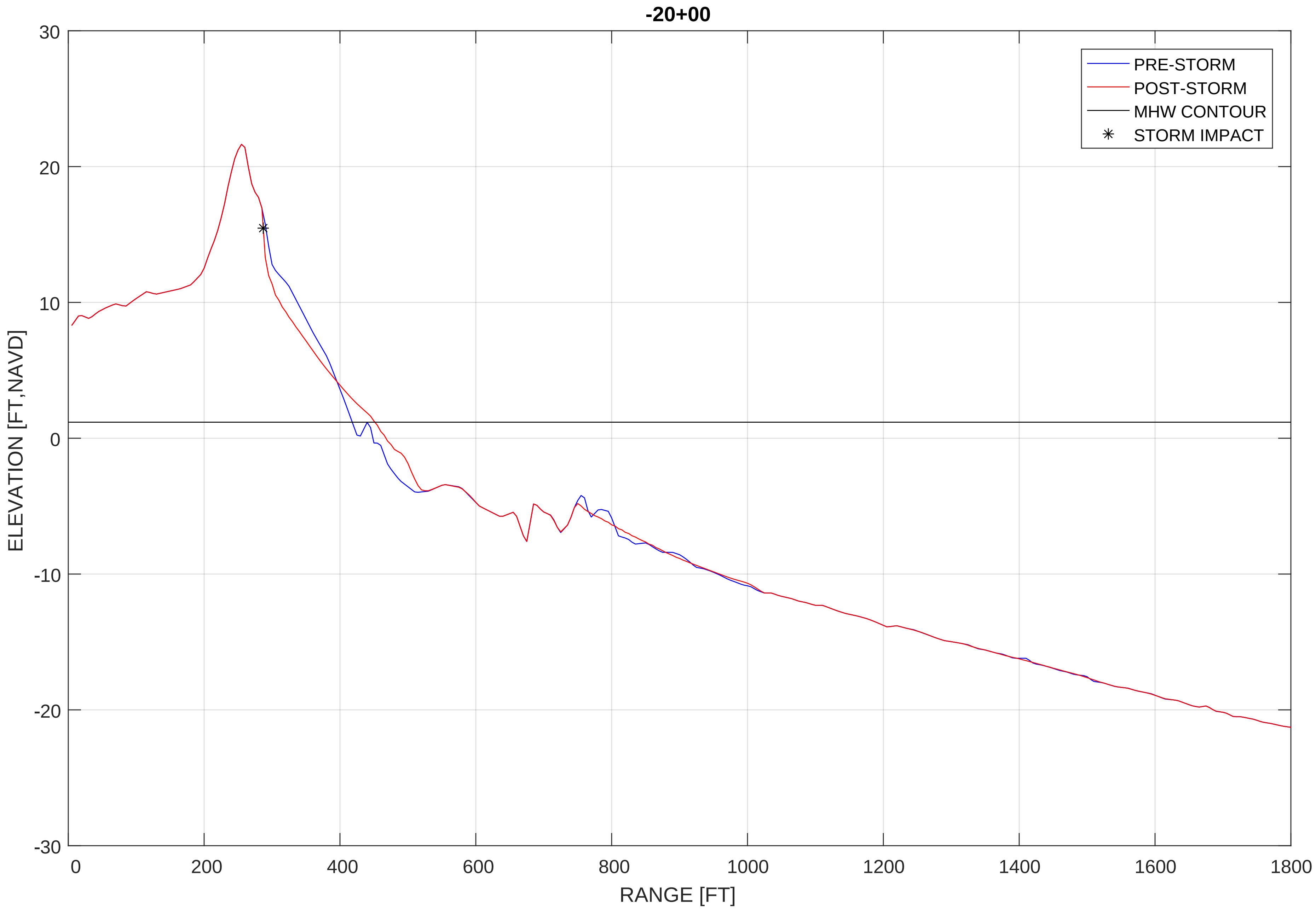
1600
1800



-20+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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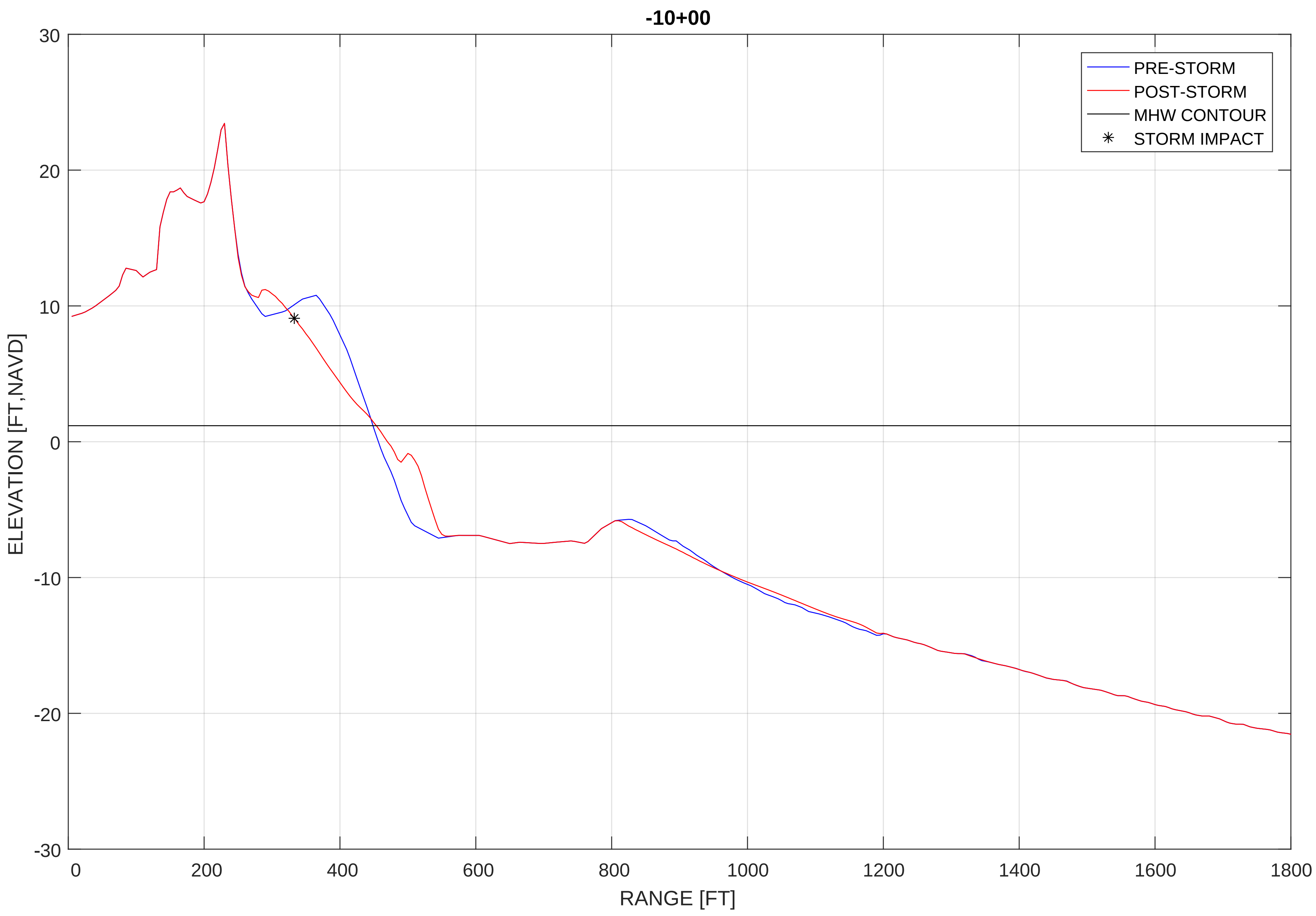

-10+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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0
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1200
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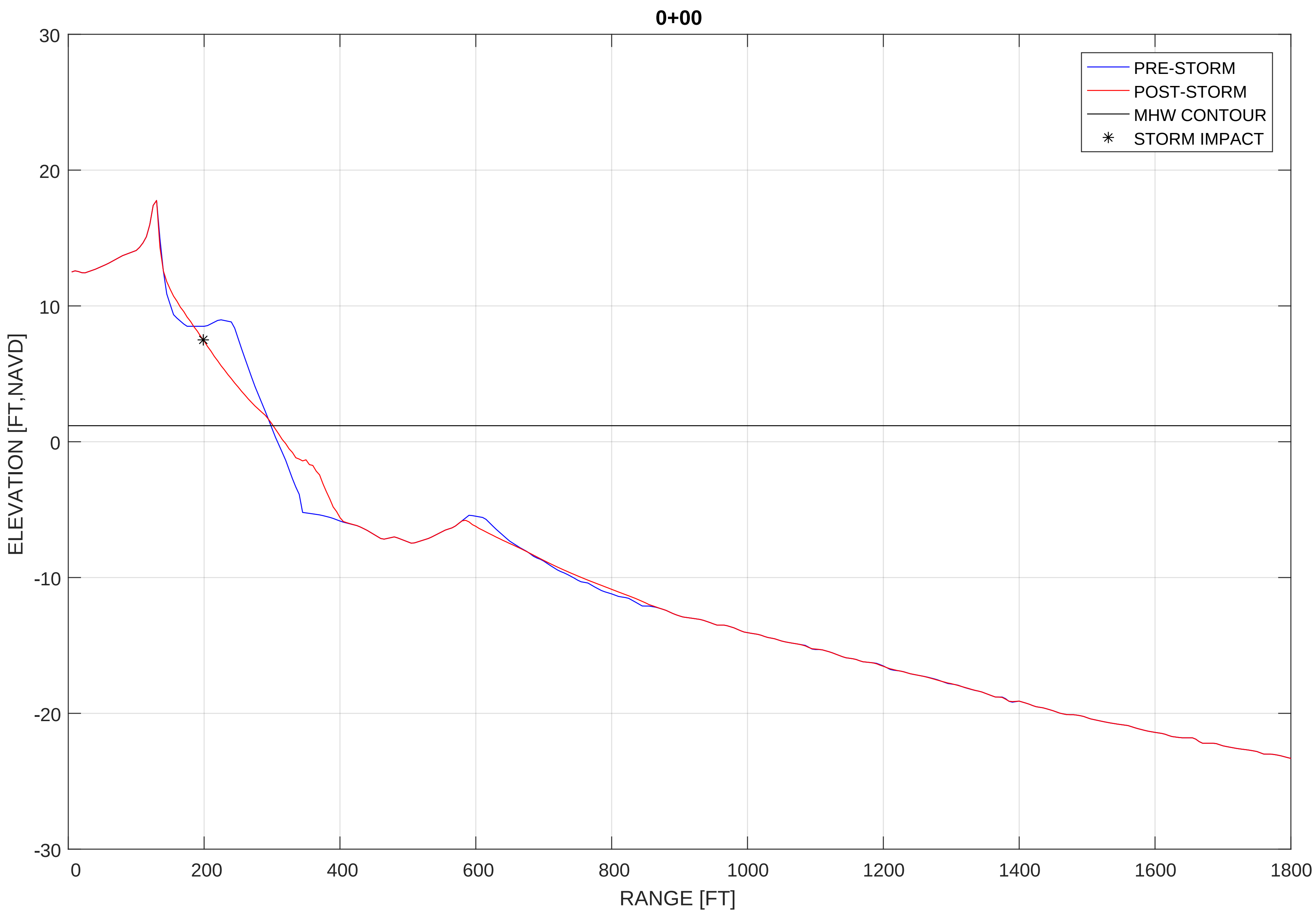
0+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
30
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-10
-20
-30
0
200
400
600
800
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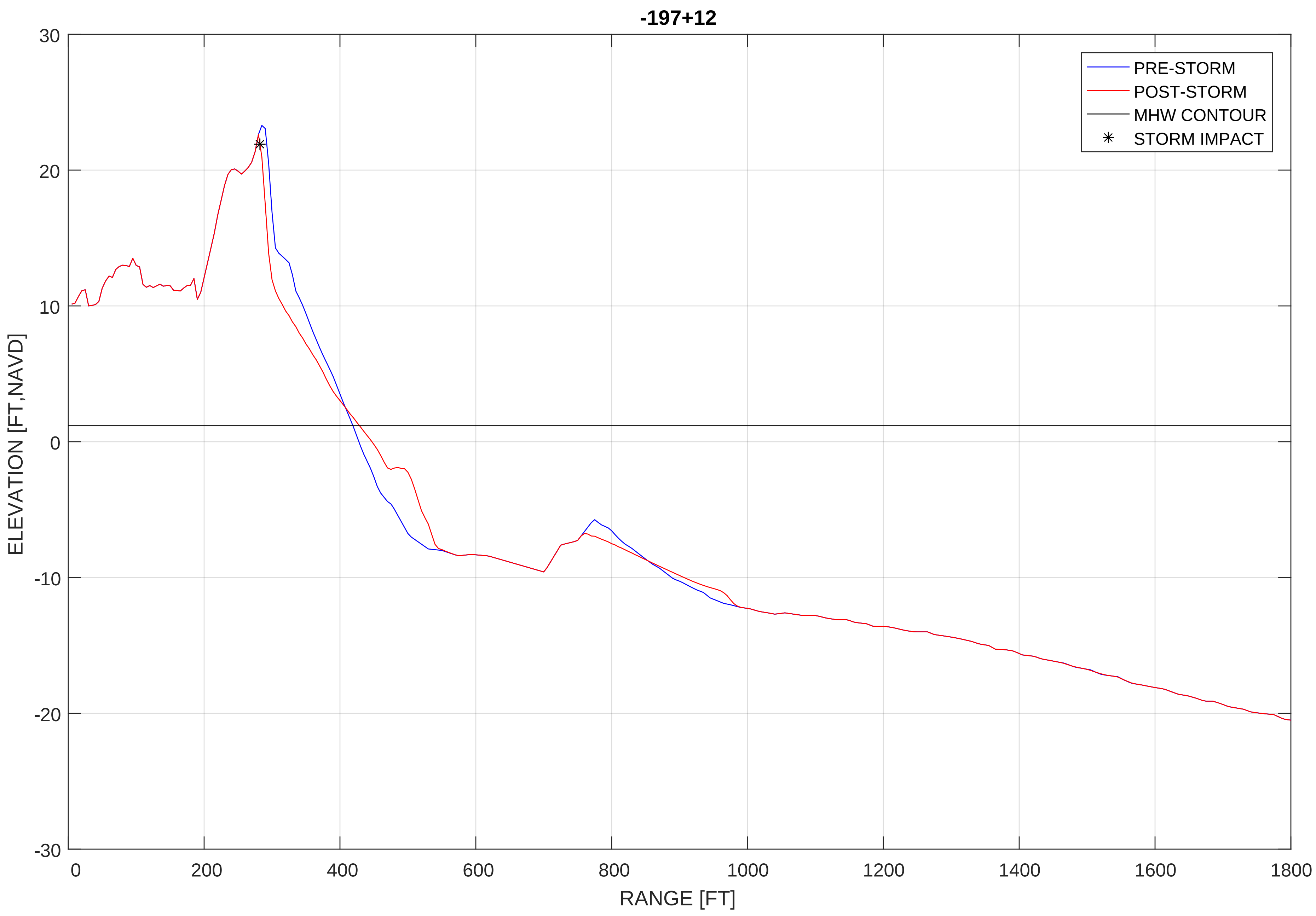
1200
1400
1600
1800

PRE-STORM AND POST-STORM SBEACH PROFILE CROSS SECTIONS
Scenario 14 (Isabel Storm with 2048 Sea Level – Assumes highest greenhouse gas concentrations trajectory used by IPCC for AR5 – RCP 8.5 and spring tides)



-197+12
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
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10
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-30
ELEVATION [FT,NAVD]
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400
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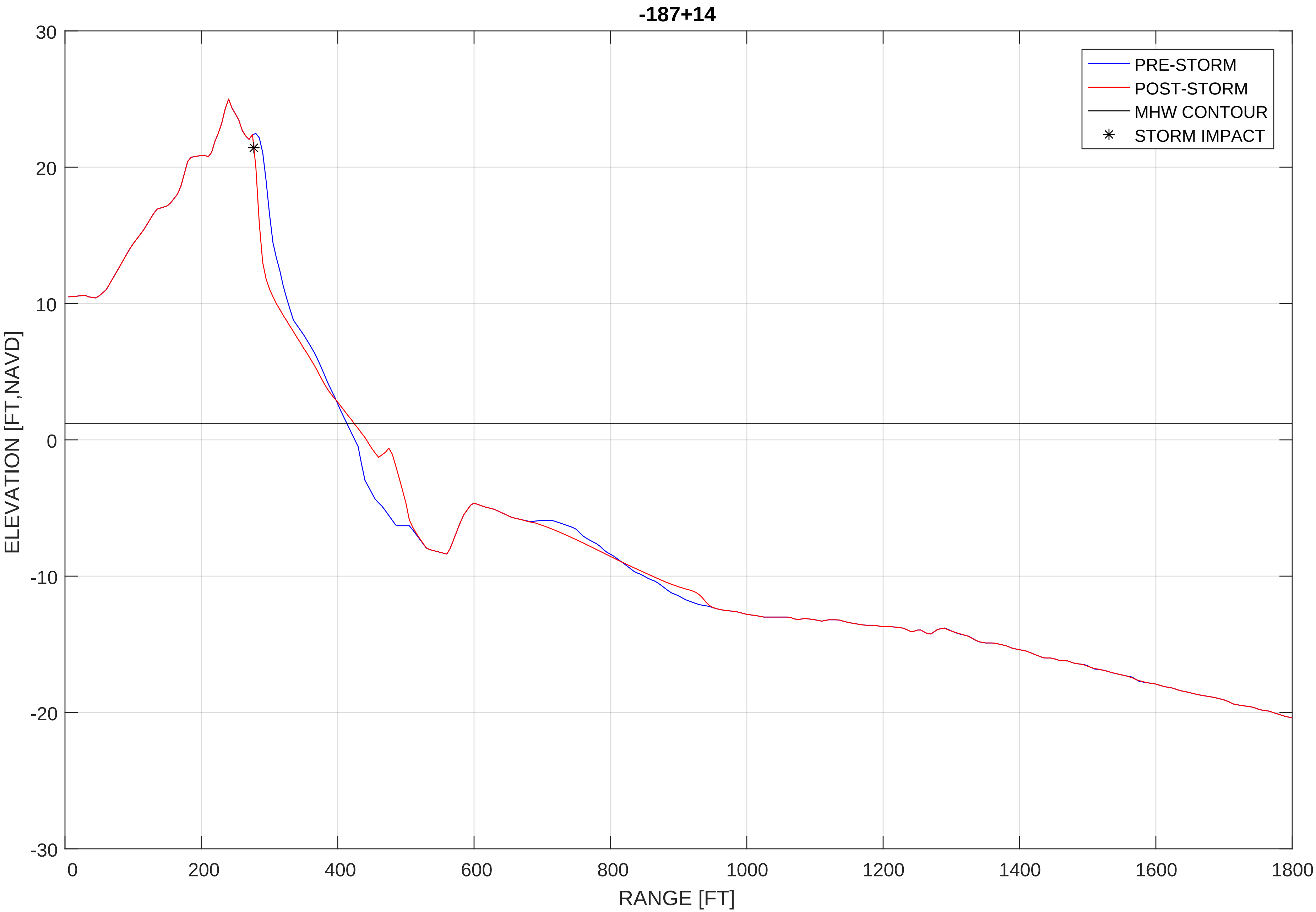
800
1000
1200
1400
1600
1800
RANGE [FT]



-187+14
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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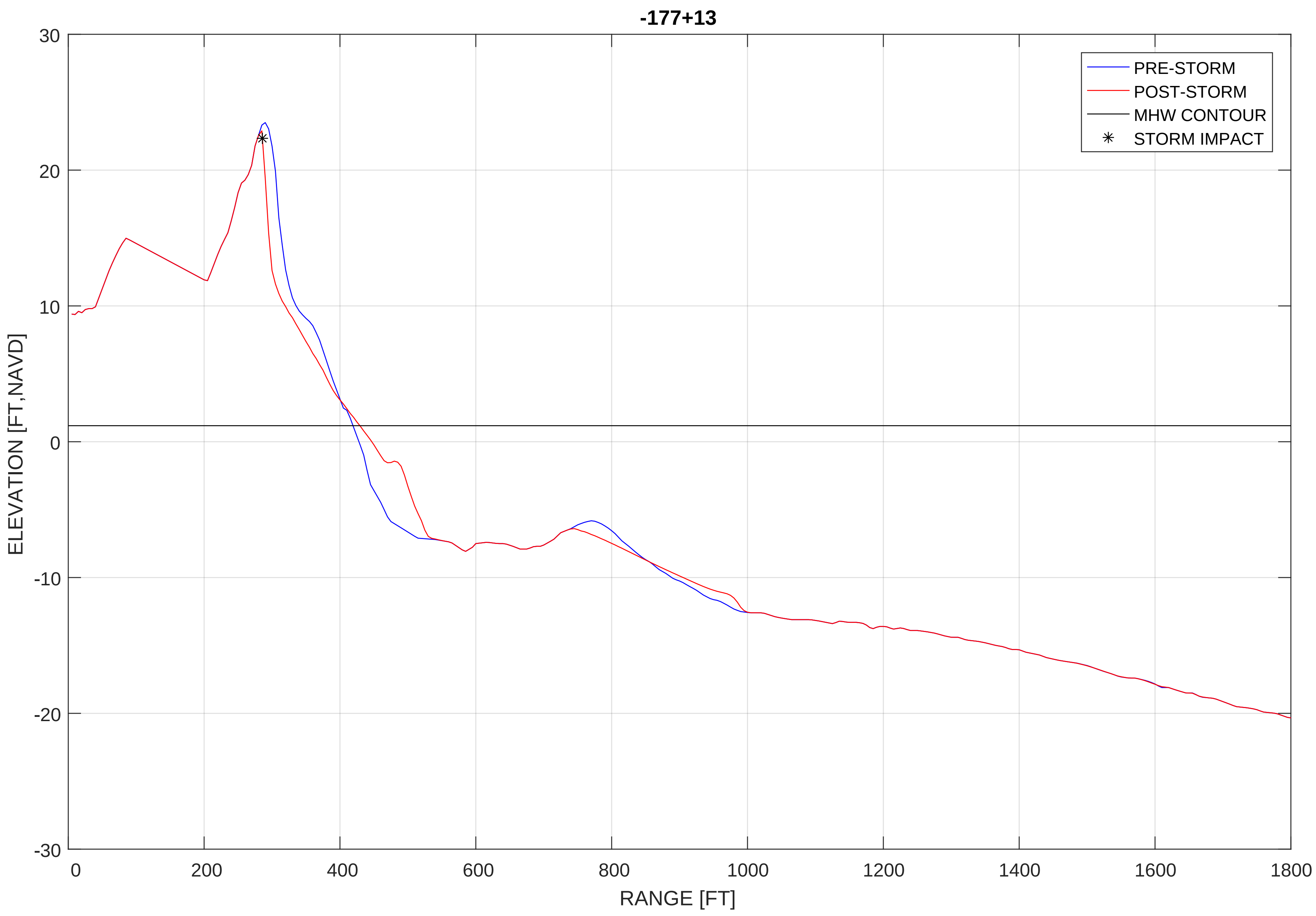
1800



-177+13
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
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1200
1400
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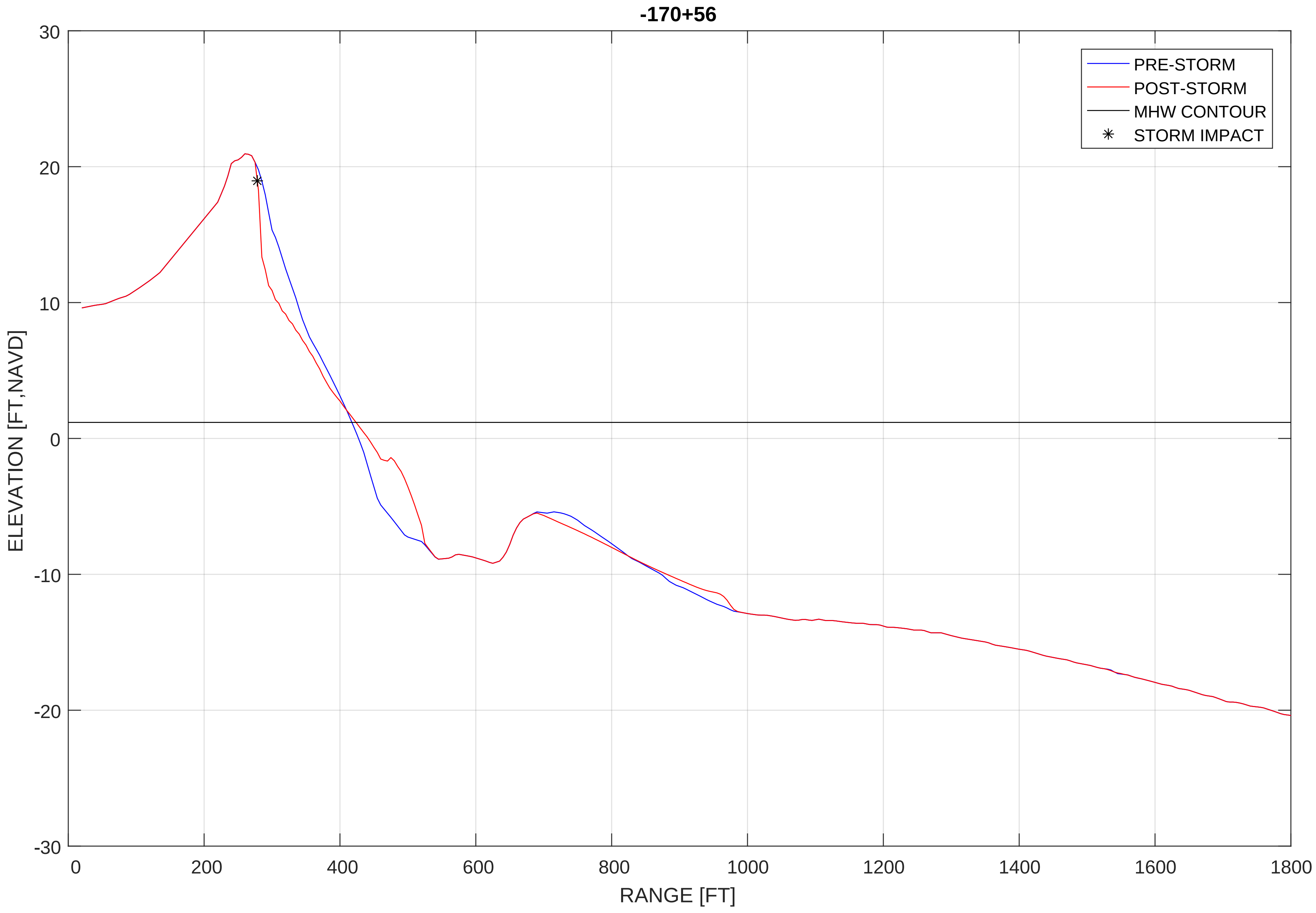
1800
ELEVATION [FT,NAVD]
RANGE [FT]



-170+56
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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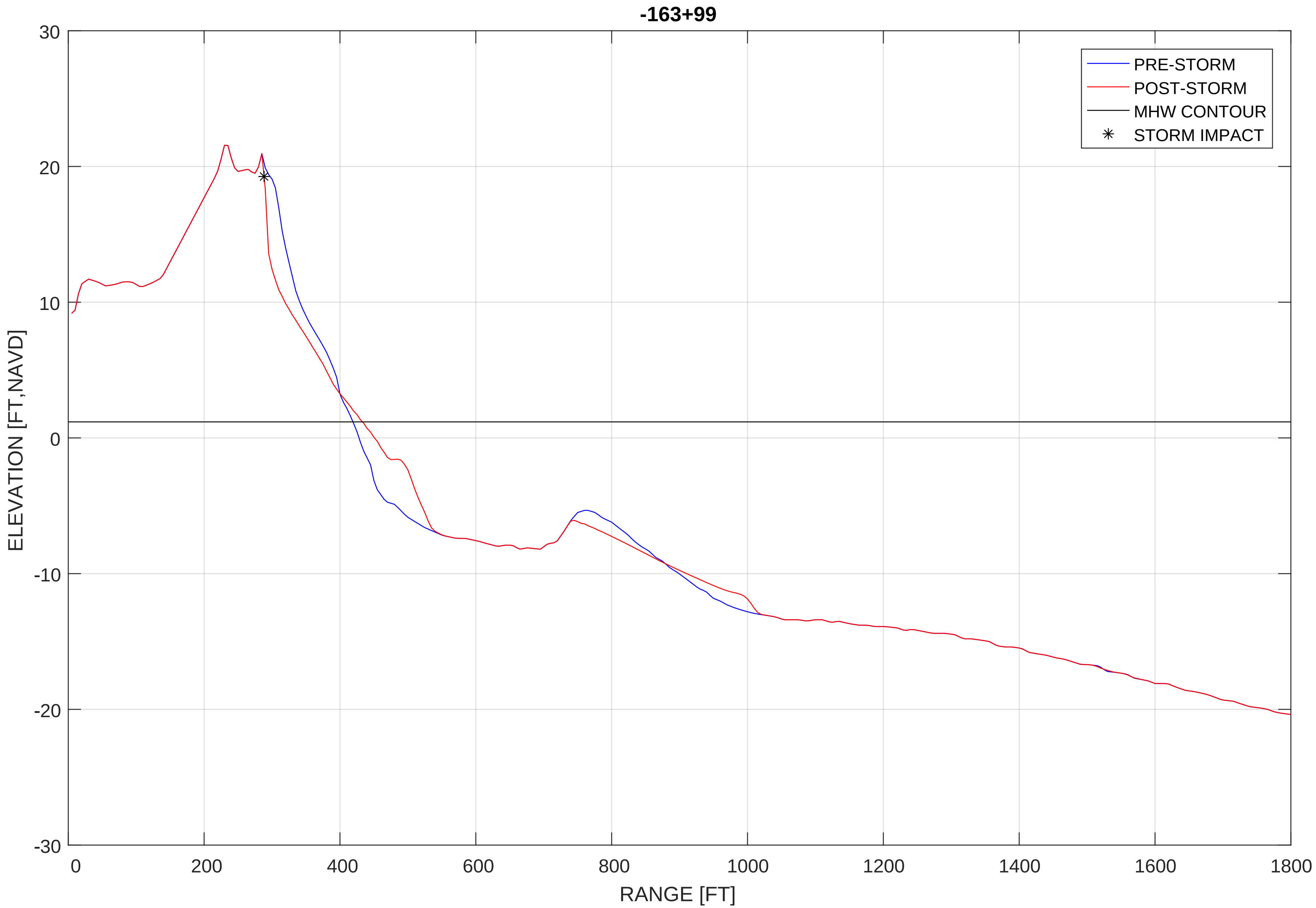

-163+99
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
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1200
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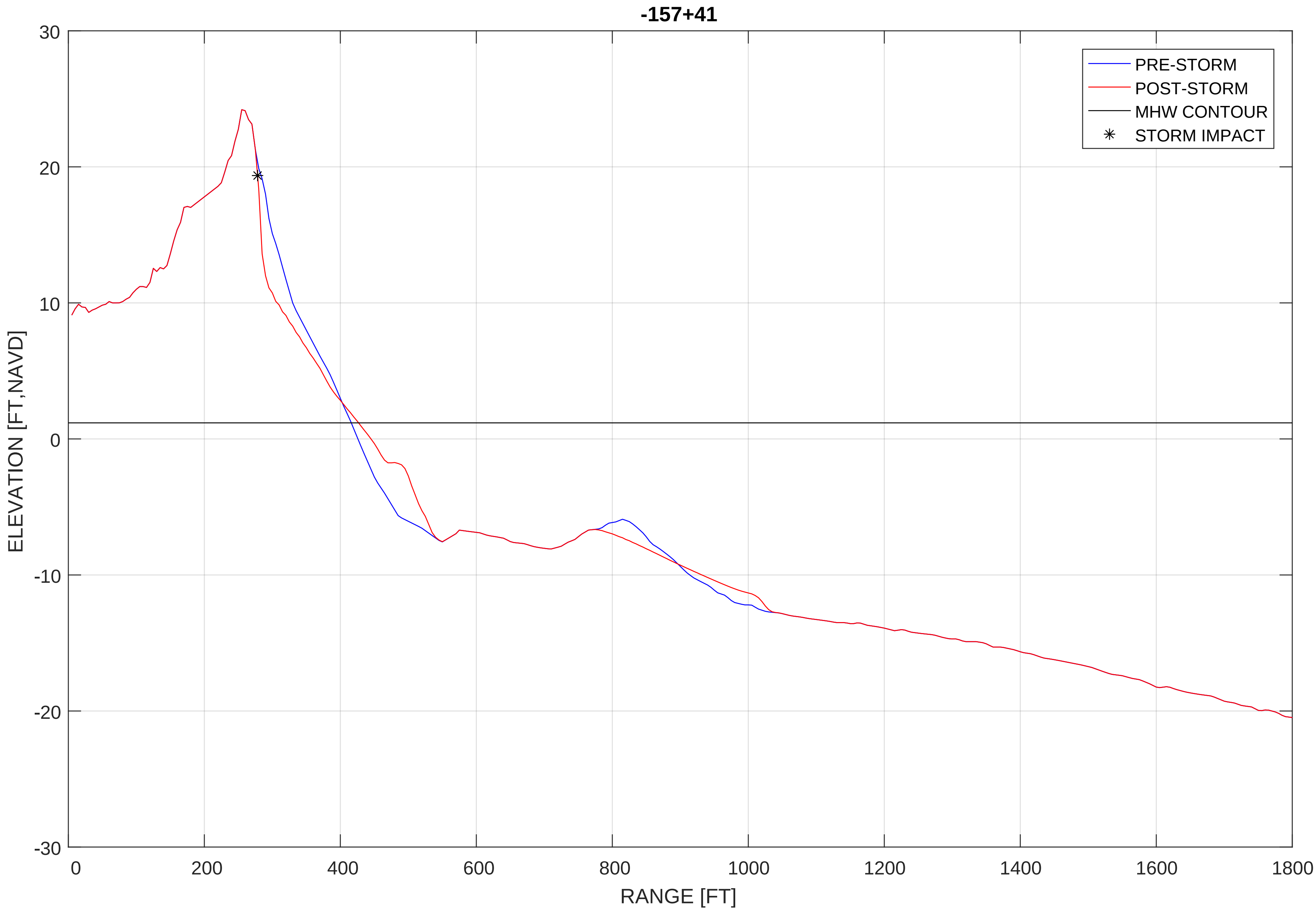
1600
1800
RANGE [FT]


-157+41
ELEVATION [FT,NAVD]
RANGE [FT]
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
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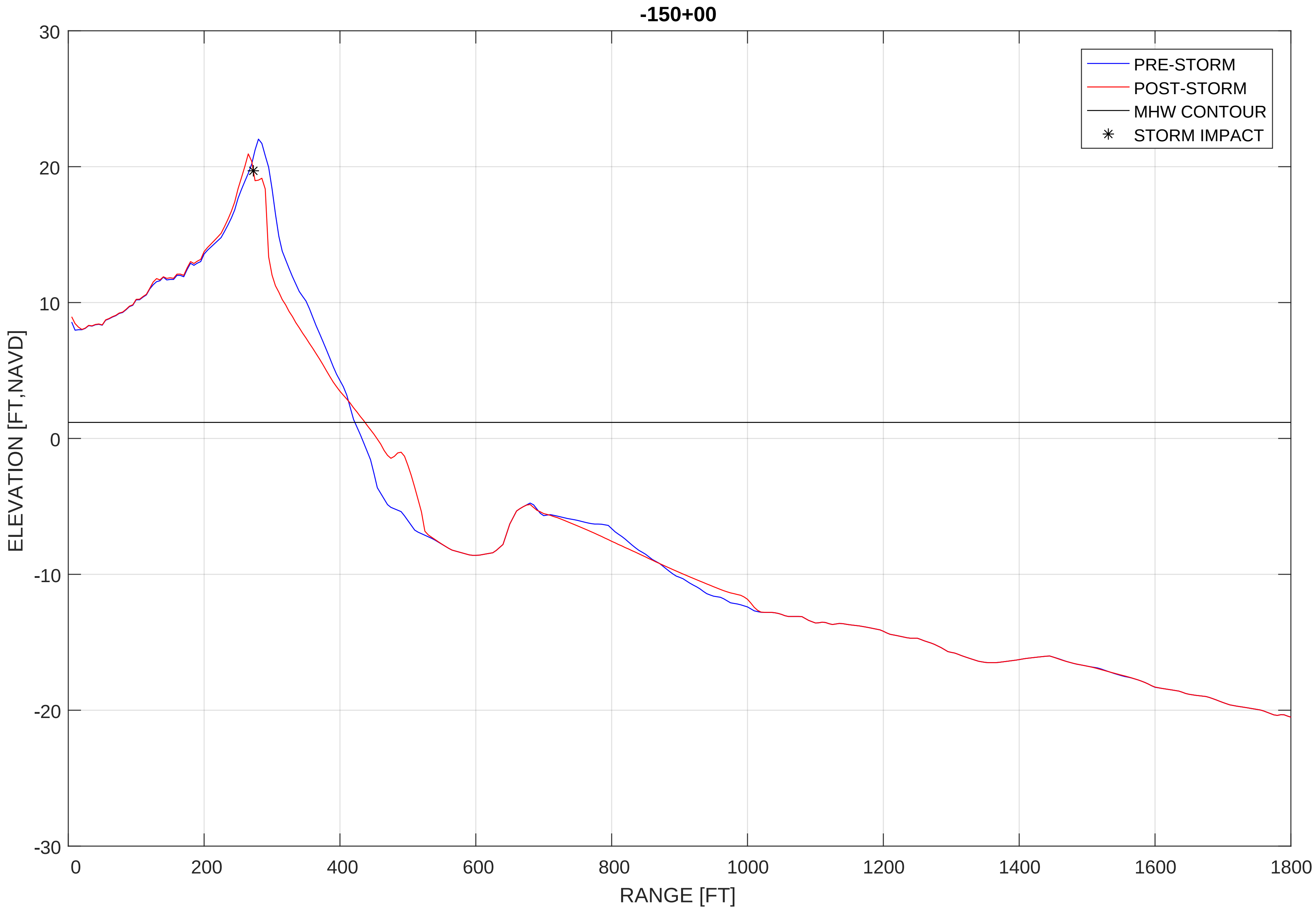

-150+00
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-30
ELEVATION [FT,NAVD]
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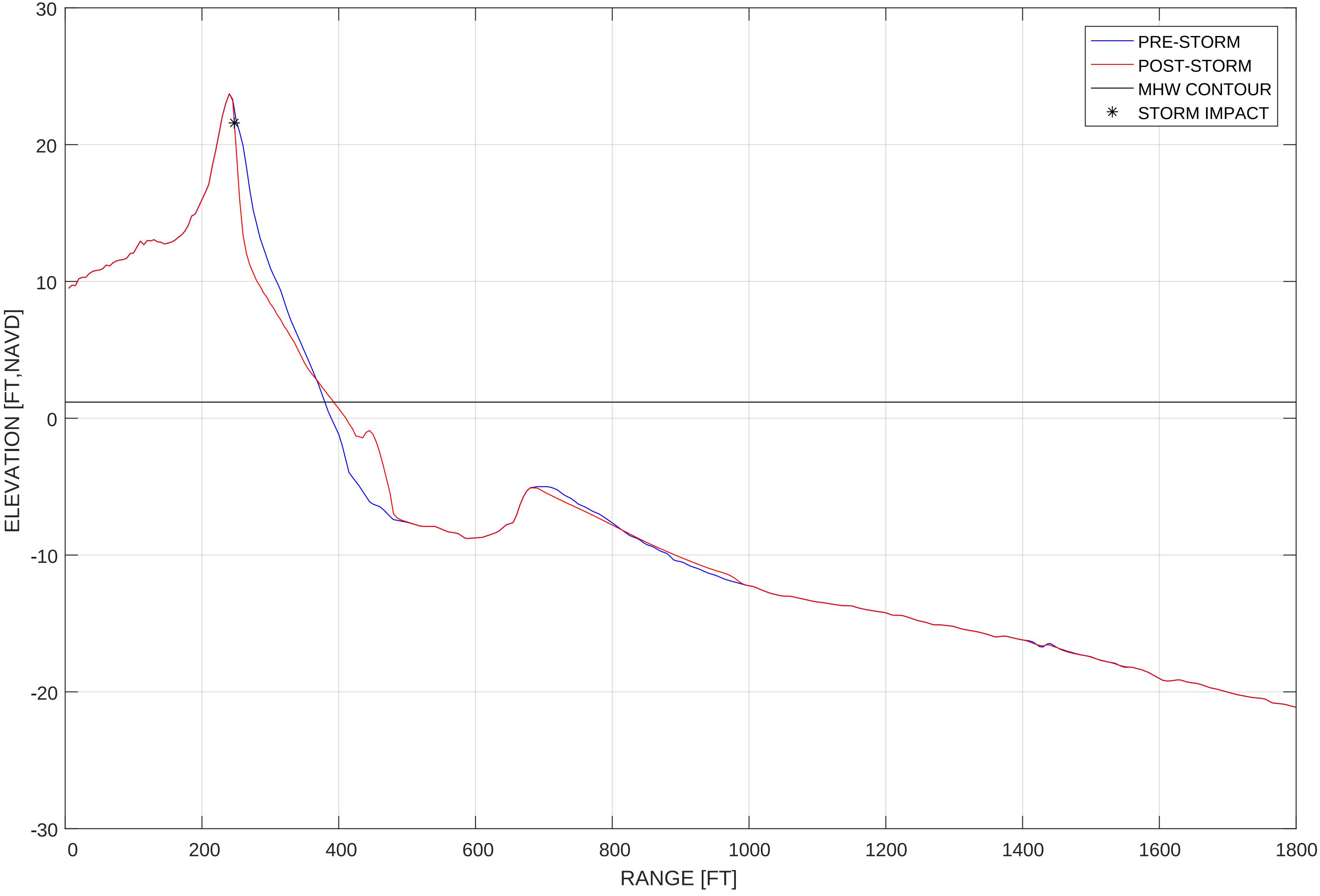
1600
1800
RANGE [FT]
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT

-140+00



PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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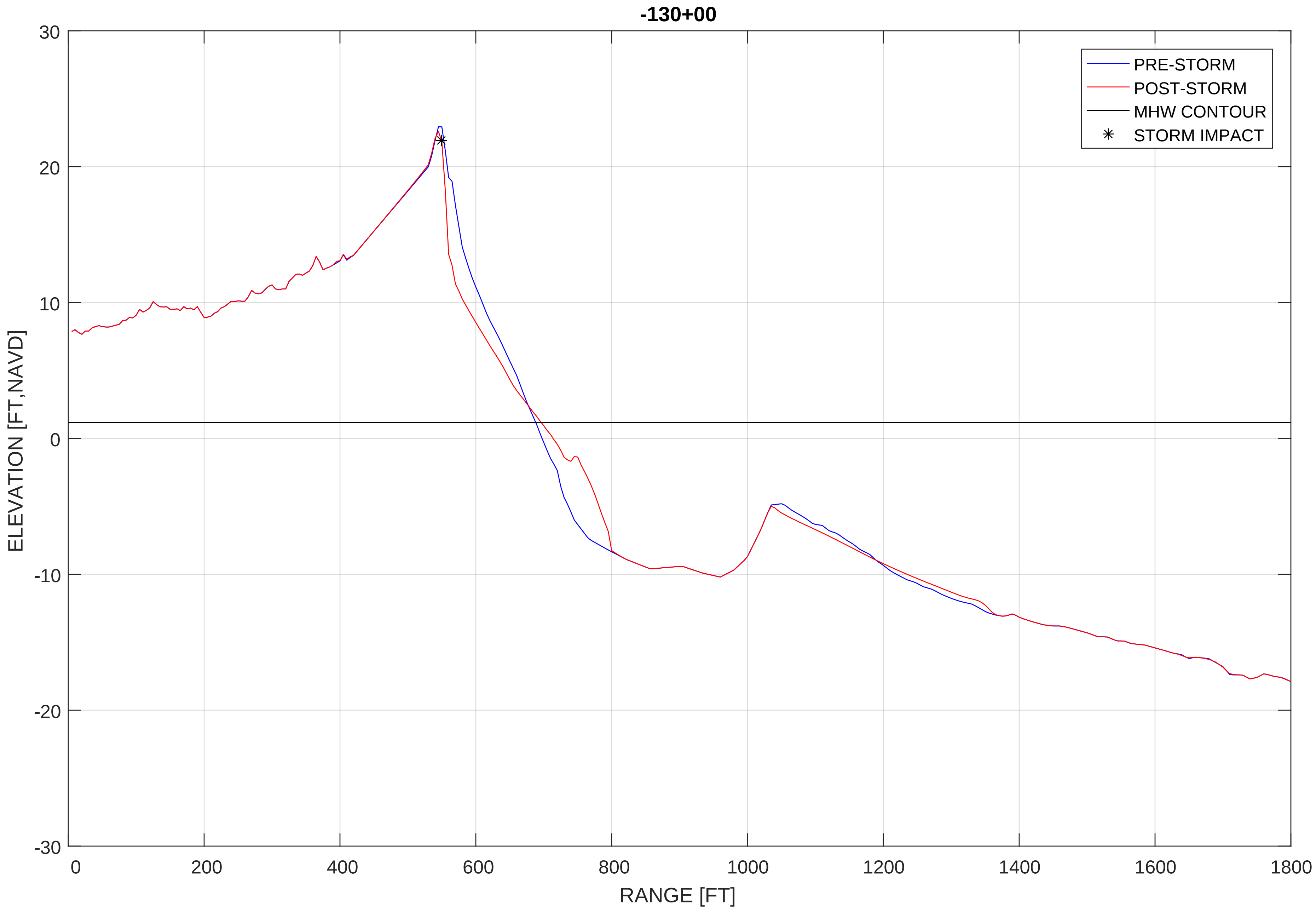

-130+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
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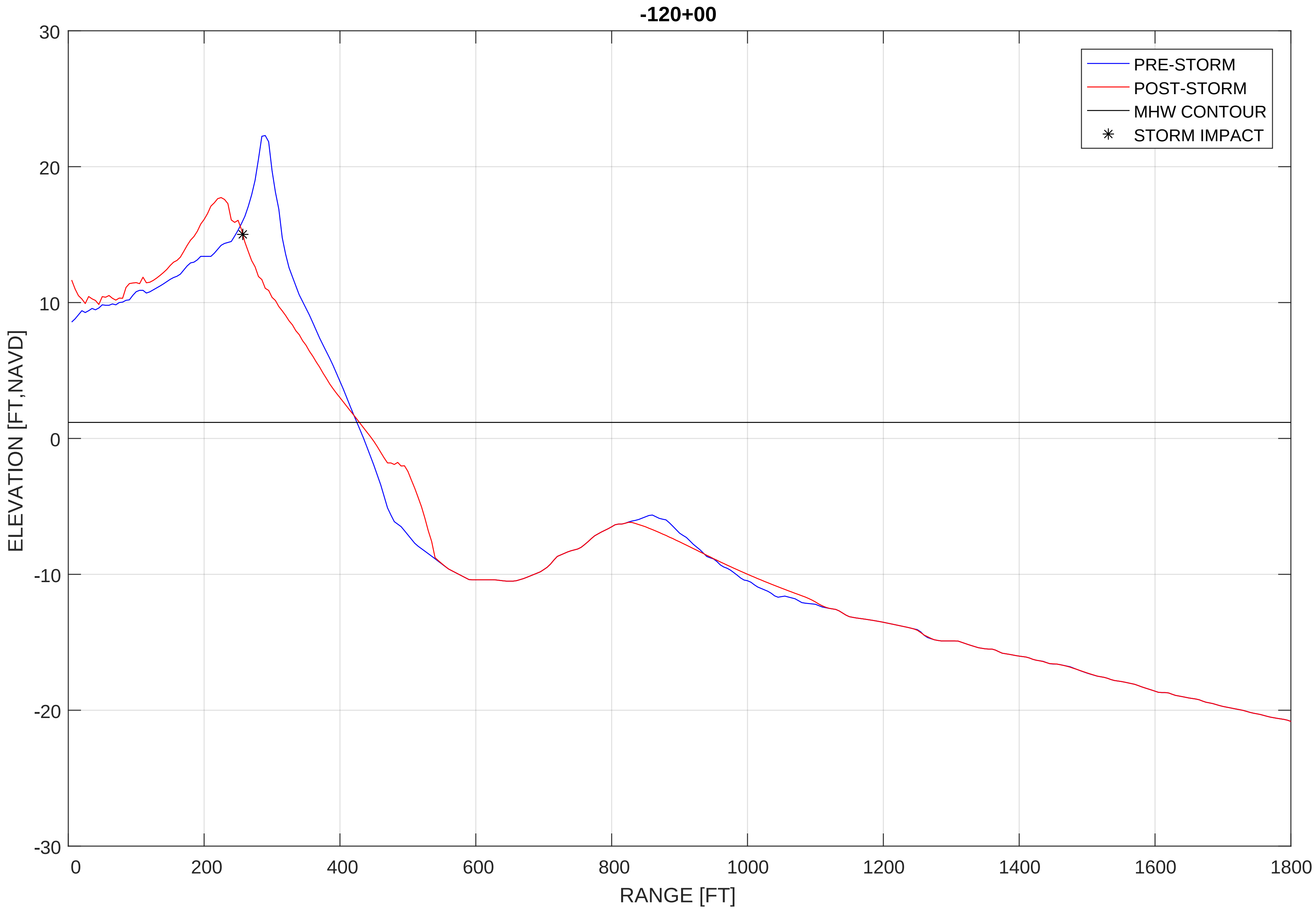
ELEVATION [FT,NAVD]
RANGE [FT]


-120+00
ELEVATION [FT,NAVD]
RANGE [FT]
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
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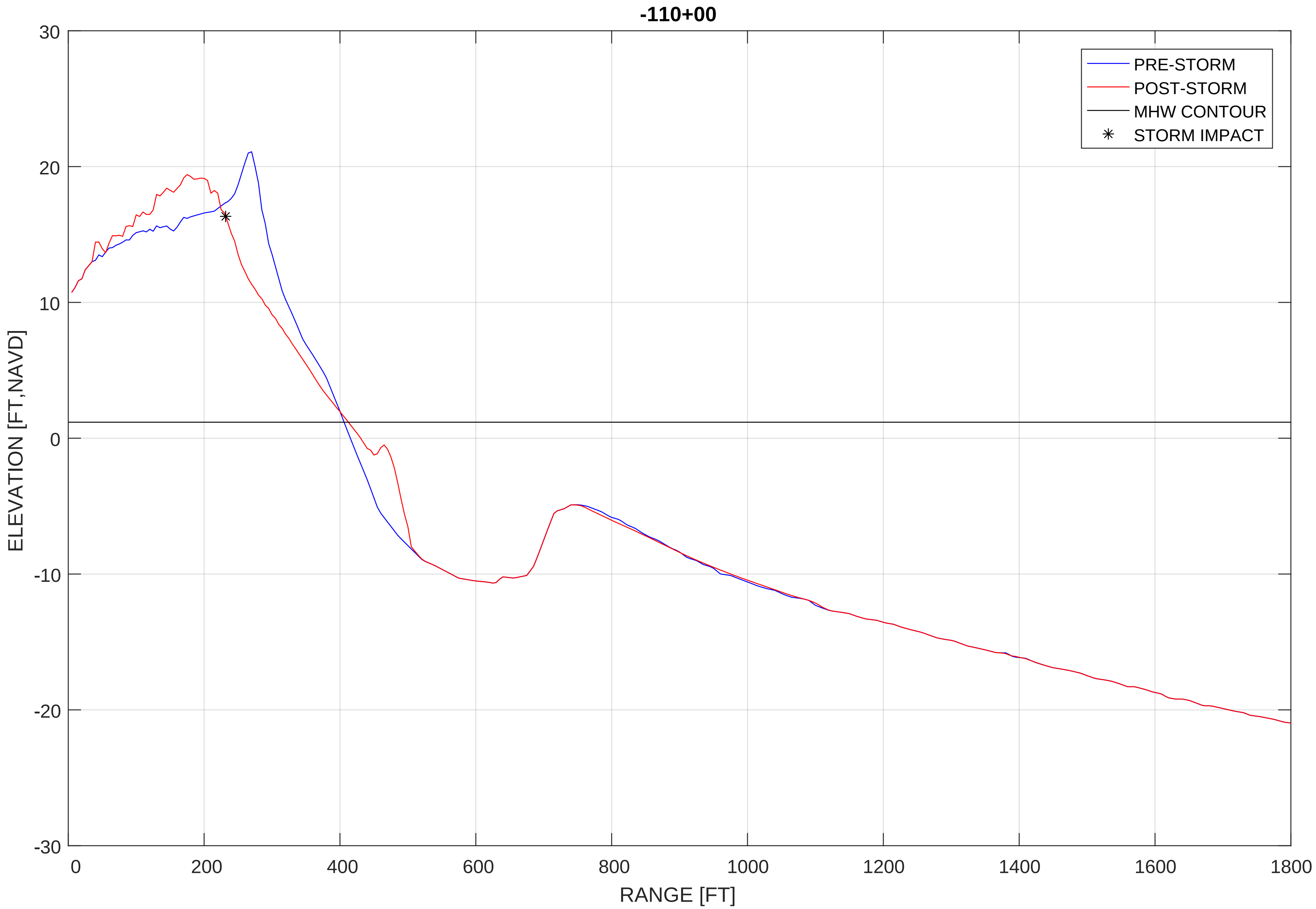

-110+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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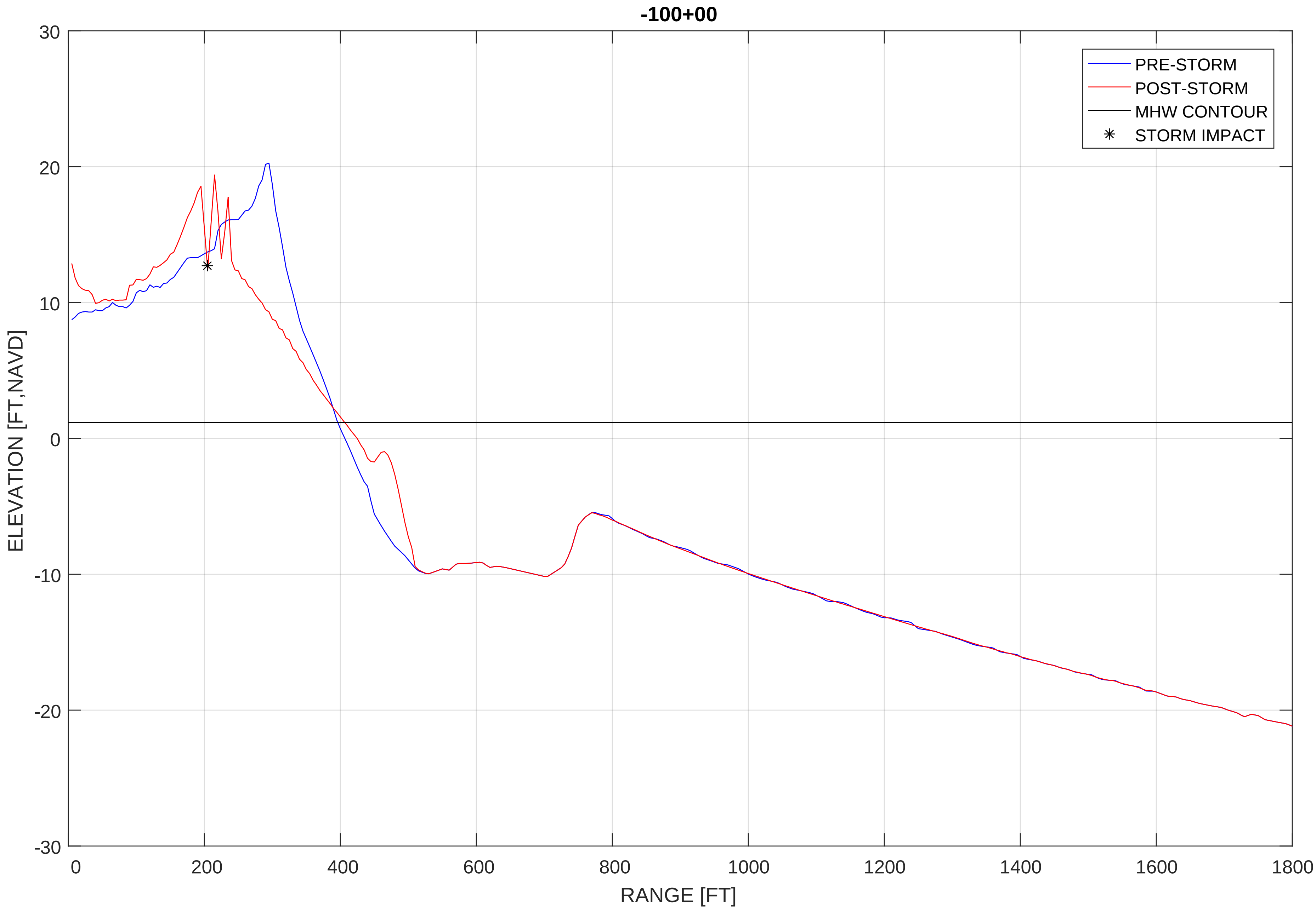

-100+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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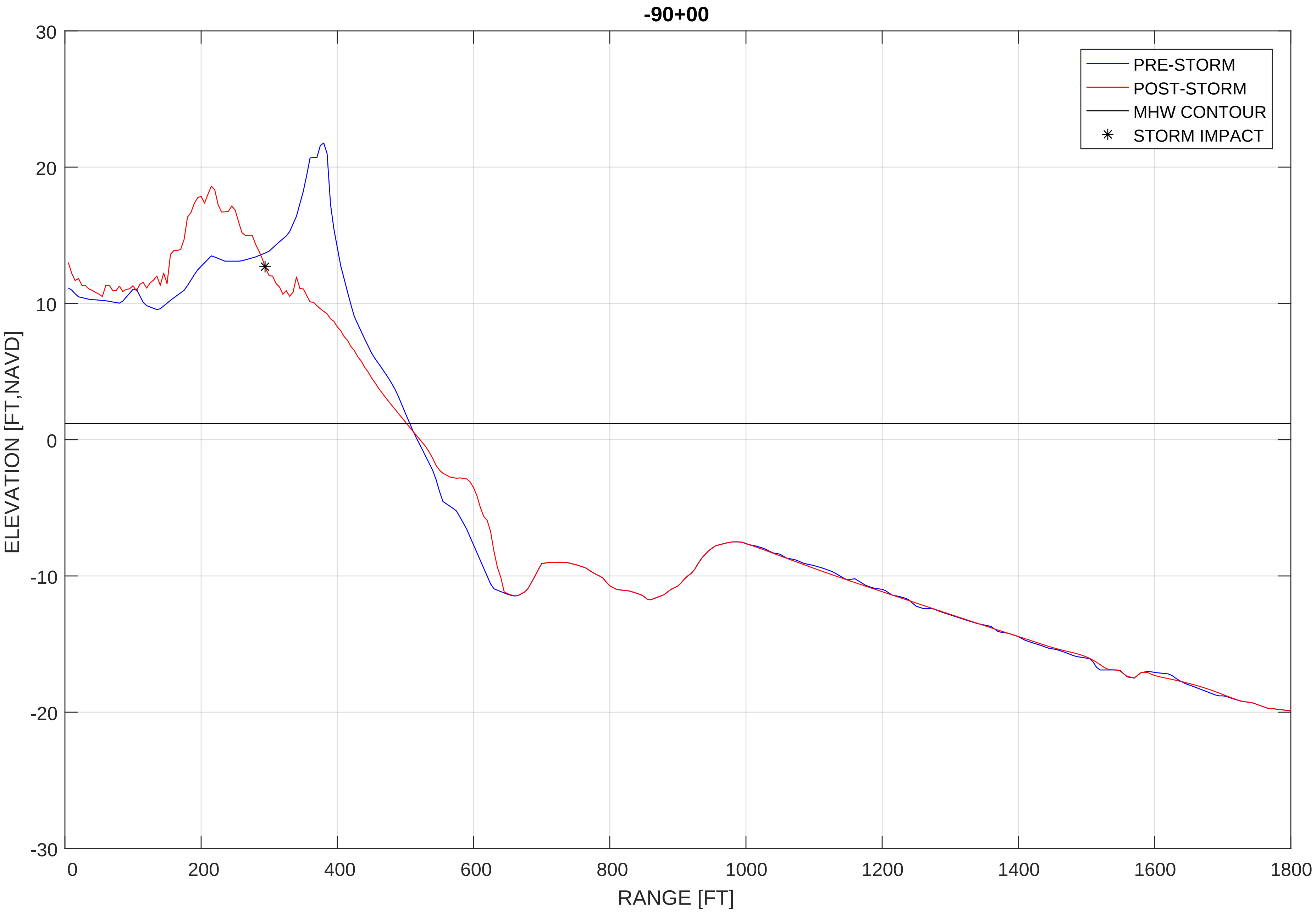

-90+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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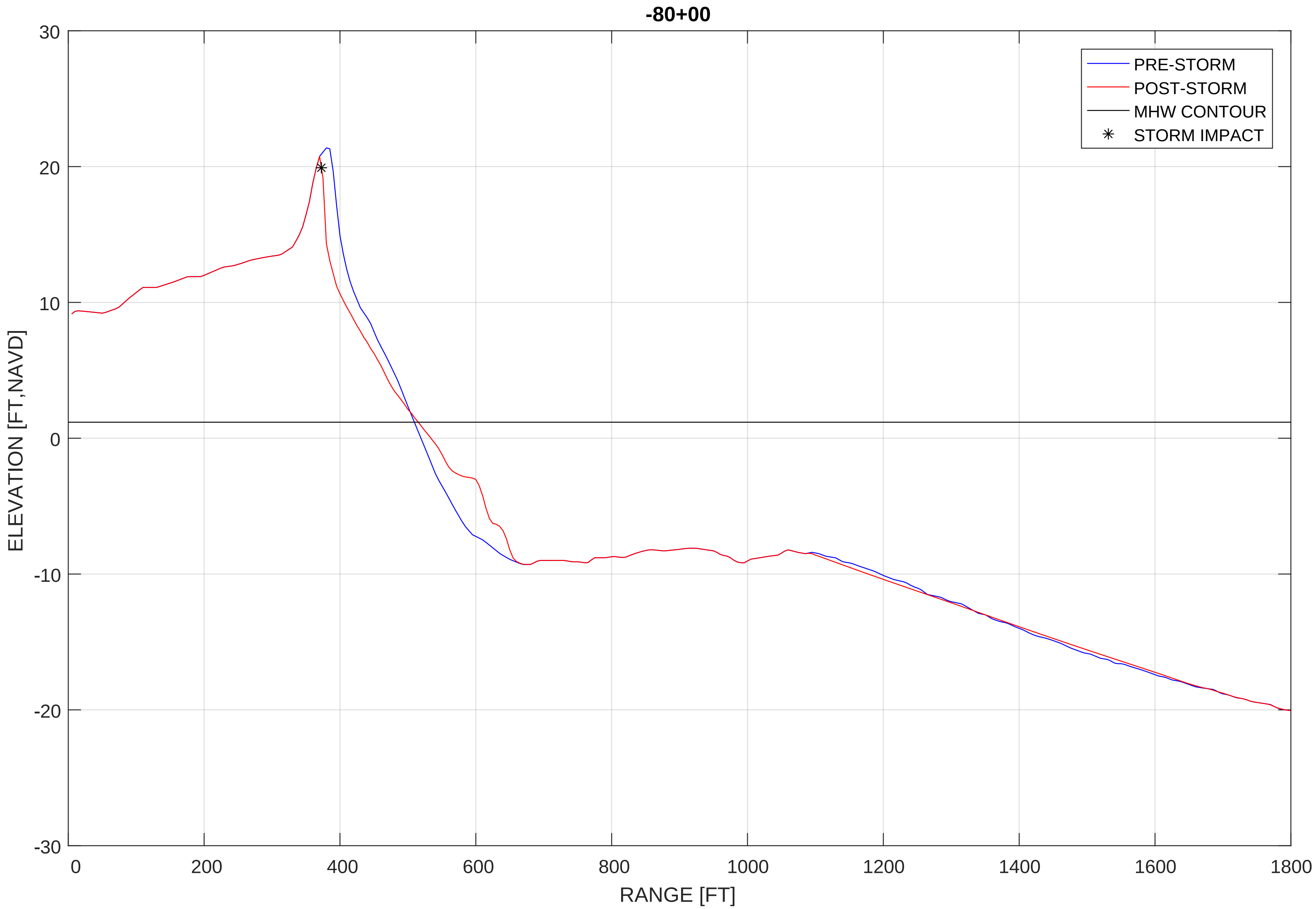
-80+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
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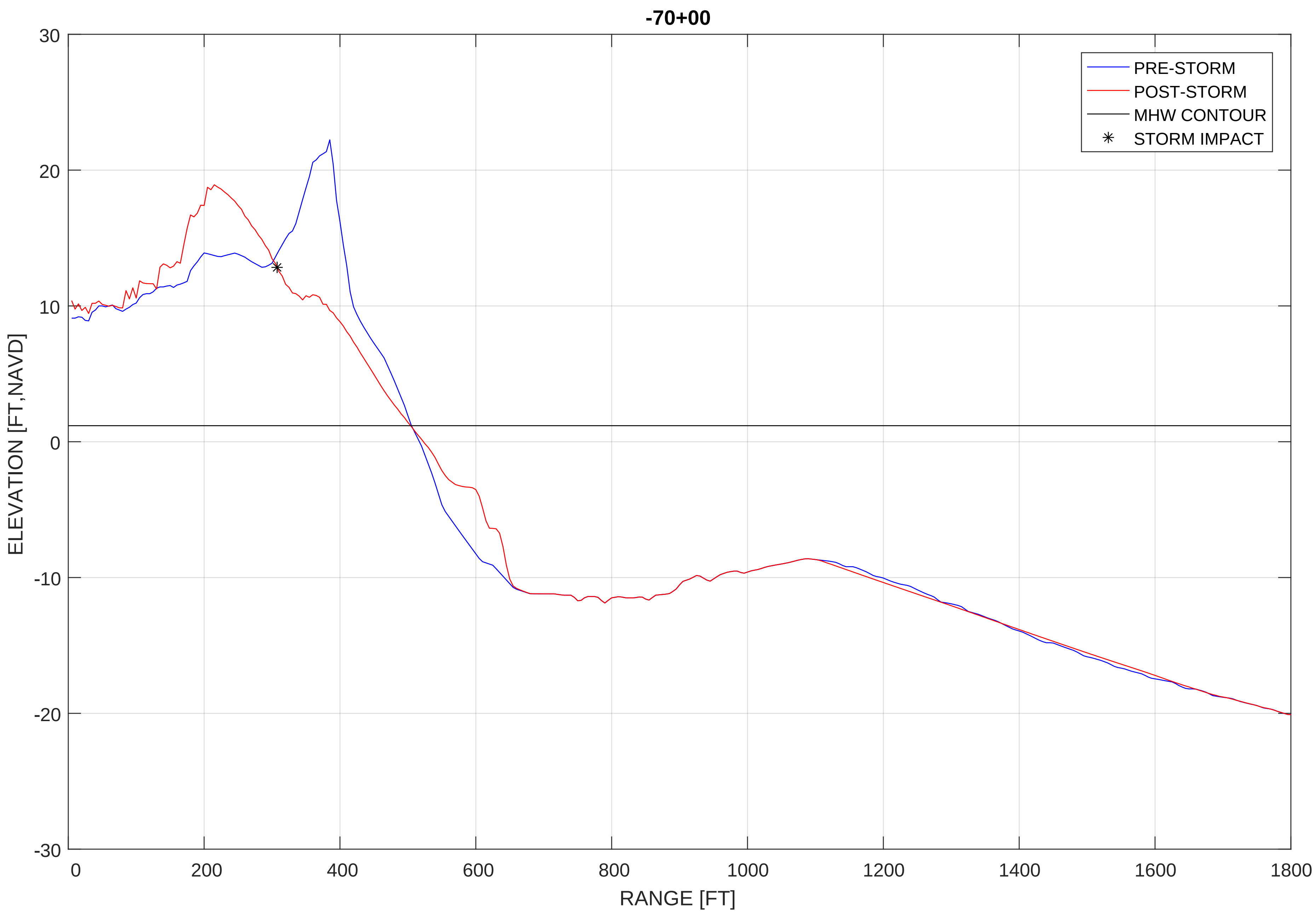
ELEVATION [FT,NAVD]
RANGE [FT]



-70+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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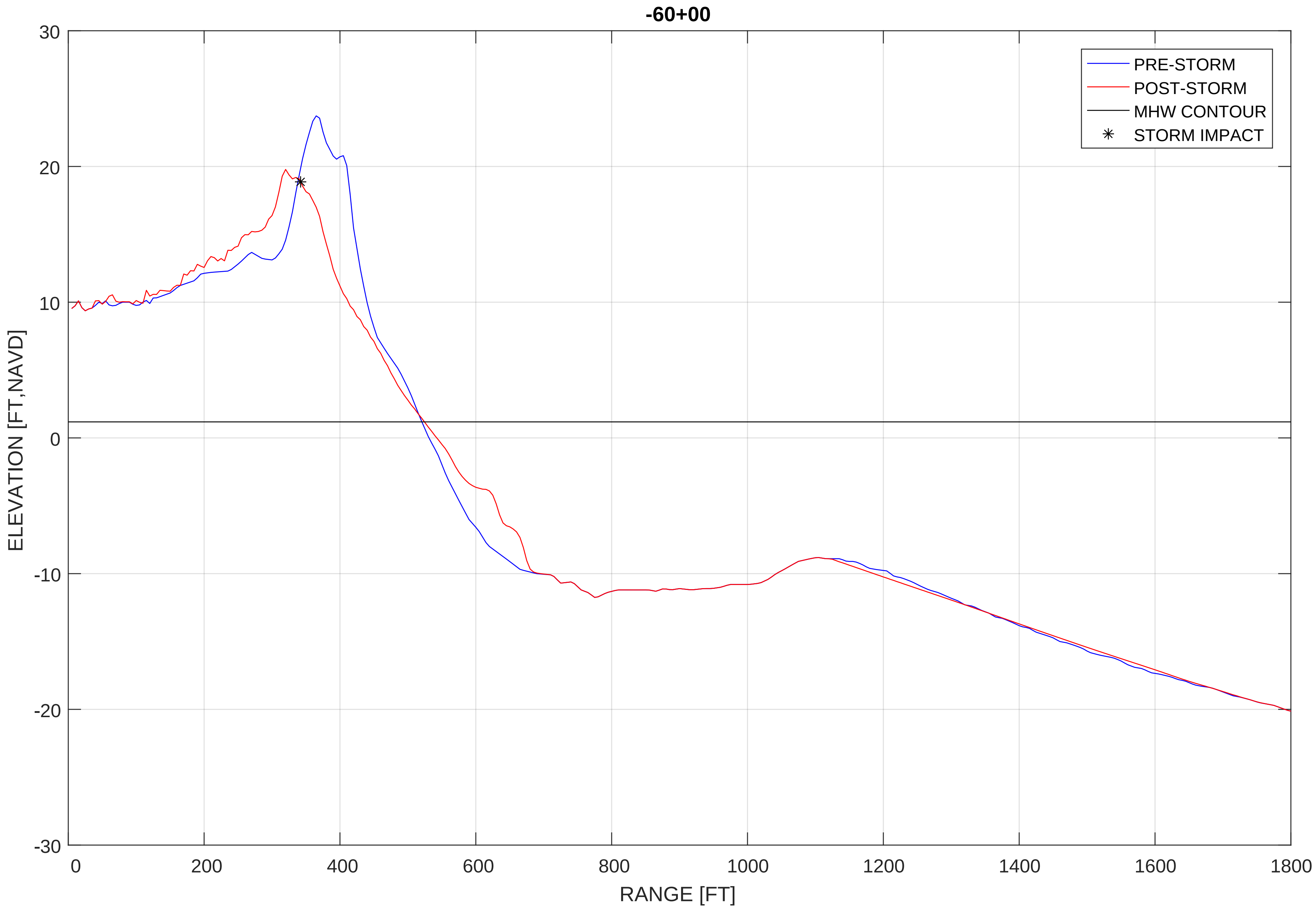

-60+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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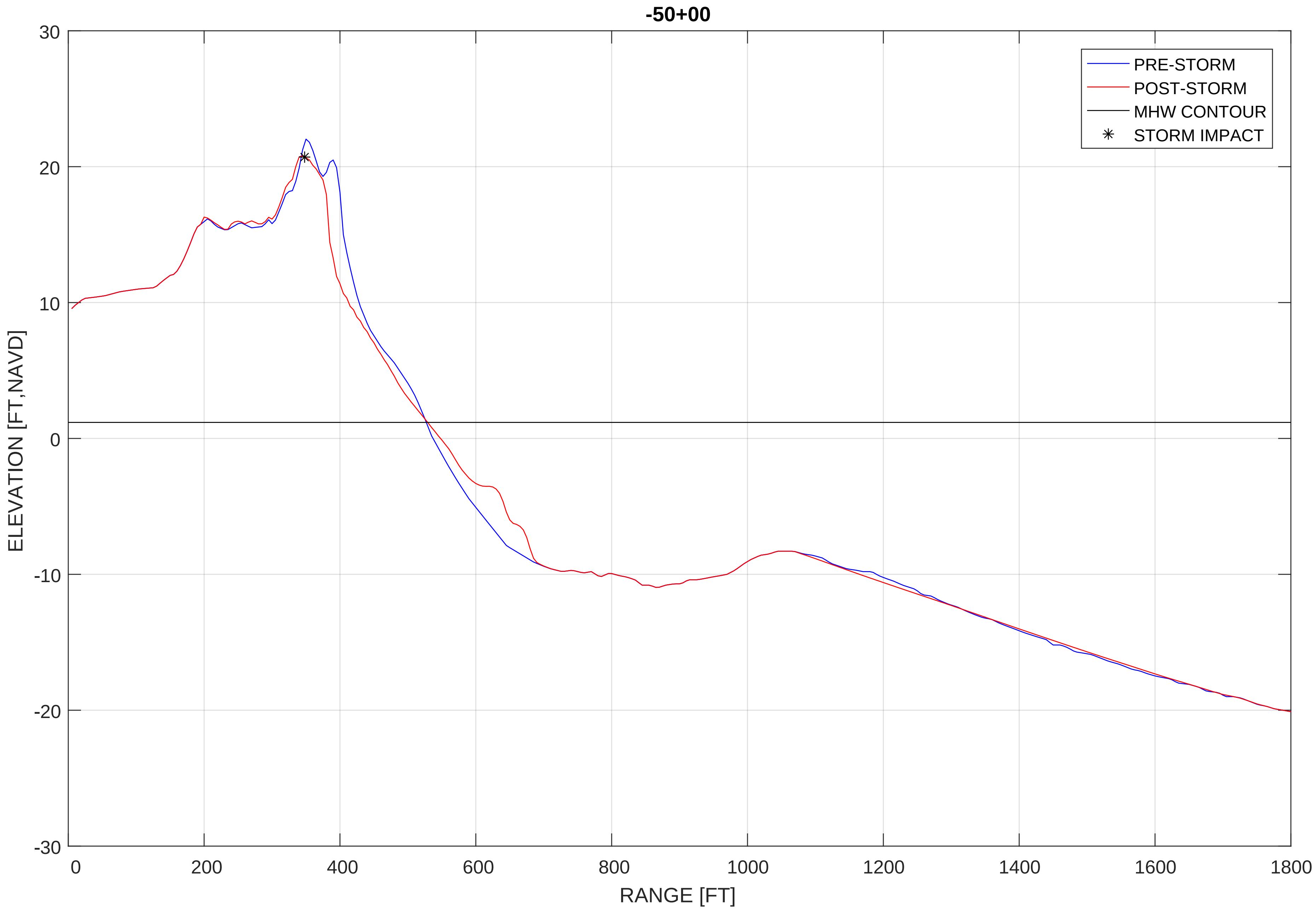

-50+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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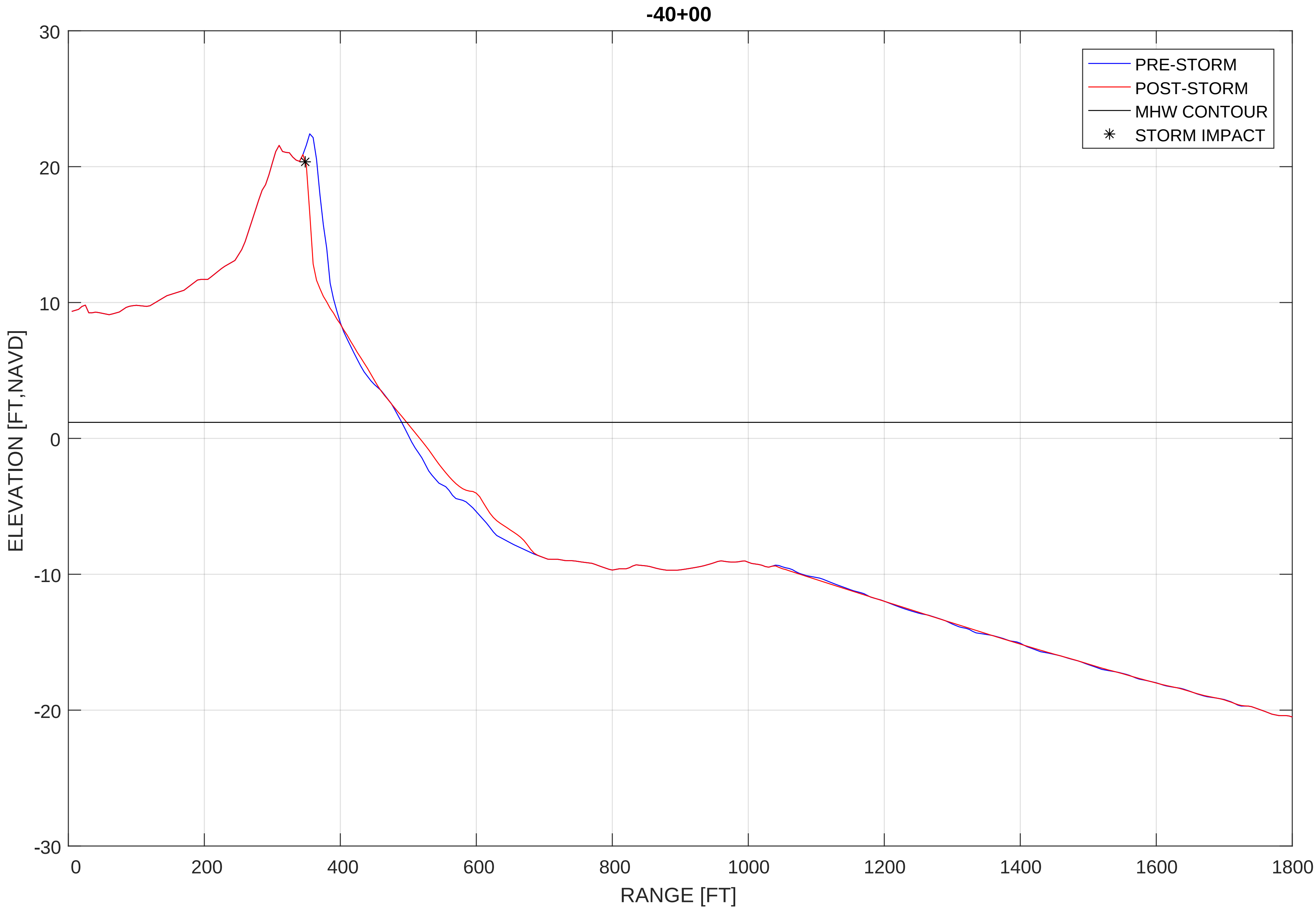
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PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
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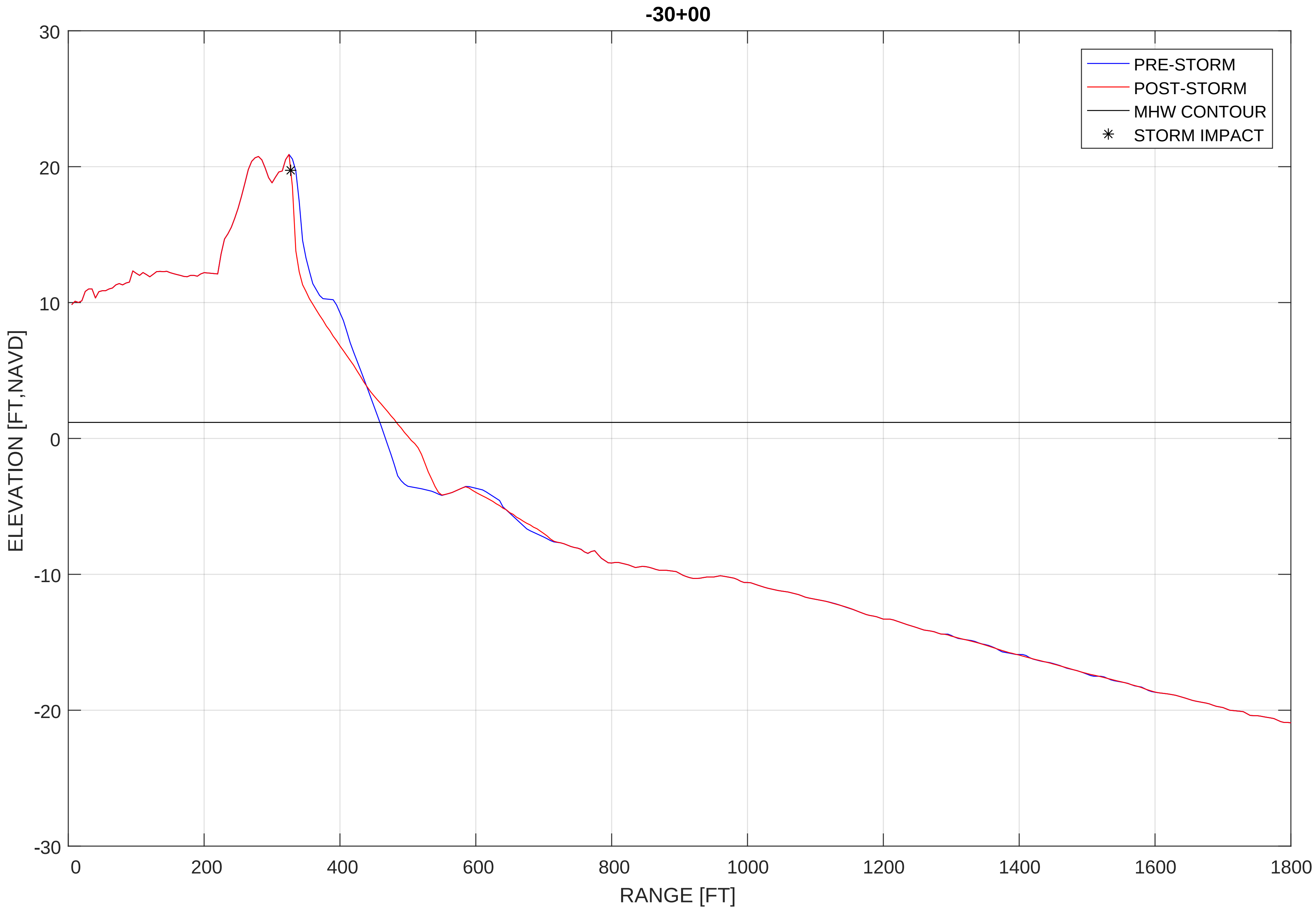
-30+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
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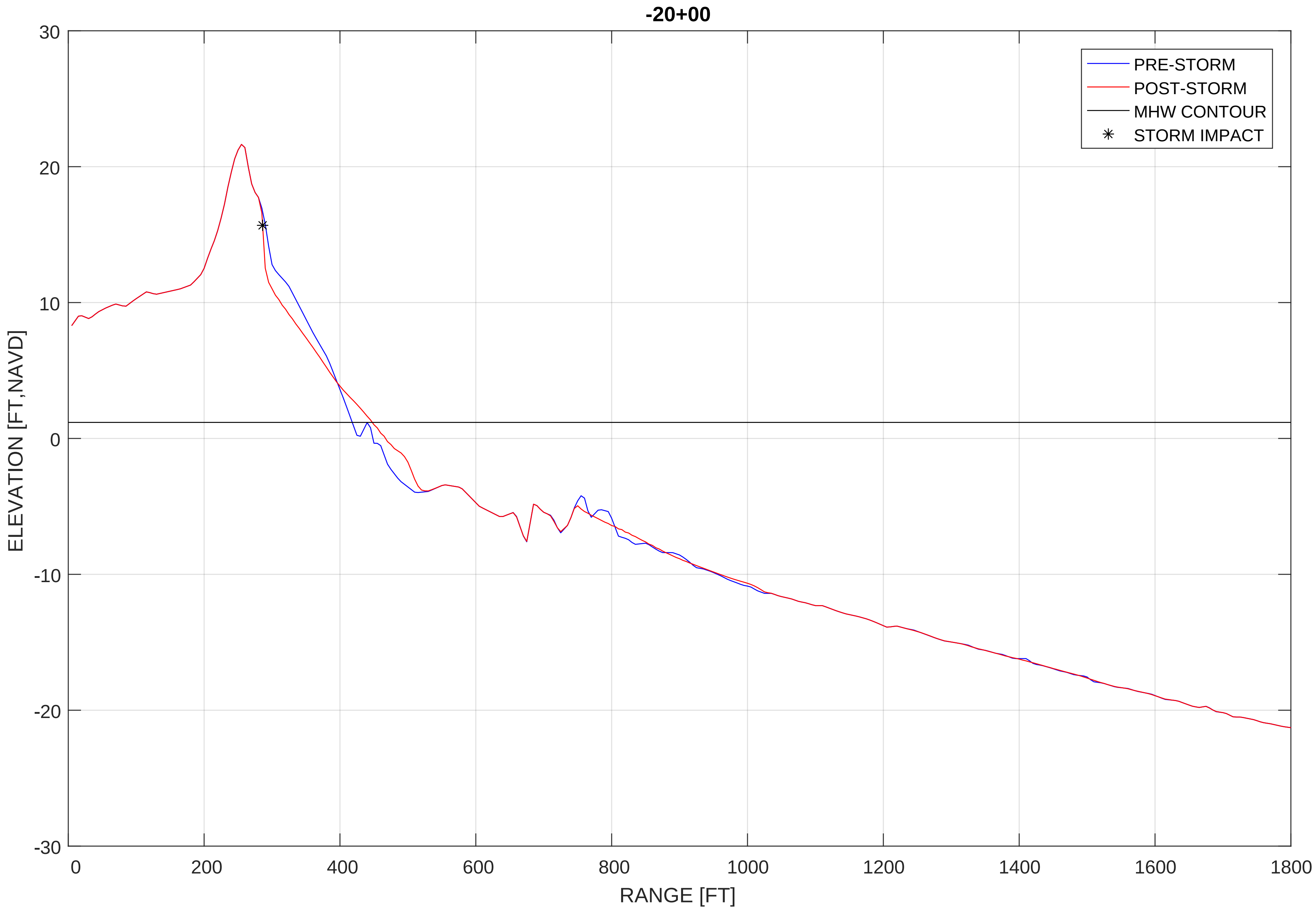
-20+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
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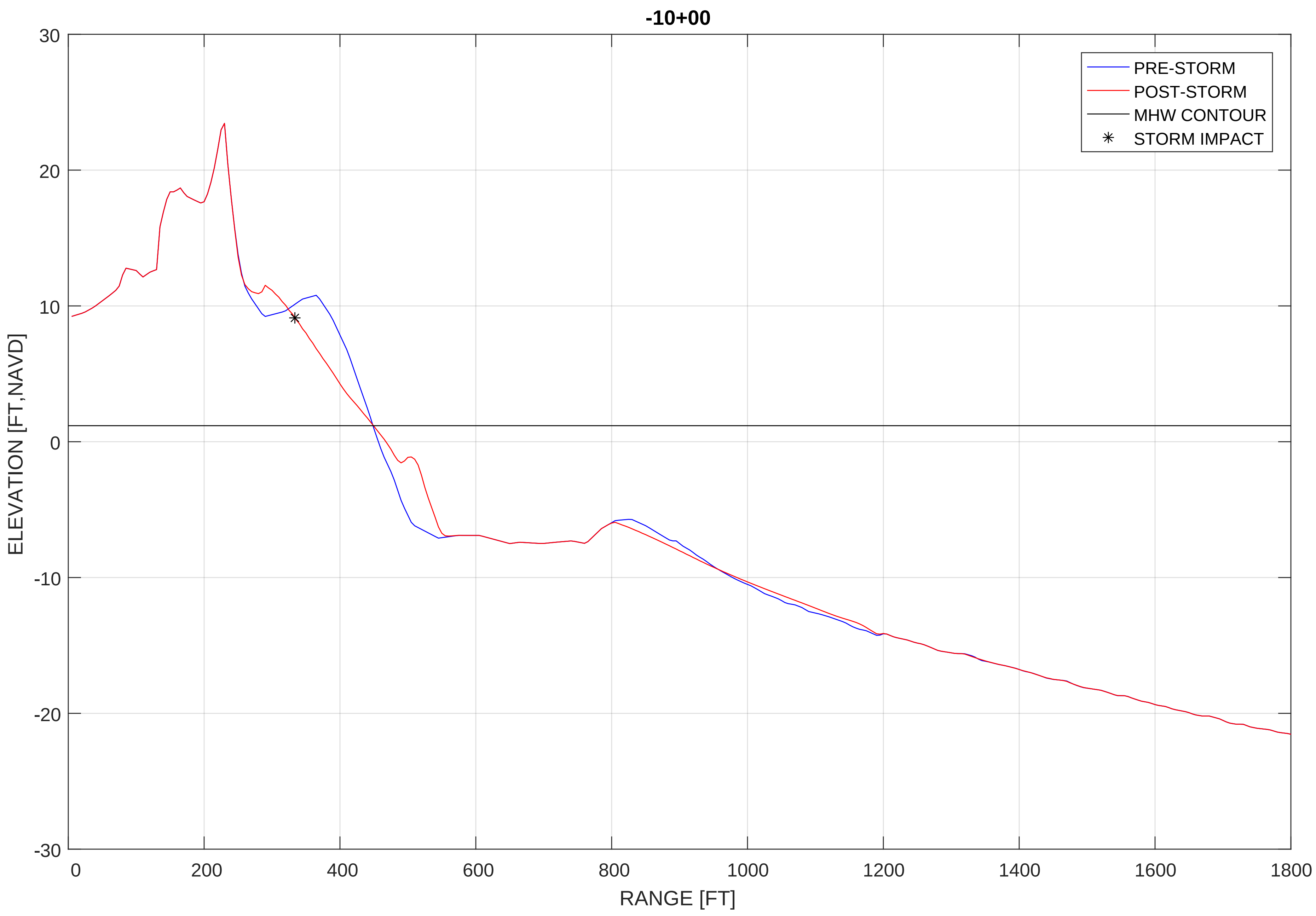

-10+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
ELEVATION [FT,NAVD]
RANGE [FT]
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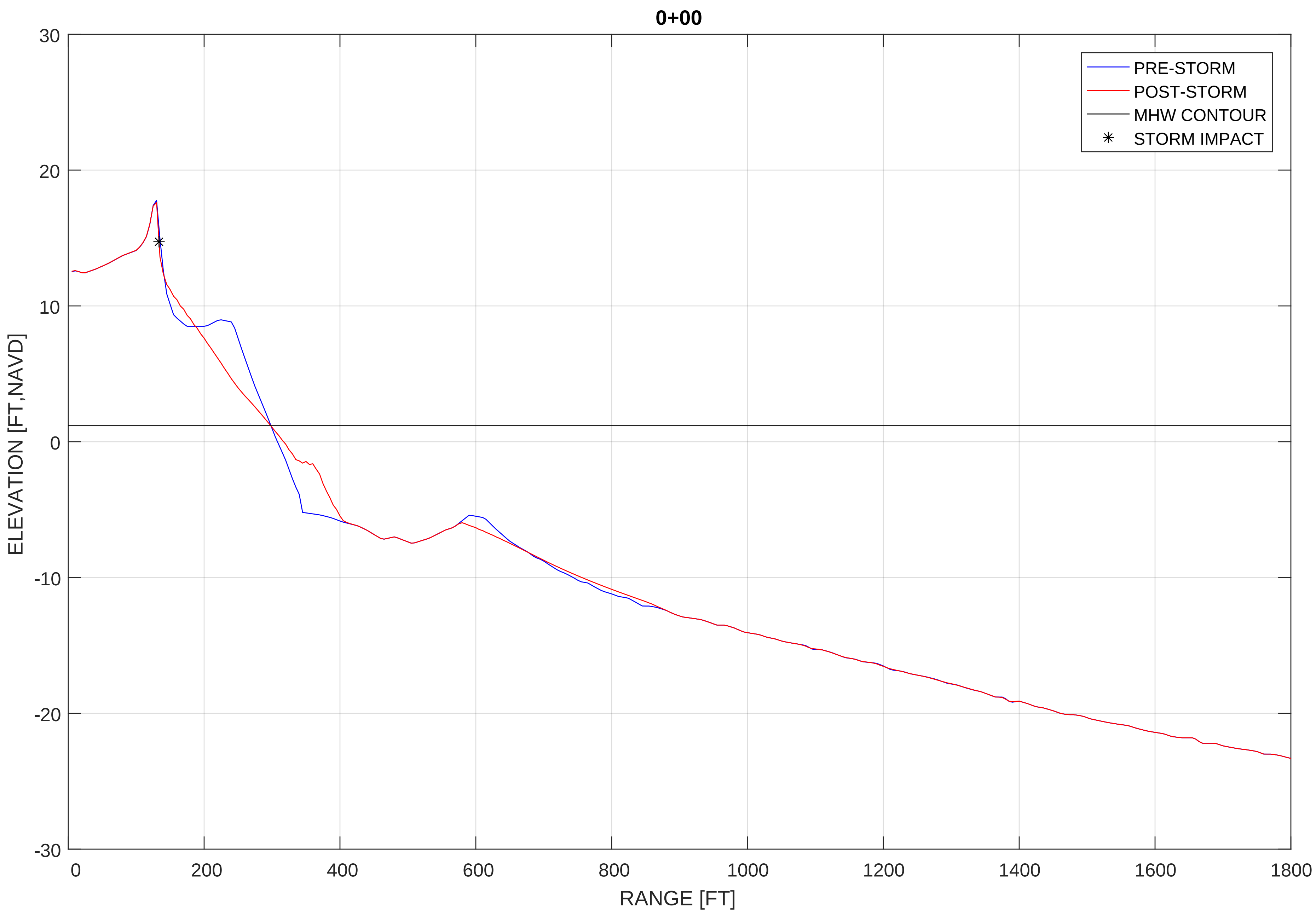

0+00
PRE-STORM
POST-STORM
MHW CONTOUR
STORM IMPACT
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ELEVATION [FT,NAVD]
RANGE [FT]