

**FINAL: TOWN OF DUCK NORTH CAROLINA  
2018 SHORELINE & VOLUME CHANGE  
MONITORING REPORT**



**SUBMITTED TO:**

**TOWN OF DUCK**

**SUBMITTED BY:**

**APTIM COASTAL PLANNING & ENGINEERING OF NORTH CAROLINA, INC.**

**September 2018**

# **TOWN OF DUCK 2018 SHORELINE & VOLUME MONITORING REPORT**

## **EXECUTIVE SUMMARY**

The Town of Duck is located on the Outer Banks of North Carolina, roughly 27 miles south-southeast of the North Carolina and Virginia border. The Town extends along 5.9 miles of Atlantic Ocean shoreline from the Dare County and Currituck County line south to the Town of Southern Shores.

Data collected in June 2018 was used to update shoreline and volume change analyses conducted during the feasibility study (CPE-NC, 2013) and the design analysis associated with the beach nourishment project (CPE-NC, 2015) as well as the previous monitoring report dated May 2018 (APTIM, 2018A).

Between May and June 2017, the Town of Duck constructed a beach nourishment project along 1.6 miles of its ocean shoreline. A total of approximately 1.26 million cubic yards of fill was distributed between Skimmer Way (station D-10) and the northern USACE Field Research Facility (FRF) property boundary (station D-19). As a result of this project, the analysis of shoreline and volume changes in the monitoring area, which extends from station PI-17 (on the south end of Pine Island) to station D-34 located near the southern Duck town limits, was divided into three areas in order to assess the performance of the beach fill project and its impacts on areas north and south of the project. The three areas are designated as: the Project Area (station D-10 to D-19), the area north of the project (PI-17 to D-10), and the area south of the project (D-19 to D-34).

For purposes of tracking the performance of the beach fill, the initial volume of material within the limits of the Project Area is defined as the volume change measured between April 2017 and December 2017. As noted in the report, beach fills undergo an initial period of adjustment during which time material is redistributed by wave action from the upper portion of the profile to deeper portions of the active profile as well as along the shore out of the placement area. This initial adjustment normally takes several months depending of wave conditions. Once the initial adjustments are completed, the beach fill should begin to mimic the behavior of the native beach. The April 2017 and December 2017 surveys were selected to determine the pre- and post-beach fill conditions.

Comparison of profile surveys indicated an increase of 963,100 cubic yards of fill within the limits of the beach nourishment project between April 2017 (Pre-Construction) and December 2017 (Post-Construction). Between December 2017 and June 2018, the beach fill area lost 98,500 cubic yards of material. Approximately 22,400 cubic yards of the fill was believed to have been transported north and deposited between stations D-06 and D-09. While there was some evidence material was also transported south and deposited in the area between D-20 and D-22, an anomalous feature consisting of a wide and deep nearshore trough, was present in the June 2018 D-21 profile which resulted in this area actually experiencing a volume loss. Future monitoring of the project will determine if the anomalous trough is still present or if it was just an ephemeral feature.

The following summarizes long-term shoreline changes measured between October 1996, December 2017 and the updated long-term changes for the October 1996 to June 2018 time period.

Average Long-Term Mean High Water (+1.2' NAVD) Shoreline Changes (feet/year)

	<u>Oct 1996 to Dec 2017</u>	<u>Oct 1996 to Jun 2018</u>
Project Area (D-10 to D-19)	4.4	1.7
North of Project Area (PI-17 to D-10)	0.9	0.1
South of Project Area (D-19 to D-34)	-0.1	-0.2

Long-term volumetric changes above the -24' NAVD contour (cubic yards/ft./year) measured between September 2013 and December 2017 and the updated long-term volume changes measured between September 2013 and June 2018 are provided below.

Volumetric Changes (cy/ft./yr.) above -24 feet NAVD

	<u>Sept 2013 to Dec 2017</u>	<u>Sep 2013 to Jun 2018</u>
Project Area (D-10 to D-19)	26.7	21.8
North of Project Area (PI-17 to D-10)	-3.5	-4.7
South of Project Area (D-19 to D-34)	2.9	-0.6

**TOWN OF DUCK  
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A     2018 Town of Duck Monitoring Survey Report

# **TOWN OF DUCK**

## **2018 SHORELINE & VOLUME MONITORING REPORT**

### **I. INTRODUCTION**

The Town of Duck is focused on a long-term shoreline management program that will serve to sustain the beaches that support a significant portion of their local economy, maintain the tax base of the Town, retain existing recreational resources, and protect existing natural resources. In order to accomplish these stated goals, the Town is taking steps to maintain and monitor its oceanfront beach and dune to a configuration that provides a reasonable level of storm damage reduction to public and private development and mitigates long-term erosion impacts.

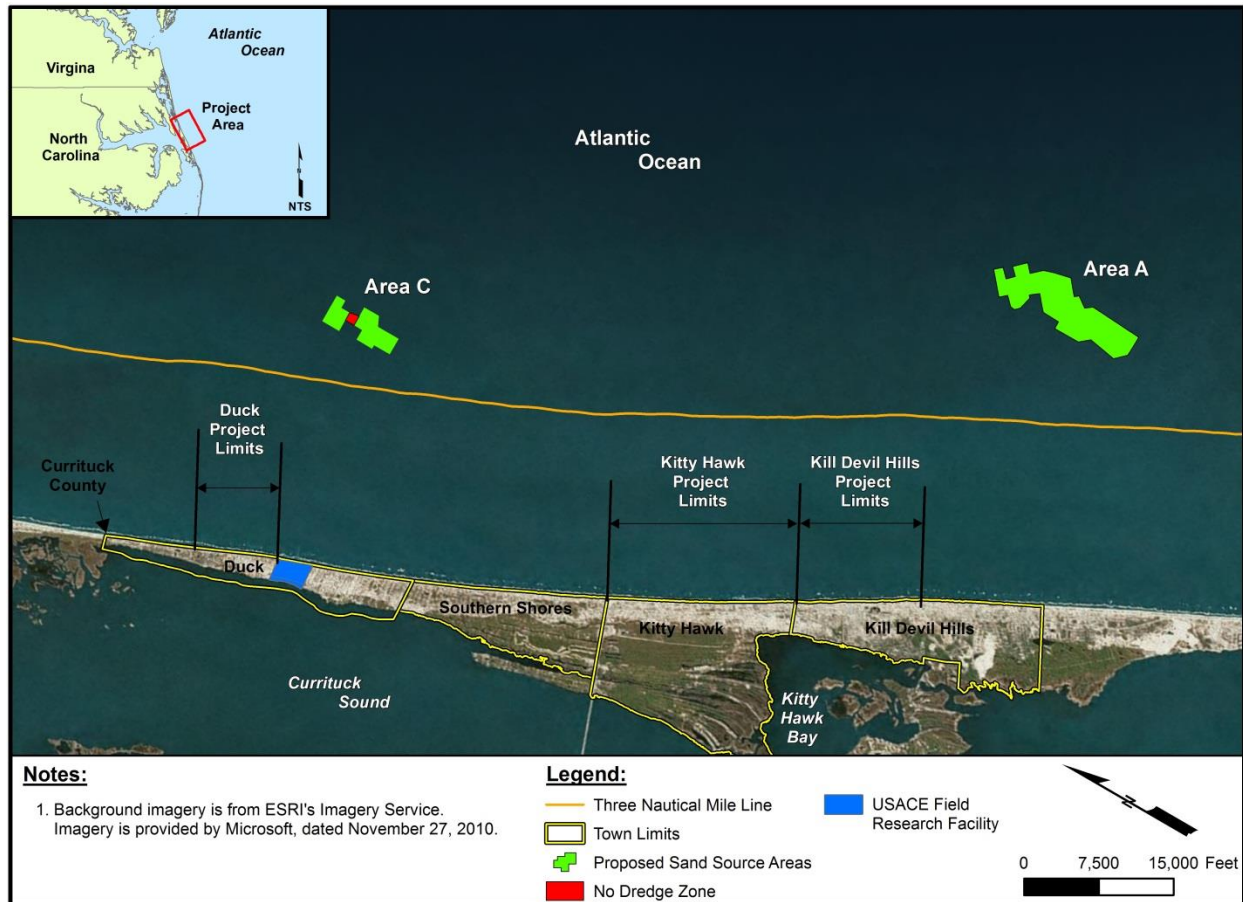
Between May and June 2017, the Town of Duck constructed a large beach nourishment project along approximately 1.6 miles of its ocean shoreline north of the US Army Corps of Engineers (USACE) Field Research Facility (FRF). The beach fill project placed approximately 1.26 million cubic yards of sand between profile D-10 near Skimmer Way and profile D-19, which is the northern boundary of the USACE FRF property.

This monitoring report describes the analysis of beach profile data for shoreline change between October 1996 and June 2018 and includes the LiDAR survey obtained in October 1996 and profile surveys obtained in September 2013, May 2015, December 2017, and June 2018. Volumetric changes were evaluated using the September 2013, May 2015, December 2017, and June 2018 surveys.

### **II. PROJECT LOCATION**

The Town of Duck is located on the Outer Banks of North Carolina roughly 27 miles south-southeast of the North Carolina and Virginia border. The Town encompasses 5.5 square miles extending along 5.9 miles of Atlantic Ocean shoreline from the Dare County and Currituck County line south-southeast to the Town of Southern Shores. The USACE Field Research Facility (FRF) is located within the Town limits near profile station D-21, and is approximately 2.3 miles north of the southern limit and 3.6 miles south of the northern limit. A Location Map is provided in Figure 1. This location map also shows the limits of the nourishment project built along a 1.6-mile section of the Town's oceanfront shoreline between May 23 and June 29, 2017, and the two Outer Continental Shelf (OCS) borrow areas located in Federal waters offshore of Dare County. While only 1.6 miles of the Town's shoreline was directly impacted by the beach nourishment project, the beach monitoring program includes the entire 5.9 miles of the Town's shoreline.

The analysis described in this report focuses on assessing shoreline and volume changes within the limits of the beach nourishment project as well as the areas north and south of the project throughout the entirety of the Town. In this regard, the area north of the project includes profile stations D-01 to D-09 within the Duck town limits and 2,000 feet of shoreline on the south end of Pine Island (profile stations PI-17 and PI-18). The area south of the project includes profile stations D-20 to D-34. The map shown in Figure 2, depicts the project area, monitoring areas north and south of the project area, and the stations at which beach profile surveys were conducted.



**Figure 1. Project Location Map.**

### III. SURVEY DATA COLLECTION

Beach profile surveys were conducted along the Town's shoreline in November 2011, September 2013, May 2015, December 2017 and June 2018. All surveys consist of a total of 34 profiles with a spacing of roughly 1,000 feet along the Town's oceanfront beach. With the exception of the June 2018 survey, two profiles were surveyed both north and south of the Town limits to evaluate adjacent trends that might impact future project formulation should these areas be included in future plans. During the June 2018 survey, the two (2) profiles located north of the Town in Pine Island (PI-17 and PI-18) were surveyed, however, the two (2) profiles south in Southern Shores (SS-01 and SS02) were not surveyed as the Town of Southern Shores recently implemented a beach monitoring program that may provide additional data during future surveys.

Survey data were collected along transects listed in Table 1. Coordinates shown in Table 1 are referenced to the North Carolina State Plane coordinate system in feet NAD83 and the profile azimuth refers to degrees referenced to true north. Transects listed in Table 1 are shown graphically in Appendix A – 2018 Town of Duck Monitoring Survey Report. Appendix A also includes detailed survey methodology, monument information, profile plots, ground digital photography, and field book notes.



Figure 2. Detailed project area map showing the Project Area, North Monitoring Area, South Monitoring Area, and the location of the monitoring profiles.

**Table 1. Profile Survey Baseline and Azimuth**

<b>Profile<sup>(1)</sup></b>	<b>Easting</b>	<b>Northing</b>	<b>Azimuth</b>
PI-17	2950657.3	920098.9	70
PI-18	2951026.0	919175.4	70
D-01	2951387.5	918267.7	70
D-02	2951733.8	917384.4	70
D-03	2952103.0	916429.4	70
D-04	2952464.0	915495.3	70
D-05	2952849.3	914598.0	70
D-06	2953224.4	913696.9	70
D-07	2953607.3	912798.8	70
D-08	2953983.0	911897.9	70
D-09	2954356.7	910994.8	70
D-10	2954759.1	910066.7	70
D-11	2955158.1	909133.1	70
D-12	2955461.4	908412.5	70
D-13	2955874.3	907478.4	70
D-14	2956252.1	906578.3	70
D-15	2956628.6	905677.8	70
D-16	2956978.7	904767.7	70
D-17	2957333.7	903863.9	70
D-18	2957718.8	902886.5	70
D-19	2957932.5	902331.0	70
D-20	2958139.7	901760.7	70
D-21	2958472.1	900958.7	70
D-22	2958754.0	900228.8	70
D-23	2958992.7	899515.6	70
D-24	2959267.2	898739.8	70
D-25	2959601.7	897824.3	70
D-26	2959928.6	896902.3	70
D-27	2960250.6	895981.9	70
D-28	2960604.1	895073.0	70
D-29	2960963.6	894166.2	70
D-30	2961317.7	893257.6	70
D-31	2961676.7	892350.7	70
D-32	2962078.1	891379.4	70
D-33	2962439.4	890553.2	70
D-34/-197+12	2962839.6	889616.1	70

<sup>(1)</sup>PI-Pine Island transects; D-Duck transects;

The 1996 LiDAR data used to measure long-term shoreline change along the portions of the Town not included in the 2017 beach nourishment project were collected by the USGS. The November 2011 beach profile data were collected by the USACE FRF staff through a combination of bathymetric surveys and terrestrial LiDAR surveys. The bathymetric data extended from the shoreline seaward to the -40-foot NAVD contour. The terrestrial LiDAR data extended from the dune seaward to the shoreline. These data were collected before Hurricane Sandy from PI-07 (10,000 feet north of PI-17) to 5,000 feet south of SS-04 (7,000 feet south of SS-02). In an effort

to create a continuous pre-Sandy profile, APTIM combined the 2011 bathymetric and terrestrial LiDAR data collected by the USACE FRF with 2009 LiDAR profile data landward of the dune.

The profile surveys collected by APTIM (formerly CPE-NC) in September 2013, May 2015, December 2017 and June 2018, extended landward until a structure was encountered or to a range 50 feet beyond the landward toe of dune, whichever was more seaward. Elevation measurements were also taken seaward along the profile to at least the -30-foot NAVD contour. Upland data collection included 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 was 25 feet. The upland survey extended into wading depths sufficiently to allow the offshore portion to overlap the upland portion by a minimum of 50 feet.

#### **IV. SHORELINE CHANGES**

A shoreline change analysis was completed to assess shoreline advance and recession along the study area. The shoreline is typically defined as a specified elevation contour. For this study, the shoreline was defined as the Mean High Water (MHW) contour, which represents the +1.2 feet NAVD elevation (CPE, 2015). Shoreline change is calculated by comparing shoreline position along shore perpendicular transects. Typically, shoreline change is then annualized to describe recession and advance rates. Regardless of whether total or annual shoreline changes are described, positive shoreline change denotes advance (seaward movement) while negative shoreline change indicates recession (landward movement).

The MHW position for each survey was identified along shore perpendicular transects spaced at approximately 1,000-foot intervals at the profiles identified in Table 1 along the monitoring area. The rate of change in the MHW shoreline position measured between the various surveys are provided in Table 2. Within the beach nourishment project (stations D-10 through D-19), shoreline change rates are shown for the period from October 1996 to May 2015, which represents long-term rates prior to construction of the project. Also shown in Table 2, are the changes in the MHW shoreline that occurred between December 2017 and June 2018 as well as an update of the long-term rates measured between October 1996 and June 2018. The updated long-term rates include the impacts of the beach nourishment project.

Outside the beach nourishment project area, shoreline change rates are provided in Table 2 for the period from October 1996 to May 2015, which again, represents long-term rates prior to construction of the project. Table 2 also provides long-term rates from October 1996 to June 2018, which include the effects of the beach nourishment projects on adjacent shorelines. Furthermore, the short-term shoreline change rates (December 2017 to June 2018) are also provided in Table 2 for the area outside of the project area.

The May 2015 survey was the last survey of the entire monitoring area (SS 17 to D-34) conducted prior to the 2017 beach nourishment operation. Even though the 2017 beach nourishment project was completed in June 2017, due to large-scale profile adjustments that normally occur immediately following the placement of a fill, the December 2017 survey has been adopted to represent the post-construction conditions within the project area. This and future annual

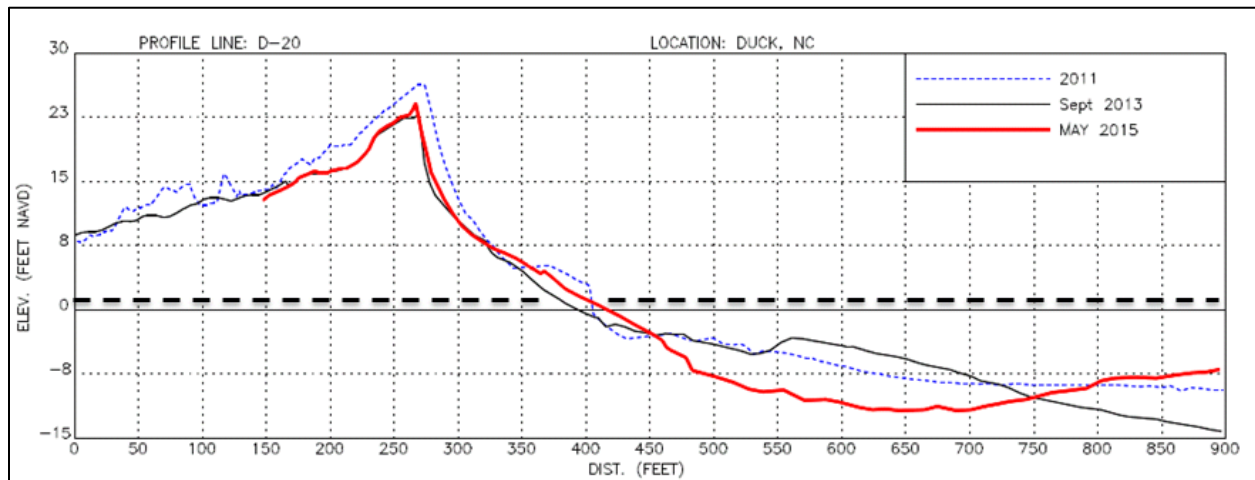
monitoring reports will reference shoreline changes and volume changes in the project area relative to the December 2017 condition.

**Table 2. MHW Shoreline Change Rates**

PROFILE	Shoreline Change Rate (FT/YR)		
	OCT. 1996 TO MAY 2015	OCT. 1996 TO JUNE 2018	DEC. 2017 TO JUNE 2018
PI-17	0.3	-0.1	-122.1
PI-18	1.2	0.2	-3.6
D-01	0.9	0.0	-64.3
D-02	1.2	-0.8	-62.7
D-03	-0.6	0.1	-45.4
D-04	-1.0	-2.2	-22.6
D-05	-4.2	-2.3	-48.7
D-06	-1.8	-1.3	-29.2
D-07	-0.4	0.3	-25.3
D-08	0.6	1.4	-27.1
D-09	3.8	2.6	61.5
D-10	0.7	N/A	-20.1
D-11	1.9	N/A	-81.6
D-12	3.9	N/A	-89.8
D-13	1.4	N/A	-132.5
D-14	-2.0	N/A	-197.4
D-15	-0.6	N/A	-185.4
D-16	-5.8	N/A	-156.1
D-17	-5.6	N/A	-106.8
D-18	-3.0	N/A	-70.3
D-19	-2.2	N/A	-70.6
D-20	-2.3	-0.3	-47.2
D-21	-3.7	-1.4	-5.5
D-22	-1.4	0.1	46.1
D-23	3.8	2.1	93.0
D-24	2.1	0.5	1.8
D-25	-1.8	-0.9	15.2
D-26	-4.2	-2.1	-0.3
D-27	-2.0	-1.4	7.5
D-28	0.9	0.5	6.9
D-29	2.0	1.2	1.6
D-30	4.8	0.9	-36.3
D-31	-0.7	0.7	9.7
D-32	-2.2	-1.6	-6.9
D-33	-1.4	-1.5	-23.2
D-34	-0.8	0.0	-31.0

<b>NORTH OF BEACH PROJECT</b> (PI-17 TO D-10)	0.1	0.1	-34.1
<b>PROJECT AREA</b> (D-10 TO D-19)	-1.1	N/A	-111.1
<b>SOUTH OF BEACH PROJECT</b> (D-19 TO D-34)	-0.6	-0.2	-2.4

The linear changes in the shoreline position represented by the MHW contour can vary considerably along the monitoring area and can sometimes differ from volume change trends along sections of a beach. This difference is often due to changes in the slope of the foreshore along the beach from one end of the monitoring area to the other. As shown in Figure 3, the position of the MHW location on the profile can vary greatly depending on the shape of the profile at the time of the survey.



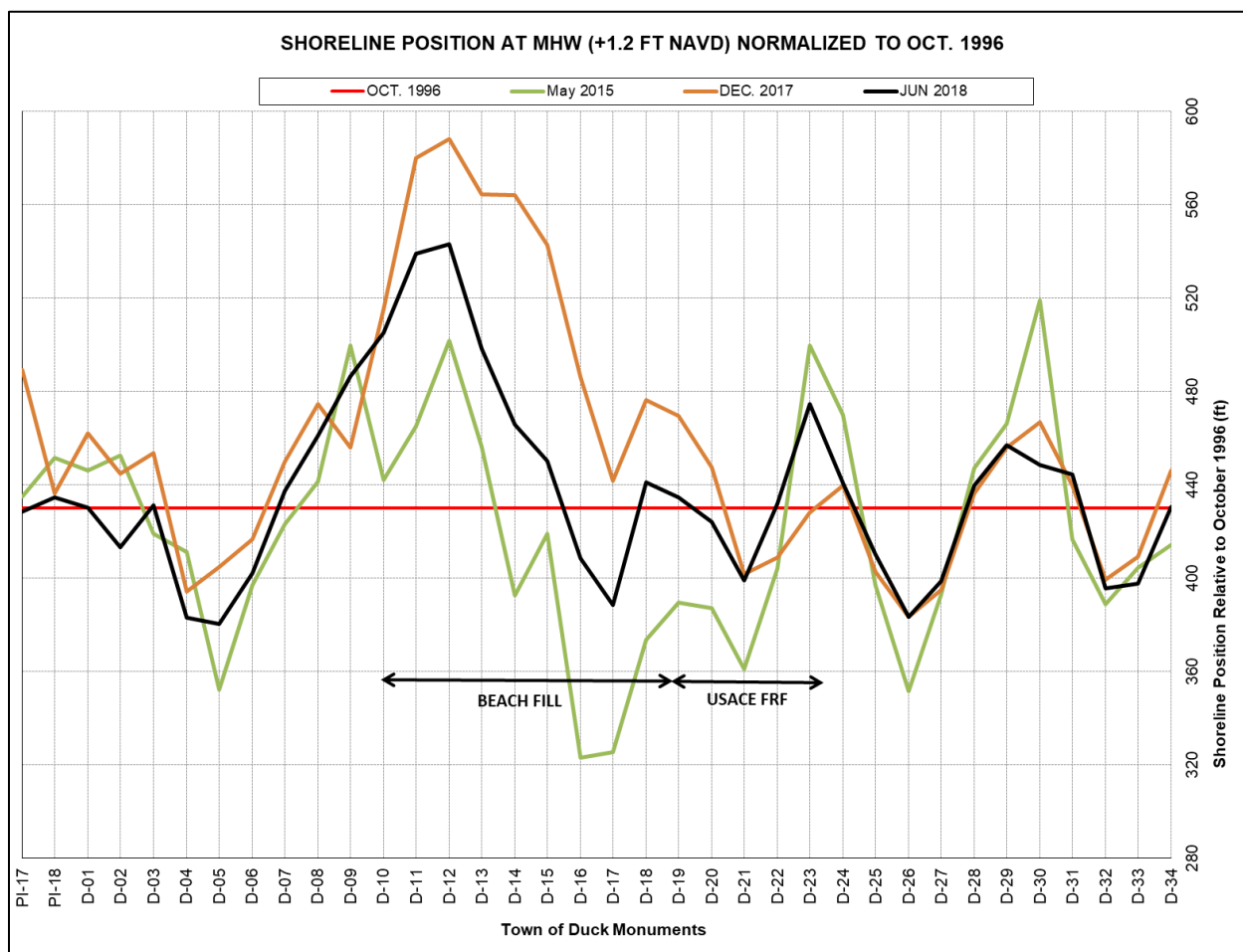
**Figure 3. MHW Shoreline Change Variation.**

Shoreline change is provided as a rate in an annualized form by dividing the shoreline change by the time period (number of years) between survey events (i.e. feet per year). These rates are described in terms of positive (“+”) or advance (shoreline moving seaward) and negative (“-”) or recession (shoreline moving landward).

For the purpose of monitoring, this report has separated the oceanfront beach of Duck into three areas: namely, the Project Area and the areas North of the Project and South of the Project. These areas are depicted on Figure 3. The Project Area includes the beach between the northern FRF property line, located near profile D-19, through profile D-10, which is near the northern end of Skimmer Way. The section referred to as North of the Project extends from profile D-10 (northern end of Skimmer Way) north to the Duck town limits (profile D-01) plus 2,000 feet on the south end of Pine Island (profiles (PI-17 and PI-18). The area designated South of the Project extends

from profile D-19 south to D-34. Profile D-34 is located near the Duck town boundary with the Town of Southern Shores.

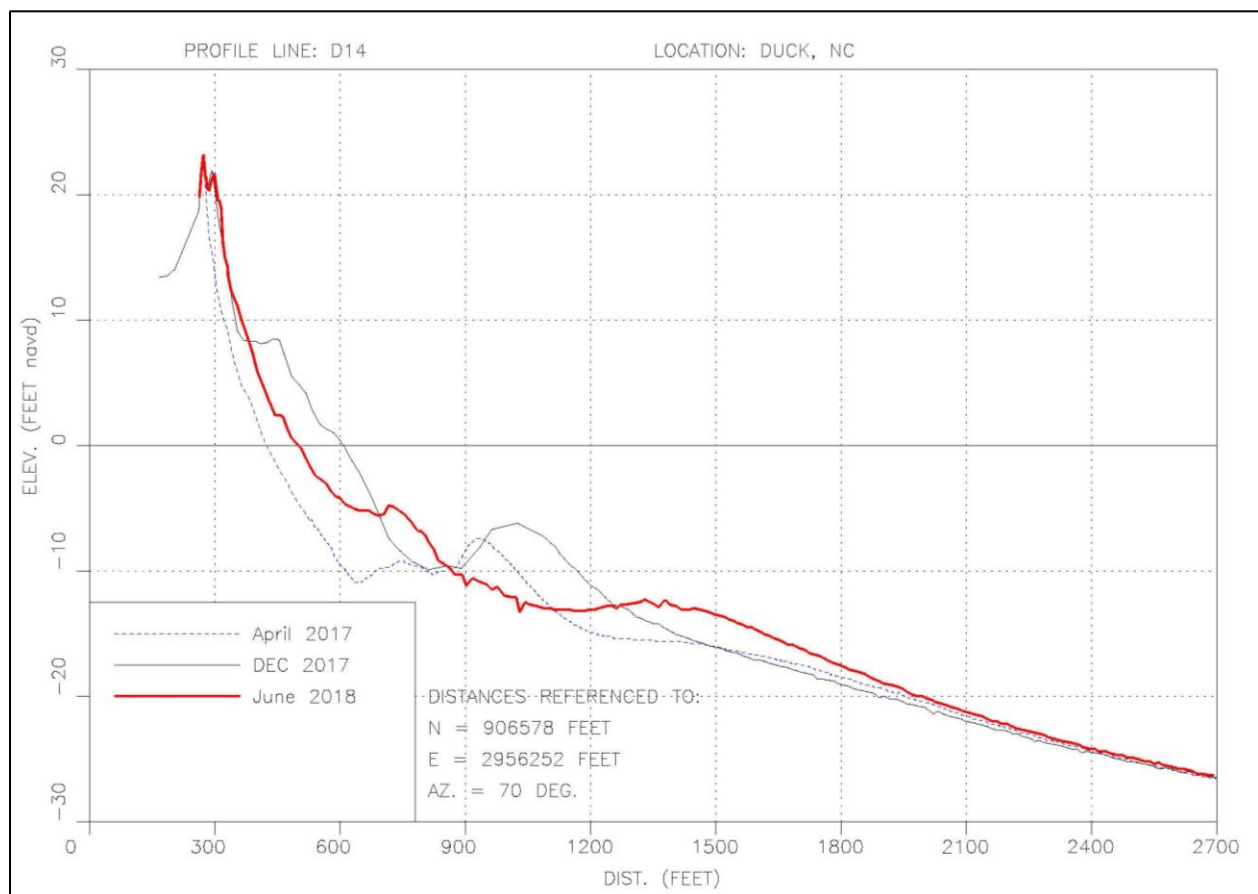
Figure 4 graphically displays the location of MHW shorelines for the entire monitoring area relative to the October 1996 shoreline. The relative shorelines shown are for May 2015, December 2017 (Post-Construction), and June 2018. As discussed in the feasibility report for the Town of Duck (CPE-NC, 2013) the Duck shoreline is known to be characterized by a series of perturbations, also called “sand waves”, which migrate along the shore. As the sand waves migrate, the behavior of shoreline from one section to the next can experience wide swings from recession to accretion. Therefore, the characterization of shoreline changes within the monitoring area is best represented by averaging shoreline trends for multiple profile lines within certain areas. As discussed below, average shoreline trends were computed for the three subareas within the monitoring area, namely; the Area North of the Project, the Project Area, and the Area South of the Project.



**Figure 4. Historical MHW (+1.2 FT NAVD) shoreline position relative to the October 1996 MHW shoreline.**

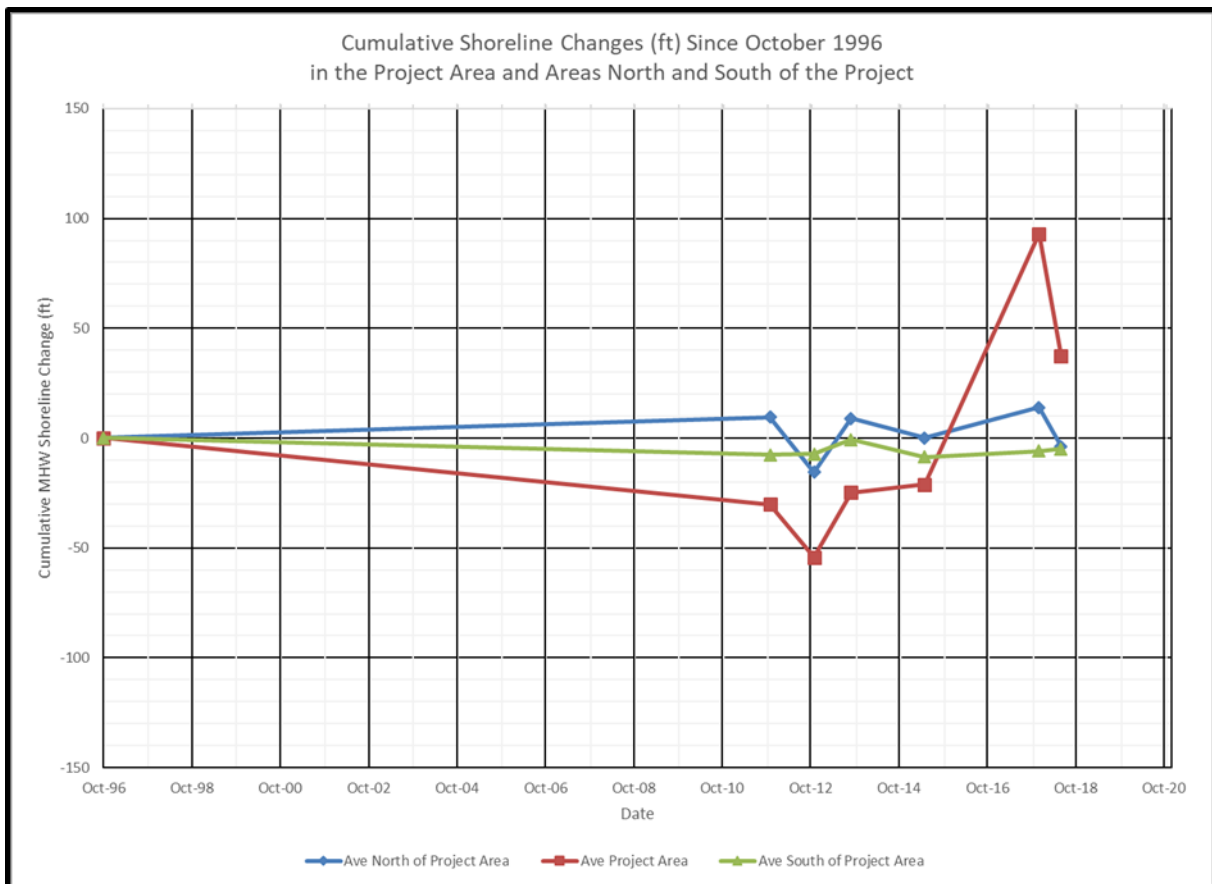
## BEACH NOURISHMENT PROJECT AREA (D-10 TO D-19)

The beach nourishment project constructed in 2017 extended the MHW line approximately 241 ft. seaward based on comparisons of the before dredge (BD) and after dredge (AD) surveys (APTIM, 2018B). However, these numbers should not be used in the determination of shoreline change analysis as these numbers represent the condition of the beach prior to any profile equilibration taking place. Based on a comparison of the April 2017 pre-construction survey and the December 2017 survey, the placement of the beach fill within the project area (D-10 to D-19) moved the mean high water (+1.2 ft. NAVD88) contour an average of approximately 111 feet seaward (APTIM, 2018B). This number is more reflective of the movement of the MHW shoreline as a result of the project, as it takes into account profile equilibration that took place between June 2017 and December 2017. From December 2017 to April 2018, the mean high water (MHW) shoreline receded an average of about 55 feet. The recession of the MHW shoreline during this period was associated with continued profile adjustments as material on the upper portion of the profile was moved seaward to deeper portions of the active profile. An example of this offshore movement of material is provided in Figure 5 for Profile D-14.



**Figure 5. Typical post-fill profile adjustments.**

The average cumulative change in the position of the MHW shoreline within the project area (i.e. average of profiles D-10 to D-19) between October 1996 and June 2018 is shown on Figure 6. The shoreline was generally receding up until November 2012 but experienced some recovery (accretion) just prior to the construction of the beach fill project. The cumulative changes in the project area reflects the 111-foot seaward advancement of the shoreline between April 2017 and December 2017 associated with the beach fill project followed by the 55-foot retreat during continued post-fill adjustments that occurred between December 2017 and June 2018.



**Figure 6. Average cumulative changes in the MHW shoreline position since October 1996 in the Project Area and in the areas north and south of the Project Area.**

## **OUTSIDE THE BEACH NOURISHMENT PROJECT AREA (PI-17 TO D-10 AND D-19 TO D-34)**

The average cumulative change in the position of the MHW shoreline in the areas north of the project and south of the project between October 1996 and June 2018 are also shown in Figure 6. Both areas were relatively stable during this period with average shoreline change rates of +0.1 and -0.2 ft./yr., respectively. However, over the long-term period of October 1996 to June 2018, two areas experienced relatively high rates of shoreline recession, one north of the Project Area and one South of the Project Area. In the north area, the shoreline from profile stations D-04 to D-06 (Sanderling Resort to Martin Lane) receded at an average rate of -1.9 ft./yr. between October 1996 and June 2018. South of the Project Area, the shoreline between profile stations D-25 and D-27 (Sea Colony to Wampum Dr.) eroded at an average rate of -1.5 ft./yr. during this period.

A comparison of data collected in September 2013 (CPE-NC, 2015) and June 2018 allows for an evaluation of trends that have occurred over the past 4.75 years. Table 3 shows a comparison of the long-term shoreline change rates outside the project area as measured between October 1996 and June 2018, as well as between September 2013 and June 2018. The average shoreline change rate north of the project areas between September 2013 and June 2018 was -1.9 ft./yr. Similar to the trend seen from 1996 to 2018, the average shoreline change rate in the section between station D-04 and D-06 (-3.0 ft./yr) was higher than the overall average north of the project area (-1.9 ft./yr.). However, the area between station PI-18 and D-03 had a shoreline change rate of -7.2 ft./yr. over the same 4.75-year period.

During the same 4.75-year period from September 2013 to June 2018, the average shoreline change rate south of the project areas between September 2013 and June 2018 was 0.0 ft./yr. This average rate is heavily influenced by the positive shoreline change experienced directly south of the beach fill project along profile D-19 and D-20. The average shoreline change rate from D-21 south along the Duck Shoreline was calculated to be -1.8 ft./yr. Similar to the trend seen from 1996 to 2018, the average shoreline change rate in the section between Station D-25 and D-27 (-2.7 ft./yr) was higher than the overall average south of the project area. However, it appears as though the area with higher shoreline change rates may have migrated south over the past 4.75 years as D-25 had a positive shoreline change rate of +0.5 ft./yr., and the section of beach from D-27 to D-29 had an average shoreline change rate of -3.8 ft./yr.

**Table 3. MHW Shoreline Change Rates Outside Project Area**

PROFILE	MHW SHORELINE CHANGES (FT/YR)	
	OCT. 1996 TO JUNE 2018	SEPT. 2013 TO JUNE 2018
PI-17	-0.1	-2.5
PI-18	0.2	-11.2
D-01	0.0	-4.9
D-02	-0.8	-6.6
D-03	0.1	-6.2
D-04	-2.2	-1.1
D-05	-2.3	-5.4
D-06	-1.3	-2.3
D-07	0.3	2.2
D-08	1.4	4.0
D-09	2.6	4.8
D-10	3.5	6.5
Beach Nourishment Project Area		
D-19	0.2	13.0
D-20	-0.3	12.1
D-21	-1.4	-1.7
D-22	0.1	-2.3
D-23	2.1	-1.5
D-24	0.5	-1.1
D-25	-0.9	0.5
D-26	-2.1	-1.6
D-27	-1.4	-6.9
D-28	0.5	-2.7
D-29	1.2	-1.9
D-30	0.9	-1.1
D-31	0.7	-0.1
D-32	-1.6	-0.7
D-33	-1.5	-3.2
D-34	0.0	-1.0
<b>NORTH OF BEACH PROJECT</b> (PI-17 TO D-10)	0.1	-1.9
<b>SOUTH OF BEACH PROJECT</b> (D-19 TO D-34)	-0.2	0.0

## V. VOLUMETRIC CHANGES

### General

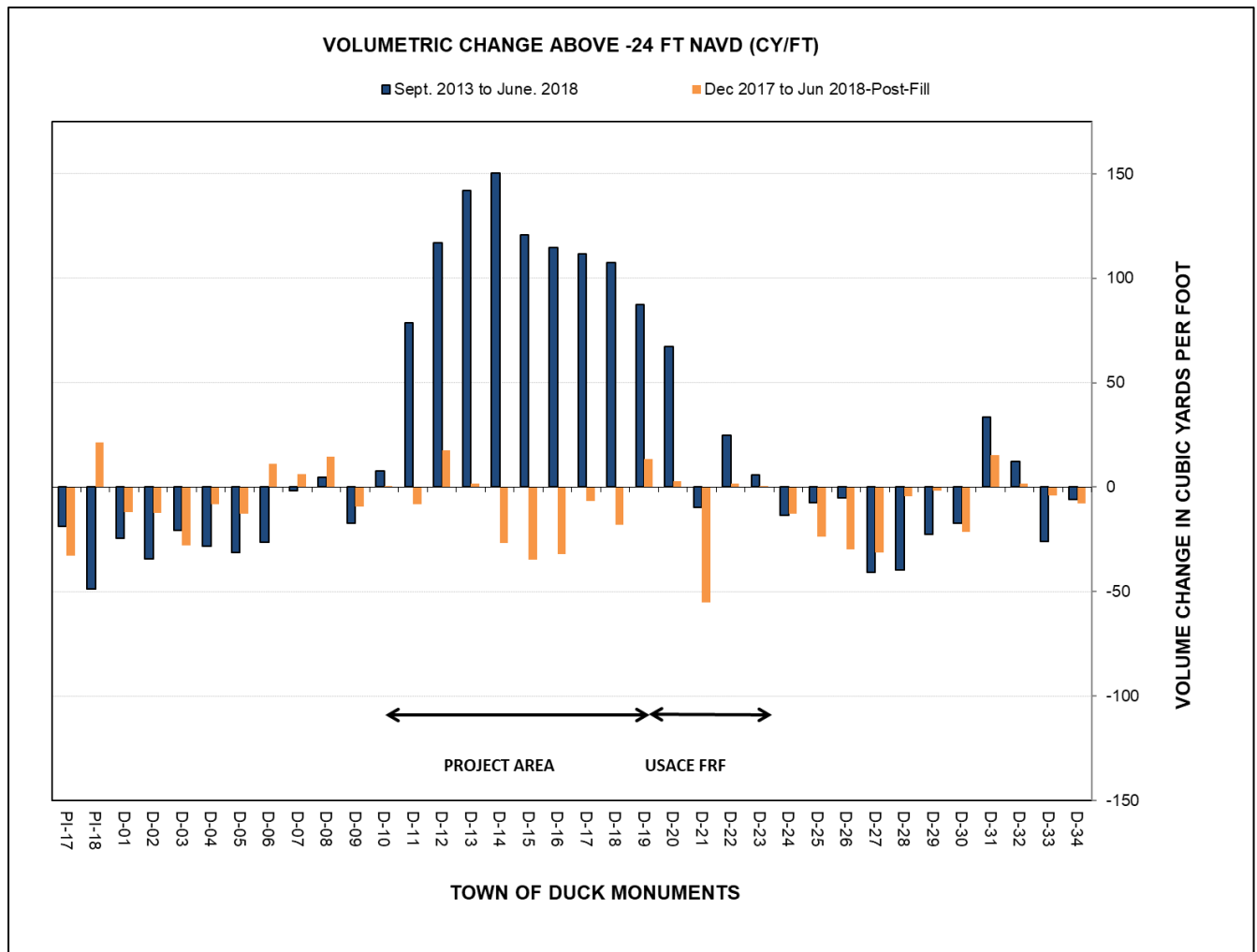
Volumetric changes measured over the entire monitoring area for various time periods are provided in Table 4. The volume changes are given in terms of cubic yards/foot of shoreline/year (cy/ft./yr.). Both within the beach nourishment project (stations D-10 through D-19), and outside the beach nourishment project, volume change rates were evaluated for the period from September 2013 to May 2015 and December 2017 to June 2018. The September 2013 to May 2015 rates represent trends occurring prior to construction of the project. The December 2017 to June 2018 surveys show short-term changes occurring after the beach nourishment project.

**Table 4. Volumetric Change Rates Pre-Project and Post-Project for the Town of Duck**

PROFILE	VOLUMETRIC CHANGES (CY/FT/YR)	
	SEPT. 2013 to May 2015	DEC 2017 TO JUNE 2018
PI-17	-14.6	-65.4
PI-18	-33.3	42.8
D-01	-10.5	-24.1
D-02	0.3	-24.4
D-03	-33.2	-55.7
D-04	-16.0	-16.5
D-05	-52.4	-25.8
D-06	-18.3	22.5
D-07	-28.4	12.8
D-08	-37.2	29.1
D-09	25.1	-18.7
D-10	-44.6	1.0
D-11	-69.9	-16.5
D-12	30.3	35.2
D-13	33.1	3.0
D-14	1.5	-53.3
D-15	12.3	-69.6
D-16	-19.5	-63.8
D-17	19.5	-13.7
D-18	5.2	-36.4
D-19	-4.4	27.2
D-20	3.9	5.4
D-21	27.1	-110.7
D-22	-9.4	3.3
D-23	67.1	0.2
D-24	38.0	-25.2
D-25	-1.1	-47.4
D-26	-28.2	-59.2
D-27	-30.6	-62.7

D-28	-10.9	-8.6
D-29	-55.3	-3.8
D-30	80.2	-42.5
D-31	-7.1	30.4
D-32	-2.8	3.1
D-33	-12.9	-7.7
D-34	-35.1	-15.9
<b>NORTH OF PROJECT</b> (PI-17 TO D-10)	-21.9	-10.2
<b>PROJECT AREA</b> (D-10 TO D-19)	-3.7	-18.7
<b>SOUTH OF PROJECT</b> (D-19 TO D-34)	1.2	-19.6

The discussion of volume changes focuses on changes occurring within the beach nourishment project area (stations D-10 to D-19) as well as changes that are occurring north and south of the Project area. Figure 7 graphically depicts the volume changes measured between September 2013 and June 2018 as well as changes measured between December 2017 and June 2018.



**Figure 7. Volume Changes (cubic yards/foot) measured between September 2013 and June 2018 and December 2017 and June 2018.**

### **PROJECT AREA (D-10 TO D-19)**

The Town of Duck Erosion & Shoreline Management Feasibility Study (CPE-NC, 2013), determined that between 1996 and 2011, the shoreline between the USACE FRF northern boundary and Diane St. had receded approximately 73 ft. It was not known if this change occurred gradually over the approximately 15 year period, or if it occurred more abruptly prior to the 2011 survey. In any event, the feasibility study determined that because of the shoreline changes that occurred during that period, a portion of the Town was vulnerable to storm impacts from a storm with similar characteristics as Hurricane Isabel. For that reason, the Town initiated the efforts that lead to the construction of the beach nourishment project in 2017.

During the design phase of the beach nourishment project, the advanced fill required for a 5 year renourishment period was estimated to be 234,000 cubic yards (CPE-NC, 2015). These estimates

were based on shoreline and volume changes measured prior to 2013 as well as estimates of diffusion losses.

In May 2015, beach profile surveys were conducted to update shoreline and volume change rates throughout the Town limits and to update the beach nourishment design during the development of project plans and specifications. Within the proposed project area (D-10 to D-19), a volumetric loss of approximately -13,300 cy was measured in the 1.7 years between September 2013 and May 2015. This translated into a rate of -3.7 cy/ft./yr.

Between May and June 2017, the 2017 beach nourishment project placed a total of 1.26 million cubic yards of fill along the Duck shoreline between profile stations D-10 and D-19. However, the performance of the 2017 beach fill project along the Town of Duck is based on changes that occur relative to the conditions depicted by the December 2017 monitoring survey. While the beach fill project was completed in June 2017, beach fill projects typically undergo an initial period of profile adjustment in which material placed on the upper portion of the profile is redistributed to lower portions of the profile in response to tide and wave conditions. In addition to the onshore-offshore profile adjustments, some of the beach fill material is removed from the ends of the fill and distributed to the adjacent shorelines. Once these initial adjustments occur, the performance of the beach fill typically begins to mimic the behavior of a natural beach. Therefore, for purposes of monitoring the performance of the beach fill, the volume of the beach fill material on the active profile determined from comparison of the Pre-Construction survey obtained in April 2017 with the December 2017 monitoring survey is used to represent the initial volume of material in the beach fill project. In this regard, the volume of beach fill material remaining on the active beach profile as of December 2017 was 963,100 cubic yards.

Over the 6-month period between December 2017 and June 2018, the volume of material within the Project Area decreased by 98,500 cubic yards. The average volume change measured along the profiles from D-10 to D-19 was approximately -9.3 cy/ft. However, as illustrated in Figure 7, there is considerable variation in the volume changes measured along the project area. The greatest positive volume change was measured along Profile D-12 (17.6 cy/ft.); whereas the greatest negative volume change was measured along Profile D-15 (-34.8 cy/ft.). Relatively high negative volume changes were measured along profiles D-14, D-15, and D-16. These three profiles had an average volume change of approximately -31.1 cy/ft. over the 6-month period. The volume changes occurring along these profiles are a result of losses that occurred from the berm as well as the truncation of a large bar that was present in December 2017 offshore of the beach in 6 to 12 feet of water. Excluding these three profiles, the remainder of the project had an average volume change of essentially 0 over the same period.

While the overall shoreline changes measured in the project area, and more specifically between D-14 and D-16, were higher than trends measured prior to the construction of the project, the changes may be influenced by the relatively short time period between surveys and the continued profile adjustments occurring as a result of the beach nourishment project. Also, a review of wave data recorded by Gage 630 operated by the FRF indicated there was a total of 11 nor'easters between December 2017 and June 2018 that generated wave heights in excess of 2 meters (6.6 ft.). Each of these nor'easters lasted several days and could have had significant impacts on the onshore-offshore movement of the beach fill material. Included in these 11 storms was Winter

Storm Riley which impacted the area from March 1 to March 4 and produced a maximum wave height at Gage 630 of 3.5 meters (11.5 ft.). In general, as the beach fill adjusts, the volume rate of change is expected to moderate.

As discussed below, some of the material lost out of the Project Area may have been transported to the north and south.

### **OUTSIDE OF BEACH NOURISHMENT PROJECT AREA**

**North of Project Area (PI-17 to D-10).** The monitoring area north of the Project Area, was eroding at an average rate of -21.9 cy/ft./yr. during the 1.7-year period from September 2013 to May 2015, prior to the construction of the beach nourishment project. During the 2.6-year period from May 2015 to December 2017, which included the construction of the beach nourishment project, this area accreted at an average rate of 8.3 cy/ft./yr. During the ensuing 6-month period from December 2017 to June 2018, the area lost an average of -10.2 cy/ft./yr. Table 5 includes pre-construction volume change rates for the area north of the Project Area, measured between September 2013 and May 2015 as well as volume change rates between May 2015 and December 2017, which includes the period of time in which the beach project was constructed.

**Table 5. Volumetric Change Rates North of Project Area**

<b>PROFILE</b>	<b>VOLUMETRIC CHANGES (CY/FT/YR)</b>		
	<b>SEPT. 2013 to May 2015</b>	<b>SEPT. 2013 to JUNE 2018</b>	<b>MAY 2015 to DEC 2017</b>
PI-17	-14.6	-3.9	12.6
PI-18	-33.3	-10.2	-5.6
D-01	-10.5	-5.2	2.3
D-02	0.3	-7.2	-8.7
D-03	-33.2	-4.3	24.4
D-04	-16.0	-5.9	2.1
D-05	-52.4	-6.6	28.1
D-06	-18.3	-5.6	-2.9
D-07	-28.4	-0.3	15.3
D-08	-37.2	1.0	20.3
D-09	25.1	-3.6	-19.3
D-10	-44.6	1.6	30.6
<b>NORTH OF PROJECT (PI-17 TO D-10)</b>	<b>-21.9</b>	<b>-4.2</b>	<b>8.3</b>

Upon closer examination of the recent trends measured between December 2017 and January 2018, the portion of the area directly north of the Project Area lying between profile stations D-06 and D-10, which covers the approximate 4,000 feet of shoreline immediately to the north of the

Project Area, gained 4.7 cy/ft., or approximately 17,000 cubic yards. The accretion along the 4,000-foot section of shoreline immediately north of the project may be associated with the northward spreading of the nourishment material during this 6-month period. In contrast, the approximately 7,000-foot section of the monitoring area north of D-06, from D-05 through PI-17, eroded an average of -12.1 cy/ft. during the same 6-month period, which equates to approximately -62,000 cy.

A check of the wave conditions measured by Gauge 630 operated by the US Army Field Research Facility (FRF) for the time period between December 2017 and June 2018 indicates there was a predominance of wave energy out of the northern quadrants that would have tended to move littoral sediment to the south. During this time, the waves out of the northern quadrants accounted for 56.3% of the wave energy with 43.7% coming from the southern quadrants. Although the predominant wave energy was directed to the southwest, it is still possible that material was transported to the north off the end of the fill. This is because the taper section would have changed the angle waves broke relative to the shoreline to such a degree that even waves coming from northern quadrants could have resulted in northward directed littoral transport along the taper section. In any event, documented performance of beach fills in other areas has shown beach fill material tends to migrate out of the nourishment area in both directions as the bulge in the shoreline created by the fill tends to flatten as the shoreline within the nourished area returns to its pre-fill position.

Over the long-term from September 2013 to June 2018 (Table 5), volumetric changes north of the Project Area averaged -4.2 cy/ft./yr. The extreme northern sections of the area between profile stations D-06 and PI-17 continued to experience higher erosion rates compared to the section between D-07 and D-09 on the southern end of the area. Between profile stations D-06 and PI-17, the long-term average rate of volume change was -6.1 cy/ft./yr. while the southern end of the area only lost an average of -1.0 cy/ft./yr. The performance of the southern end of the area is again an indication of the positive impacts the beach nourishment project is having in this area.

**South of Project Area (D-20 to D-34).** Prior to the construction of the nourishment project (September 2013 to May 2015), the area south of the project between profiles D-19 and D-34 was relatively stable with an average accretion rate of 1.6 cy/ft./yr. Although the average volume change was relatively small, the behavior of the shoreline from profile station to profile station was highly variable. Within this area, volume changes between profile stations varied from an accretion rate of 80.2 cy/ft./yr. at station D-30 to an erosion rate of -35.1 cy/ft./yr. at station D-34. Table 6 includes pre-construction volume change rates measured south of the Project Area, between September 2013 and May 2015 as well as volume change rates between May 2015 and December 2017, which includes the period of time in which the beach project was constructed.

**Table 6. Volumetric Change Rates South of Project Area**

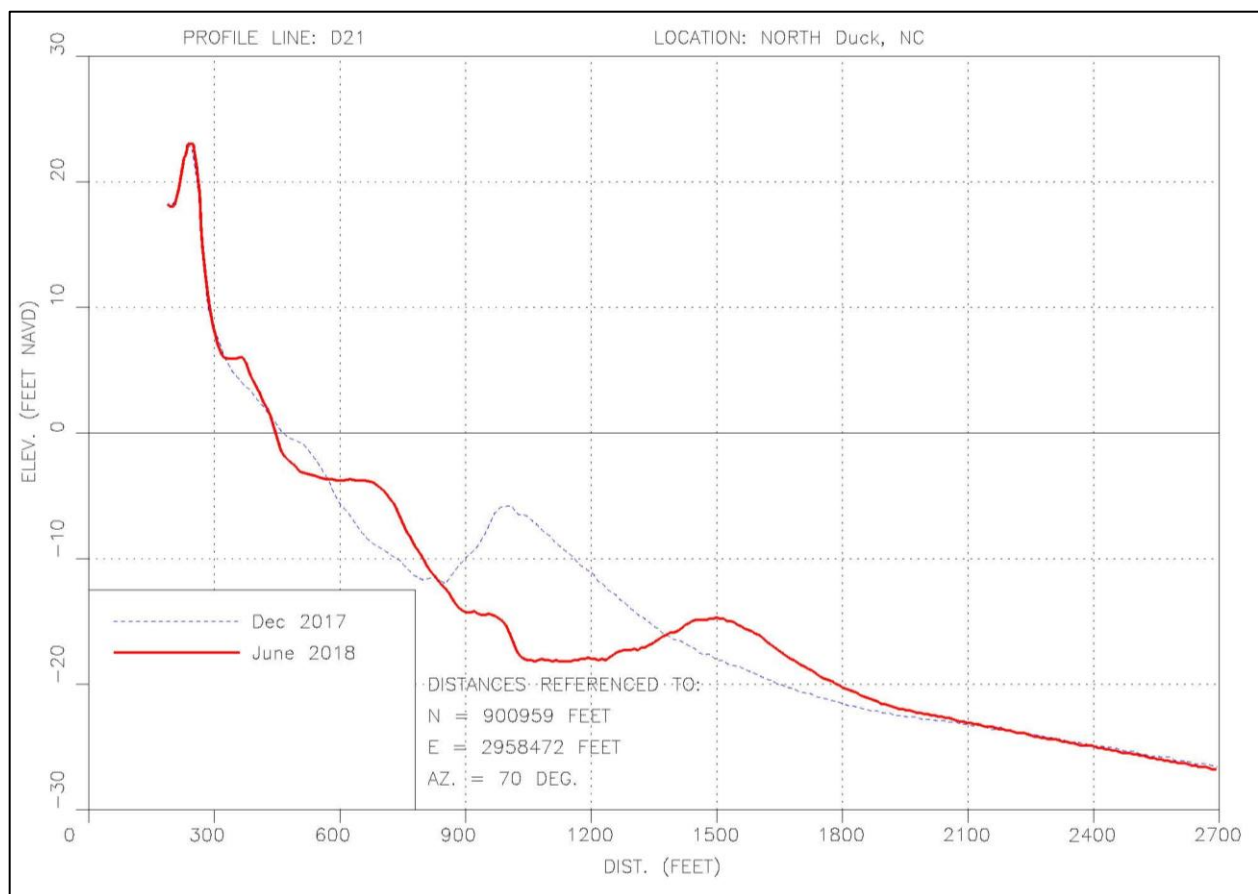
PROFILE	VOLUMETRIC CHANGES (CY/FT/YR)		
	SEPT. 2013 to May 2015	SEPT. 2013 to JUNE 2018	MAY 2015 to DEC 2017
D-19	-4.4	18.4	31.8
D-20	3.9	14.2	22.4
D-21	27.1	-2.0	0.2
D-22	-9.4	5.2	15.0
D-23	67.1	1.3	-41.3
D-24	38.0	-2.8	-24.8
D-25	-1.1	-1.5	7.0
D-26	-28.2	-1.1	27.5
D-27	-30.6	-8.6	16.1
D-28	-10.9	-8.3	-6.6
D-29	-55.3	-4.8	27.6
D-30	80.2	-3.7	-50.2
D-31	-7.1	7.1	11.5
D-32	-2.8	2.6	6.7
D-33	-12.9	-5.5	0.0
D-34	-35.1	-1.2	23.5
<b>SOUTH OF PROJECT</b> (D-19 TO D-34)	1.2	0.6	4.2

During the period from May 2015 to December 2017, which included construction of the beach fill project, the average accretion of the area increased to 4.2 cy/ft./yr., however, volumetric changes were still highly variable from profile to profile particularly along the area between D-23 and D-34. In the 4,000-foot section of shoreline immediately south of the southern terminus of the beach fill project (stations D-19 to D-23), the shoreline gained an average of 17.4 cy/ft./yr. between May 2015 and December 2017, which equates to approximately 122,300 cy. The remainder of the area (D-24 to D-34) had an average volume loss of -0.3 cy/ft./yr. over the same time period. Even so, the volume changes continued to be highly variable from profile to profile with volume changes ranging from accretion of 27.6 cy/ft./yr. at station D-26 to erosion of 50.2 cy/ft./yr. at station D-30. Some of the accretion in the 4,000-foot segment just south of the Project Area can be attributed to spreading of the fill material to the south. However, the variable nature of the volume changes throughout the area makes generalizations difficult.

During the 6-month period from December 2017 to June 2018, the 4,000-foot section immediately south of the Project Area (D-19 through D-23) lost an average of -14.9 cy/ft./yr. An examination of volume changes measured station to station for this time period (Table 4) shows an anomalous volume loss of -110.7 cy/ft./yr. at station D-21 while stations D-19 and D-20 to the north and D-22 and D-23 to the south exhibited an average accretion of 9.0 cy/ft./yr. The anomalous changes

at D-21 appear to be influenced by the truncation of the bar that was present in depths of 6 to 10 feet of water at the time of the December 2017 survey and the formation of a rather deep and wide trough in the same location as shown on Figure 8. While a similar truncation of the bar and formation of a trough occurred along most of the profiles along the Town of Duck between December 2017 and June 2018, the trough that formed along profile D-21 appears to be 4 to 6 feet deeper than those observed along adjacent profiles (see Appendix A). With profile D-21 located immediately north of the FRF pier, some of the profile changes at D-21 could have been influenced by the piles supporting the pier. The anomalous behavior of D-21 will be reexamined during the next monitoring survey to see if this feature persists or if it was just an ephemeral change that eventually disappeared over time. In any event, the behavior of D-21 prevents any definitive assessment as to possible southward spreading of the fill material.

The area south of D-23, between profile stations D-24 and D-30 (Shipwatch to Four Seasons Lane), exhibited the highest concentration of negative volume change in the area south of the project. In this approximately 6,000-foot long span of beach, the average volume change measured over the 6-month period between December 2017 and June 2018 was -17.4 cy/ft. That equates to a volume loss of approximately 121,000 cy over the 6-month period.



**Figure 8. Profile D-21 showing deep and wide trough measured during the June 2018 compared to December 2017 survey.**

The long-term volume changes south of the Project Area measured between September 2013 and June 2018 (Table 6) was a gain of 0.6 cy/ft./yr. This is a slight decrease in the positive volume change as measured between September 2013 and December 2017 (+2.9 cy/ft./yr.). The major difference in the shoreline response for these two periods occurred between profile stations D-24 and D-30 (Shipwatch to Four Seasons Lane), in the area where the highest volume losses occurred over the 6-month period between December 2017 and June 2018. For the previous long-term period between September 2013 and December 2017, this section of the shoreline lost an average of -0.7 cy/ft./yr., whereas the updated long-term rate in this section measured between September 2013 and June 2018 was a loss of -4.4 cy/ft./yr. The area should be closely monitored to see if the risk of damage to development in the area increases.

## VI. SUMMARY

This monitoring report evaluated shoreline and volume changes along the 5.9 mile shoreline of the Town of Duck and 2,000 feet of shoreline on the southern end of Pine Island. Data collected in June 2018 was used to update shoreline and volume change analyses presented in the previous monitoring report (APTIM, 2018A) as well as the feasibility study (CPE-NC, 2013) and the design analysis associated with the beach nourishment project (CPE-NC, 2015). Both the shoreline and volume change results were influenced by the beach fill project constructed in June 2017, which placed 1,263,181 cy of material along the beach between station D-10 and D-19.

The monitoring area extends south from profile station PI-17, located on the south end of Pine Island, to profile station D-34, located near the Town of Duck town limits with the Town of Southern Shores. With the construction of the beach nourishment project in June 2017, the monitoring area was divided into three sections, namely; the Project Area (D-10 to D-19), the Area North of the Project (PI-17 to D-10), and the Area South of the Project (D-19 to D-34).

### **Shoreline Change Analysis:**

**Project Area.** Within the Project Area, the beach fill project moved the MHW shoreline an average of 111 feet seaward between the April 2017 pre-construction survey and the December 2017 monitoring survey. During the ensuing 6-months from December 2017 to June 2018, the MHW shoreline retreated 55 feet as the constructed beach profile adjusted to tide and wave conditions. Most of the retreat of the MHW shoreline was due to movement of sediment from the upper portions of the profile, where it was initially placed during construction, to deeper portions of the active beach profile in response to tide and wave conditions. Such adjustments in the shape of the nourished profile are normal for beach nourishment projects. Over time, the movement of the MHW shoreline is expected to moderate as the profile moves toward an equilibrium configuration.

In terms of shoreline changes, the beach fill project has performed as expected and has added a layer of protection to upland development against damage associated with long-term erosion and has reduced the damage potential due to coastal storms.

**Area North of the Project.** Long-term changes in the position of the MHW shoreline in the area north of the Project Area were not significantly changed by the placement of the beach fill. The long-term shoreline change rate in the area prior to the beach nourishment project, as measured between October 1996 and May 2015, was 0 ft/yr. indicating, on average, the shoreline was stable. For the updated long-term period from October 1996 to June 2018, which included the beach fill project, the average rate of change in the MHW shoreline was -0.2 ft/yr. which is also considered to represent a stable condition. One area located between the Sanderling Resort (station D-04) and Martin Lane (station D-06) did appear to experience an increase in the rate of recession of the MHW shoreline.

**South of the Project Area.** Long-term shoreline change rates computed between October 1996 and May 2015 prior to the construction of the beach nourishment project averaged -0.6 ft/yr. For the updated long-term period that includes the beach fill project (October 1996 to June 2018), the shoreline change rate remained about the same, averaging -0.2 ft/yr. One section of the shoreline south of the project located between profile stations D-25 and D-27 (Sea Colony to Wampum Dr.) eroded at an average rate of -1.5 ft./yr. for the October 1996 to June 2018 period as did another section between D-32 and D-33 (Seahawk Dr. to Tides Dr.). Even though the recession rates in these two sections was considerably greater than the overall average, the rates are considered to be moderate. These two areas will need to be closely monitored to see if threat levels increase.

### **Volume Change Analysis:**

**Project Area.** During the 6-month period from December 2017 to June 2018, the project area lost 98,500 cubic yards or about 9.5% of the fill measured in the Project Area in December 2017. Some of the volume loss from the project area appeared to be due to material being transported to the north and south out of the Project Area. For example, the 4,000-foot section of shoreline just north of the Project Area (between stations D-10 and D-06) gained approximately 17,000 cubic yards between December 2017 and June 2018. However, the 2,000-foot section of shoreline immediately south of the Project Area (stations D-20 to D-23), lost 38,300 cubic yards. This negative volume change was driven by changes in the profile measured at station D-21 which exhibited an anomalous wide and deep trough just offshore. A similarly sized trough was not observed on the profiles immediately north and south of D-21. With profile D-21 immediately north and adjacent to the FRF pier, the configuration of the project could have been influenced by wave interacting with the pier's piles. Changes in the profile at D-21 will be closely examined following the next monitoring survey to determine if the abnormal trough is still present or if it was just an ephemeral feature associated with antecedent wave conditions.

### **North of Project Area.**

The updated long-term volume changes in the area north of the project, measured between September 2013 and June 2018, averaged -4.2 cy/ft./yr. The extreme northern sections of the area between profile stations D-07 and PI-17 continued to experience higher erosion rates compared to the southern end between profile stations D-07 and D-10. Between profile stations D-06 and PI-17, the long-term average rate of volume change was -6.1 cy/ft./yr. while the southern end of the area only lost an average of -1.0 cy/ft./yr. The performance of the southern end of the area is an indication of the positive impacts the beach nourishment project is having in this area.

**South of Project Area.** As previously reported in the May 2018 monitoring report (APTIM, 2018A), the average long-term volume change between profile station D-19 to D-34, measured between September 2013 and December 2017, was a gain of 2.9 cy/ft./yr. The updated long-term trend for this area, based on the September 2013 and June 2018 surveys, indicates an average loss of -0.6 cy/ft./yr. The major difference in the shoreline response for these two periods occurred between profile stations D-24 and D-30 (Shipwatch to Four Seasons Lane). For the previous long-term period between September 2013 and December 2017, this section of the shoreline lost an average of -0.7 cy/ft./yr. whereas the updated long-term rate in this section measured between

September 2013 and June 2018 was a loss of -4.4 cy/ft./yr. This area should be closely monitored to see if the risk of damage to development in the area increases.

## **VII. RECOMMENDATIONS**

APTIM recommends the Town continue to monitor the entire Town oceanfront shoreline in order to assess if the trends measured in the volume change analysis persist in those regions identified. Based on the most recent analysis and observations made during the monitoring of the beach nourishment projects in Kitty Hawk and Kill Devil Hills, APTIM is recommending that future monitoring surveys also include tighter bathymetric survey grid spacing in the nearshore portion of the profile. We recommend that 200-foot spaced, shore-parallel lines be surveyed at the same time the beach profile surveys are conducted. These shore-parallel surveys should lead to a better understanding of how features in the nearshore may be influencing volume change calculations conducted using 1000-foot beach profile surveys alone. Furthermore, APTIM recommends that the 2019 annual monitoring survey include an updated analysis of the vulnerability of structures located outside the project area.

Future monitoring will be instrumental for the Town to evaluate future areas of concerns and to develop successful shoreline management strategies to deal with issues as they arise. The monitoring program will continue to provide valuable information on the performance of the 2017 beach fill project and aid in the determination as to when additional nourishment is needed in the project area. The measured performance of the beach fill will also serve as a valuable tool to aid in the development and design of future beach nourishment projects the Town may consider. Along those lines, the monitoring of the beach fill project is necessary for the Town to be eligible for federal Public Assistance funds should the project be impacted by a storm.

## VIII. REFERENCES

APTIM, 2018A. Aptim Coastal Planning & Engineering of North Carolina, Inc., *Town of Duck North Carolina Shoreline & Volume Change Monitoring Report*, Wilmington, NC.

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

CPE-NC, 2016. Coastal Planning & Engineering of North Carolina, Inc., *Town of Duck North Carolina Shoreline & Volume Change Monitoring Report*, Wilmington, NC.

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

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## **APPENDIX A**

### **2018 TOWN OF DUCK MONITORING SURVEY REPORT**



# **2018 Town of Duck Annual Monitoring Beach Profile Survey Report**

**Prepared for:**

**Town of Duck, North Carolina**

**Prepared by:**

**Aptim Coastal Planning & Engineering of North Carolina, Inc.  
4038 Masonboro Loop Road  
Wilmington, NC 28409**

**September 2018**



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## **ABSTRACT**

Aptim Coastal Planning & Engineering of North Carolina, Inc. (APTIM) was contracted by Duck, North Carolina to provide a topographic and hydrographic survey for the 2018 Annual Monitoring Beach Profile Survey. The 2018 annual monitoring consisted of thirty-six (36) profile stations. APTIM surveyors conducted the beach and hydrographic surveys June 13, 2018 through June 16, 2018.

The physical monitoring of the Town of Duck included topographic and hydrographic surveys of the beach and offshore areas. The monitoring data is necessary to observe and assess beach conditions for future construction. Monitoring surveys are further needed to continually observe the performance of the nourishment project as well as assess effects of said project on adjacent shorelines.

The scientific monitoring processes provide information necessary to plan, design, and optimize subsequent follow up projects. The information gathered may potentially reduce the need for, and cost of, unnecessary work as well as potentially reducing any environmental impacts that may have occurred or are to be expected.

## **SURVEY METHODOLOGIES**

The surveys were conducted in accordance with the Minimum Performance Standards for the U.S. Army Corps of Engineers (USACE), Engineering and Design Hydrographic Surveying Manual (EM 1110-2-1003).

This survey is in accordance with Chapter 56.1606 of the North Carolina Administrative Code (NCAC) specifications established by The North Carolina Engineering and Land Surveying Act (GS89C). In addition, all hydrographic surveying was conducted under the direct supervision of an American Congress of Surveying and Mapping (ACSM) Certified Hydrographer (CH). Included in this Hydrographic and Topographic Survey Report are seven (7) maps visualizing profiles, one (1) project location map, and six (6) plan view maps. The plan view maps show reduced true position elevation data collected during the survey. The location of all published control, as well as control found and used for survey purposes, is presented in the Monument Information Report provided in **Appendix 1**.

Vertical data was collected in the North American Vertical Datum of 1988 (NAVD88). All Horizontal data is provided in the North Carolina State Plane Coordinate System, North American Datum of 1983/2011 (NAD 83/2011). Profile data is presented in xyz format relative to The North American Vertical Datum of 1988 (NAVD88) in **Appendix 2**. Profile plots are provided in **Appendix 3**. Ground digital photography obtained during the survey is provided in **Appendix 4**. Copies of all field book pages are provided in **Appendix 5** (digital format only).

The field survey and data collection activities encompassed four (4) phases. Brief descriptions of each survey phase, including methodologies and quality control/quality assurance procedures, are described below.

### **Phase One: Control Reconnaissance/Establishment/Verification**

Prior to the start of the survey, reconnaissance of the monuments was conducted to confirm that survey control was in place and undisturbed. Real Time Kinematic Global Positioning System (RTK GPS) was used to locate and confirm survey control for this project. The horizontal and vertical accuracy of control data meets the accuracy requirements as set forth in the Engineering and Design Hydrographic Surveying Manual (EM 1110-2-1003). In order to achieve required accuracy, the topographic and hydrographic surveys were controlled using 2<sup>nd</sup> order monuments, specifically C255 and TIDAL C from the National Geodetic Survey (NGS). Horizontal and vertical positioning checks were conducted at the beginning and end of each day using at least two 2<sup>nd</sup> order monuments in the project area. The RTK GPS utilizes statistical methods to ensure accuracy of RTK GPS data remains within the 95% confidence interval. The control check shots were acquired using a minimum of five (5) epochs which results in a high accuracy location. Results from 2<sup>nd</sup> order control checks are displayed showing northing, easting,

monument elevation, inverses, horizontal and vertical root mean square error, location description and photographs as indicated in the Monument Information Report (**Appendix 1**).

## **Phase Two: Beach Profiles**

Upon completion of the control reconnaissance survey, beach/upland and nearshore operations were initiated. Cross-sections of the beach in the project area were surveyed using extended rod RTK GPS rovers, and standard RTK GPS rovers. Extended rod RTK GPS rovers were used to augment RTK GPS survey capability into the nearshore. The current systems allow surveyors from APTIM to collect the entire beach profile with RTK GPS technology. Incorporation of RTK GPS into monitoring surveys greatly reduces the potential for human error during data collection and reduction. Furthermore, RTK GPS provides accuracies of two (2) centimeters  $\pm$  one (1) part per million with true horizontal positioning to the survey data point regardless of sea state.

Profiles commenced from the onshore control point and extend seaward overlapping the offshore data. Nearshore portions of the profiles were surveyed by two (2) surveyors with an Extended Rod Trimble R8 RTK GPS rover who entered the water wearing Personal Floatation Devices (PFD). Trimble TSC3 data collectors are equipped with Bluetooth technology allowing wireless communication with the GPS receiver at a data exchange speed of 2.1 megabits per second. The rover system allows surveyors from APTIM to reach a maximum water depth of eleven (11) feet. The nearshore survey extended seaward to a point overlapping the offshore portion of the profiles by at least fifty (50) feet.

The upland portion of the survey commenced at the waterline and extended 25 feet landward of the dune or until an obstacle was encountered. The upland portions of the profiles were surveyed using an RTK GPS. Elevations were taken at approximately twenty-five (25) foot intervals along each profile line and at all grade breaks. To maintain online accuracy surveyors utilized the RTK GPS feature *stakeout point*. *Stakeout point* allows surveyors to maintain the profile azimuth without relying on survey lathe or conventional compass bearings.

## **Phase Three: Nearshore/Offshore Profiles**

The Nearshore/Offshore profiles were conducted at each required profile station. The profiles were obtained 2,500 feet beyond the shoreline or to the -30 NAVD88 contour, whichever is more landward. The landward limits of the nearshore profiles were based on a minimum overlap of fifty (50) feet beyond the seaward extent of beach profiles. Soundings were collected at a maximum of twenty-five (25) foot intervals with an Odom Hydrotrac, sufficient to provide an accurate depiction of the seafloor. Offshore data at the pier was obtained from the U.S Army Corps of Engineers Field Research Facility.

Nearshore/offshore profiles were collected using an Odom Hydrotrac single frequency sounder with digitizer on APTIM's twenty-eight (28) foot Parker survey vessel with a centrally located hull-mounted transducer. Data was digitally stored using HYPACK 2017 Software. A Trimble R-8 RTK GPS and a TSS DMS-25 dynamic motion sensor were used onboard the survey vessel to provide instantaneous tide corrections and attitude corrections. Manual tide readings were taken while conducting the onshore portion of the profile to verify onboard tide readings. In order to maintain the vessel navigation along the profile lines, HYPACK 2017 navigation software was used. This software provided horizontal position to the sounding data allowing real-time review of the data in plan view or cross-section format. HYPACK 2017 also provided navigation to the helm to minimize deviation from the online azimuth.

Horizontal and vertical positioning checks were conducted at the beginning and end of each day as described in phase one (1) of the survey. The sounder was calibrated via bar-checks and a sound velocity probe at the beginning and end of the day. The DIGIBAR PRO sound velocity meter offers a fast additional calibration for sound velocity as compared to the traditional bar-check. Bar-checks were performed from a depth of five (5) feet to a depth of at least twenty-five (25) feet. Analog data showing the results of the bar-check calibration was displayed on the sounder charts at five (5) foot increments during descent of the bar. Offshore data was collected within one (1) week of onshore data collection for each line.

#### **Phase Four: Data Reduction/Submittals**

Upon completion of the field work, data was edited and reduced with Trimble Business Center, HYPACK 2017, and APTIM's internal software programs. The upland and nearshore portions of the beach profile were viewed and edited in Trimble Business Center and a comma delimited XYZ file was created. The offshore raw digital data was viewed and edited in HYPACK 2017's *Single Beam Editor*. The offshore RTK GPS tide data that was collected was compared to the manually collected RTK GPS nearshore tide data, local observed, and predicted tides for data verification purposes. Tide corrected offshore data was exported and a comma delimited XYZ file was created. All overlapping profile data was compared in cross section to ensure system accuracy. The edited beach profile data and offshore profile data were merged and a representative cross-section was derived for each profile line. The cross sections were developed using internal APTIM plotting programs.

The final plots were edited and reviewed with comparisons to previous years; discrepancies were noted and resolved. The final approved cross-section data was prepared in the required formats for submittal (**Appendix 3**). Digital data is provided in the State required vertical datum NAVD88.

### **Map Preparation:**

Upon completion of the surveys and data reduction, the survey maps were prepared in ArcGIS 10.3. In order to avoid congestion, the survey maps do not show all of collected elevations but enough to give an accurate depiction of the cross sections. The survey maps display profile data and control monument locations plotted against United States Army Corps of Engineers (USACE) 2016 aerial photographs.

### **Ground Digital Photography:**

Surveyors from APTIM collected three (3) digital photos at a mid-beach location at each profile location. The three (3) photos included one (1) in each shore-parallel direction and one (1) landward toward the monument. Wherever possible, an additional digital photo was taken of the control identification or stamping on the monument.

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**LEGEND**

	PROFILE STATION
	CONTROL MONUMENT
PV	PLAN VIEW
CS	COVER SHEET
APTIM	APTIM COASTAL PLANNING & ENGINEERING OF NORTH CAROLINA INC.
C.O.L.	CERTIFICATE OF LICENSURE
NAVD	NORTH AMERICAN VERTICAL DATUM
NAD	NORTH AMERICAN DATUM
NTS	NOT TO SCALE
Rd	ROAD
NC	NORTH CAROLINA
AZ	AZIMUTH
MON	MONUMENT
ID	IDENTIFICATION
MK	MARK
U.S.	UNITED STATES OF AMERICA



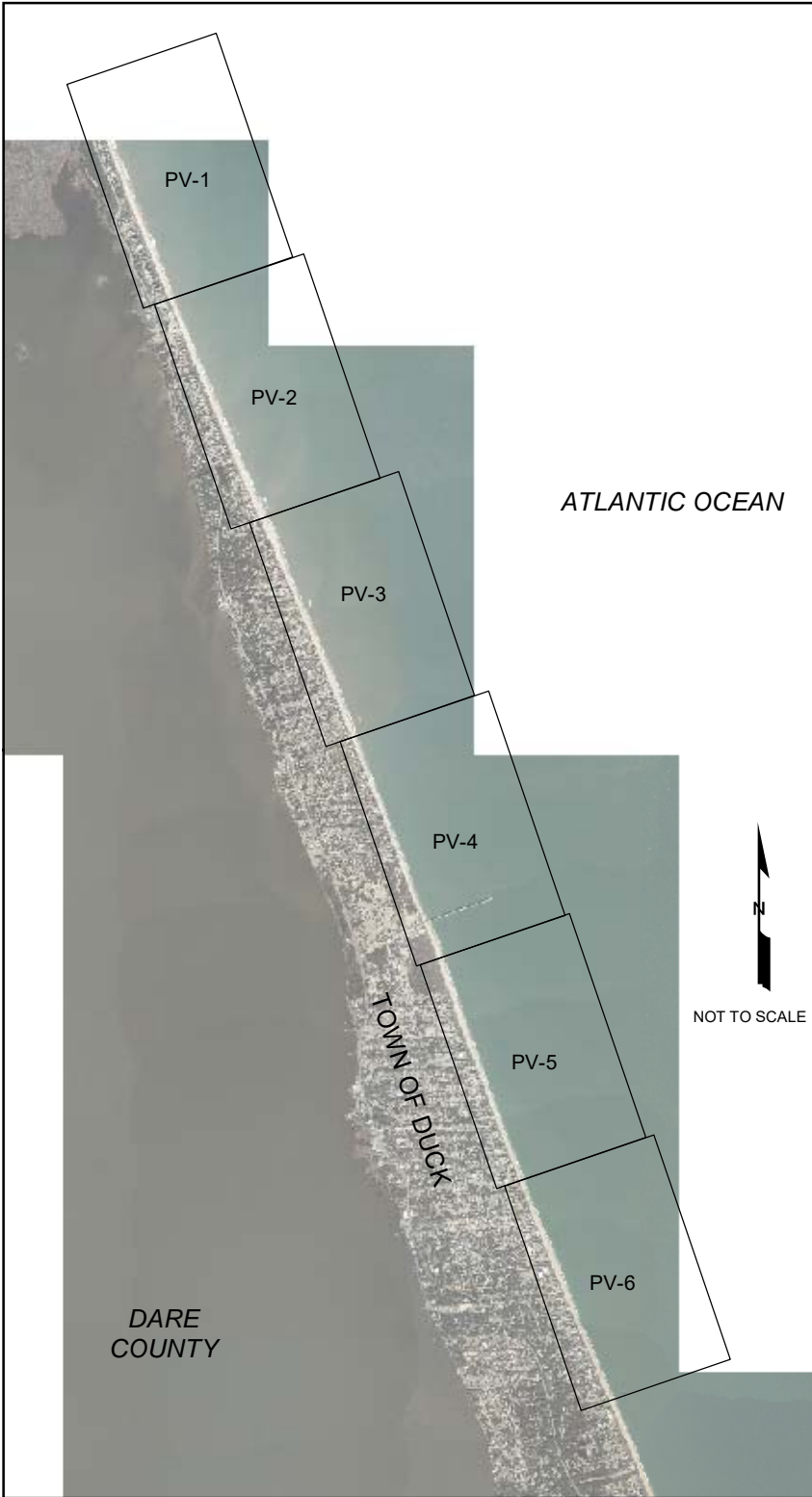
# 2018 TOWN OF DUCK ANNUAL MONITORING BEACH PROFILE SURVEY REPORT

INDEX TO SHEETS

- 1 COVER SHEET AND PROJECT LOCATION MAP  
2-7 PROJECT PLAN VIEWS

CONTROL USED BY APTIM 2018 SURVEY			
DATUMS: NAD83/2011 / NAVD88			
STATION	NORTHING	EASTING	AZIMUTH
PI-17	920098.90	2950657.30	70.00
PI-18	919175.40	2951026.00	70.00
D-01	918267.70	2951387.50	70.00
D-02	917384.40	2951733.80	70.00
D-03	916429.40	2952103.00	70.00
D-04	915495.30	2952464.00	70.00
D-05	914598.00	2952849.30	70.00
D-06	913696.90	2953224.40	70.00
D-07	912798.80	2953607.30	70.00
D-08	911897.90	2953983.00	70.00
D-09	910994.82	2954356.65	70.00
D-10	910066.74	2954759.12	70.00
D-11	909133.14	2955158.05	70.00
D-12	908412.53	2955461.41	70.00
D-13	907478.35	2955874.29	70.00
D-14	906578.33	2956252.15	70.00
D-15	905677.78	2956628.57	70.00
D-16	904767.65	2956978.72	70.00
D-17	903863.92	2957333.66	70.00
D-18	902886.47	2957718.79	70.00
D-19	902331.03	2957932.45	70.00
D-20	901760.74	2958139.73	70.00
D-21	900958.70	2958472.10	70.00
D-22	900228.80	2958754.00	70.00
D-23	899515.60	2958992.70	70.00
D-24	898739.80	2959267.20	70.00
D-25	897824.30	2959601.70	70.00
D-26	896902.30	2959928.60	70.00
D-27	895981.90	2960250.60	70.00
D-28	895073.00	2960604.10	70.00
D-29	894166.20	2960963.60	70.00
D-30	893257.60	2961317.70	70.00
D-31	892350.70	2961676.70	70.00
D-32	891379.40	2962078.10	70.00
D-33	890553.20	2962439.40	70.00
D-34	889616.10	2962839.60	70.00

DARE COUNTY A-MON CONTROL			
MON STAMPING	NORTHING	EASTING	M. ELEV.
Y167	871368.17	2970021.75	30.85
C255 1981	900856.11	2958600.06	16.89
865 1370 C TIDAL	900621.51	2957662.02	18.46



**APTIM COASTAL PLANNING & ENGINEERING  
OF NORTH CAROLINA, INC.**

4038 MASONBORO LOOP RD.  
WILMINGTON, NC 28409  
PH: (910) 791-9494  
FAX (910) 791-4129  
COL #C2331

2018 TOWN OF DUCK ANNUAL MONITORING  
BEACH PROFILE SURVEY REPORT

**COVER SHEET**

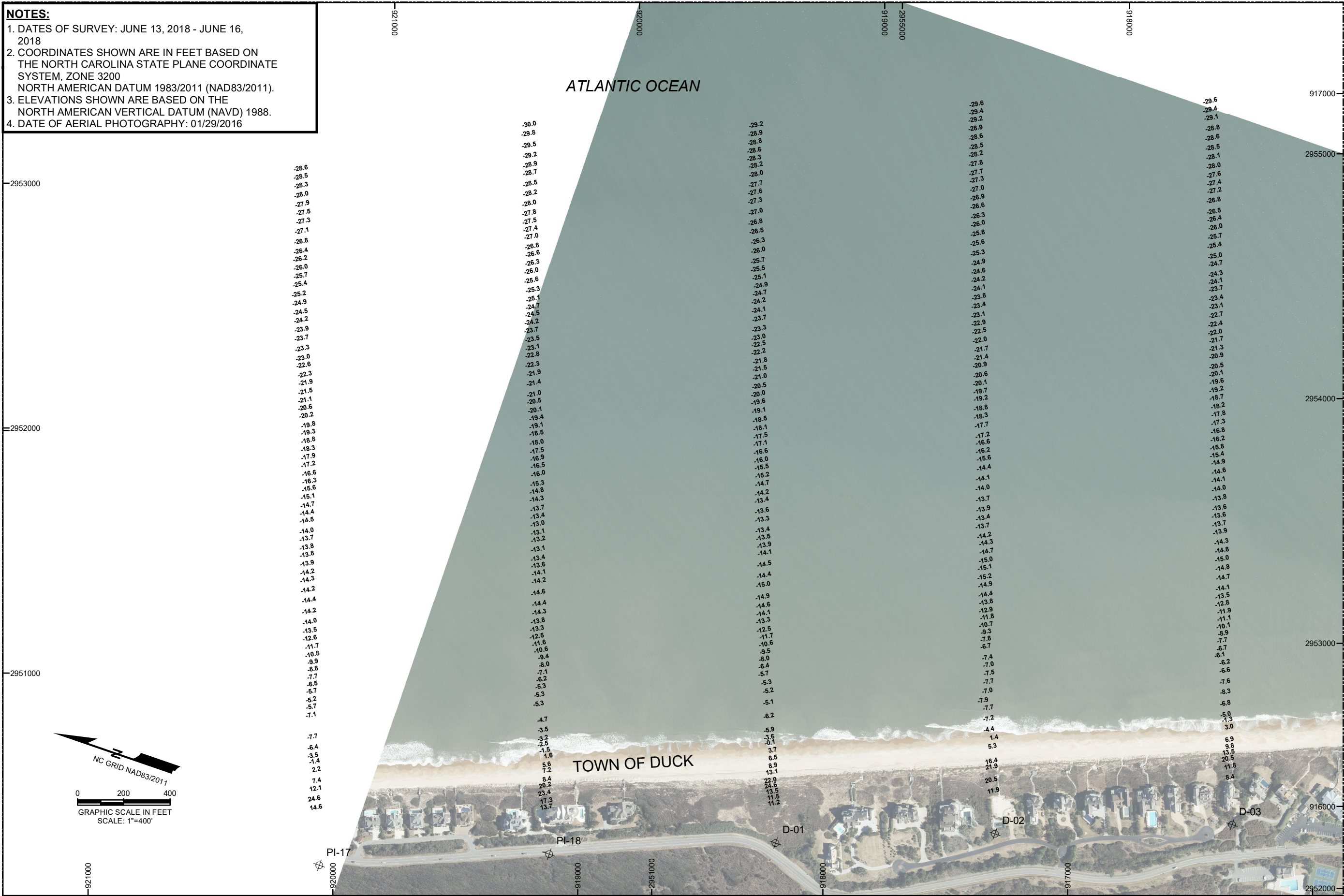
DRAWING NO.

**CS**

SHEET 1 OF 7

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- NOTES:**
1. DATES OF SURVEY: JUNE 13, 2018 - JUNE 16, 2018
  2. COORDINATES SHOWN ARE IN FEET BASED ON THE NORTH CAROLINA STATE PLANE COORDINATE SYSTEM, ZONE 3200  
NORTH AMERICAN DATUM 1983/2011 (NAD83/2011).
  3. ELEVATIONS SHOWN ARE BASED ON THE NORTH AMERICAN VERTICAL DATUM (NAVD) 1988.
  4. DATE OF AERIAL PHOTOGRAPHY: 01/29/2016

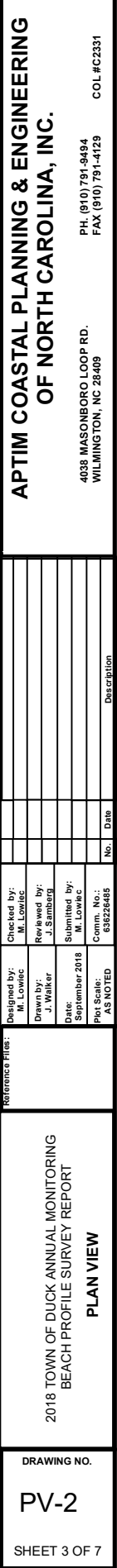


MATCHLINE SHEET 3 OF 7

Reference Files:		Designed by:	Checked by:	APTIM COASTAL PLANNING & ENGINEERING OF NORTH CAROLINA, INC. 4038 MASONBORO LOOP RD. WILMINGTON, NC 28409 PH: (910) 791-9494 FAX: (910) 791-4129 COL #C2331	
		Drawn by:	Reviewed by:		
2018 TOWN OF DUCK ANNUAL MONITORING BEACH PROFILE SURVEY REPORT		Date:	Submitted by:	DRAWING NO. <b>PV-1</b> SHEET 2 OF 7	
		Plot Scale:	Comm. No.:		
PLAN VIEW		AS NOTED		Description	
		No. Date			

**NOTES:**

1. DATES OF SURVEY: JUNE 13, 2018 - JUNE 16, 2018
2. COORDINATES SHOWN ARE IN FEET BASED ON THE NORTH CAROLINA STATE PLANE COORDINATE SYSTEM, ZONE 3200 NORTH AMERICAN DATUM 1983/2011 (NAD83/2011).
3. ELEVATIONS SHOWN ARE BASED ON THE NORTH AMERICAN VERTICAL DATUM (NAVD) 1988.
4. DATE OF AERIAL PHOTOGRAPHY: 01/29/2016



Document Path: G:\Enterprise\NorthCarolina\636226485 486 487 Dare 1YRPOST\Survey Charts\MXD\IDuck PV3.mxd

**NOTES:**

1. DATES OF SURVEY: JUNE 13, 2018 - JUNE 16, 2018
2. COORDINATES SHOWN ARE IN FEET BASED ON THE NORTH CAROLINA STATE PLANE COORDINATE SYSTEM, ZONE 3200 NORTH AMERICAN DATUM 1983/2011 (NAD83/2011).
3. ELEVATIONS SHOWN ARE BASED ON THE NORTH AMERICAN VERTICAL DATUM (NAVD) 1988.
4. DATE OF AERIAL PHOTOGRAPHY: 01/29/2016



MATCHLINE SHEET 5 OF 7

**APTIM COASTAL PLANNING & ENGINEERING  
OF NORTH CAROLINA, INC.**

COL #C2331

FAX (910) 791-4129

WILMINGTON, NC 28409

2018 TOWN OF DUCK ANNUAL MONITORING  
BEACH PROFILE SURVEY REPORT

DRAWING NO.

PV-3

SHEET 4 OF 7

**NOTES:**  
1. DATES OF SURVEY: JUNE 13, 2018 - JUNE 16, 2018  
2. COORDINATES SHOWN ARE IN FEET BASED ON THE NORTH CAROLINA STATE PLANE COORDINATE SYSTEM, ZONE 3200  
NORTH AMERICAN DATUM 1983/2011 (NAD83/2011).  
3. ELEVATIONS SHOWN ARE BASED ON THE NORTH AMERICAN VERTICAL DATUM (NAVD) 1988.  
4. DATE OF AERIAL PHOTOGRAPHY: 01/29/2016



Offshore data collected by  
Army Corps of Engineers  
Field Research Facility  
D-21 to D-24

2018 TOWN OF DUCK ANNUAL MONITORING  
BEACH PROFILE SURVEY REPORT

PV-4

SHEET 5 OF 7

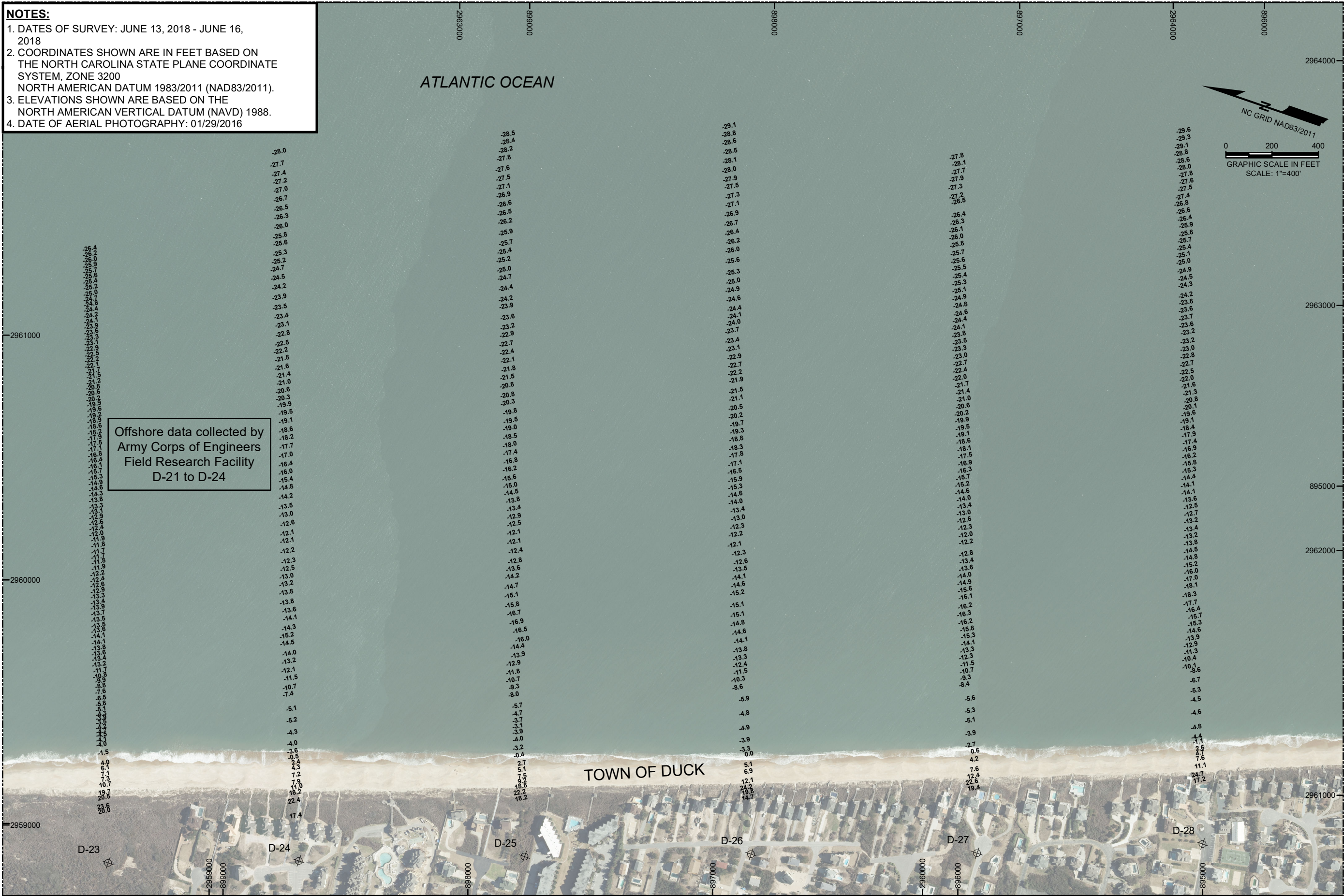
APTIM COASTAL PLANNING & ENGINEERING  
OF NORTH CAROLINA, INC.

PH: (910) 791-9494  
FAX: (910) 791-4129  
4038 MASONBORO LOOP RD.  
WILMINGTON, NC 28409  
COL #C2331

Designed by:	Checked by:	No.	Date	Description
W. Lowrie	W. Lowrie			
J. Walker	J. Walker			
September 2018	Submitted by:			
Plot Scale:	Comm. No.:			
AS NOTED	636226485			

- NOTES:**
1. DATES OF SURVEY: JUNE 13, 2018 - JUNE 16, 2018
  2. COORDINATES SHOWN ARE IN FEET BASED ON THE NORTH CAROLINA STATE PLANE COORDINATE SYSTEM, ZONE 3200  
NORTH AMERICAN DATUM 1983/2011 (NAD83/2011).
  3. ELEVATIONS SHOWN ARE BASED ON THE NORTH AMERICAN VERTICAL DATUM (NAVD) 1988.
  4. DATE OF AERIAL PHOTOGRAPHY: 01/29/2016

MATCHLINE SHEET 5 OF 7



**NOTES:**

1. DATES OF SURVEY: JUNE 13, 2018 - JUNE 16, 2018
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3. ELEVATIONS SHOWN ARE BASED ON THE NORTH AMERICAN VERTICAL DATUM (NAVD) 1988.
4. DATE OF AERIAL PHOTOGRAPHY: 01/29/2016



4038 MASONBORO LOOP RD.  
WILMINGTON, NC 28409  
PH. (910) 791-9494  
FAX (910) 791-4129  
COL #C2331

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PH. (910) 791-9494  
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COL #C2331

2018 TOWN OF DUCK ANNUAL MONITORING  
BEACH PROFILE SURVEY REPORT

DRAWING NO.

PV-6

SHEET 7 OF 7



### Survey Report Notes

**Survey Title:** 2018 Town of Duck Annual Monitoring Beach Profile Survey Report

**Prepared Date:** September 2018

**Prepared For:** Town of Duck, NC

**Prepared By:** APTIM Coastal Planning & Engineering of North Carolina, Inc.

**Dates of Survey:** June 13, 2018 through June 16, 2018

**Survey Location:** Town of Duck PI-17 through D-34

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#### Notes:

1. The survey is neither valid nor complete without both the survey report and described survey maps. Digital data files encompassing the following have also been provided in the following formats listed.
  - *Monument Information Report (Appendix 1)*
  - *ASCII file (profile xyz data. Digital only) (Appendix 2)*
  - *Profile Plots (Appendix 3)*
  - *Ground Digital Photography (Appendix 4)*
  - *Project field books (Digital Only)(Appendix 5)*
2. The information on this map represents the results of the survey on the dates indicated and can only be considered as indicating the general conditions existing at the time.
3. The coordinates shown are in US survey feet based on the vertical and horizontal data that was collected and presented relative to the North American Vertical Datum of 1988 (NAVD88) and the North Carolina State Plane Coordinate System, North American Datum of 1983/2011 (NAD 83/2011).
4. Vertical measurements are based on second order monuments C255 and TIDAL C per published NGS coordinates.

5. Bearings are based on a bearing of South 255° 57' 31" East between NGS second order monuments C255 and TIDAL C per published NGS coordinates.
6. Underground and subaqueous improvements and/or utilities were not located as part of this survey and should be field verified prior to any dredging or construction activities.
7. Refer to APTIM field book OBX 2018 for the onshore portion and book No. 50 for the offshore portion.
8. Aids to navigation were not located during this survey.
9. Soundings were collected using an Odom Hydrotrac, Single Frequency, survey grade sounder. The sounder was calibrated prior to the start of the survey following manufacturers recommended procedures.
10. This survey was conducted for Town of Duck for use as a topographic and hydrographic survey.

## **APPENDIX OVERVIEW**

### **1) Monument Information Report**

Data collected during the survey is entered in a spreadsheet format and compared to data provided by NGS. This comparison shows differences in northings, eastings and elevation of NGS published control, what was collected in the field, and what was used during profile reduction.

### **2) Profile XYZ data (digital only)**

Offshore survey data was converted into APTIM files. Onshore data was reduced by standard means of reduction and also entered into APTIM format and merged with the offshore data. APTIM format is used for in-house plotting, volume computations and other engineering analyses. The APTIM formatted data was converted into xyz format. The xyz data is provided in the datum collected (NAVD88) as per state standards.

### **3) Profile Plots**

Profile plots of this survey data compared with historical profile data.

### **4) Ground Digital Photography**

APTIM surveyors collected three (3) digital photos at a mid-beach location at each profile location. The three (3) photos included one (1) in each shore-parallel direction and one (1) landward toward the monument. In addition, wherever possible a digital photo was taken of the control identification or stamping on the monument.

### **5) Field Book Pages (digital only)**

This appendix includes copies of the field book pages used for the survey. Refer to APTIM field book OBX 2018 for the onshore portion. Navigation field book No. 50 for the offshore survey.

## APPENDIX 1

### MONUMENT INFORMATION REPORT

## TOWN OF DUCK STATION INFORMATION

June 2018

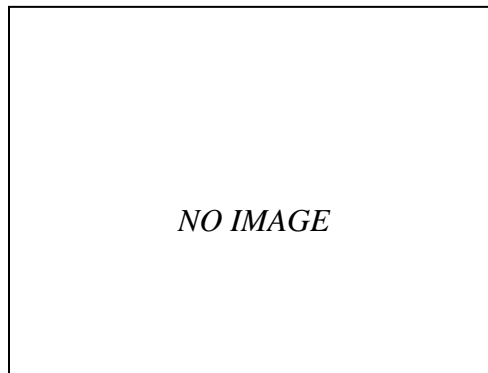
DATUMS: NAD83/2011 & NAVD88

STATION	NORTHING	EASTING	AZIMUTH
PI-17	920098.86	2950657.32	70
PI-18	919175.36	2951025.99	70
D-01	918267.75	2951387.52	70
D-02	917384.44	2951733.76	70
D-03	916429.37	2952102.95	70
D-04	915495.29	2952464.03	70
D-05	914597.97	2952849.30	70
D-06	913696.93	2953224.38	70
D-07	912798.76	2953607.33	70
D-08	911897.95	2953983.04	70
D-09	910994.82	2954356.65	70
D-10	910066.74	2954759.12	70
D-11	909133.14	2955158.05	70
D-12	908412.53	2955461.41	70
D-13	907478.35	2955874.29	70
D-14	906578.33	2956252.15	70
D-15	905677.78	2956628.57	70
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D-17	903863.92	2957333.66	70
D-18	902886.47	2957718.79	70
D-19	902331.03	2957932.45	70
D-20	901760.74	2958139.73	70
D-21	900958.69	2958472.08	70
D-22	900228.83	2958754.03	70
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D-25	897824.26	2959601.68	70
D-26	896902.26	2959928.60	70
D-27	895981.88	2960250.61	70
D-28	895072.97	2960604.07	70
D-29	894166.25	2960963.56	70
D-30	893257.57	2961317.69	70
D-31	892350.69	2961676.73	70
D-32	891379.42	2962078.13	70
D-33	890553.16	2962439.37	70
D-34	889616.07	2962839.65	70

<b>CONTROL MONUMENT USED BY APTIM FOR 2018 DARE COUNTY ANNUAL MONITORING TOPOGRAPHIC AND HYDROGRAPHIC SURVEY REPORT JUNE 2018</b>	
<b>DATUMS: NAD83/2011 - NAVD1988</b>	
<b>Designation</b>	C255
<b>Stamping</b>	C255 1981
<b>Northing</b>	900856.11
<b>Easting</b>	2958600.06
<b>Horizontal Root Mean Square Error</b>	0.230
<b>Elevation</b>	16.89
<b>Vertical Root Mean Square Error</b>	0.114
<b>Description</b>	A National Geodetic Survey pin inside a protective casing with lid approximately 3 inches below ground and located between the two steps on the West side of the Army Corp of Engineer's Field Research Facility (1261 Duck Road), approximately 355 feet East of the main parking lot gate, 15 feet South of the Northerly steps, 15 feet North of the Southerly steps, and 2.7 feet West of the flag pole.



Monument: C255



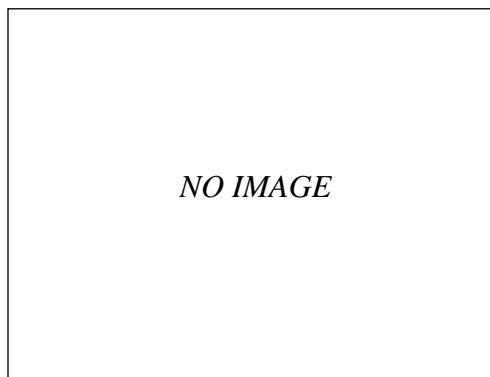
Location Verification: C255

<b>Mean of Inverse Shots - Published Versus APTIM Found</b>				
Monument	No. of Shots	$\Delta N$	$\Delta E$	$\Delta Z$
C255	10	-0.10	-0.04	0.09

<b>CONTROL MONUMENT USED BY APTIM FOR 2018 DARE COUNTY ANNUAL MONITORING TOPOGRAPHIC AND HYDROGRAPHIC SURVEY REPORT JUNE 2018</b>	
<b>DATUMS: NAD83/2011 - NAVD1988</b>	
<b>Designation</b>	TIDAL C
<b>Stamping</b>	865 1370 1977
<b>Northing</b>	900621.51
<b>Easting</b>	2957662.02
<b>Horizontal Root Mean Square Error</b>	0.229
<b>Elevation</b>	18.46
<b>Vertical Root Mean Square Error</b>	0.015
<b>Description</b>	A National Ocean Survey disk protected by an open pipe approximately 6 inches above ground and located on the Army Corp of Engineer's Field Research Facility property (1261 Duck Road) approximately 600 feet East of Duck Road, 300 feet West of the gazebo, and 100 feet North of the access road.



Monument: TIDAL C



Location Verification: TIDAL C

<b>Mean of Inverse Shots – OPUS Solution Versus APTIM Found</b>				
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TIDAL C	10	0.05	0.12	0.00

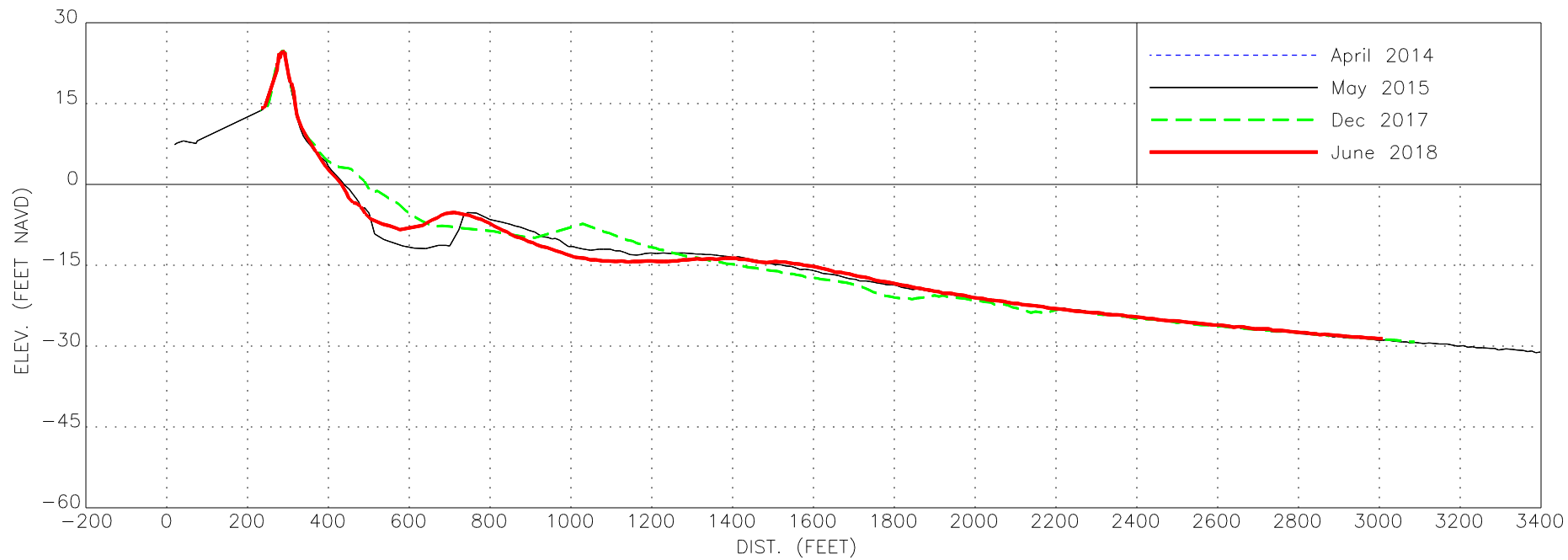
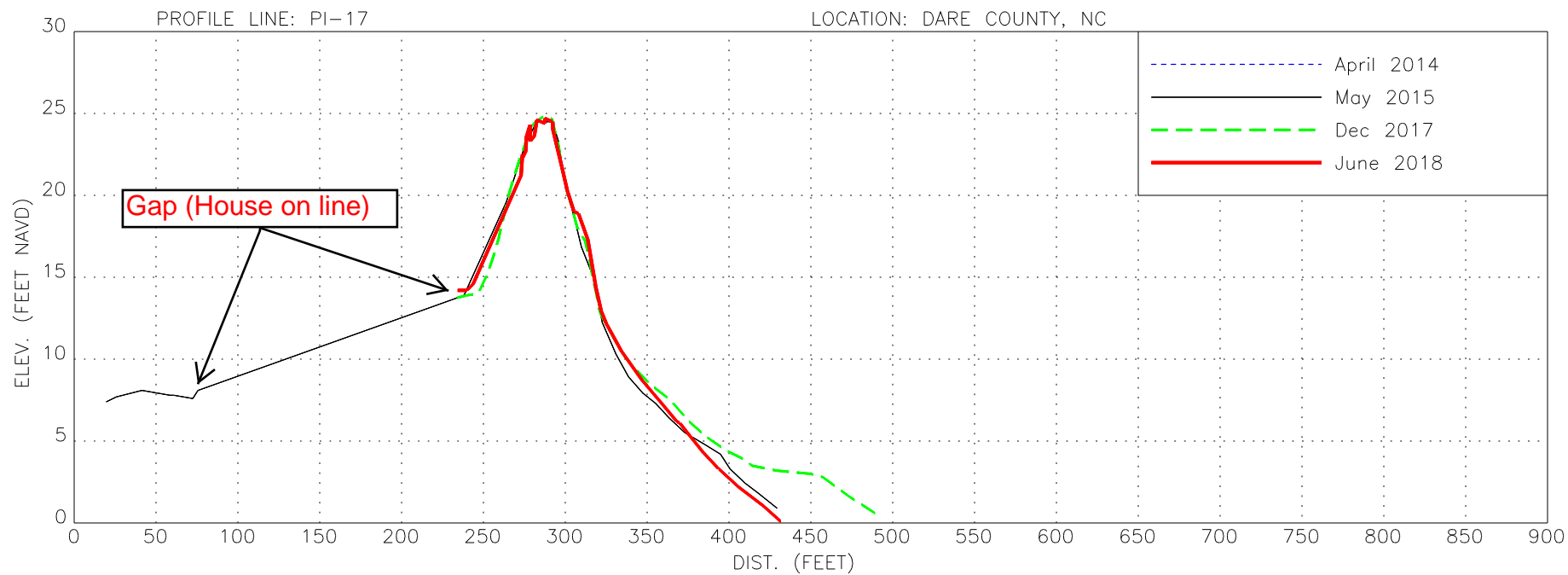
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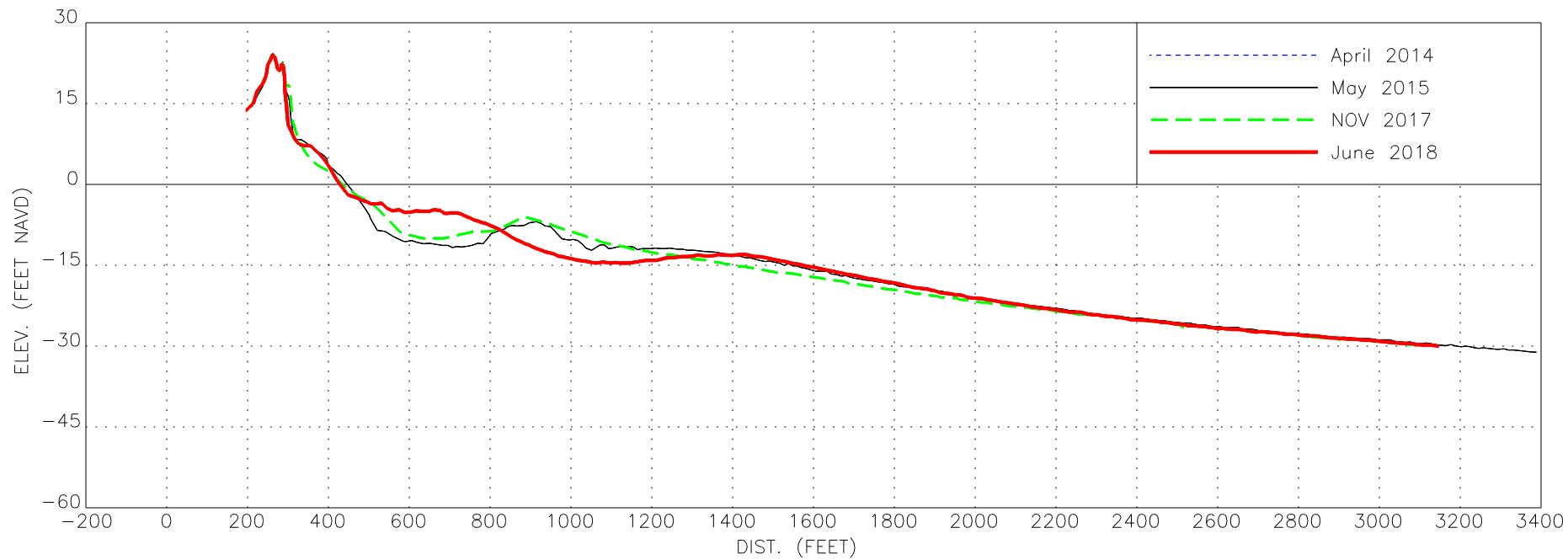
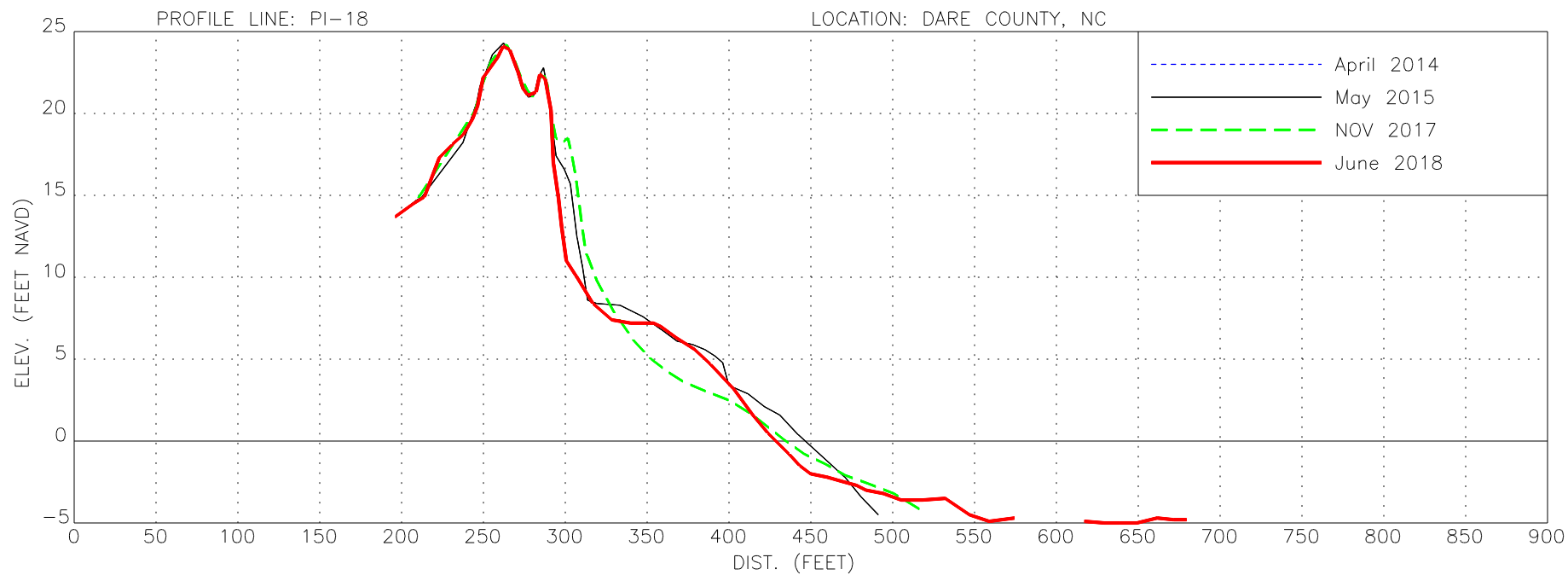
PROFILE XYZ DATA

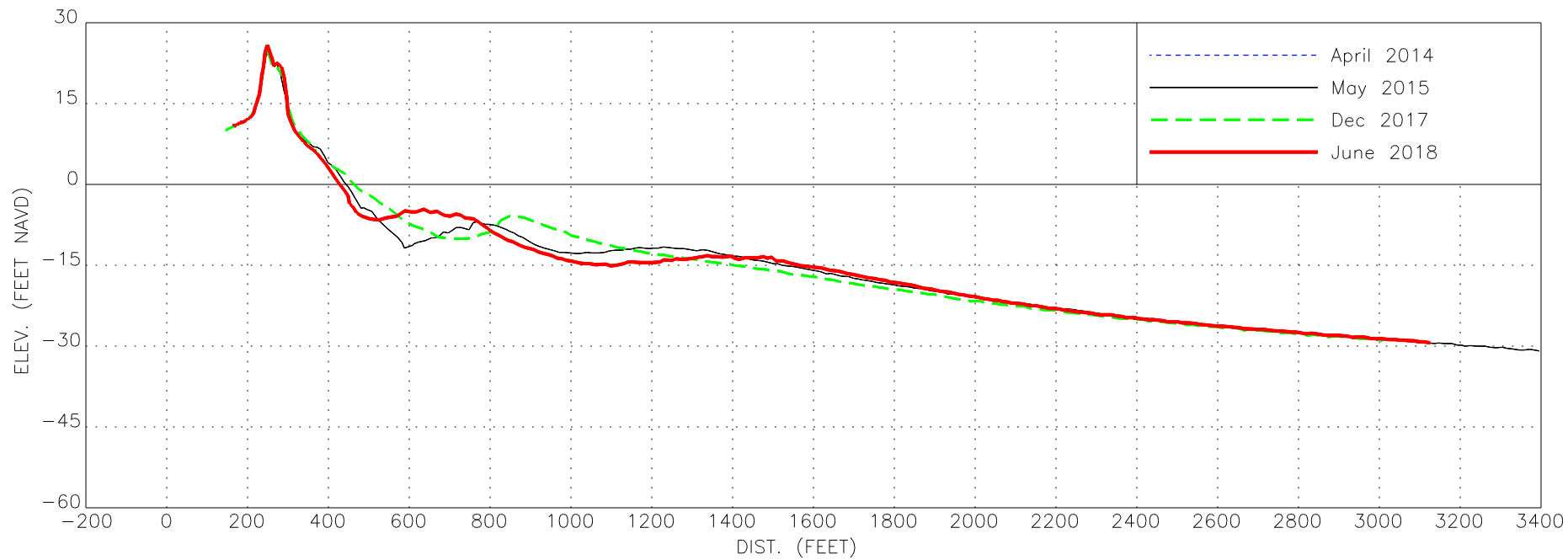
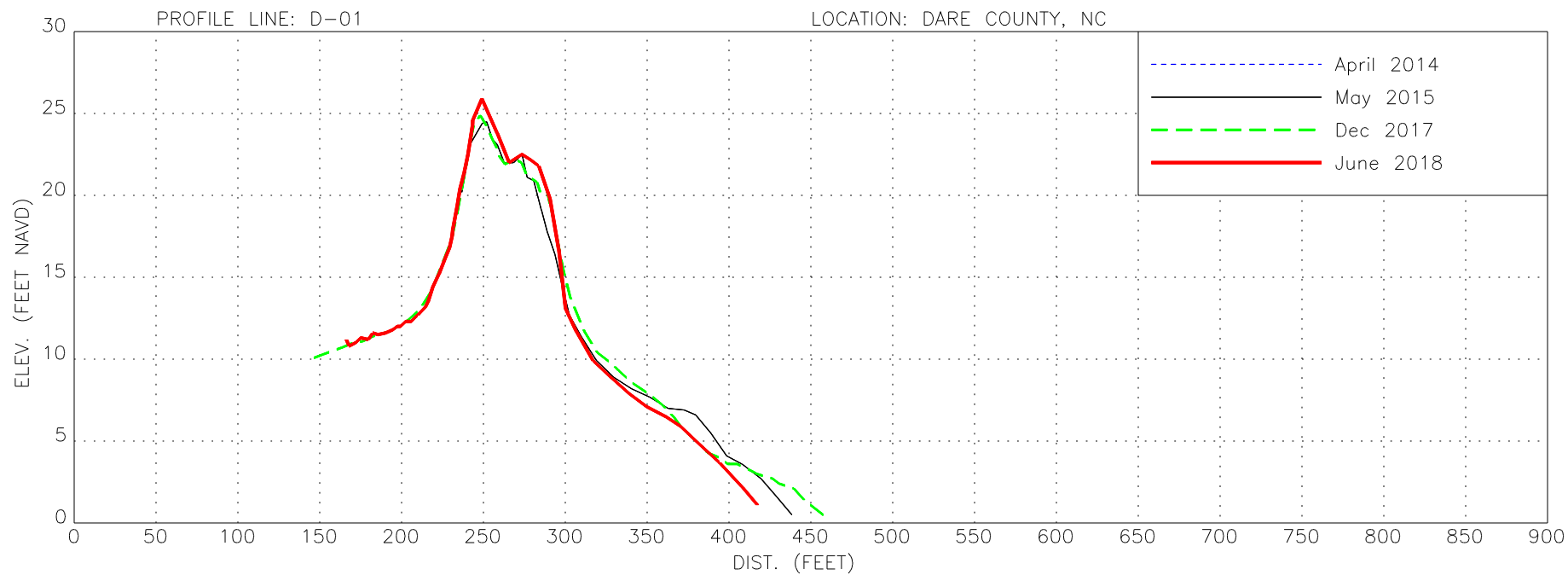
*(Available in digital format only)*

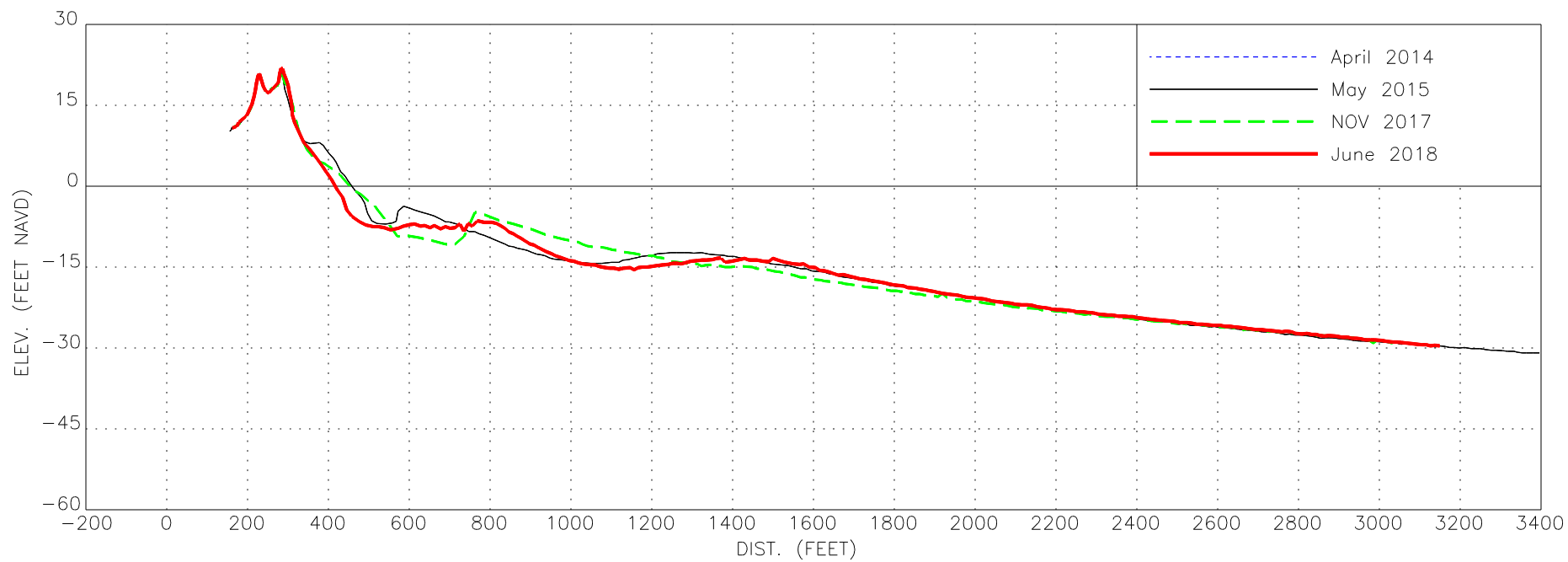
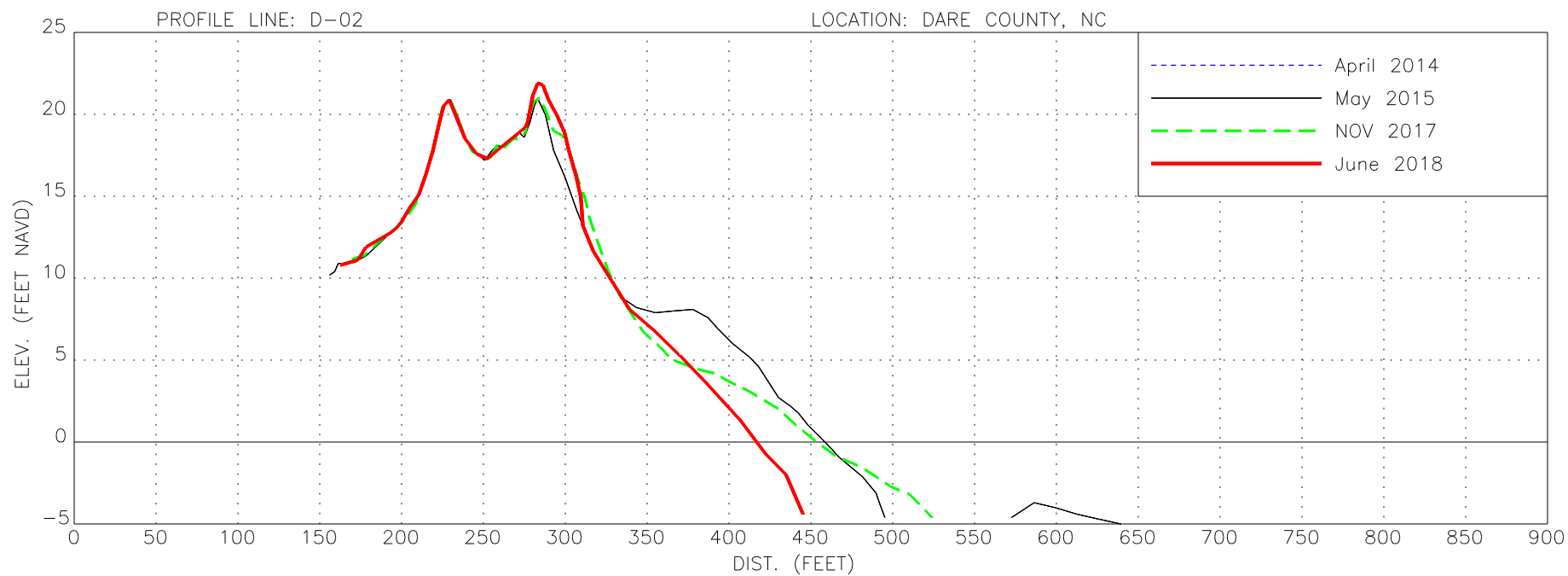
APPENDIX 3

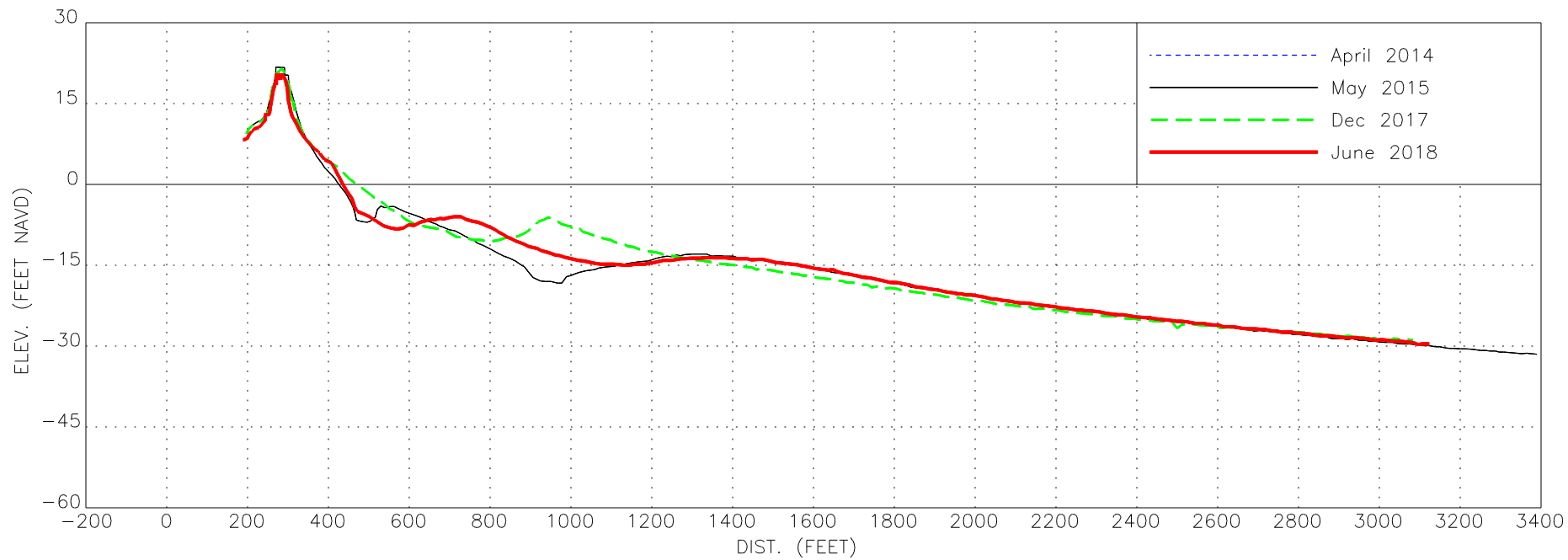
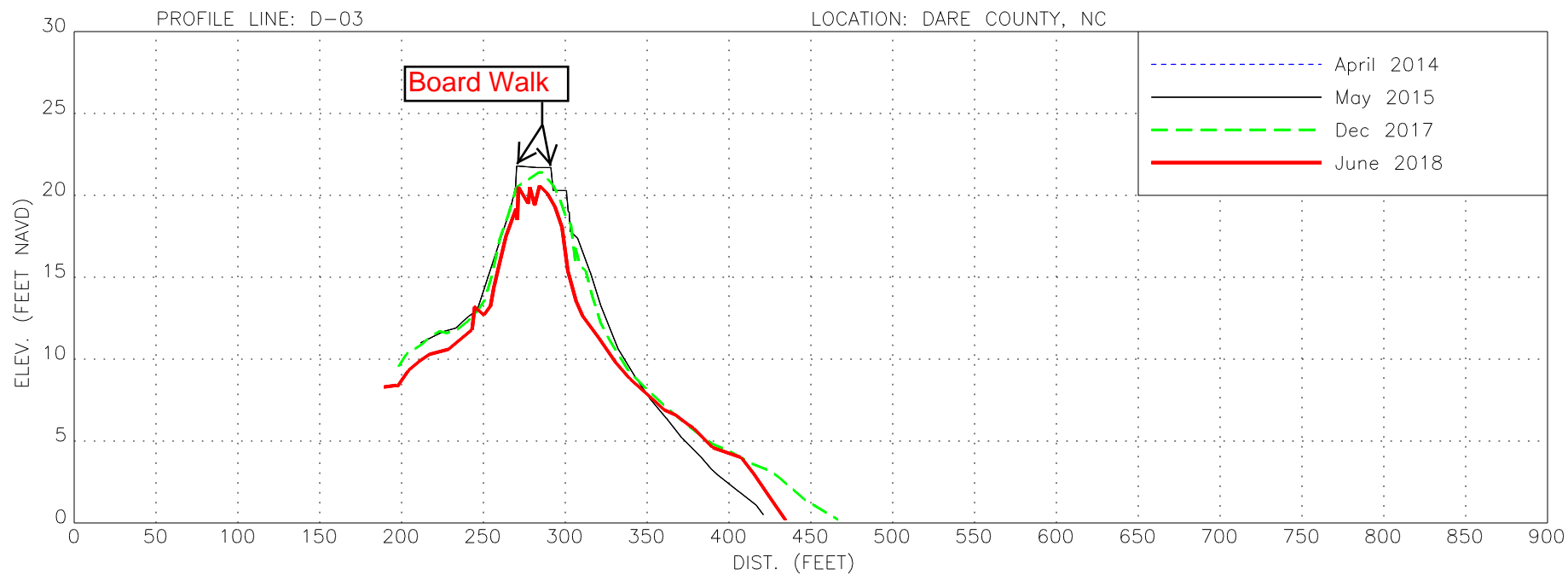
PROFILE PLOTS

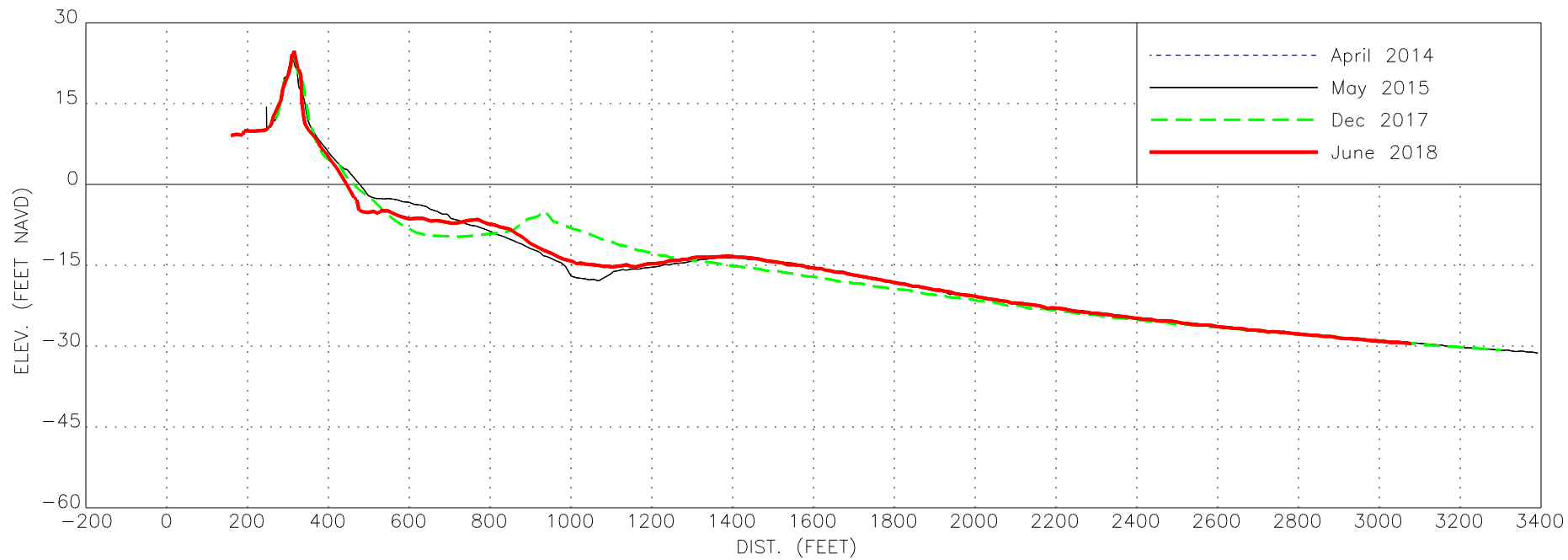
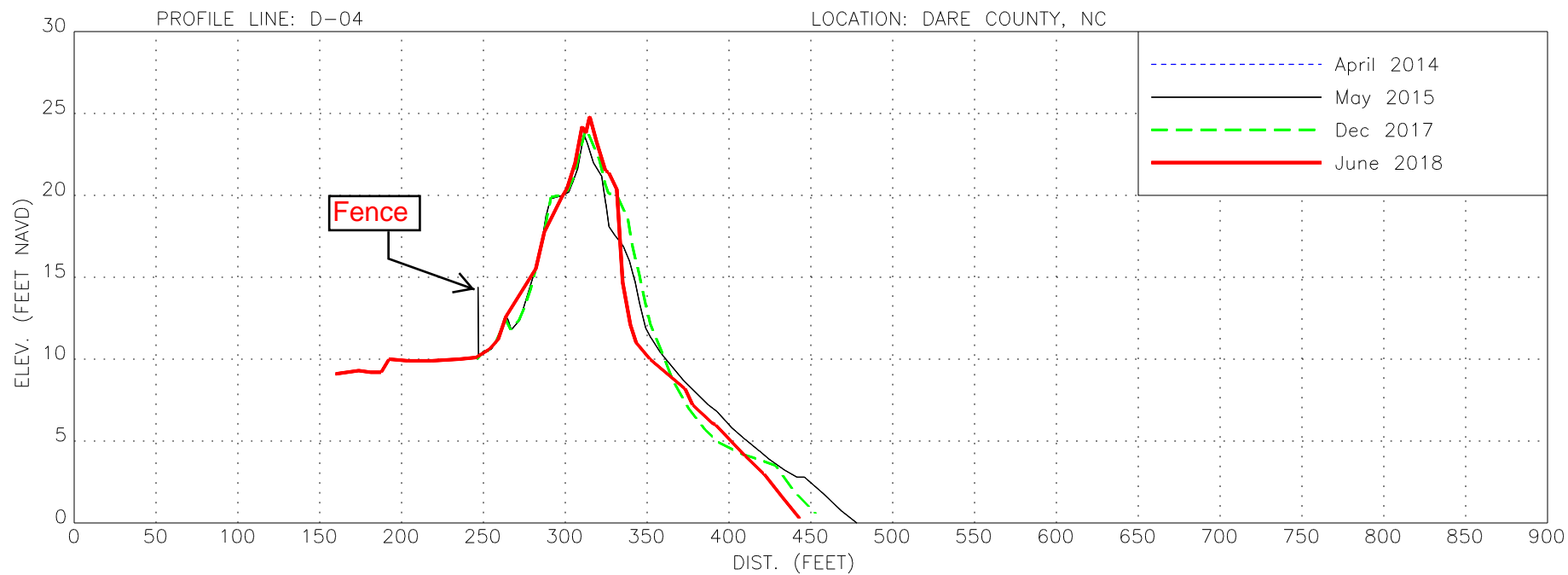


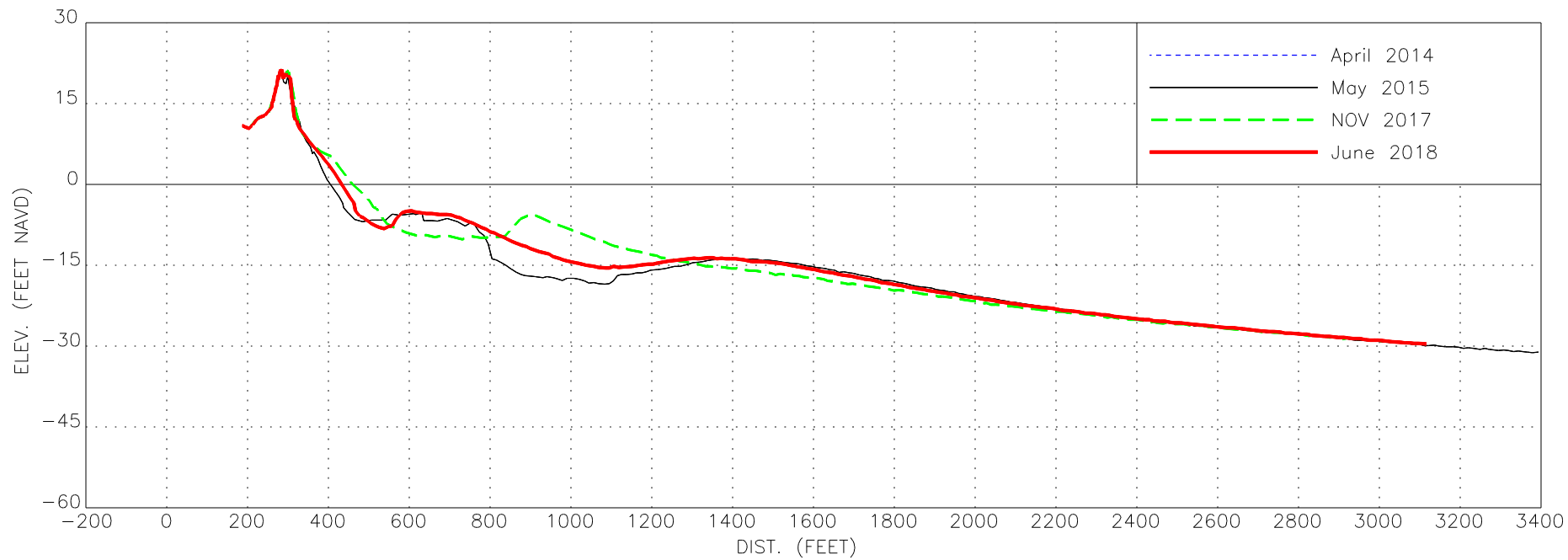
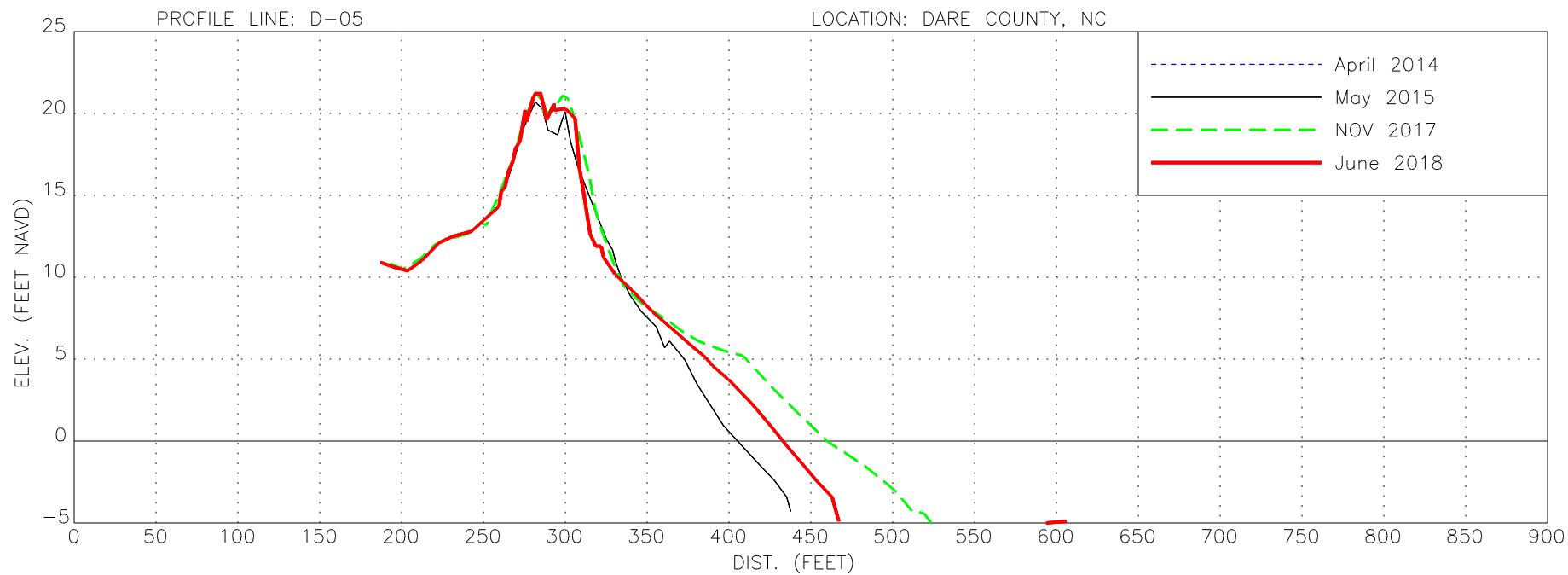


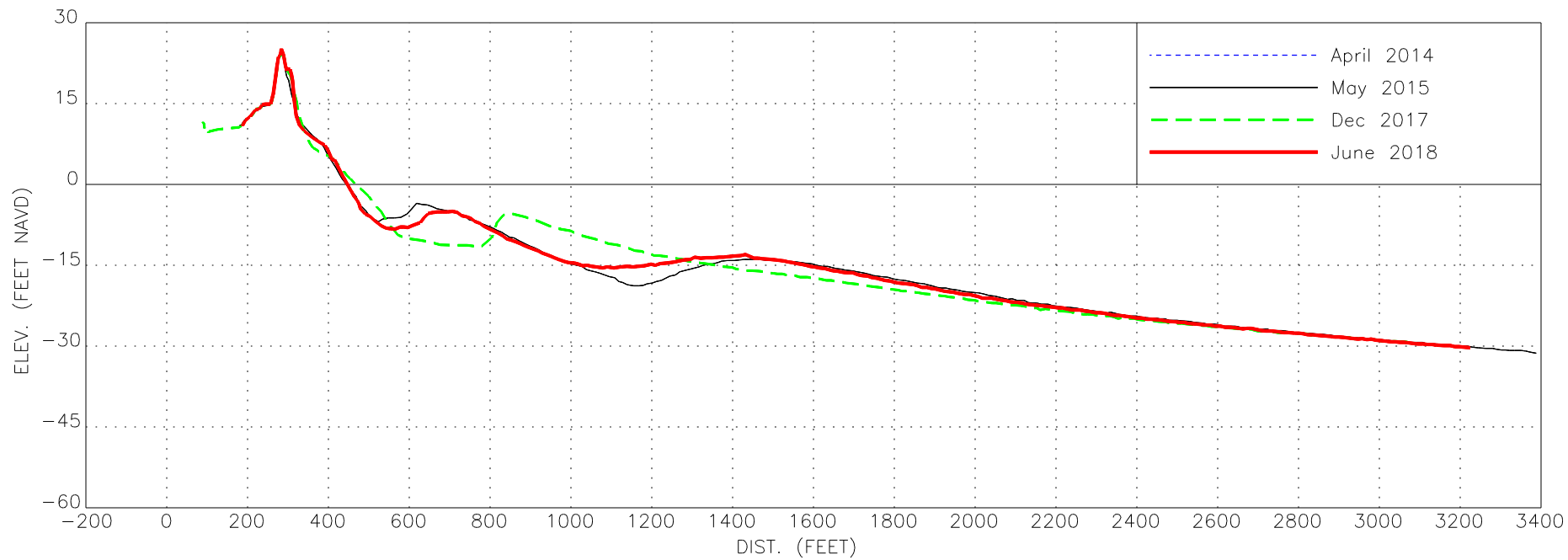
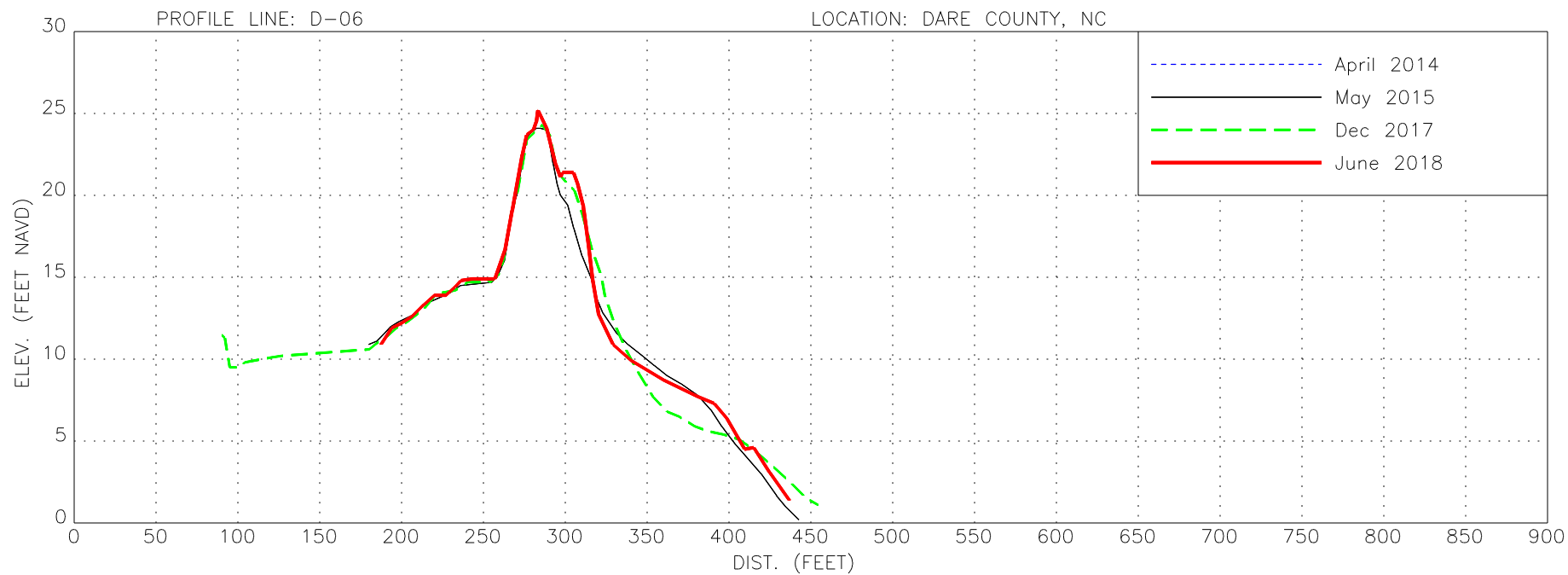


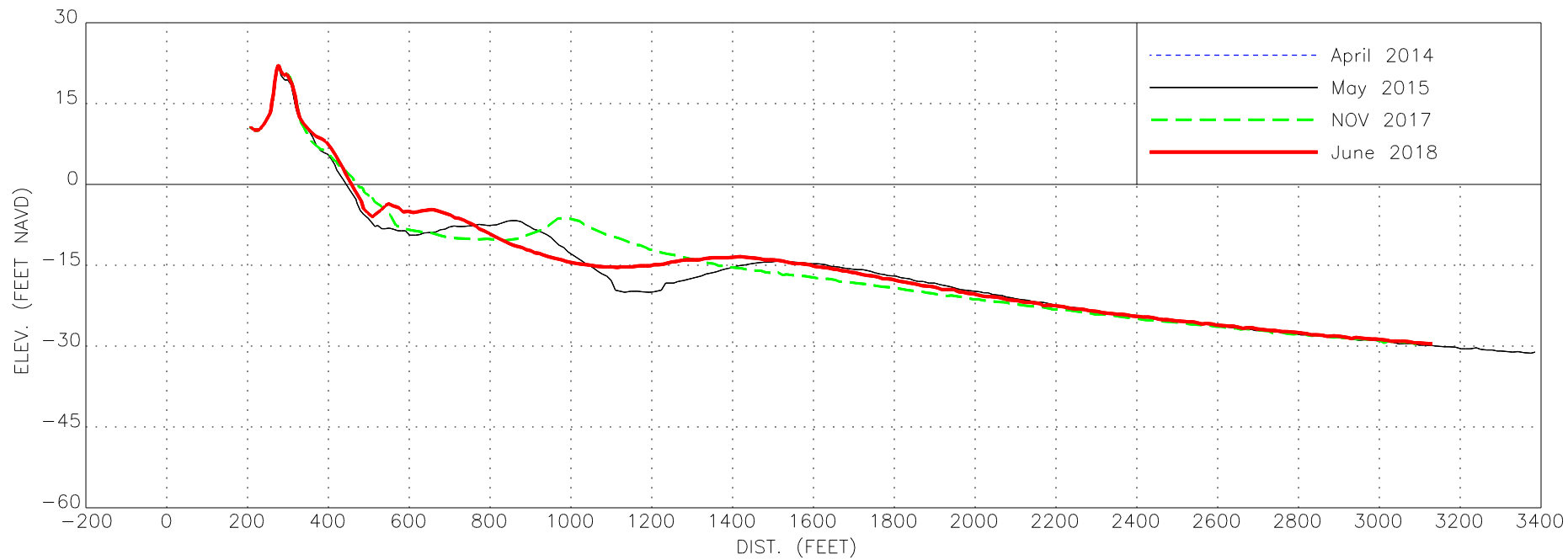
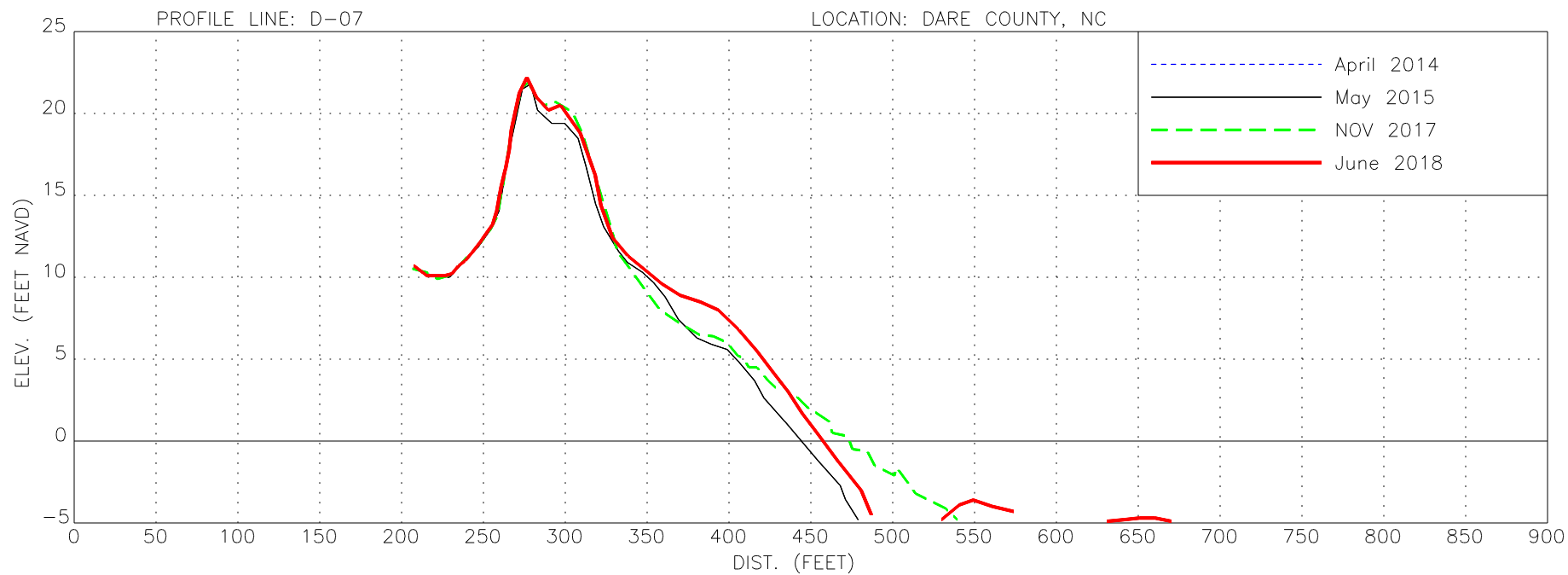


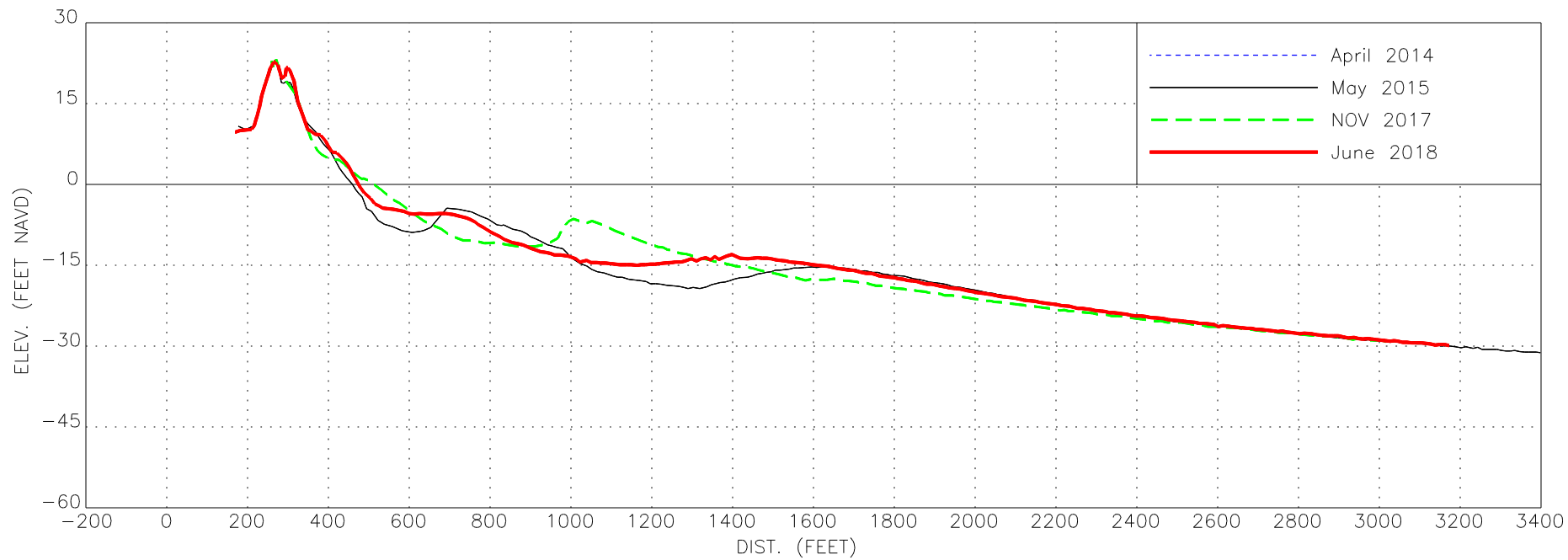
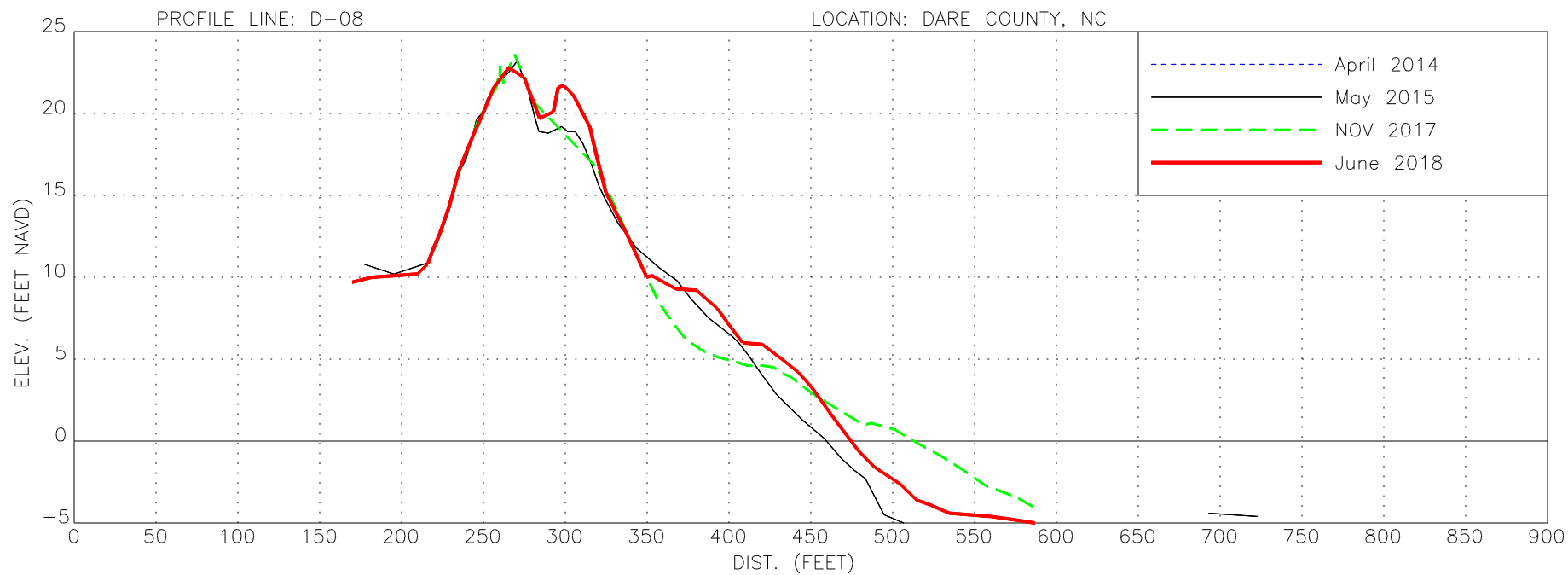


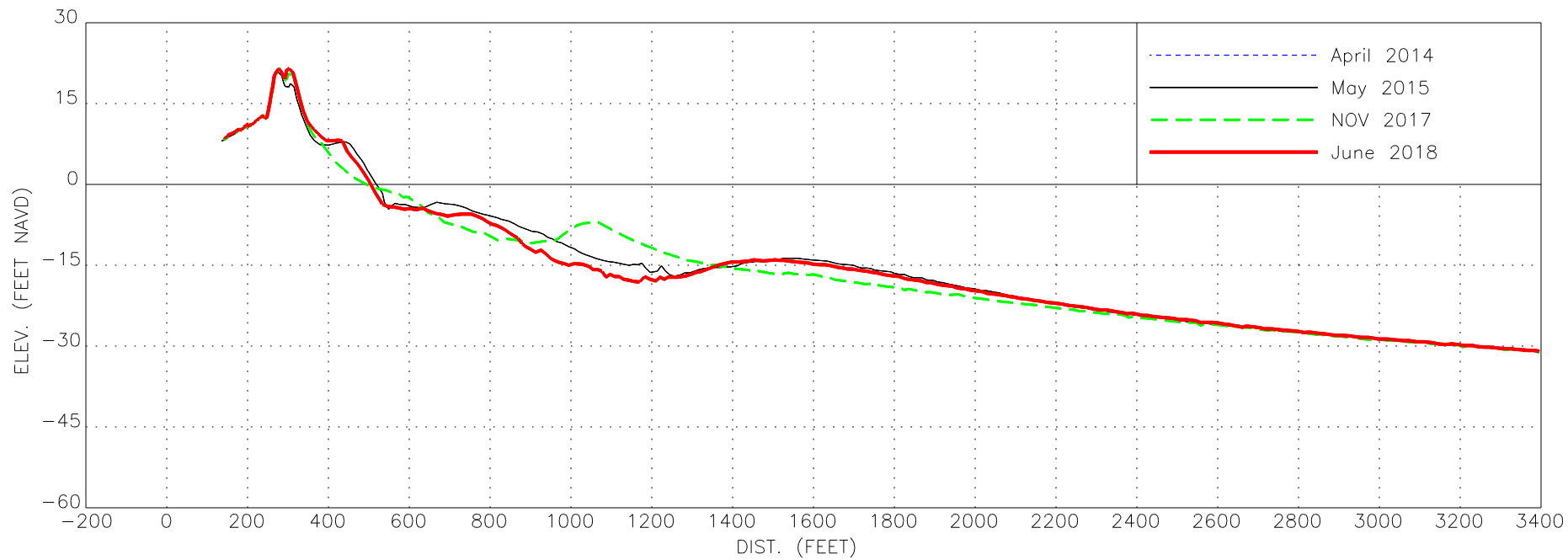
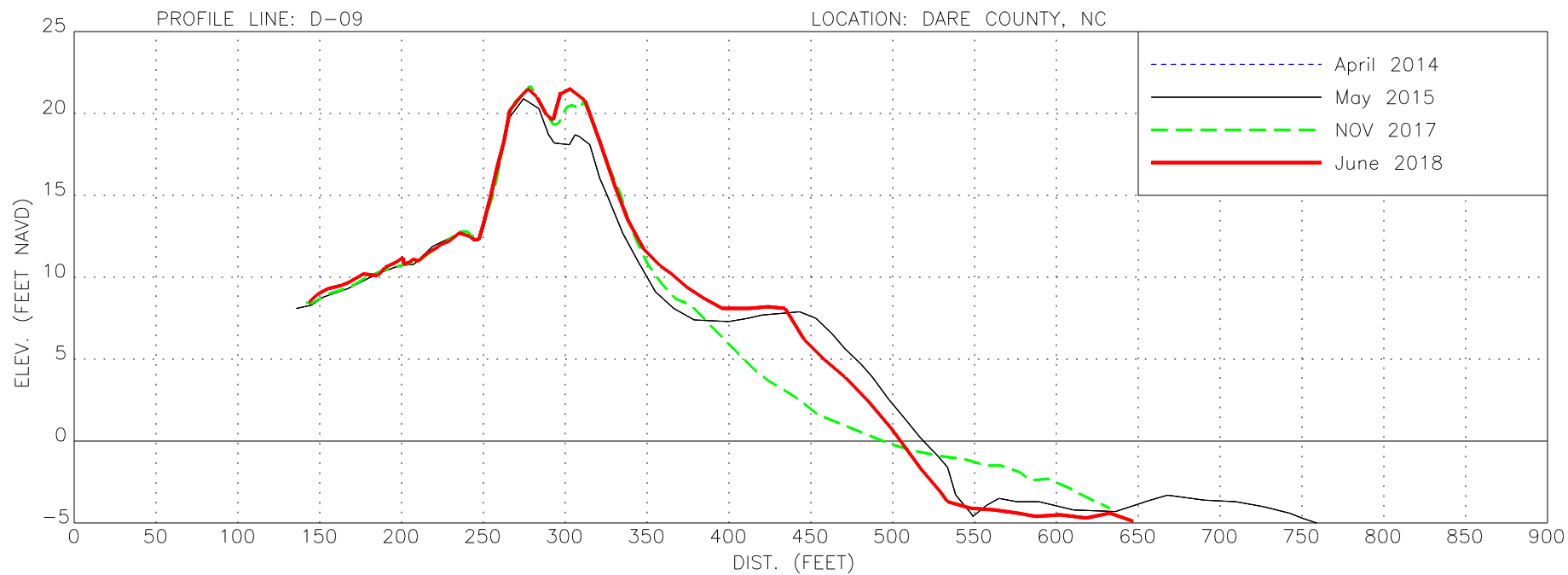


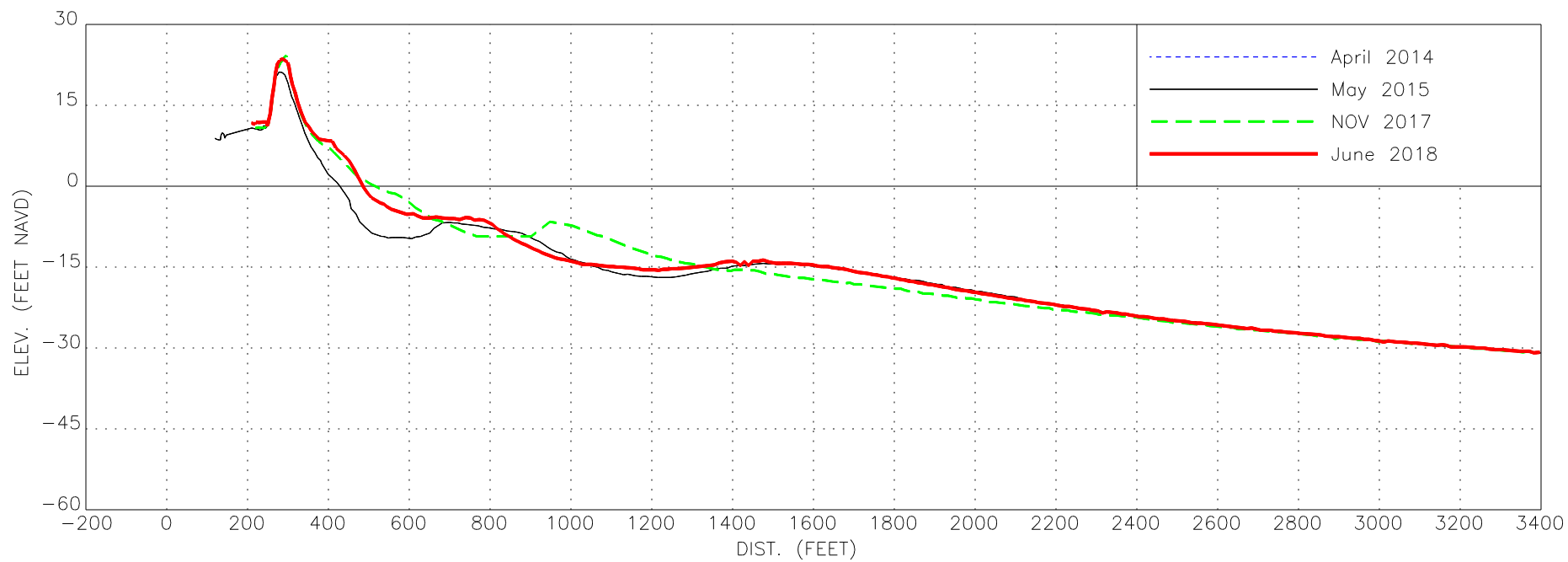
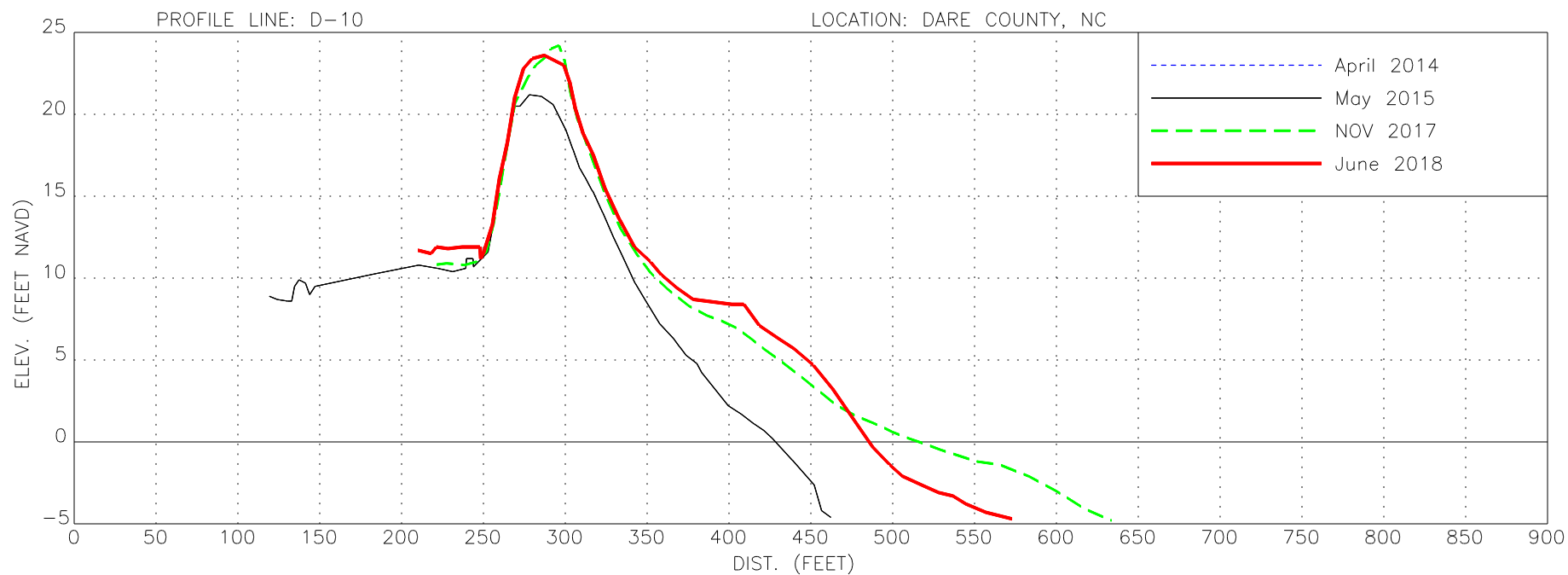


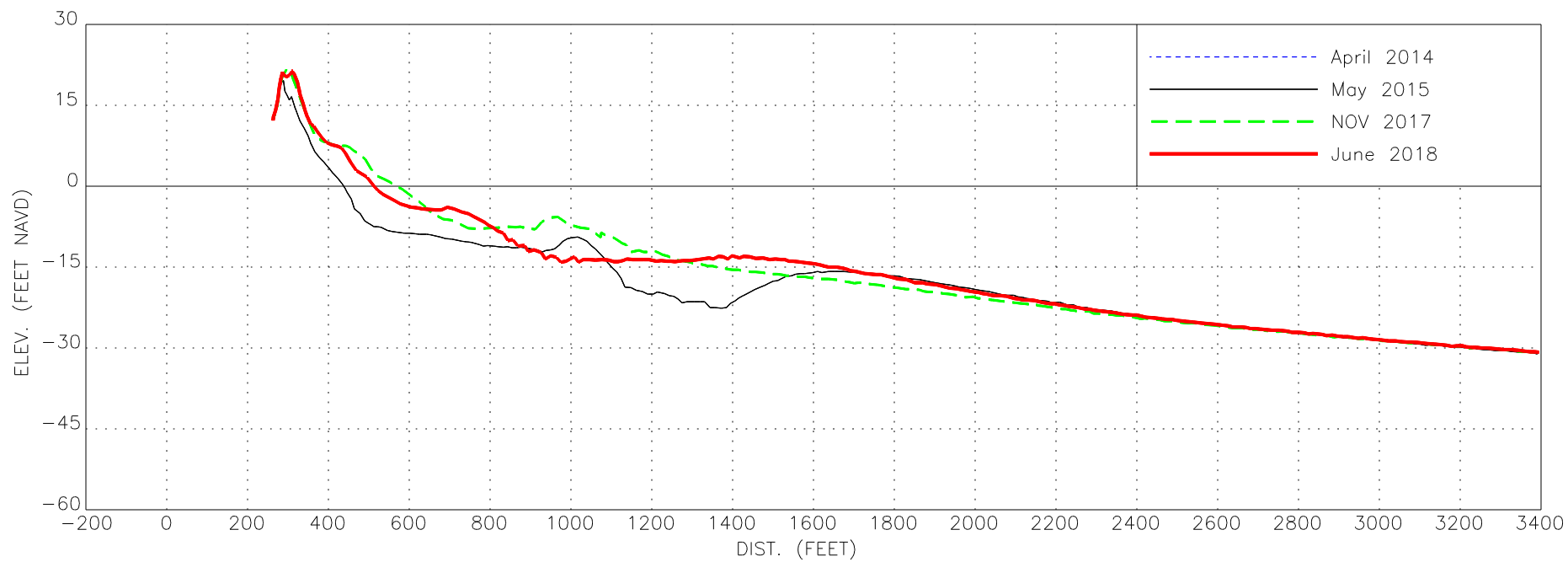
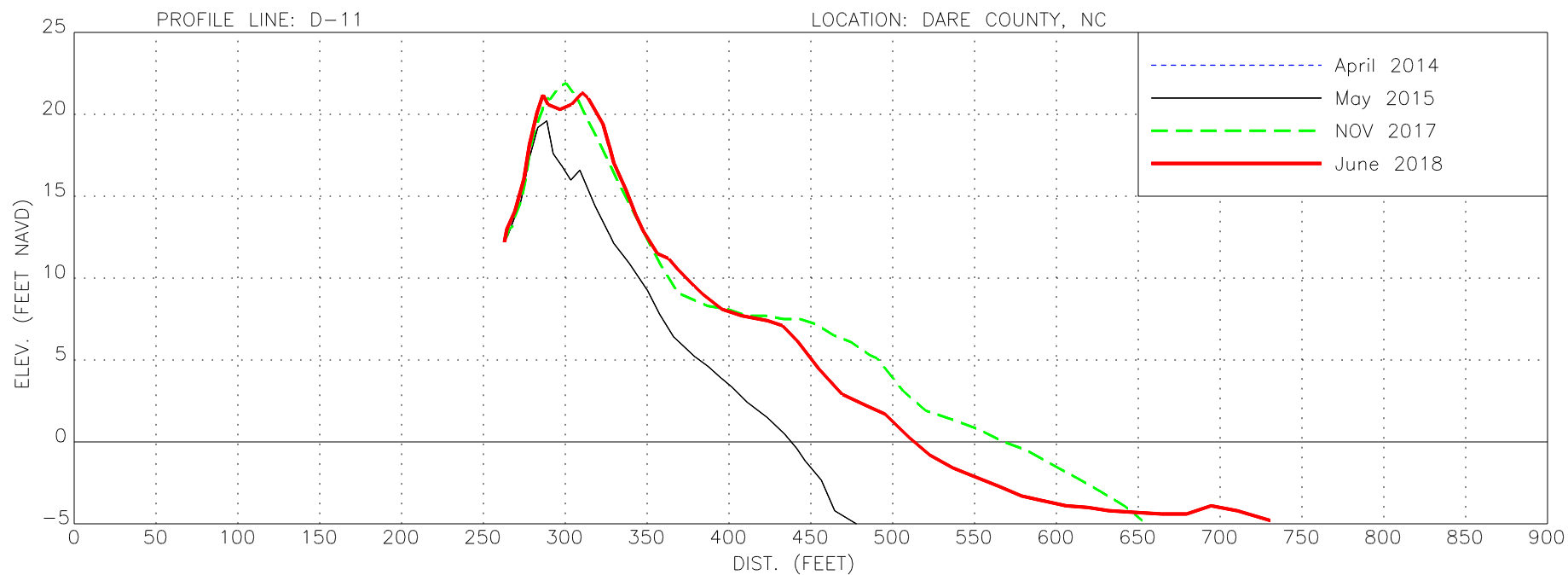


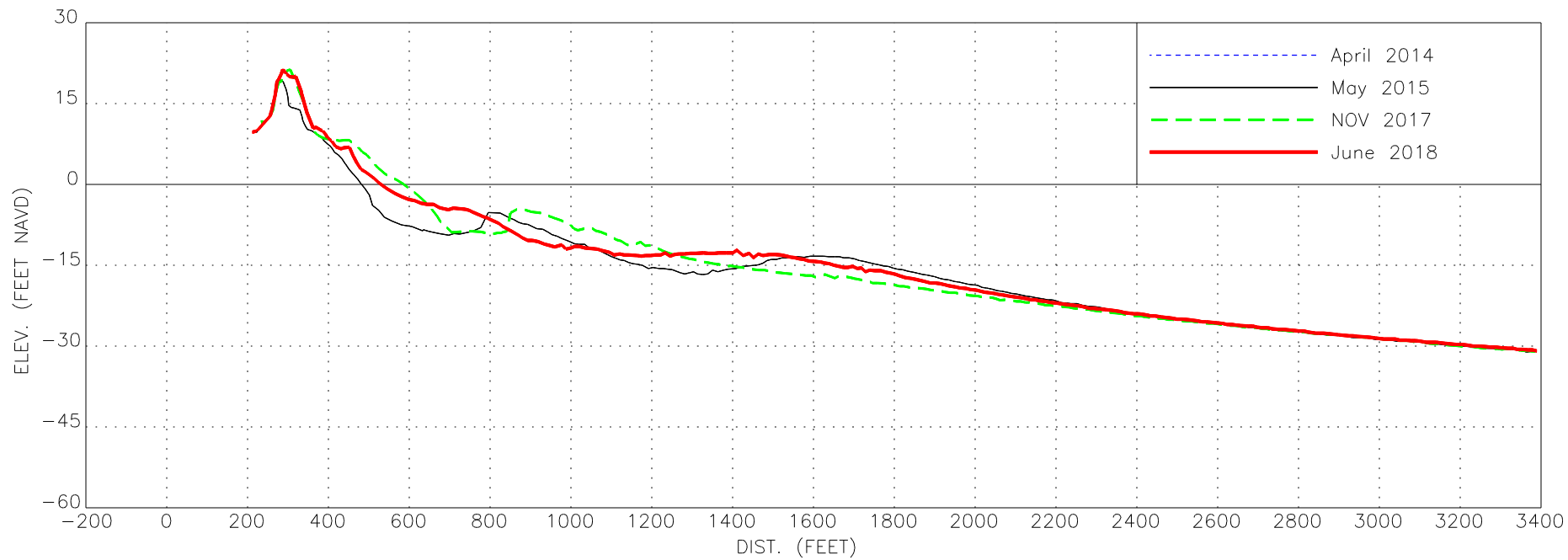
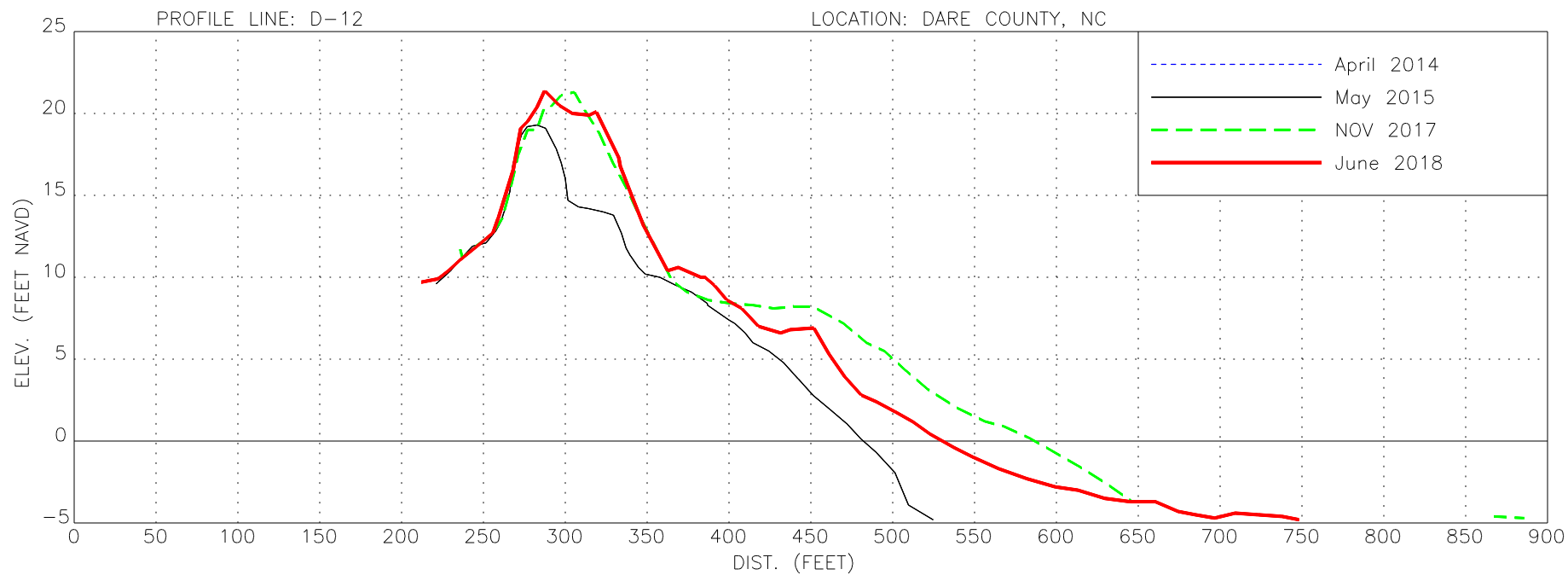


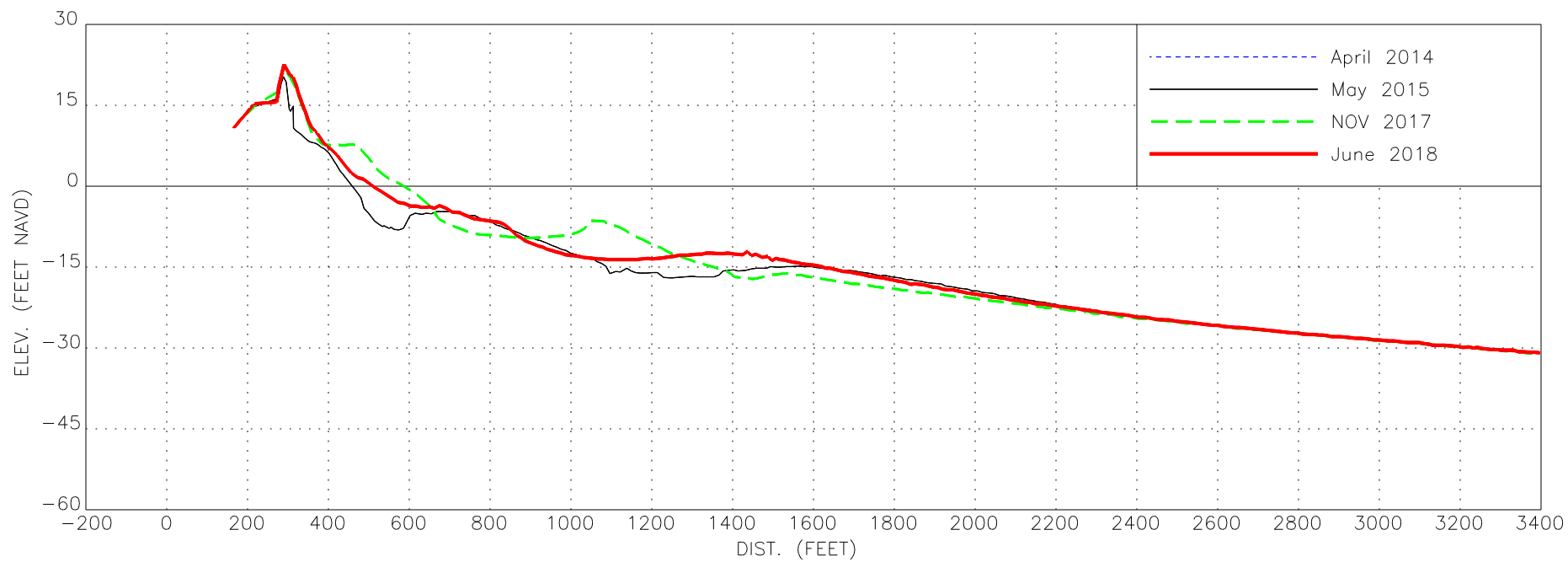
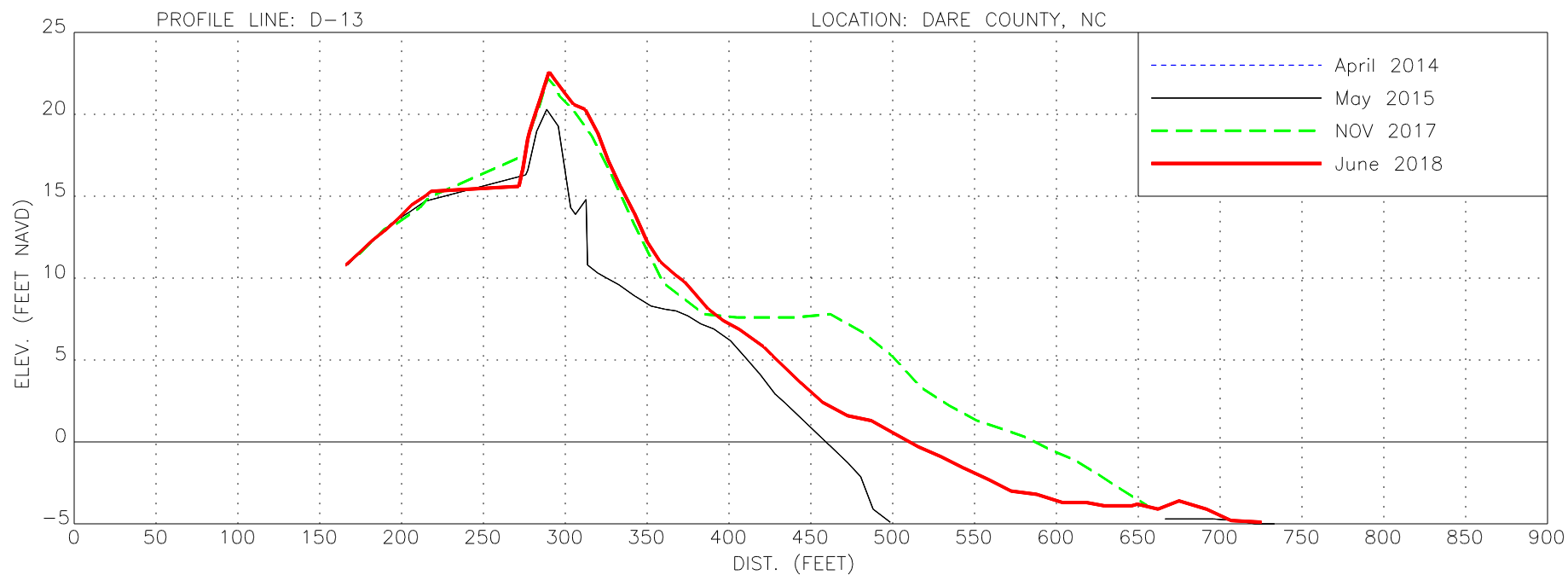


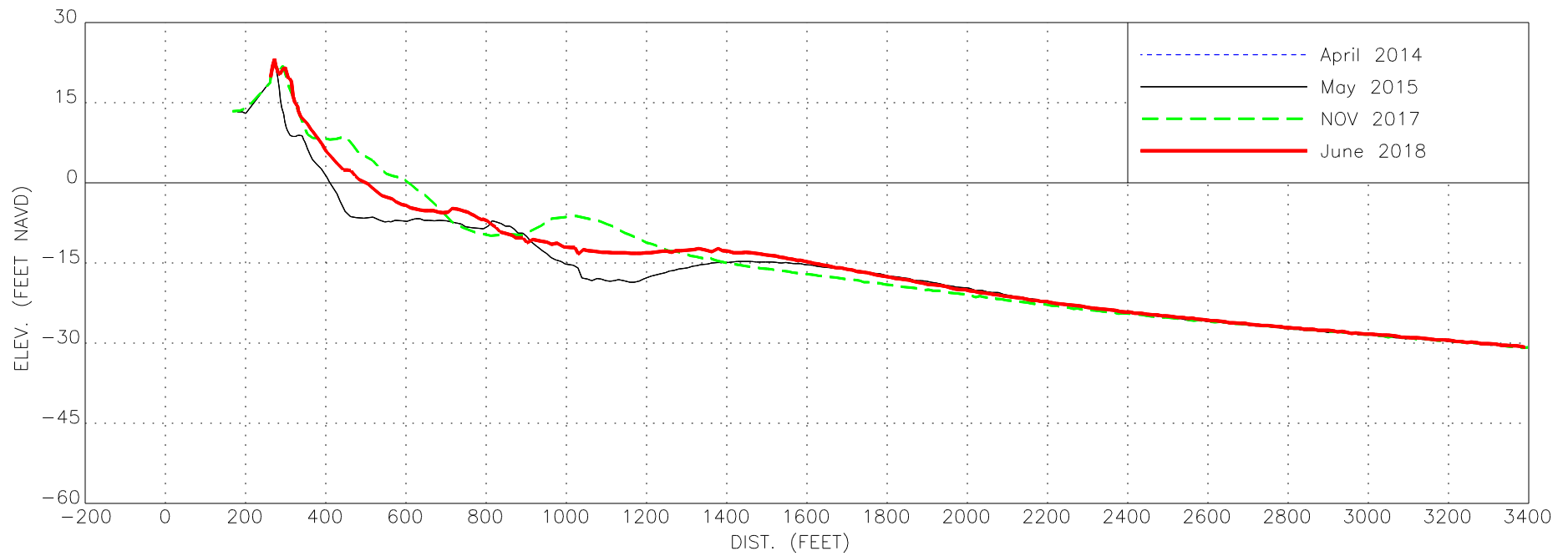
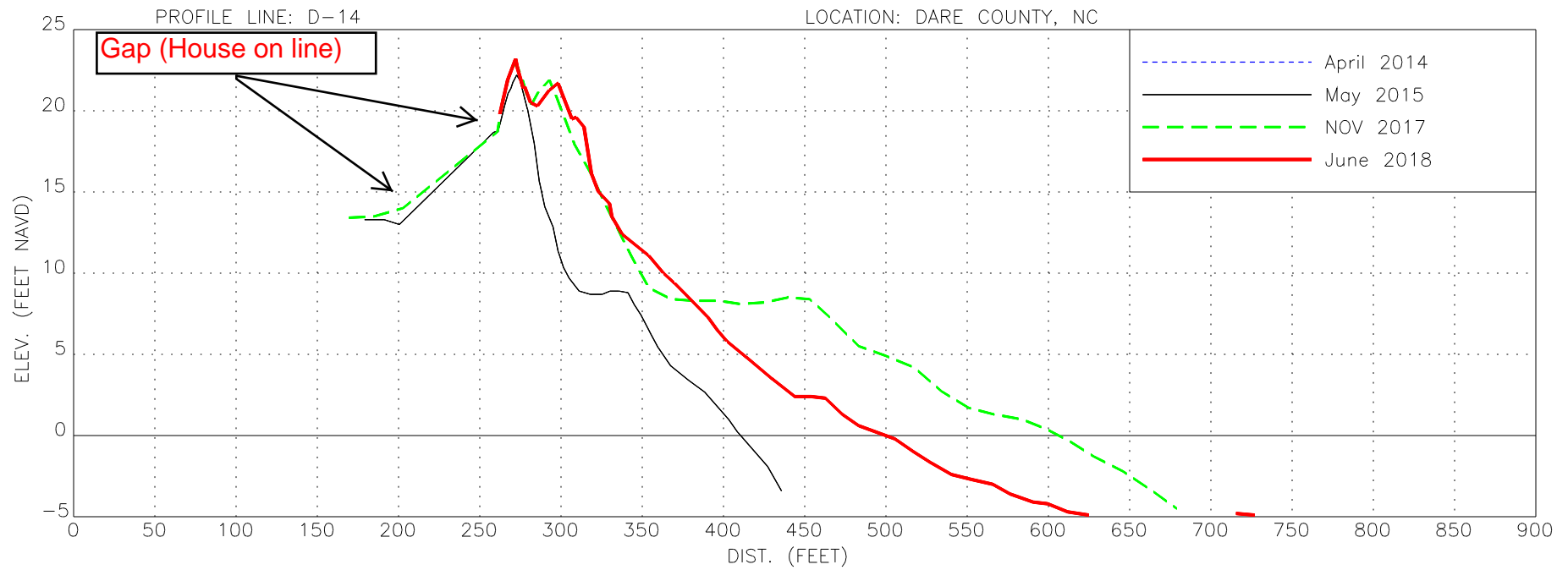


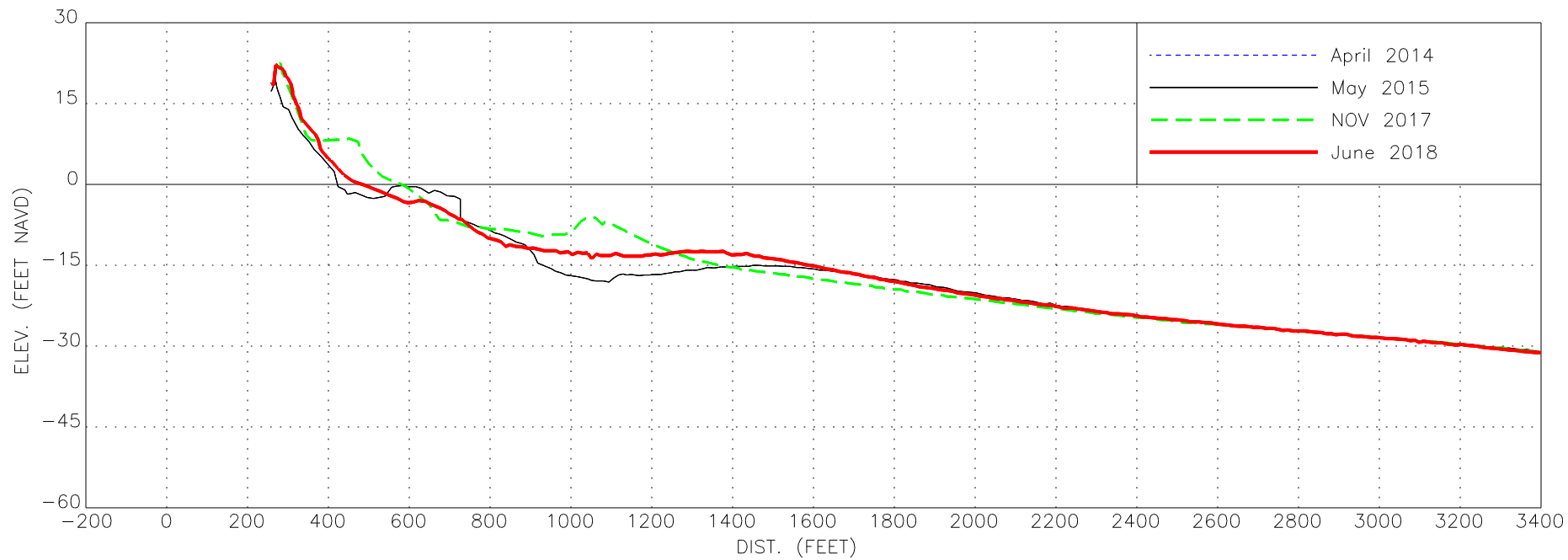
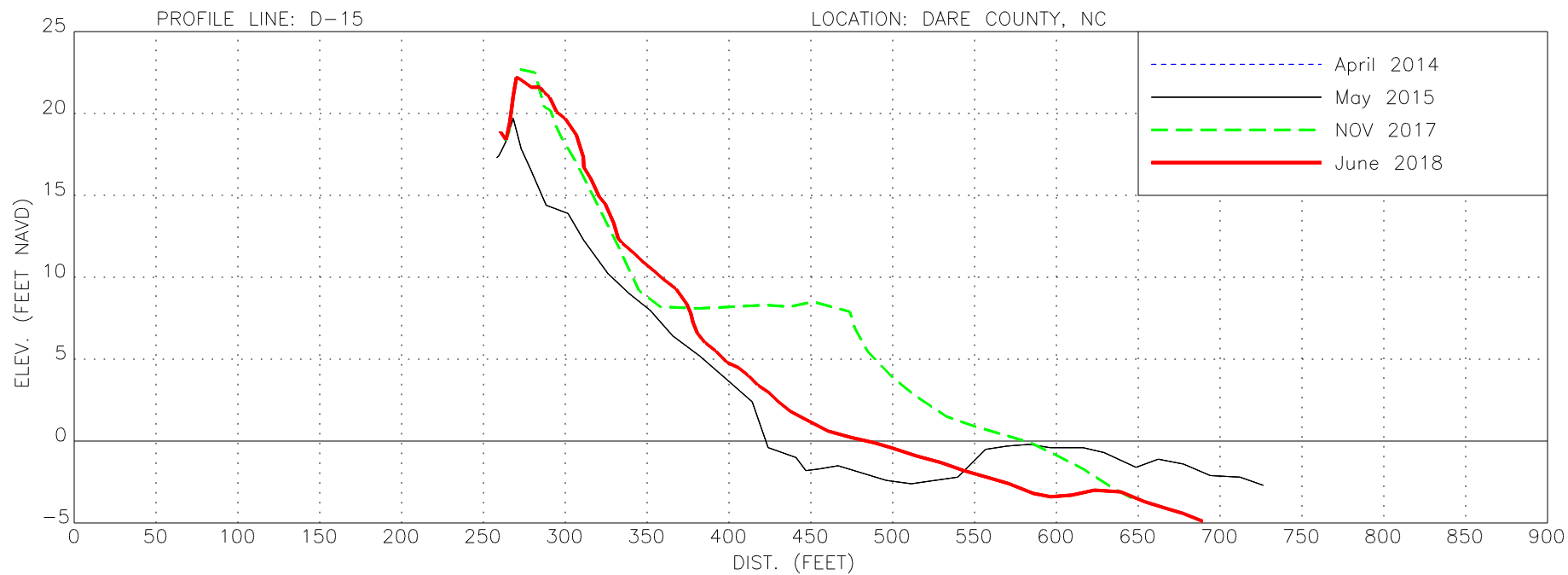


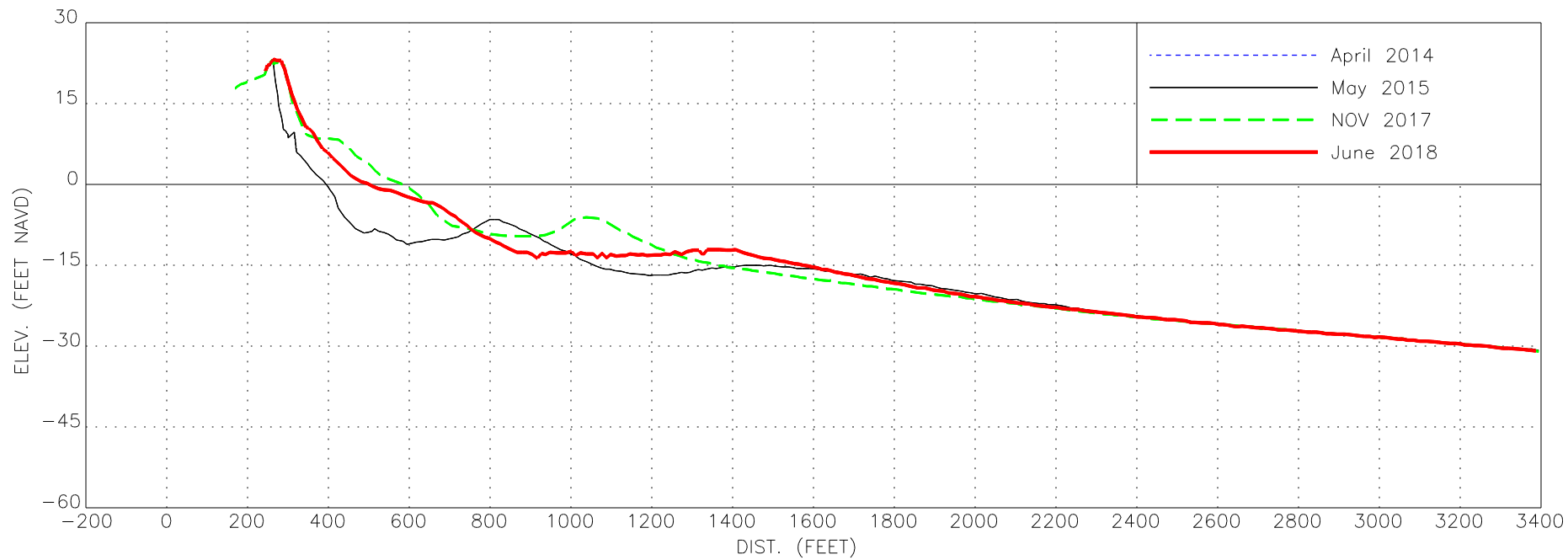
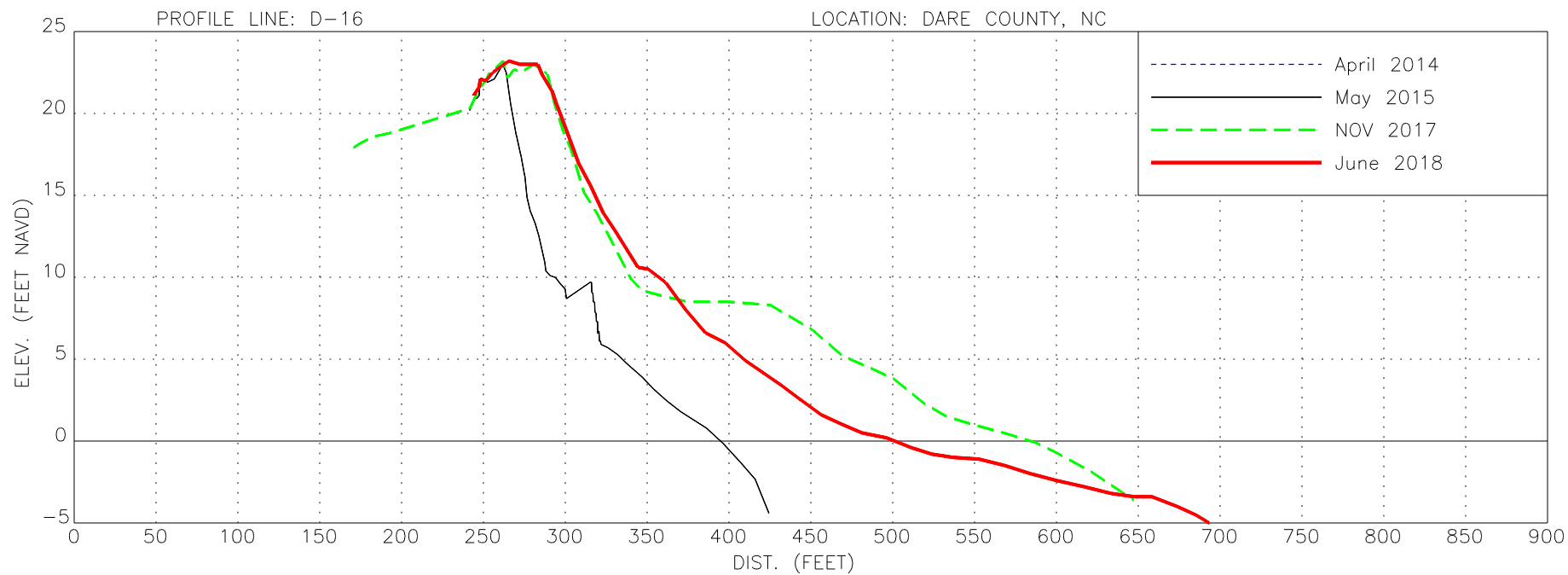


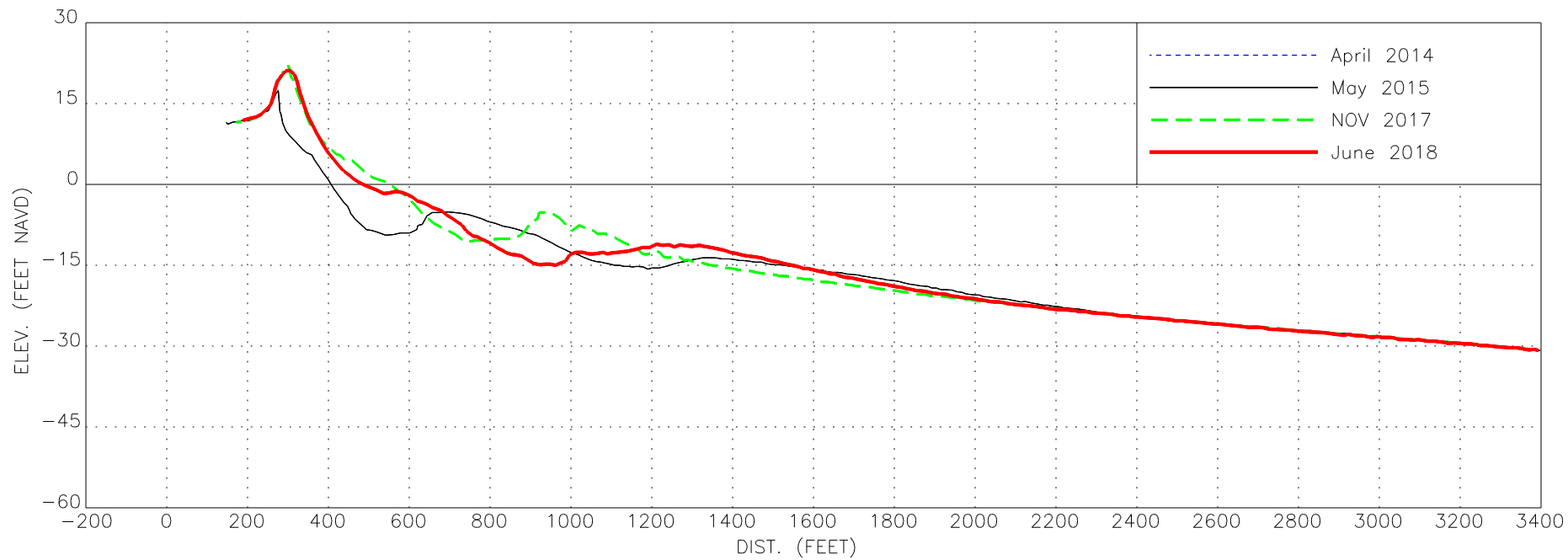
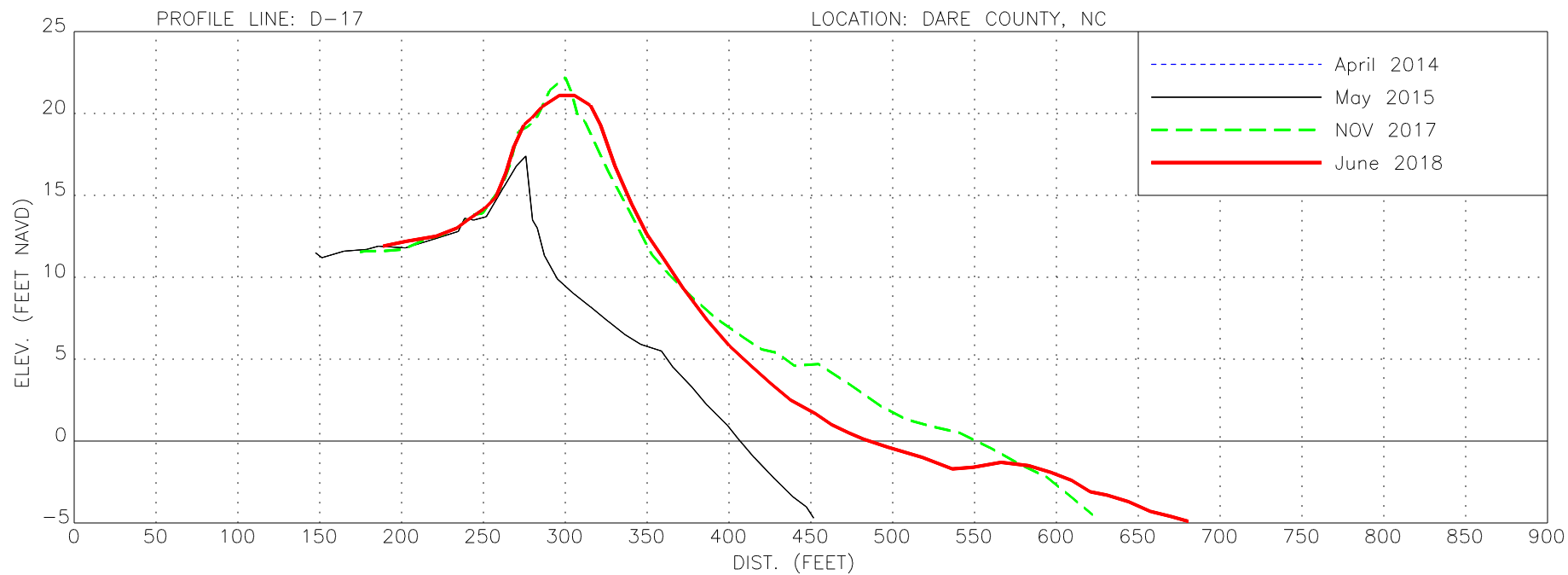


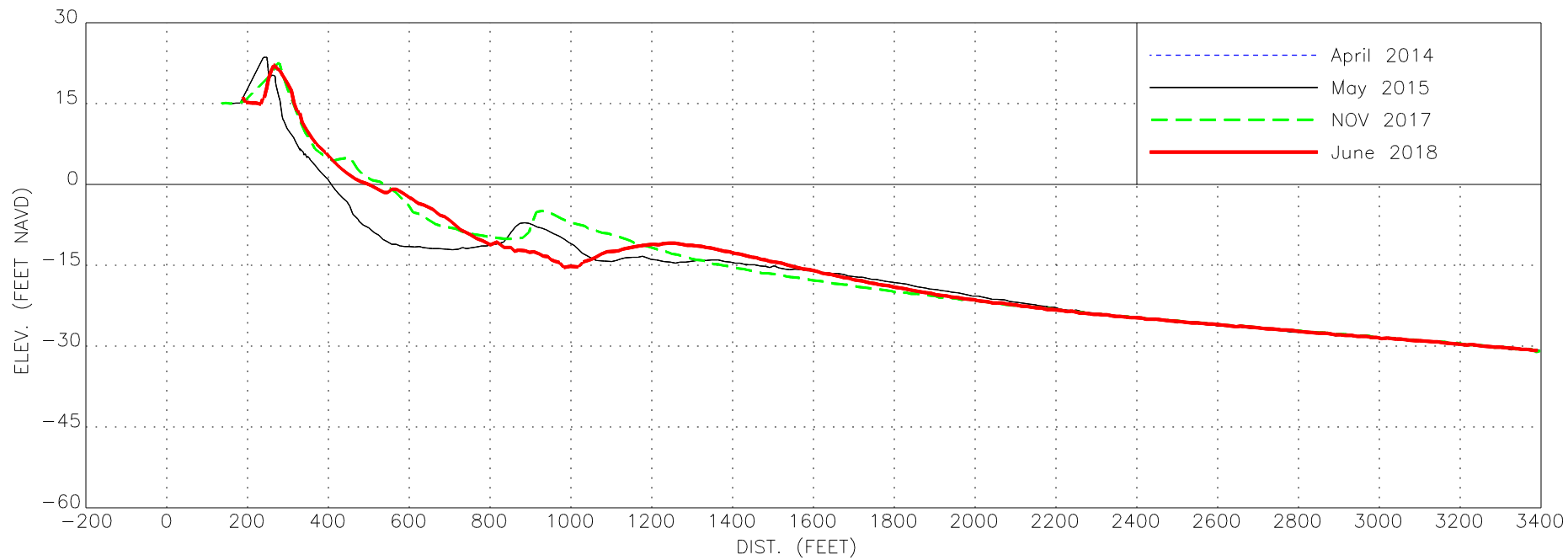
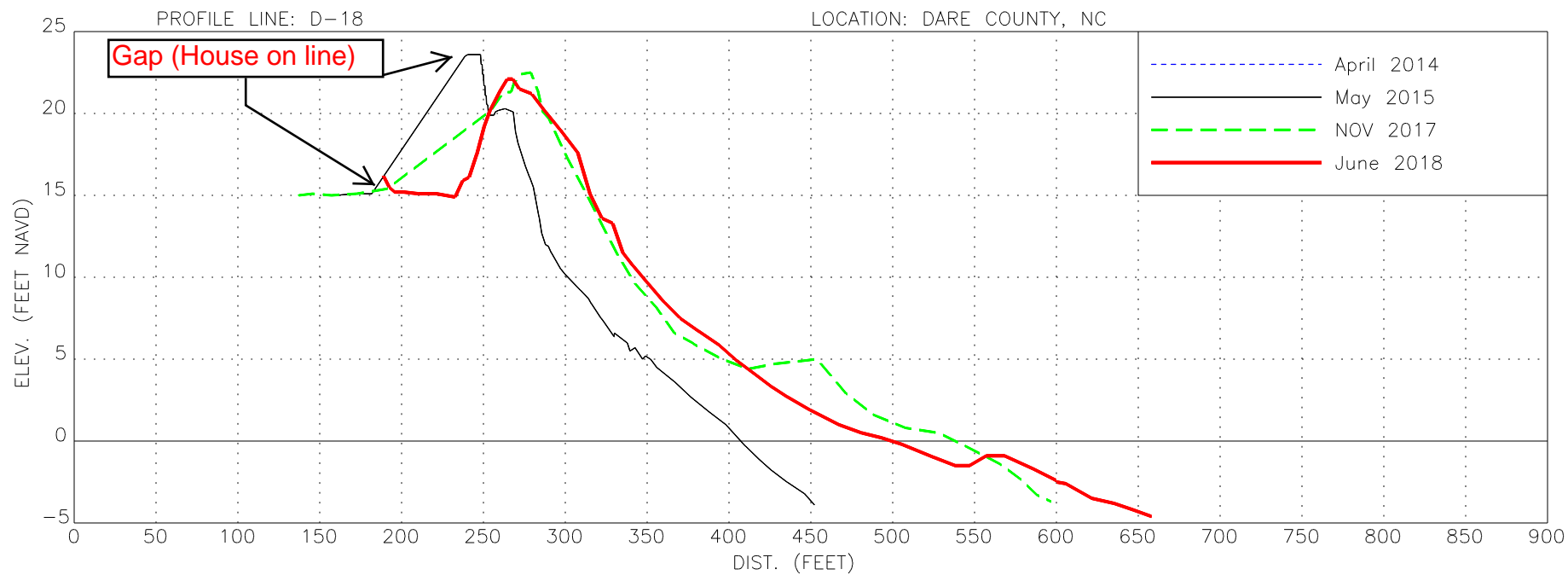


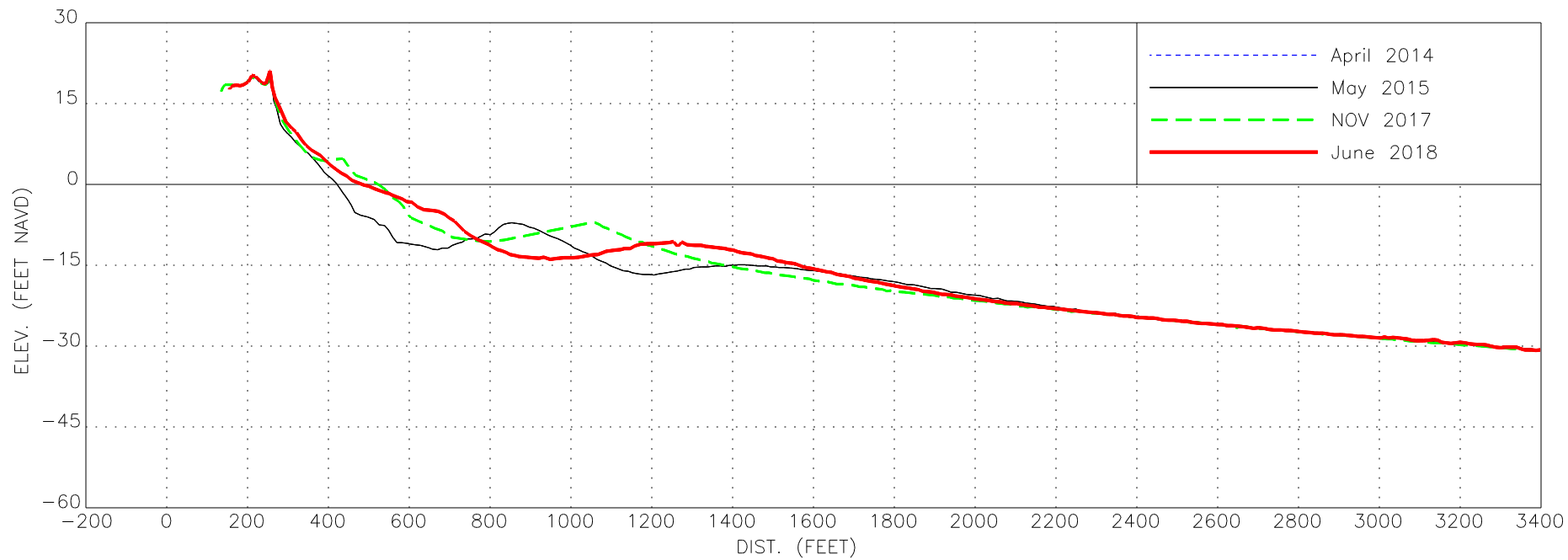
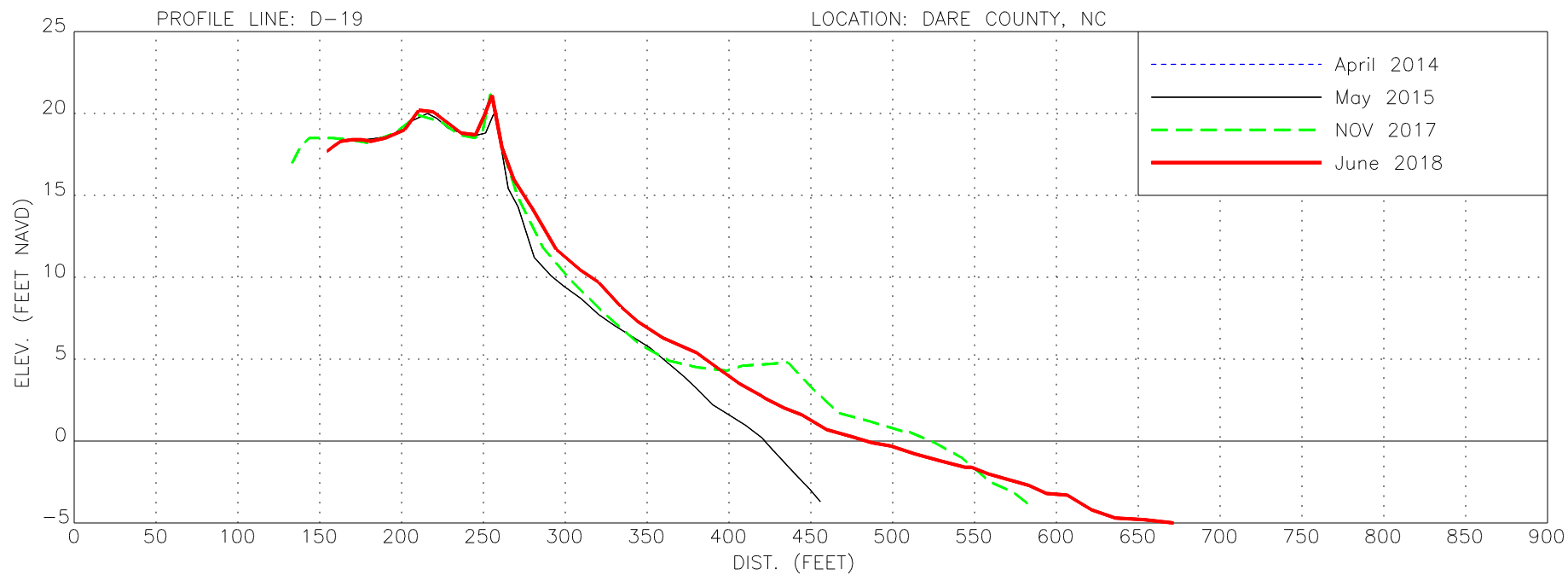


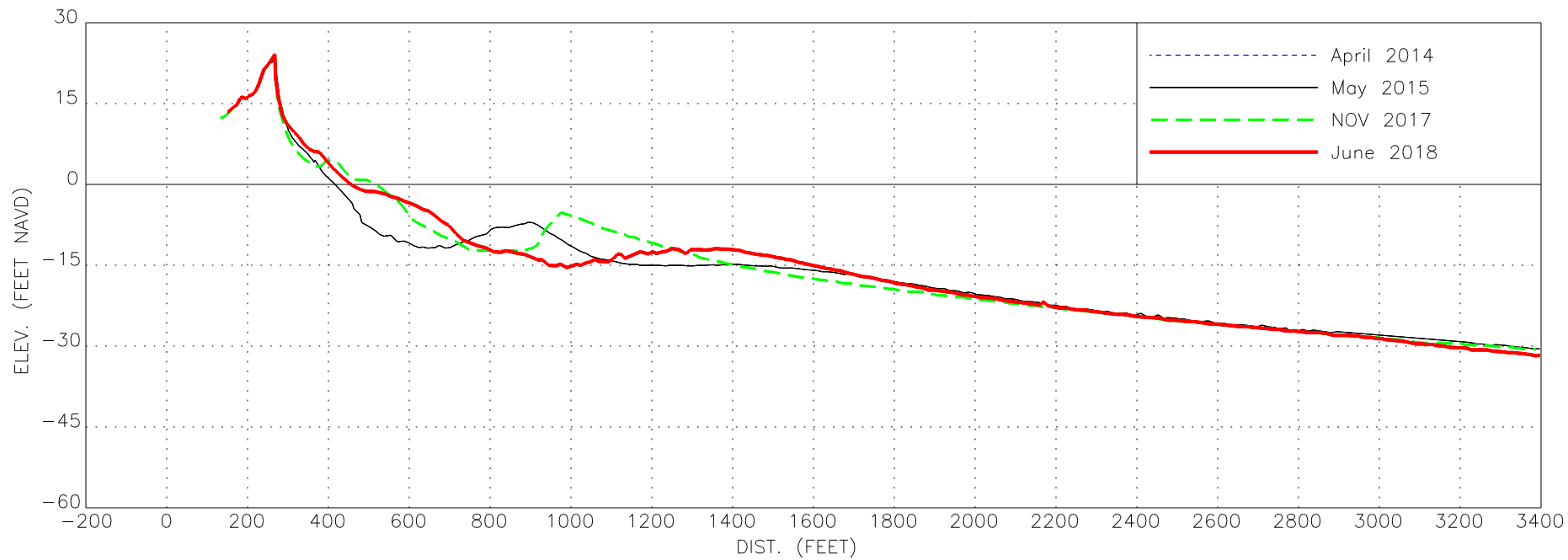
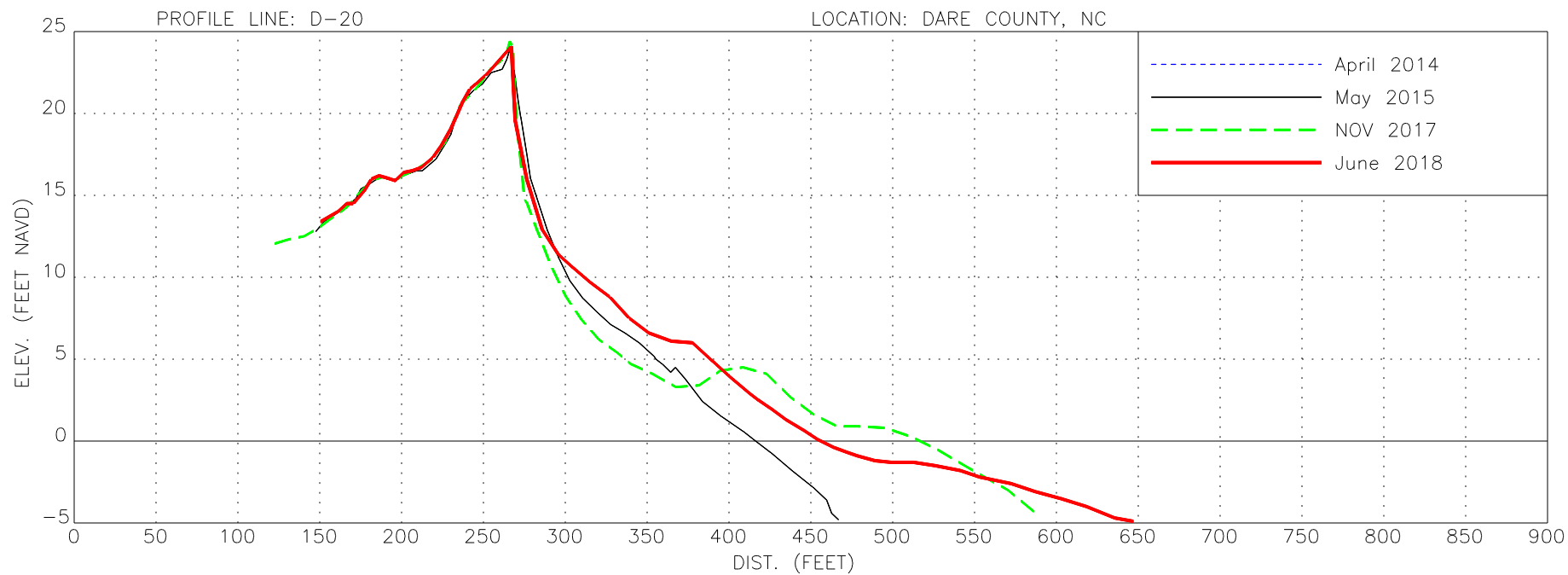


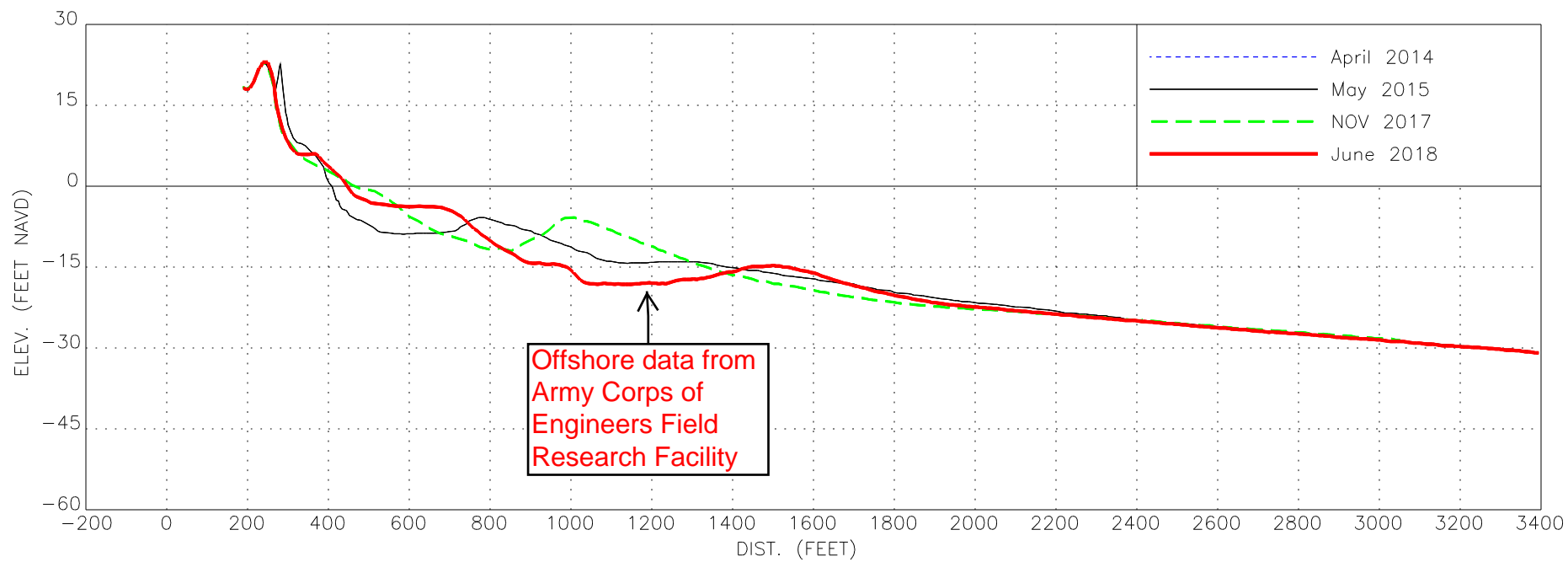
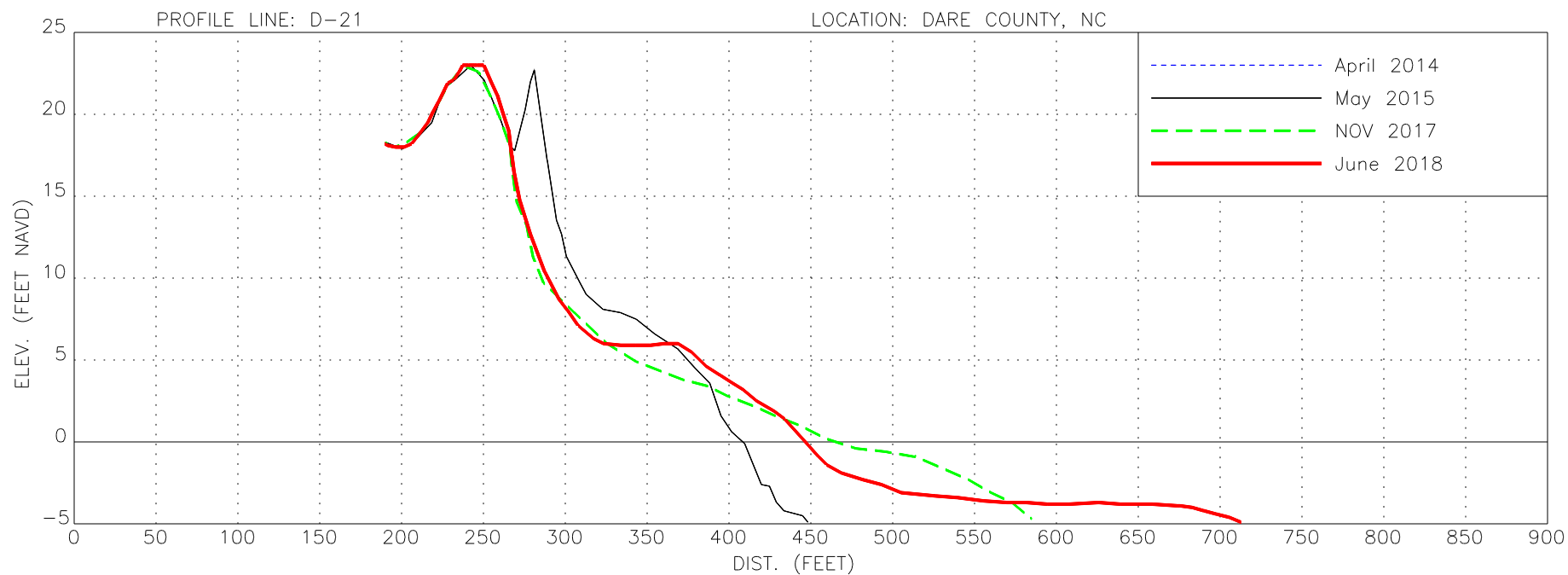


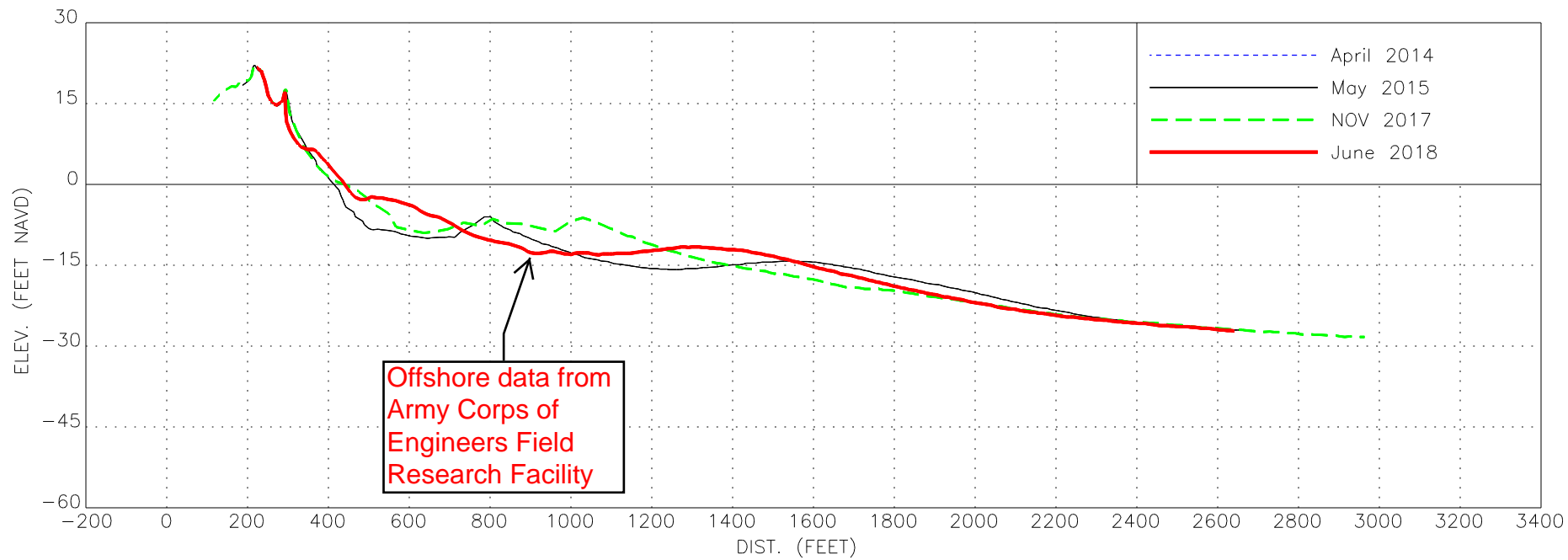
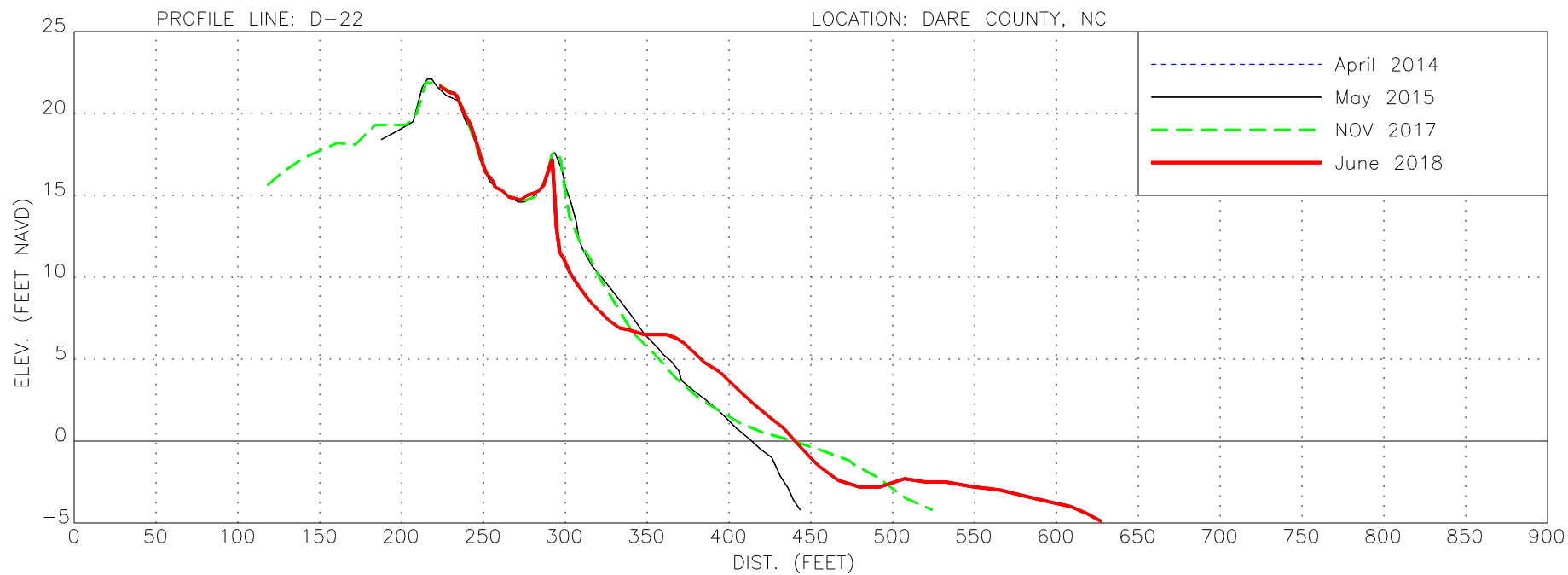


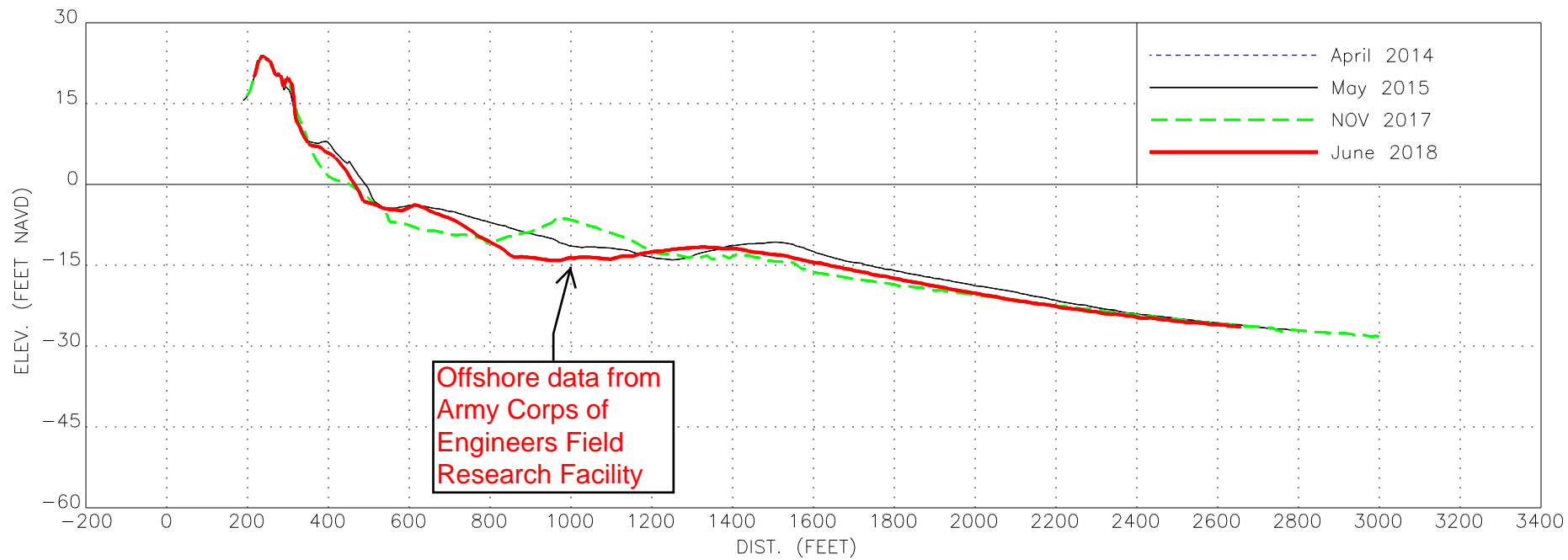
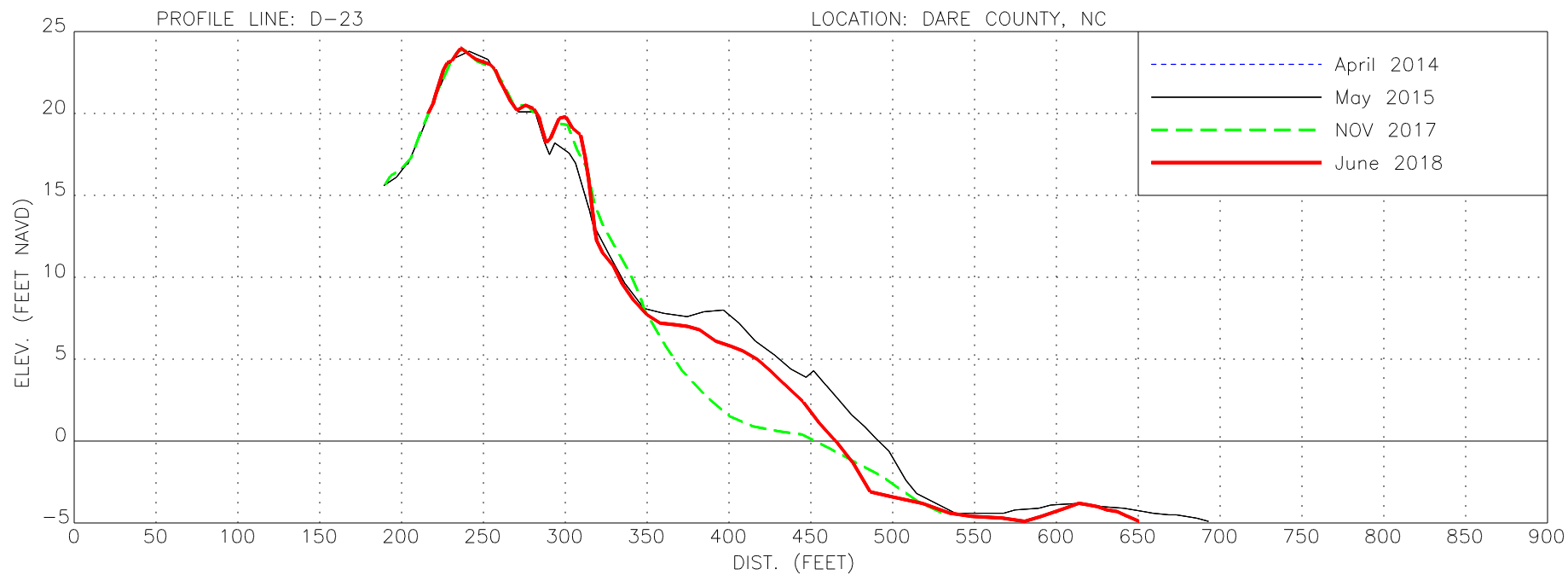


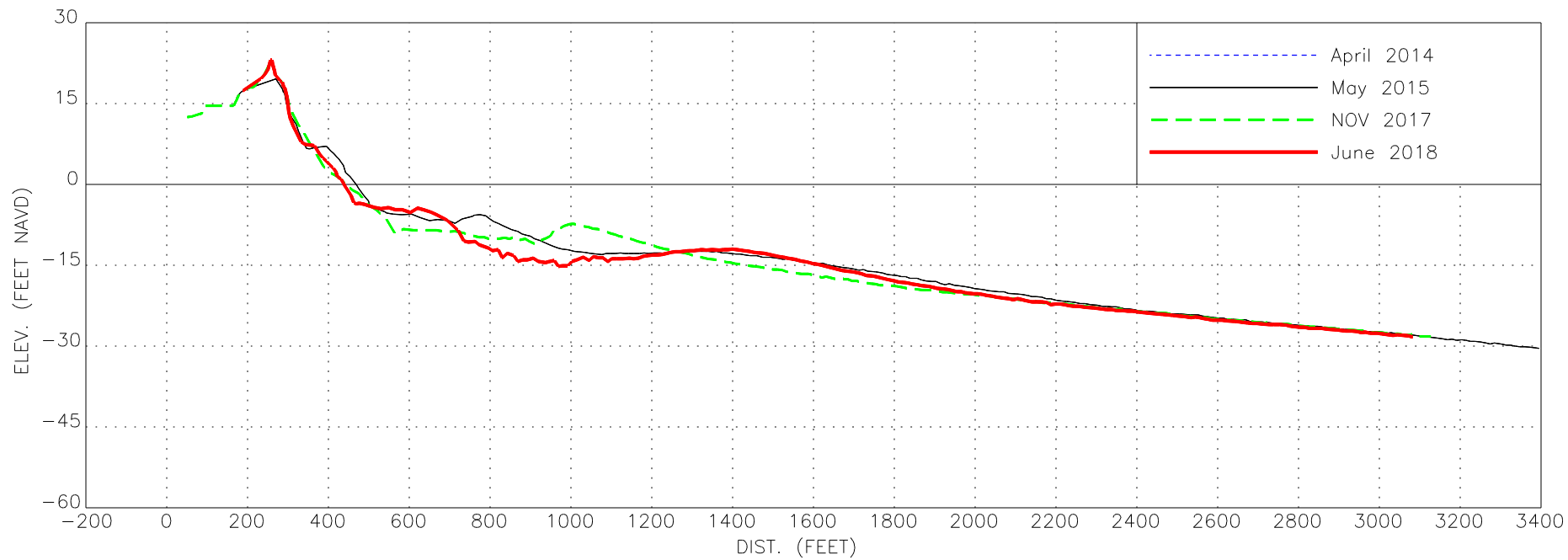
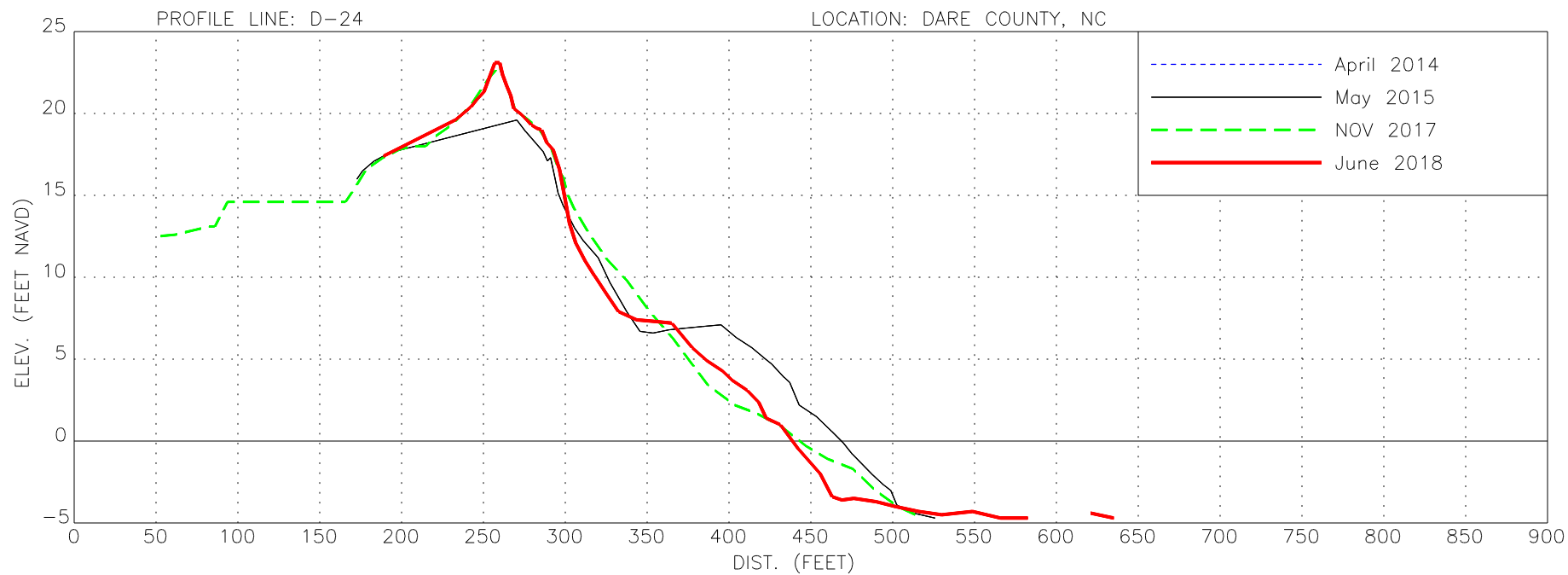


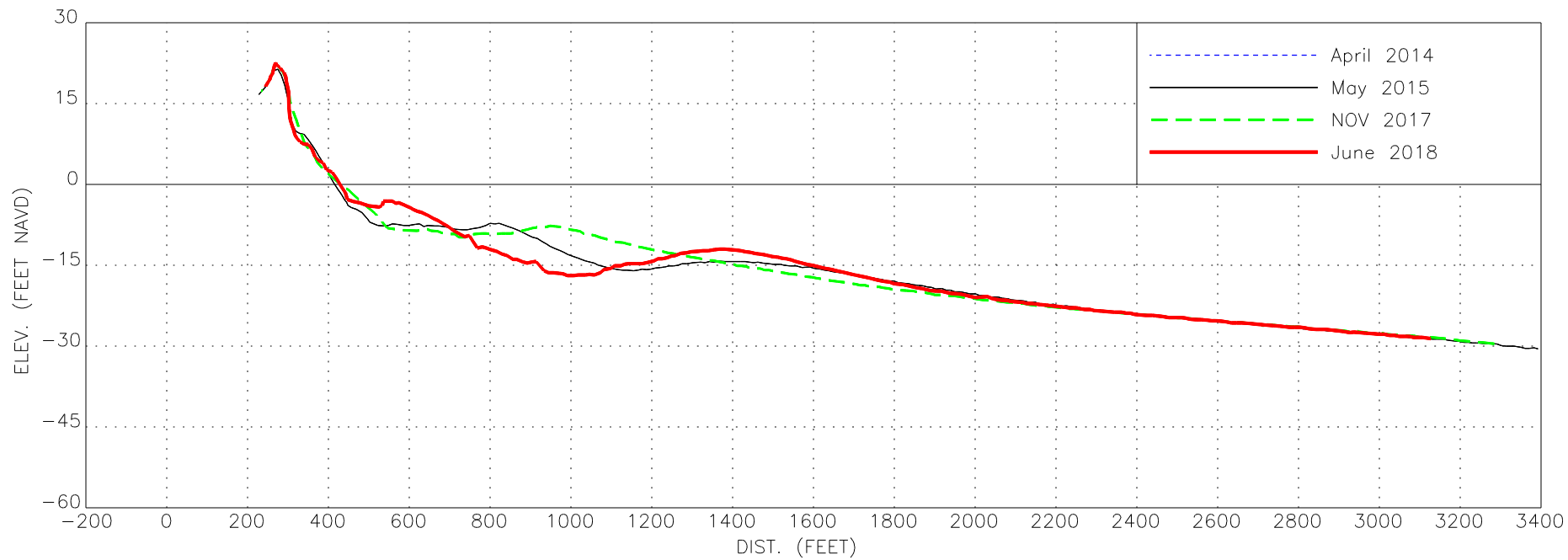
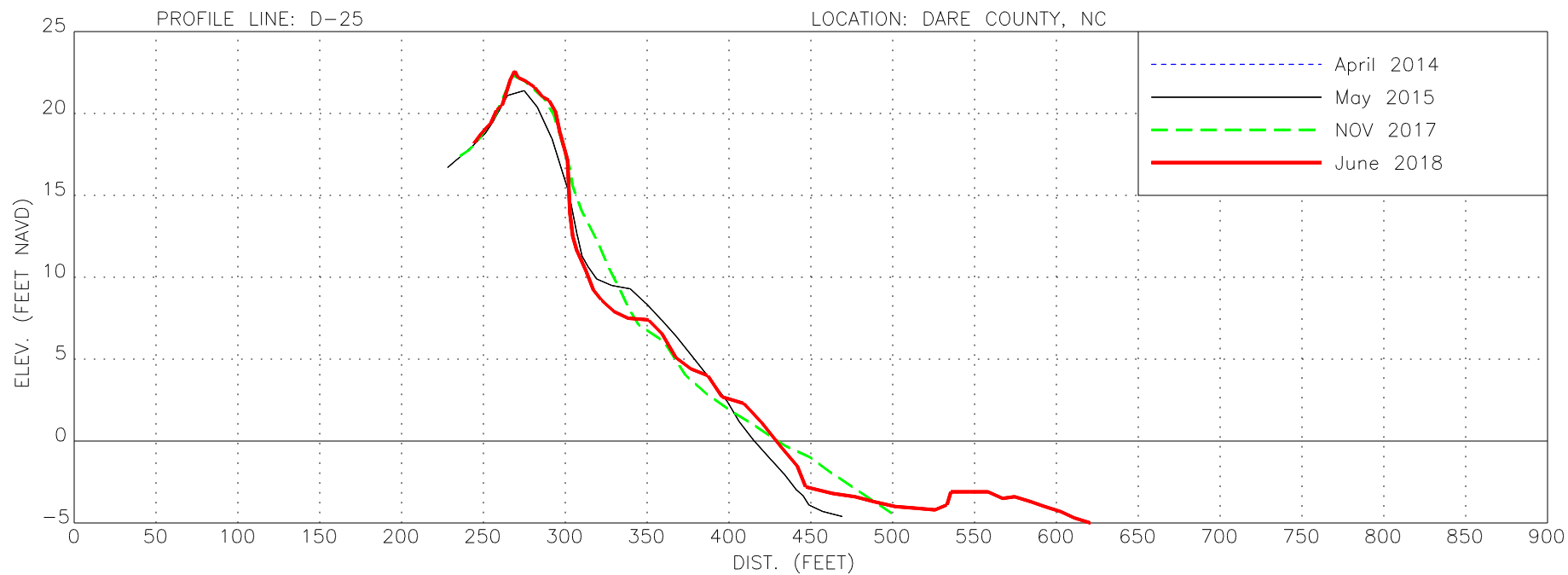


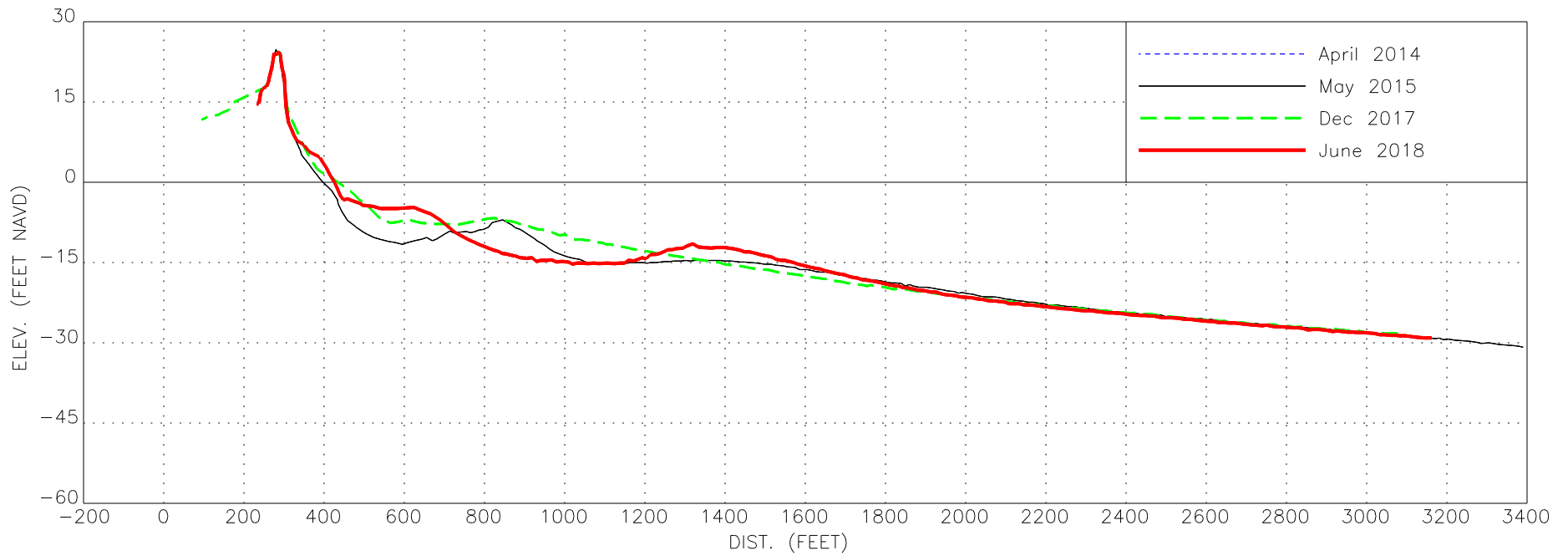
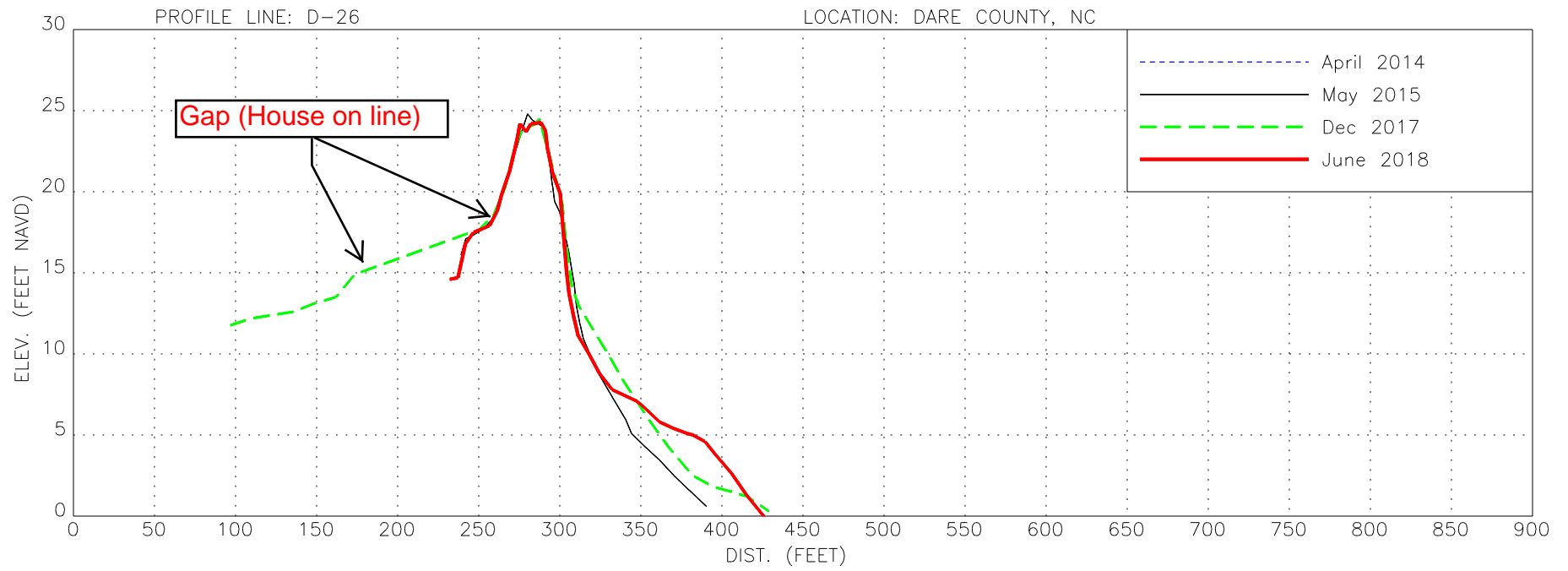


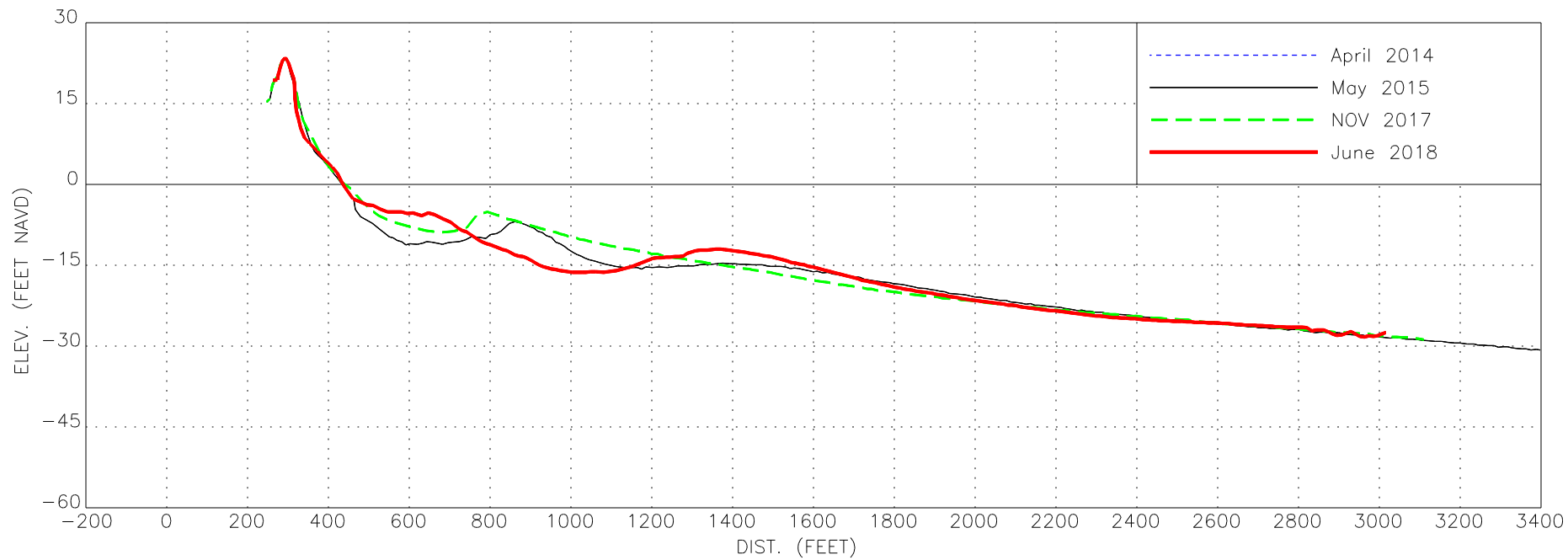
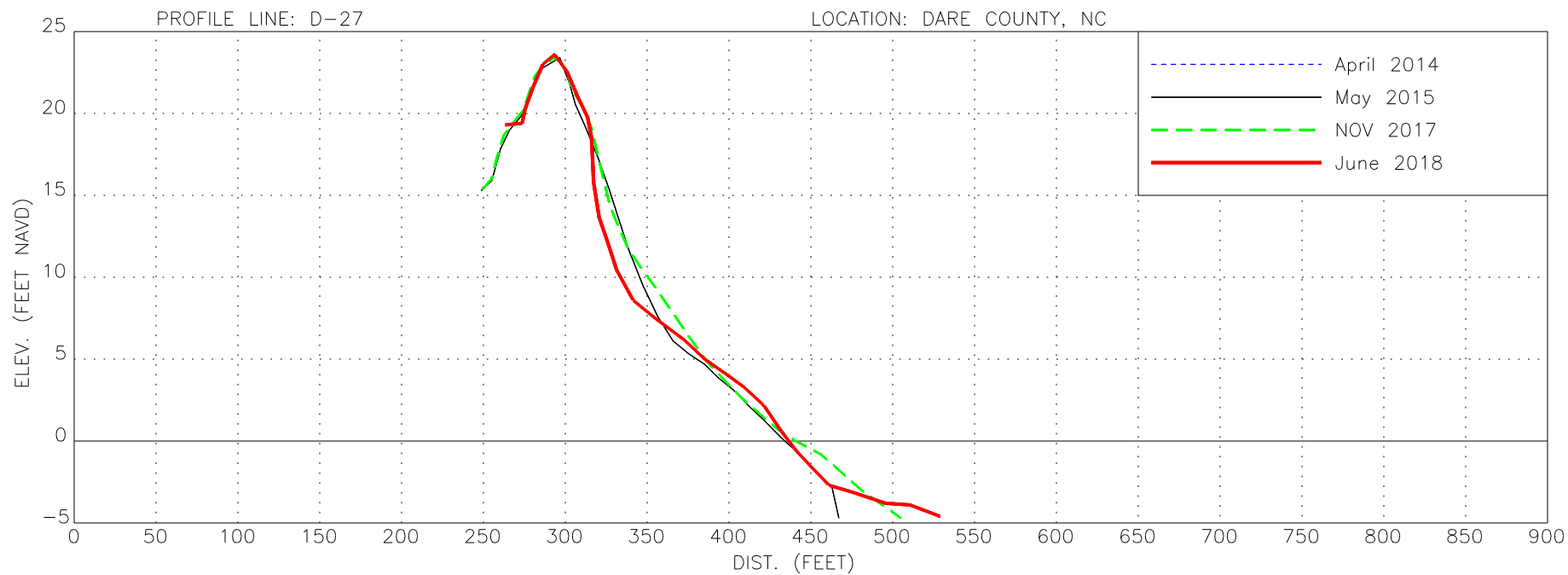


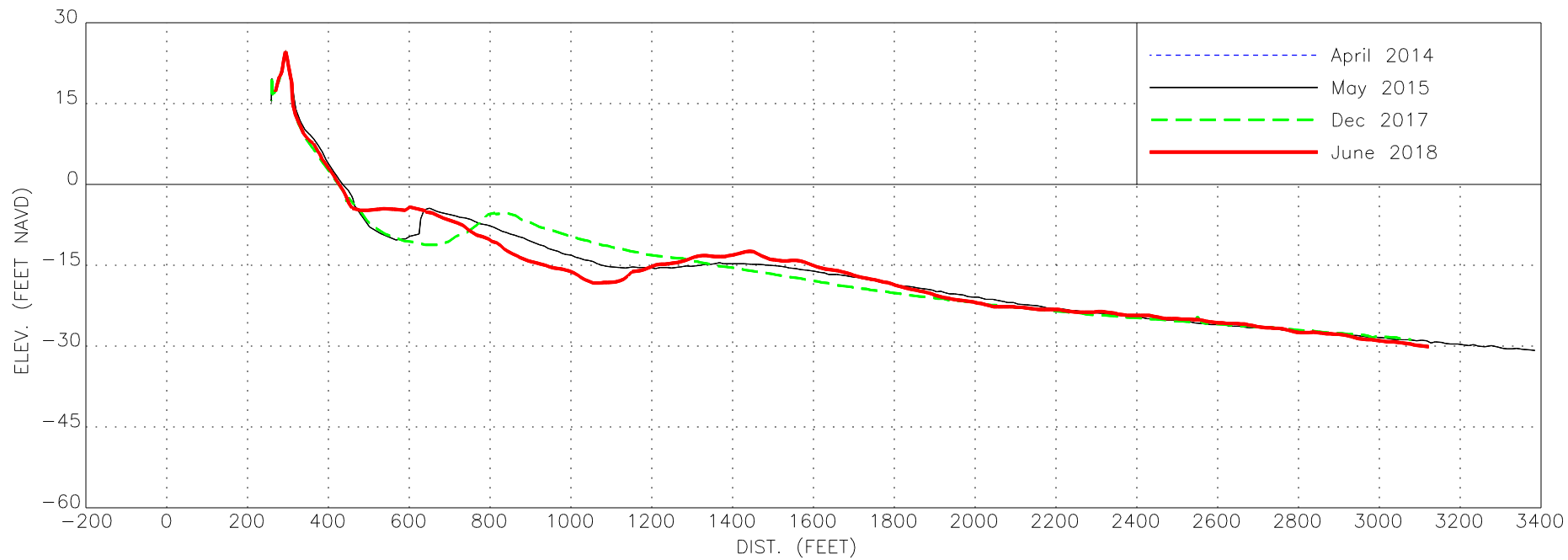
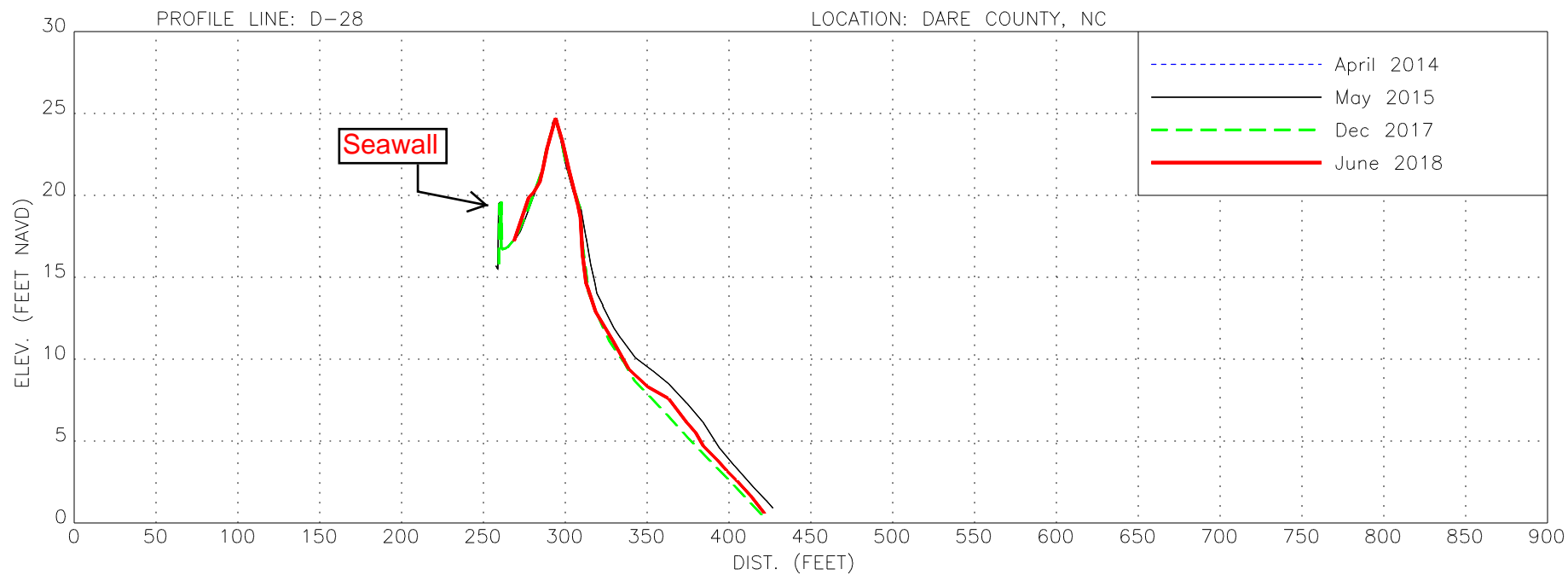


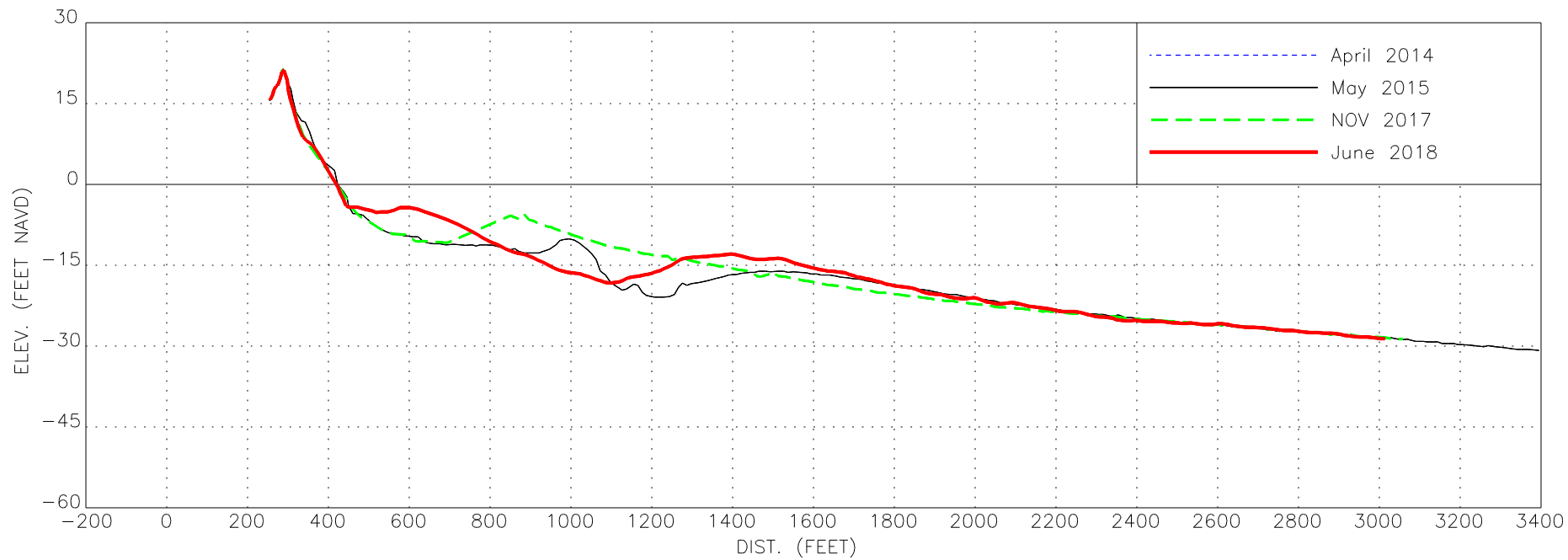
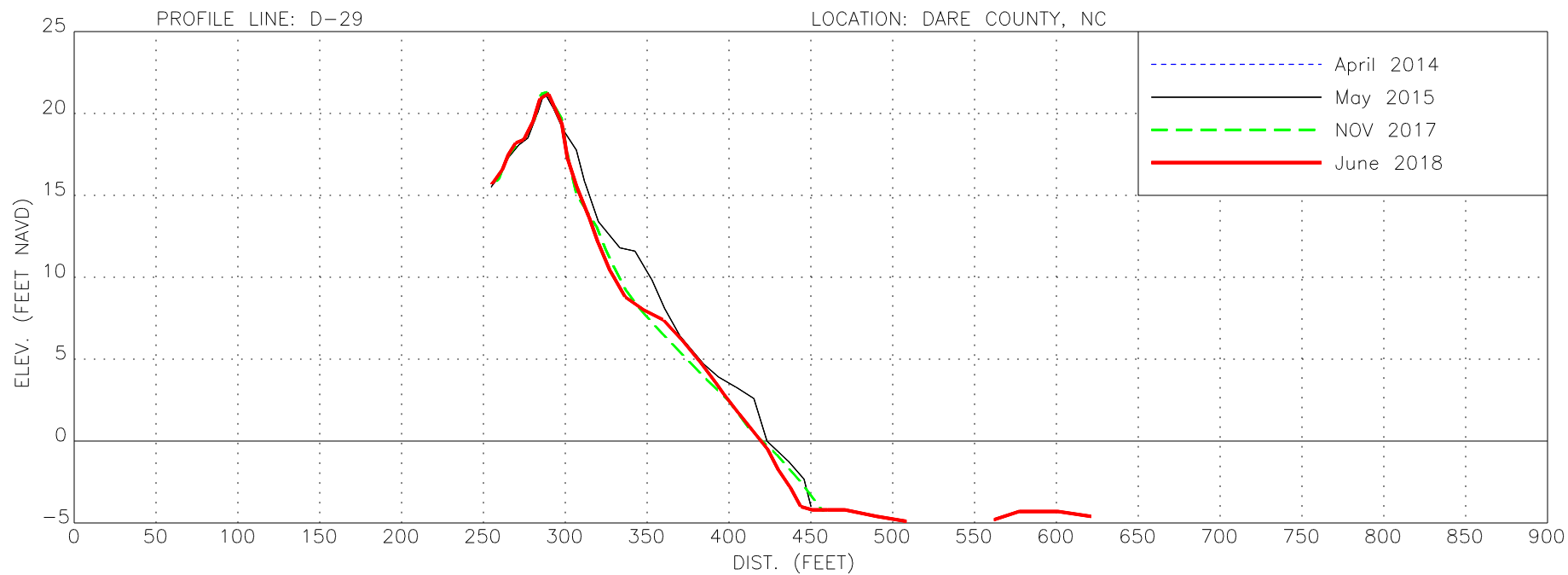


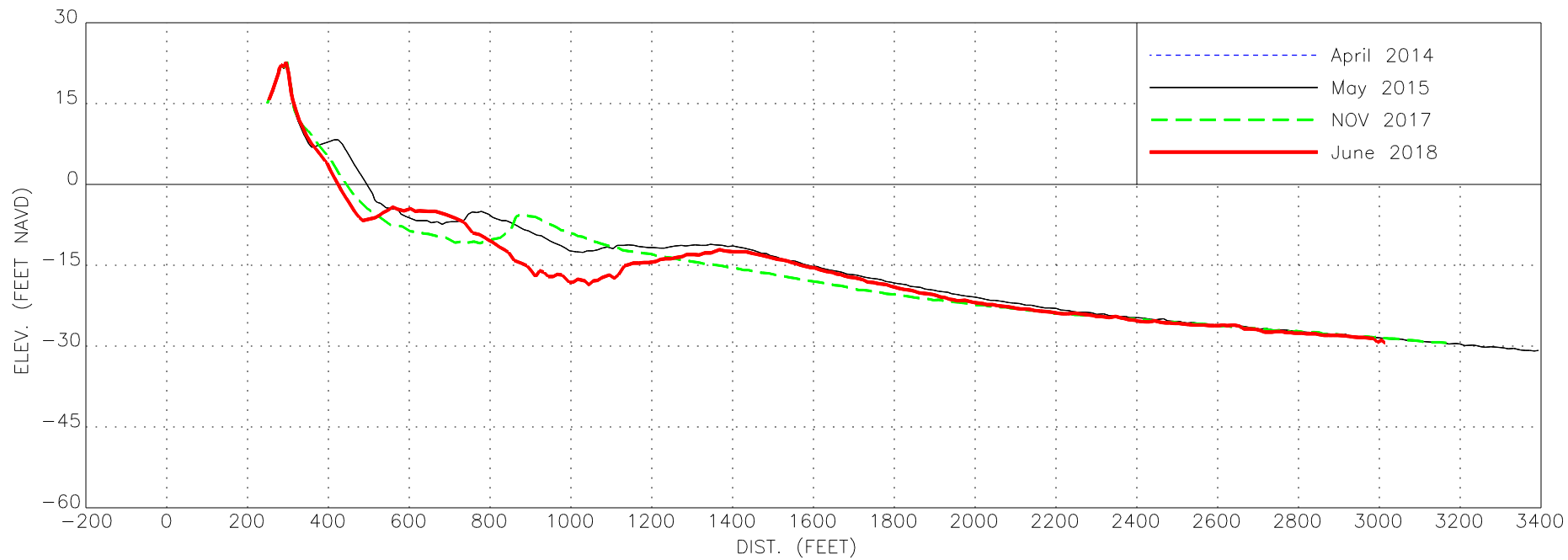
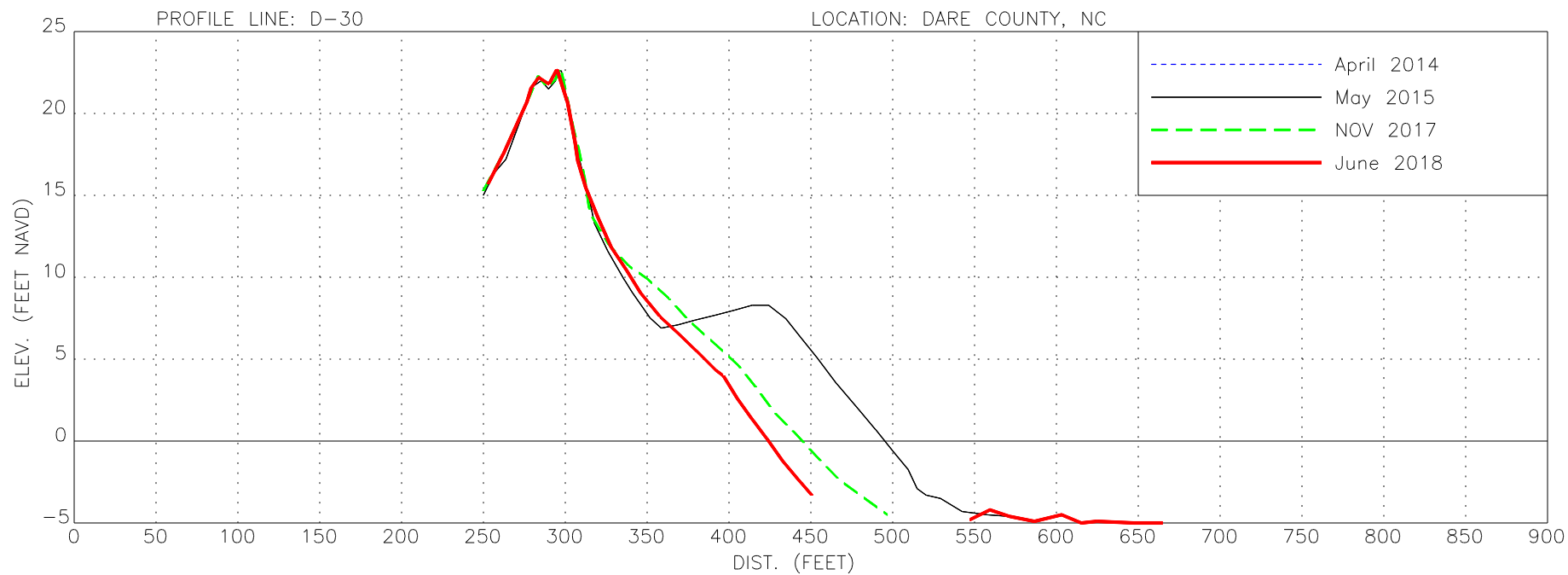


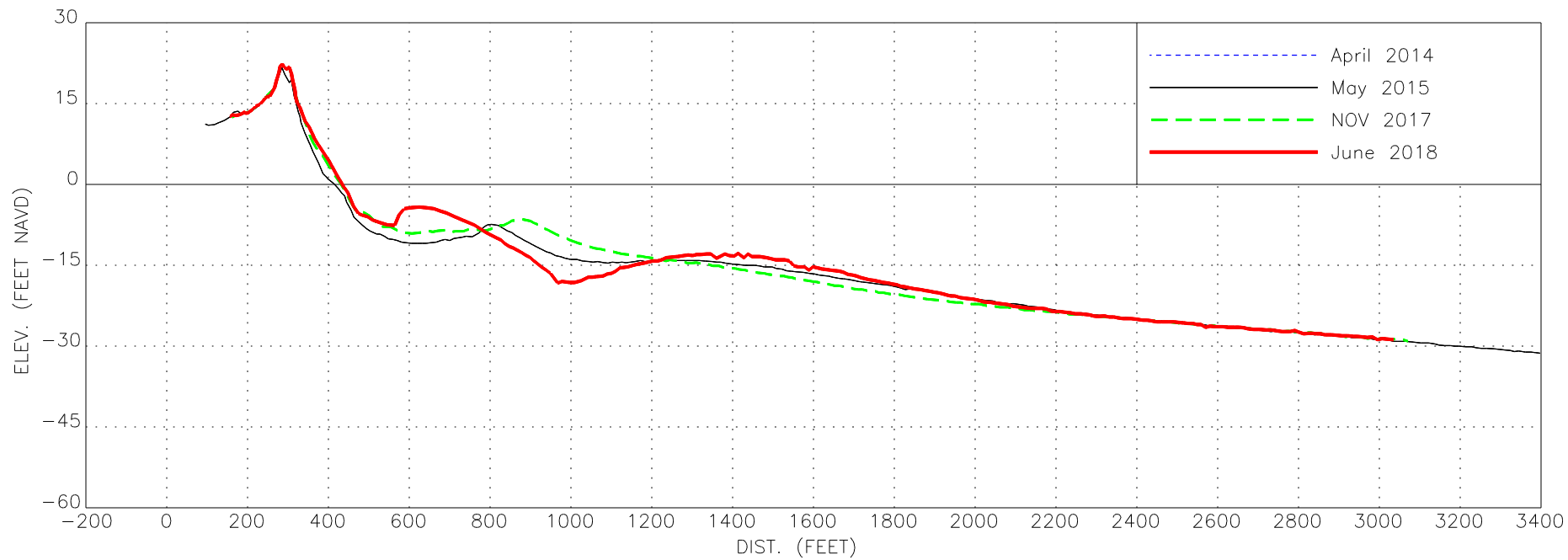
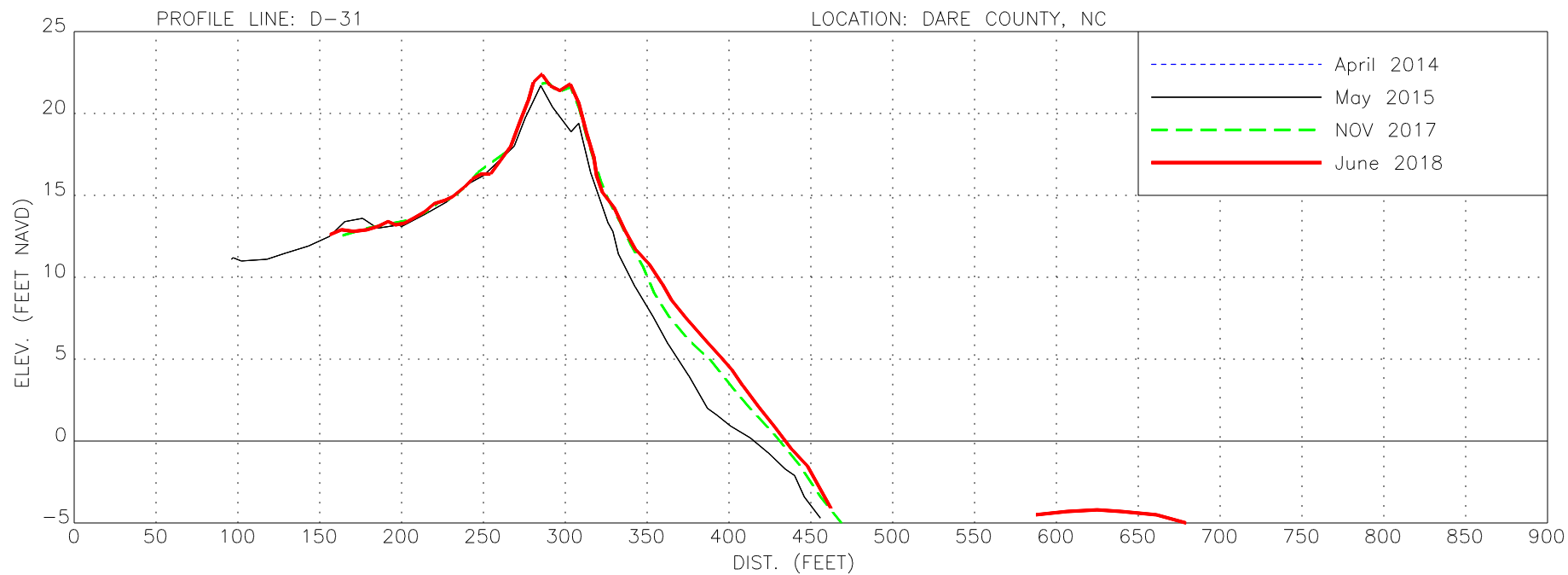


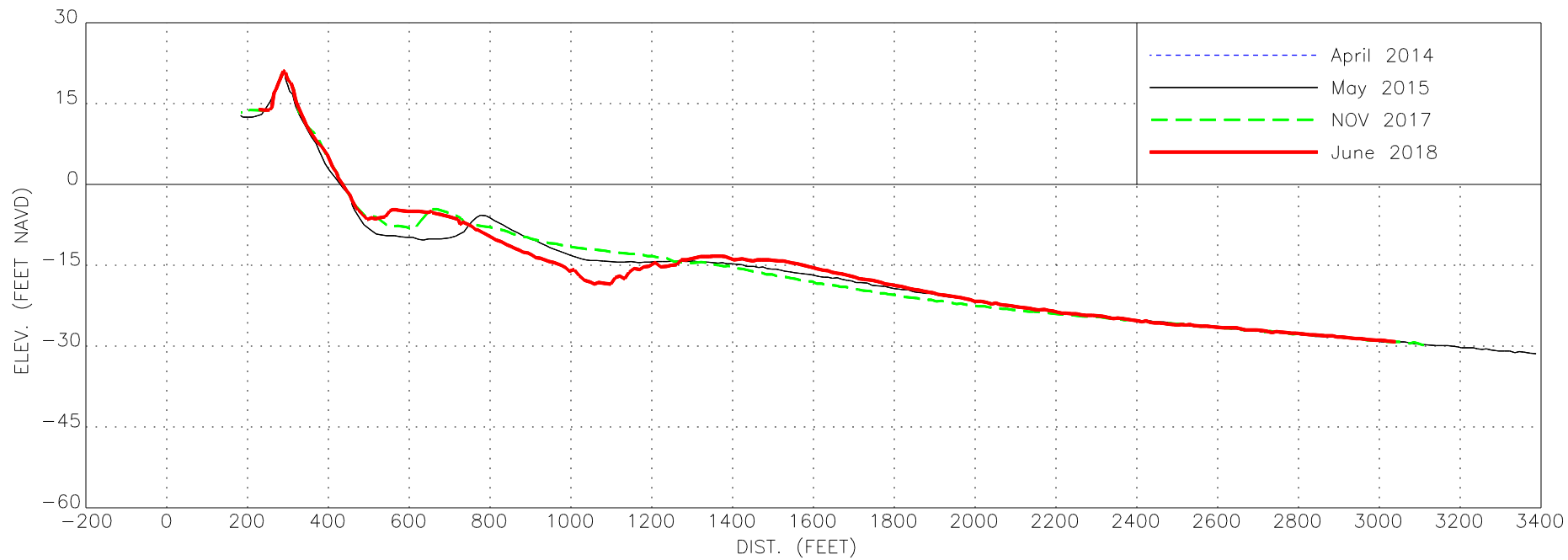
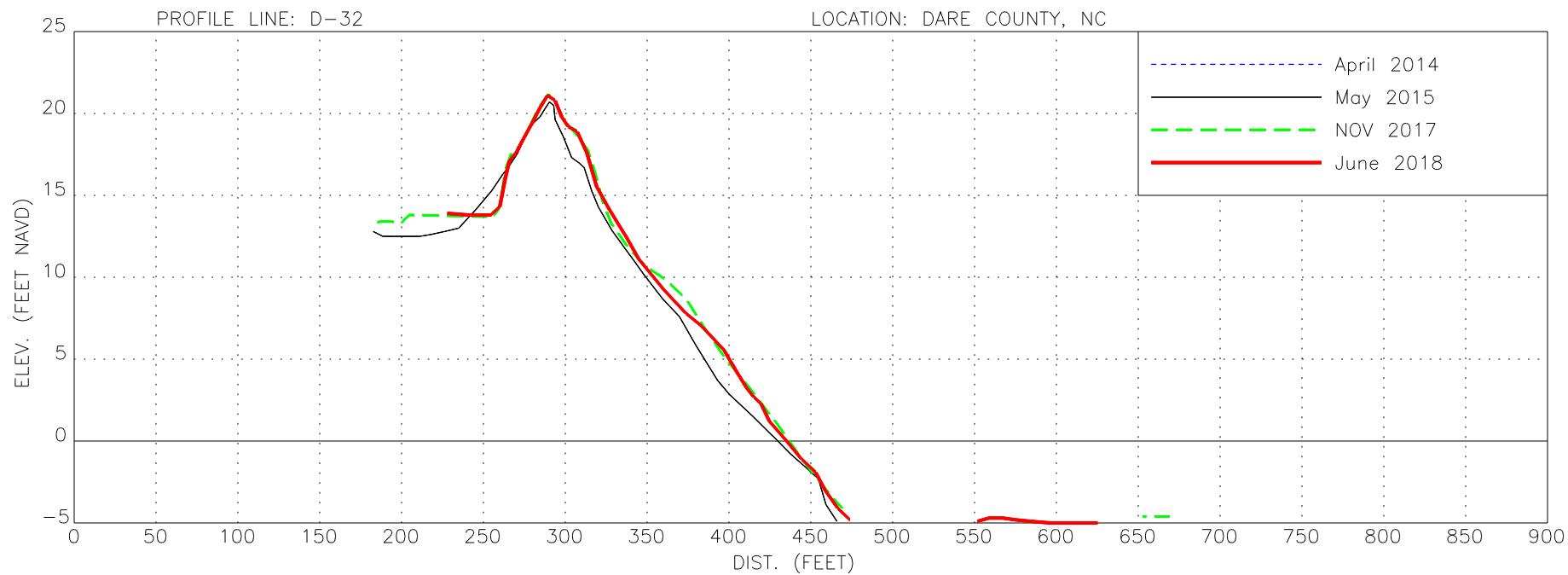


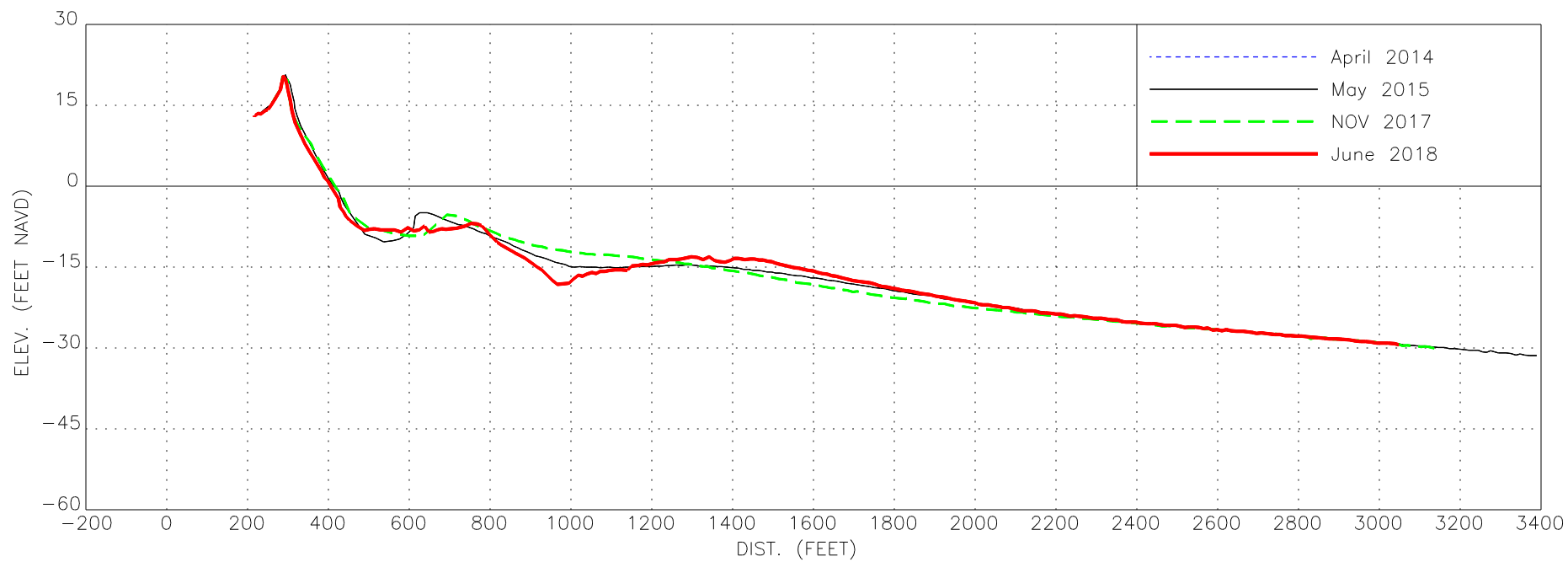
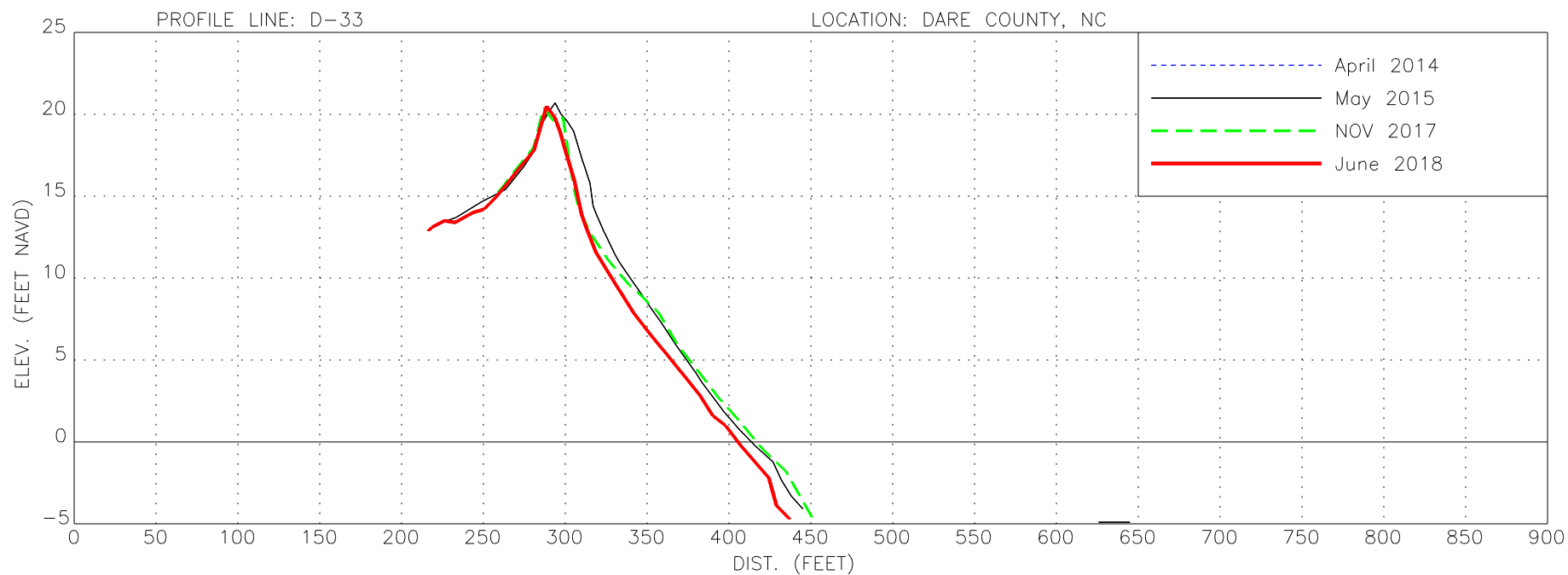


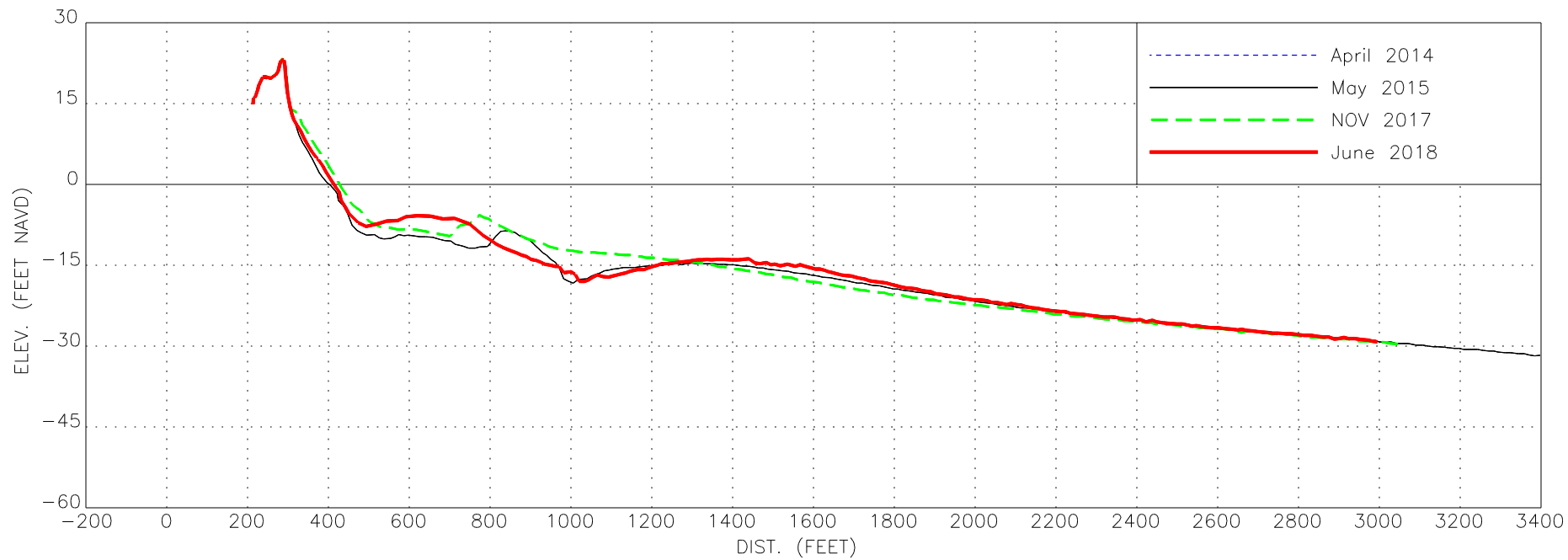
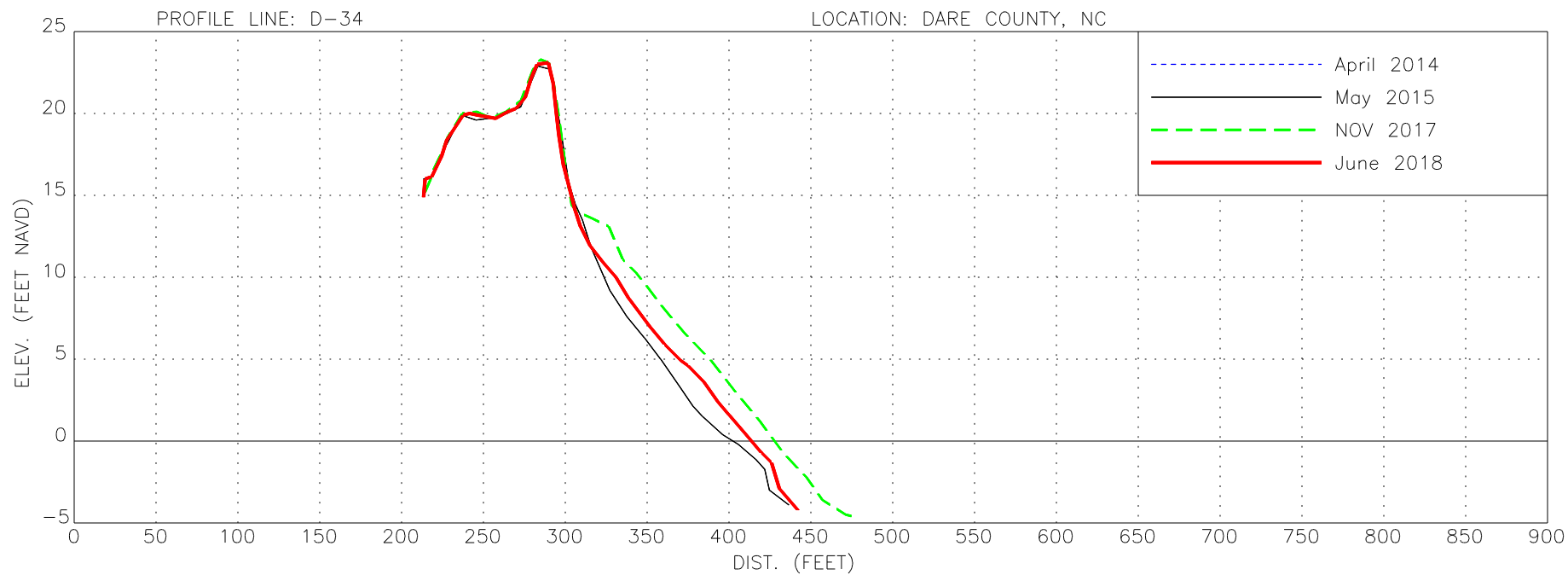












## APPENDIX 4

### GROUND DIGITAL PHOTOGRAPHY

**Ground Digital Photography  
Monument**

**PI-18**



**North View**



**South View**



**Landward View**



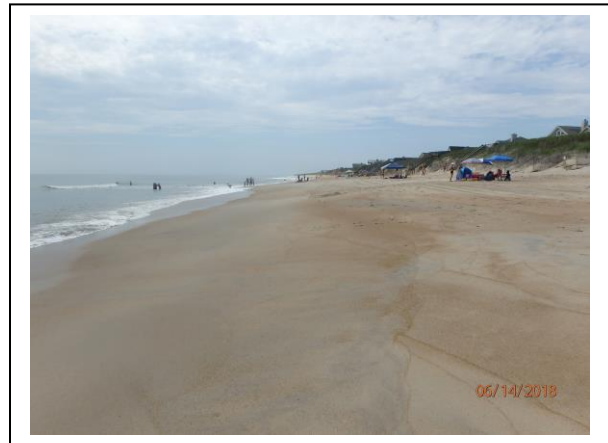
**Monument – No RTK**

**Ground Digital Photography  
Monument**

**PI-17**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-01**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-02**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-03**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-04**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-05**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-06**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-07**



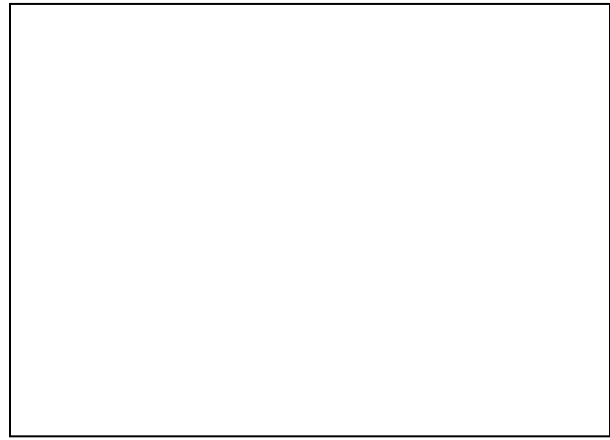
**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-08**



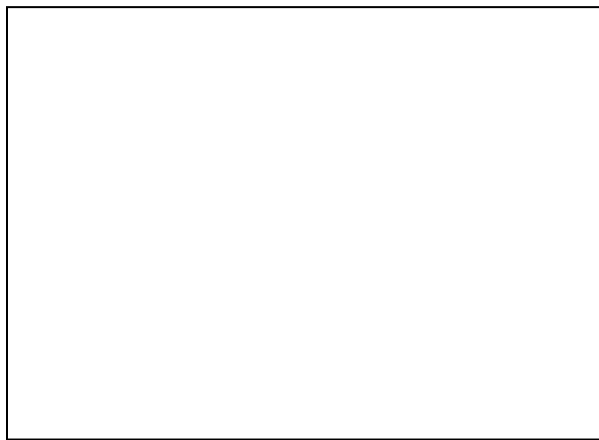
**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-09**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-10**



**North View**



**South View**



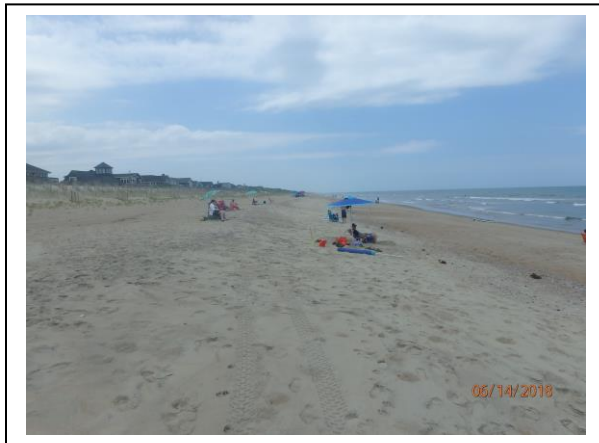
**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-11**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-12**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-13**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-14**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-15**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-16**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-17**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-18**



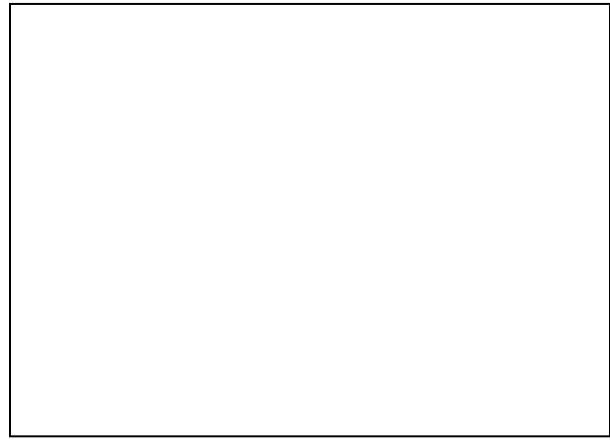
**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-19**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-20**



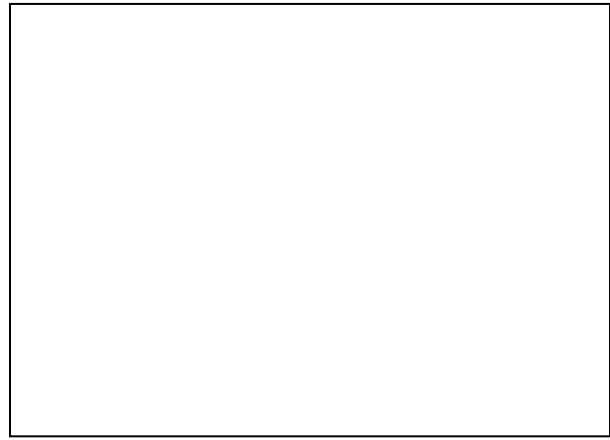
**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-21**



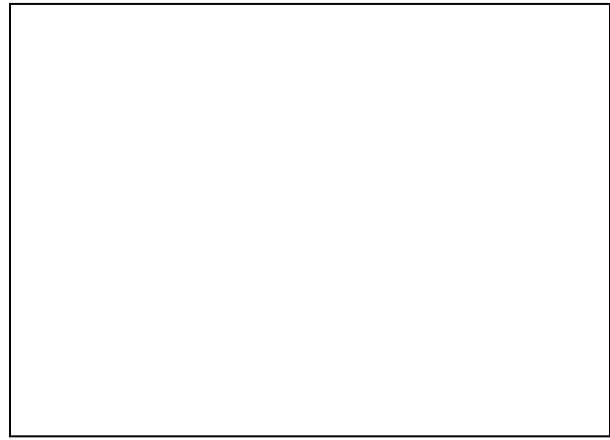
**North View**



**South View**



**Landward View**



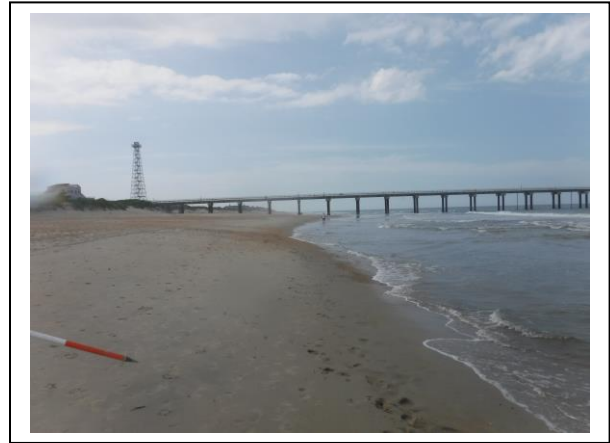
**Monument – No RTK**

**Ground Digital Photography  
Monument**

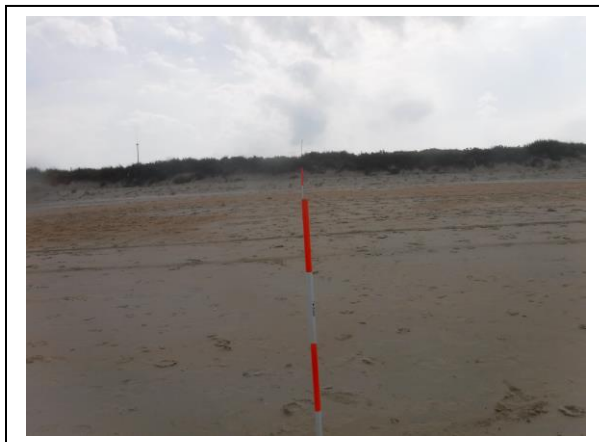
**D-22**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-23**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-24**



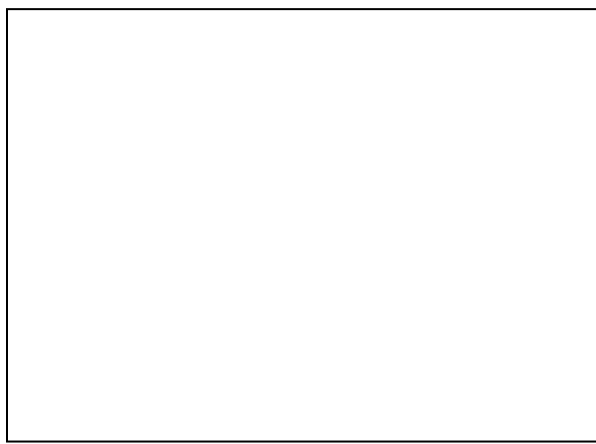
**North View**



**South View**



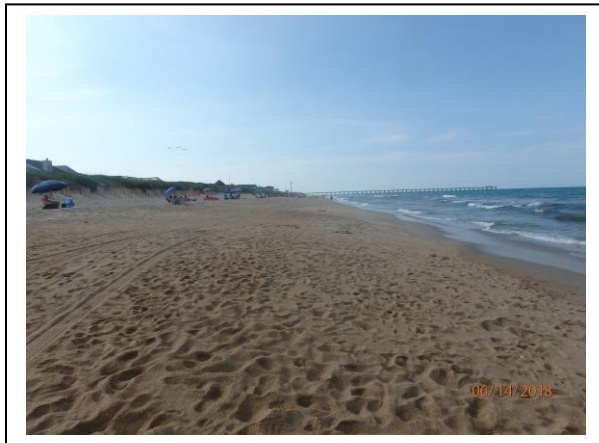
**Landward View**



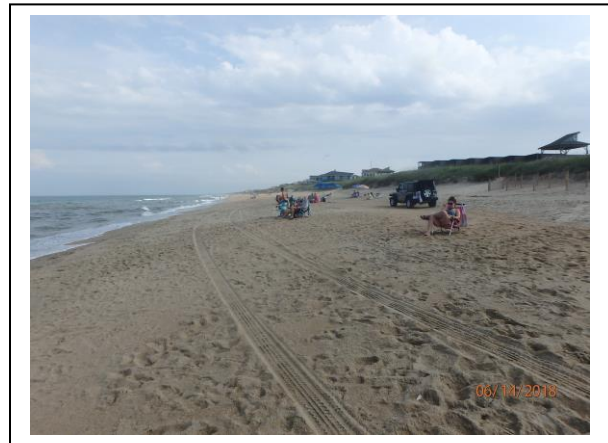
**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-25**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-26**



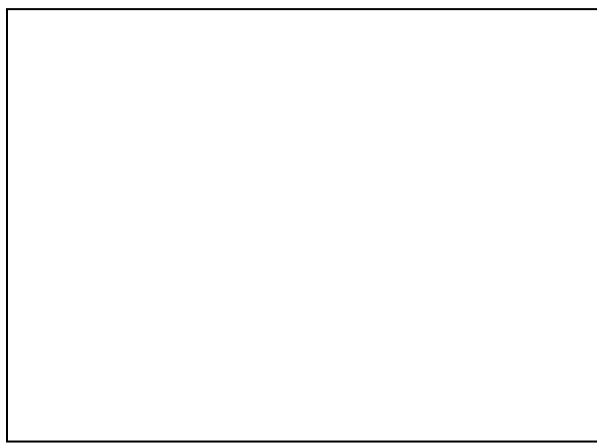
**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-27**



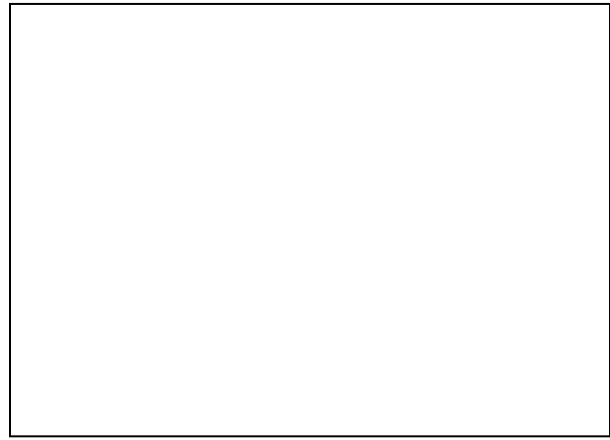
**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

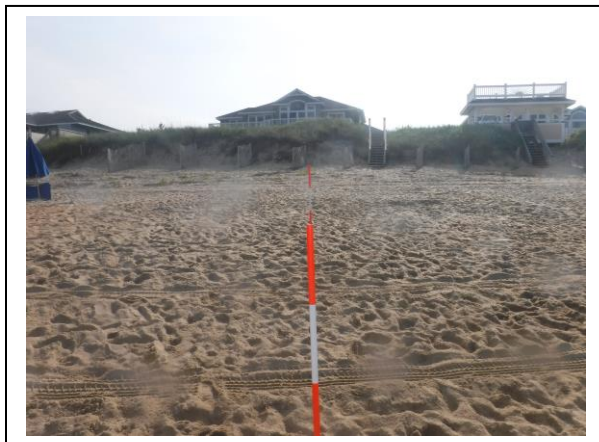
**D-28**



**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-29**



**North View**



**South View**



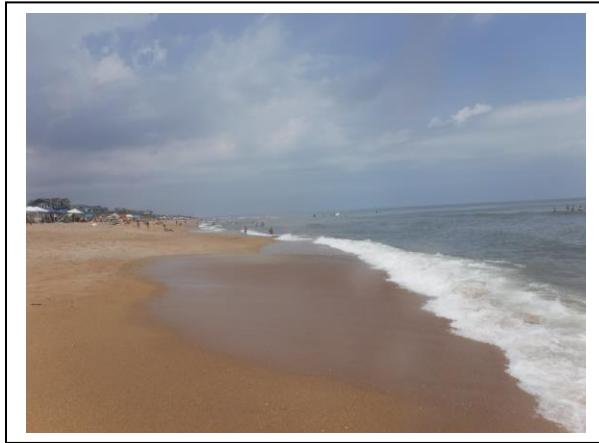
**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-30**



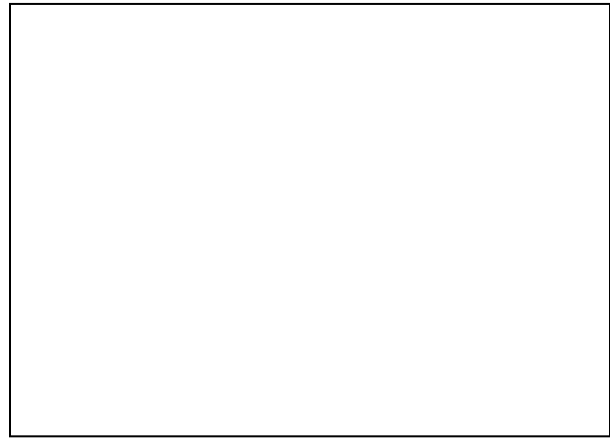
**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-31**



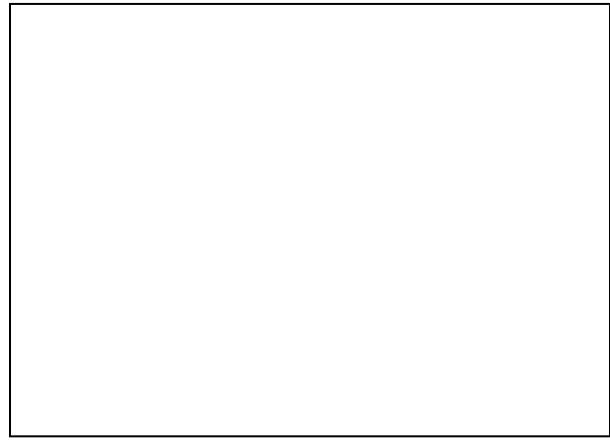
**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-32**



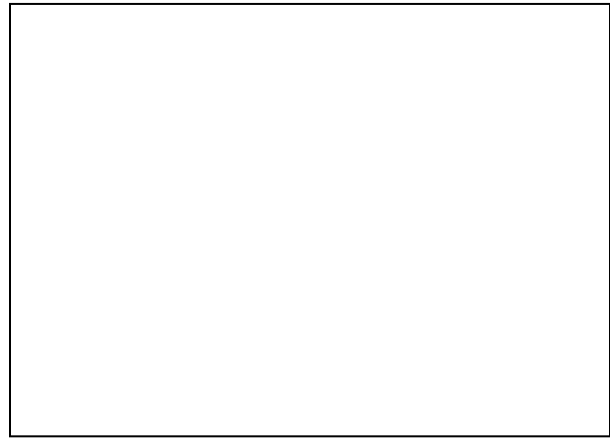
**North View**



**South View**



**Landward View**



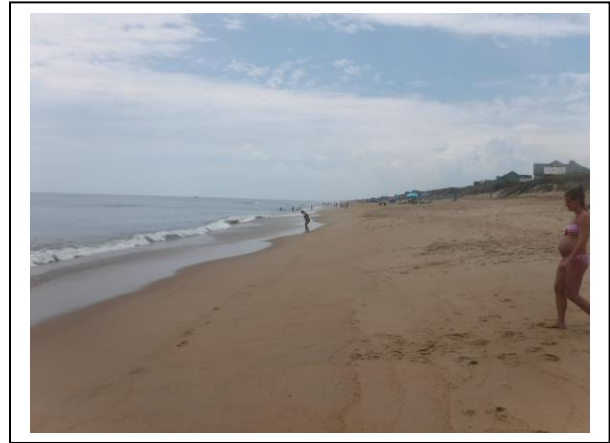
**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-33**



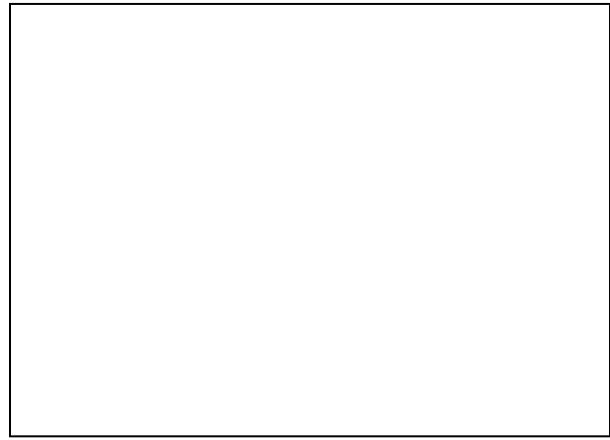
**North View**



**South View**



**Landward View**



**Monument – No RTK**

**Ground Digital Photography  
Monument**

**D-34**



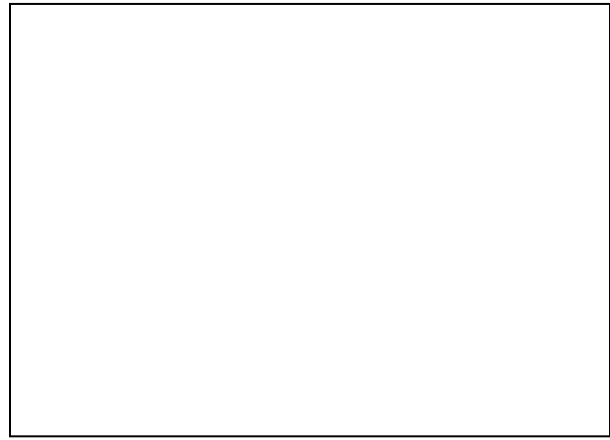
**North View**



**South View**



**Landward View**



**Monument – No RTK**

## APPENDIX 5

### FIELD BOOK PAGES

*(Available in digital format only)*