TOWN OF DUCK NORTH CAROLINA
2020 SHORELINE & VOLUME CHANGE MONITORING REPORT

SUBMITTED TO:
TOWN OF DUCK

SUBMITTED BY:

COASTAL PROTECTION & ENGINEERING OF NORTH CAROLINA, INC.
ENGINEERING LICENCE CERTIFICATE #: C-2331

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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.

The Town of Duck has implemented a long-term beach management program to sustain the beaches that support a significant portion of their local economy and maintains the tax base of the Town. In May and June 2017, the Town constructed a beach nourishment project along 1.6 miles of its oceanfront that was shown to be the most vulnerable portion of the Town's oceanfront. 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 part of its long-term beach management program, the Town has implemented an annual monitoring program to assess both the performance of the beach nourishment project and to track the overall health of the beach along the entire Town. The annual monitoring focuses on analyzing shoreline and volume changes. The monitoring area is divided into three areas designated as the Project Area (station D-10 to D-19); the area North of the Beach Project (D-01 to D-10), which extends south from the Town limit to Skimmer Way; and the area South of the Beach Project (D-19 to D-34), which extends from the northern boundary of the FRF property south to the Town boundary with Southern Shores.

A shoreline change analysis was completed to assess shoreline advance and recession along the study area. The contour used to monitor shoreline change throughout the Town of Duck is the +6.0 ft. NAVD88 contour. The shoreline change analysis compared the position of the +6.0 ft. NAVD88 contour in September 2013, December 2017, May 2019 and June 2020. The following table summarizes the average shoreline changes (ft.) measured between September 2013 and June 2020 (Long-term), December 2017 and June 2020 (Post-Project), and May 2019 and June 2020 (Short-term), for the Project Area and Areas North and South of the Project.

Table ES-1
Summary of Average Shoreline Changes (ft.) within the Project Area and North and South Monitoring Areas

PROFILE	September 2013 (Baseline) to June 2020 (Year-3)	Dec. 2017 (Post-Con to June 2020 (Year-3)	May 2019 (Year-2) to June 2020 (Year-3)
AREA NORTH OF PROJECT (D-01 TO D-10)	-6.3	8.3	2.8
PROJECT AREA (D-10 TO D-19)	3.9	-74.8	-49.0
AREA SOUTH OF PROJECT (D-19 TO D-34)	-8.3	4.6	-14.5

Similar to the shoreline change analysis, the tracking of long-term volumetric changes within the project area as well as north and south of the project area, are measured by comparing the September 2013 data with the most recent annual monitoring. Volumetric changes that have occurred Post-Project are

determined by comparing the December 2017 data with the most recent annual monitoring data. The monitoring report also provides short-term volumetric changes that occurred over the past annual monitoring cycle (May 2019 to June 2020). Average volumetric change rates above the -24-foot NAVD88 contour (cubic yards/ft./year) for the Project Area and areas North and South of the Project are provided in Table ES-2.

Table ES-2
Summary of Average Volume Changes (cy/ft./yr.) within the Project Area and North and South Monitoring Areas

MONITORING AREAS	September 2013 (Baseline) to June 2020 (Year-3)	December 2017 (Post-Con) to June 2020 (Year-3)	May 2019 (Year-2) to June 2020 (Year-3)
AREA NORTH OF PROJECT (D-01 TO D-10)	1.2	8.3	16.9
PROJECT AREA (D-10 TO D-19)	12.2	-12.4	-4.8
AREA SOUTH OF PROJECT (D-19 TO D-34)	3.1	3.5	11.8

The long-term average volumetric change rates indicate a positive trend throughout the Town; however, the Project Area rate is clearly being influenced by the beach nourishment project constructed in 2017. Since the project was completed, both the area north and south of the project experienced higher rates of positive volumetric change than the long-term rates since 2013. North of the project, the increase in the positive volumetric change rate is nearly 7 times greater than the long-term rate. In the south, the increase in the positive volumetric change rate is a minimal and may be heavily influenced by short-term changes.

With regards to the Project Area, comparison of profile surveys conducted in April 2017 (Pre-Construction) and December 2017 (Post-Construction) suggests the effective volumetric gain to the Project Area due to the 2017 beach nourishment project was 963,100 cubic yards. Monitoring data collected in June 2020 indicate a negative volumetric change within the Project Area of approximately -271,000 cubic yards since December 2017 (Post-construction). This equates to a rate of -12.4 cy/ft./yr. when annualized. As of June 2020, the analysis indicates that the Town of Duck beach nourishment project had approximately 72% of the initial fill volume remaining as measured above the -24-foot NAVD88 contour.

The initial monitoring of the project over the first 3 years following construction indicates a volumetric change rate higher than estimated in the initial project design, which may be related to a number of factors. The Town's maintenance plan calls for an estimated renourishment fill density of approximately 30 cy/ft., every 5 years, which translates to an annual average loss of approximately 6 cy/ft. The actual rate of volumetric change measured since 2017, in the first three years pos-construction, has been 12.4 cy/ft., which is twice the rate programed in the beach management plan. It must be considered, however, that the loss of material from a beach nourishment project typically does not occur in a linear pattern;

rather the trend is to observe higher losses immediately following construction of the project followed by a tapering off of rates over time as the project equilibrates with the surroundings and fill diffusion losses decrease. Given the 2017 project was the initial construction of the Town's project and beach profile data along the Project Area was limited prior to the construction of the 2017 project, the monitoring program is revealing the true erosion rate. The true erosion rate is influenced by the construction of the project itself, recent impacts of storms, alongshore variability, and other factors that may be contributing to the erosion rate beyond the initial estimate. Furthermore, the volumetric change measured over the most recent monitoring period (May 2019 to June 2020) indicates a volumetric change rate of -4.8 cy/ft./yr. as shown in Table ES-2.

While the post-project volumetric change rate may decrease over the next two years, prior to the 2022 project, the Town may need to place additional material on the project in excess of the 30 cy/ft. fill density prescribed in the beach maintenance plan to re-establish and maintain the present design objectives. CPE is currently working on updating these numbers as part of the design of the 2022 project, which can be re-evaluated as additional monitoring data become available.

Following the impact of Hurricane Dorian on the project, the Town contracted with CPE to conduct post-storm surveys to determine storm impacts. CPE completed a volume analysis and design report stating that Hurricane Dorian caused the loss of approximately 170,800 cy of sand (~20 cy/ft.) that should be eligible for FEMA Public Assistance funding. While CPE is working on updating the design for the 2022 project to account for the higher observed erosion rates as discussed previously, it is recommended that the Town plan to at least replace the 170,800 cy of material lost as a result of Hurricane Dorian in addition to the programed placement of 254,000 cy of sand. In the report prepared for FEMA, CPE estimated the additional cost to replace the 170,800 cy of sand to be approximately $2,972,000.

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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.

As part of the long-term shoreline management program, the Town of Duck, in cooperation with Dare County, constructed a large beach nourishment project in 2017 that placed approximately 1.26 million cy of sand along approximately 1.6 miles of the Town's shoreline. The project extends from profile station D-10 in the north, which is located near 140 Skimmer Way, to station D-19 in the south, which is located at the south property line of 137 Spindrift Lane (northern boundary of the USACE FRF property). The beach fill design for the Town of Duck included a 20-foot wide dune at elevation +20.0 feet NAVD88 fronted by a variable width berm at elevation +6.0 feet NAVD88.

The Town has implemented a beach monitoring program to track both the performance of the beach fill project constructed in 2017 and the overall health of the beach along the entire Town. This monitoring report describes shoreline changes and volume changes measured along the Town's oceanfront shoreline.

The shoreline change analysis evaluated changes between profile surveys conducted by Coastal Protection Engineering of North Carolina, Inc. (CPE) (formerly Aptim Coastal Planning & Engineering of North Carolina, Inc.) in September 2013, May 2015, December 2017, May 2019 and June 2020. Volumetric changes were evaluated by comparing beach profile surveys collected in September 2013, May 2015, December 2017, May 2019, and June 2020.

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 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.

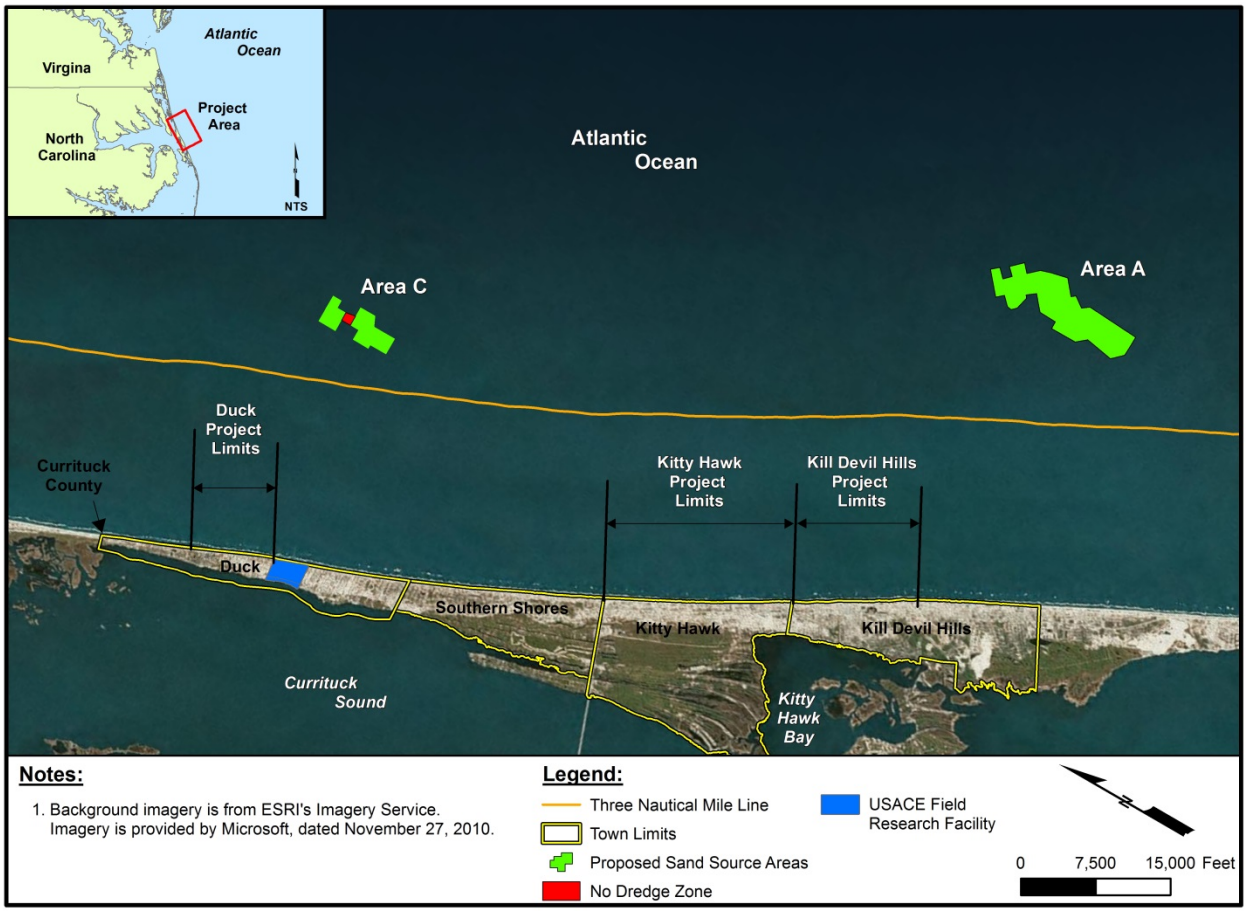

Figure 1. Project Location Map.

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 2. The Project Area includes the beach between the northern FRF property line, located near station D-19, through station D-10, which is near the northern end of Skimmer Way. The section referred to as North of the Project extends from station D-10 (northern end of Skimmer Way) north to the Duck town limits (station D-01). The area designated South of the Project extends from station D-19 south to D-34 and includes the shoreline along the USACE FRF property. Profile D-34 is located near the Duck town boundary with the Town of Southern Shores. Figure 2 also depicts the stations at which beach profile surveys were conducted.

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

III. SURVEY DATA COLLECTION

As previously stated, beach profile surveys were conducted along the Town's shoreline by CPE in September 2013, May 2015, December 2017, May 2019, and June 2020. Each of these surveys include the 34 profile transects shown in Figure 2. The profile transects are spaced 1,000 feet along the Town's oceanfront beach. CPE also conducted an additional survey in December 2019 following Hurricane Dorian. The December 2019 survey included only the profiles within the project area (D-10 to D-19). Beach profile data was 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 – 2020 Town of Duck Topographic and Hydrographic Survey Report. Appendix A also includes detailed survey methodology, monument information, profile plots, profile digital photography, and field book notes.

Beach profile surveys 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 NAVD88 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. More detailed information on survey data acquisition is available in Appendix A.

Data along profiles D-19, D-20, D-21, D-22, and D-23 were only be collected by CPE for the upland portion of the profiles due the United States Army Corps of Engineers (USACE) Field Research Facility's (FRF) request not to approach the shoreline with survey vessels. Offshore data was obtained from the USACE FRF who regularly surveys the offshore portions of those profiles. The USACE FRF data was collected on June 23, 2020.

IV. SHORELINE CHANGE RESULTS

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 +6.0 ft. NAVD88 contour, which represents the beach nourishment project design berm elevation (CPE-NC, 2015A). Shoreline change is calculated by comparing shoreline position along shore perpendicular transects or profiles. Typically, shoreline change is then annualized to describe recession and advance rates. Annualized shoreline change rates are calculated by dividing the shoreline change by the time period (number of years) between survey events (i.e. feet per year). These changes are described in terms of positive ("+") or advance (shoreline moving seaward) and negative ("-") or recession (shoreline moving landward).

Table 1. Profile Survey Baseline and Azimuth

Profile	Easting	Northing	Azimuth
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	2962839.6	889616.1	70

The analysis discussed in this report for the Town of Duck evaluated the +6.0 ft. NAVD88 contour positions measured during the September 2013, December 2017, May 2019 and June 2020 beach profiles surveys. Even though the 2017 beach nourishment project was completed in June 2017, the December 2017 survey has been adopted to represent the post-construction conditions within the project area due to large-scale profile adjustments that normally occur immediately following the placement of beach fill. This and future annual monitoring reports will reference shoreline changes and volume changes in the project area relative to the December 2017 condition. This report also includes a shoreline comparison of what are referred to as baseline surveys, which represent the initial surveys conducted by CPE during the planning process for the projects. The first survey conducted along Duck by CPE, was conducted in September 2013. The September 2013 data were used as the existing condition in the design of the berm and dune design for the Town's project. The last survey conducted prior to the 2017 beach nourishment operation by CPE was conducted in May 2015. The +6.0 ft. NAVD88 contour position for each survey was identified along shore perpendicular transects spaced at approximately 1,000-foot intervals at the profiles along the monitoring area identified in Table 1.

The changes in the position of the +6.0 ft. NAVD88 contour measured between the September 2013 baseline survey and June 2020 are provided in Table 2. Short-term measured changes of the +6.0 ft. NAVD88 contour that occurred between May 2019 and June 2020 are also provided in Table 2. These values represent actual changes and not rates.

Table 3 shows rates of change for the +6.0 ft. contour between September 2013 (baseline survey) and June 2020, December 2017 (Post-Construction) to June 2020, and May 2019 to June 2020. The September 2013 to June 2020 time period represents long-term rates since CPE began monitoring the Town's Shoreline. The Table also includes average shoreline changes measured from 1996 to 2011 using historic LiDAR data. These rates represent the rate of change of the MHW contour as opposed to the +6.0 ft. contour, however they allow for a comparison of historic rates with more current rates.

Figure 3 graphically displays the location of +6.0 ft. NAVD88 shorelines for the entire monitoring area relative to the September 2013 shoreline. The relative shorelines shown are for December 2017 (Post-Construction), May 2019, and June 2020. A review of Figure 3 shows the Project Area shoreline retreated landward between May 2019 and June 2020. This period includes the impacts of Hurricane Dorian on the project. During the same time period from May 2019 to June 2020 the shoreline 5,000 ft. north of the Project Area (stations D-05 and D-10) experienced positive shoreline change. South of the Project Area, between stations D-20 and D-25, the shoreline experienced negative shoreline change. In this regard, the characterization of shoreline changes within the monitoring areas is best represented by averaging shoreline trends for multiple profile lines within certain sections. As discussed below, average shoreline trends were computed for the three subareas within the monitoring area, namely, North of the Beach Project, the Project Area, and South of the Beach Project.

Table 2. +6.0 FT NAVD88 Shoreline Changes (ft.)

PROFILE		September 2013 (Baseline) to June 2020 (Year-3)	May 2019 (Year-2) to June 2020 (Year-3)
Area North of Project	D-01	-45.5	-25.3
	D-02	-43.1	-44.5
	D-03	-9.6	12.1
	D-04	-16.0	-6.5
	D-05	45.6	77.9
	D-06	4.3	10.3
	D-07	-8.5	13.5
	D-08	-5.0	-4.5
	D-09	35.8	49.2
Project Area	D-10	-21.2	-54.5
	D-11	3.3	-50.8
	D-12	3.7	-51.0
	D-13	6.4	-81.3
	D-14	23.2	-51.7
	D-15	21.1	-63.9
	D-16	0.3	-31.9
	D-17	7.4	-37.9
	D-18	10.6	-24.8
	D-19	-15.5	-42.0
Area South of Project	D-20	0.3	-46.6
	D-21	-26.2	-81.0
	D-22	-29.3	-64.2
	D-23	7.0	1.0
	D-24	-23.6	-30.0
	D-25	10.6	13.0
	D-26	-14.4	-34.0
	D-27	-18.6	6.4
	D-28	-18.2	-7.6
	D-29	-19.5	-1.9
	D-30	-14.8	4.8
	D-31	17.9	15.1
	D-32	1.6	8.6
	D-33	12.0	34.0
	D-34	-2.4	-8.0
AREA NORTH OF PROJECT (D-01 TO D-10)		-6.3	2.8
PROJECT AREA (D-10 TO D-19)		3.9	-49.0
AREA SOUTH OF PROJECT (D-19 TO D-34)		-8.3	-14.5

Table 3. +6.0 FT NAVD88 Shoreline Change Rates (ft./yr.)

	PROFILE	MHW Shoreline Change from 1996 to 2011*	September 2013 (Baseline) to June 2020 (Year-3)	December 2017 (Post-Con) to June 2020 (Year-3)	May 2019 (Year-2) to June 2020 (Year-3)
Area North of Project	D-01		-6.7	-14.1	-23.4
	D-02		-6.4	-2.2	-41.1
	D-03		-1.4	6.1	11.2
	D-04		-2.4	1.7	-6.0
	D-05		6.8	22.7	71.9
	D-06		0.6	8.4	9.5
	D-07		-1.3	-5.2	12.4
	D-08		-0.7	4.1	-4.1
	D-09		5.3	21.8	45.4
Project Area	D-10		-3.1	-10.1	-50.3
	D-11		0.5	-30.8	-46.9
	D-12		0.6	-34.1	-47.1
	D-13		1.0	-47.9	-75.0
	D-14		3.4	-44.7	-47.7
	D-15		3.1	-52.7	-59.0
	D-16		0.0	-40.5	-29.5
	D-17		1.1	-22.3	-35.0
	D-18		1.6	-10.6	-22.9
	D-19		-2.3	-5.3	-38.8
Area South of Project	D-20		0.0	3.8	-43.1
	D-21		-3.9	-0.4	-74.7
	D-22		-4.3	2.2	-59.3
	D-23		1.0	22.7	0.9
	D-24		-3.5	2.0	-27.7
	D-25		1.6	3.4	12.0
	D-26		-2.1	2.9	-31.4
	D-27		-2.8	2.3	5.9
	D-28		-2.7	2.6	-7.0
	D-29		-2.9	-1.8	-1.7
	D-30		-2.2	-10.1	4.5
	D-31		2.7	5.9	13.9
	D-32		0.2	-1.2	7.9
	D-33		1.8	6.9	31.4
	D-34		-0.4	-6.3	-7.4
AREA NORTH OF PROJECT (D-01 TO D-10)		1.0	-0.9	3.3	2.6
PROJECT AREA (D-10 TO D-19)		-2.2	0.6	-29.9	-45.2
AREA SOUTH OF PROJECT (D-19 TO D-34)		-0.4	-1.2	1.9	-13.4

* Average MHW shoreline change rates provided as a reference only.

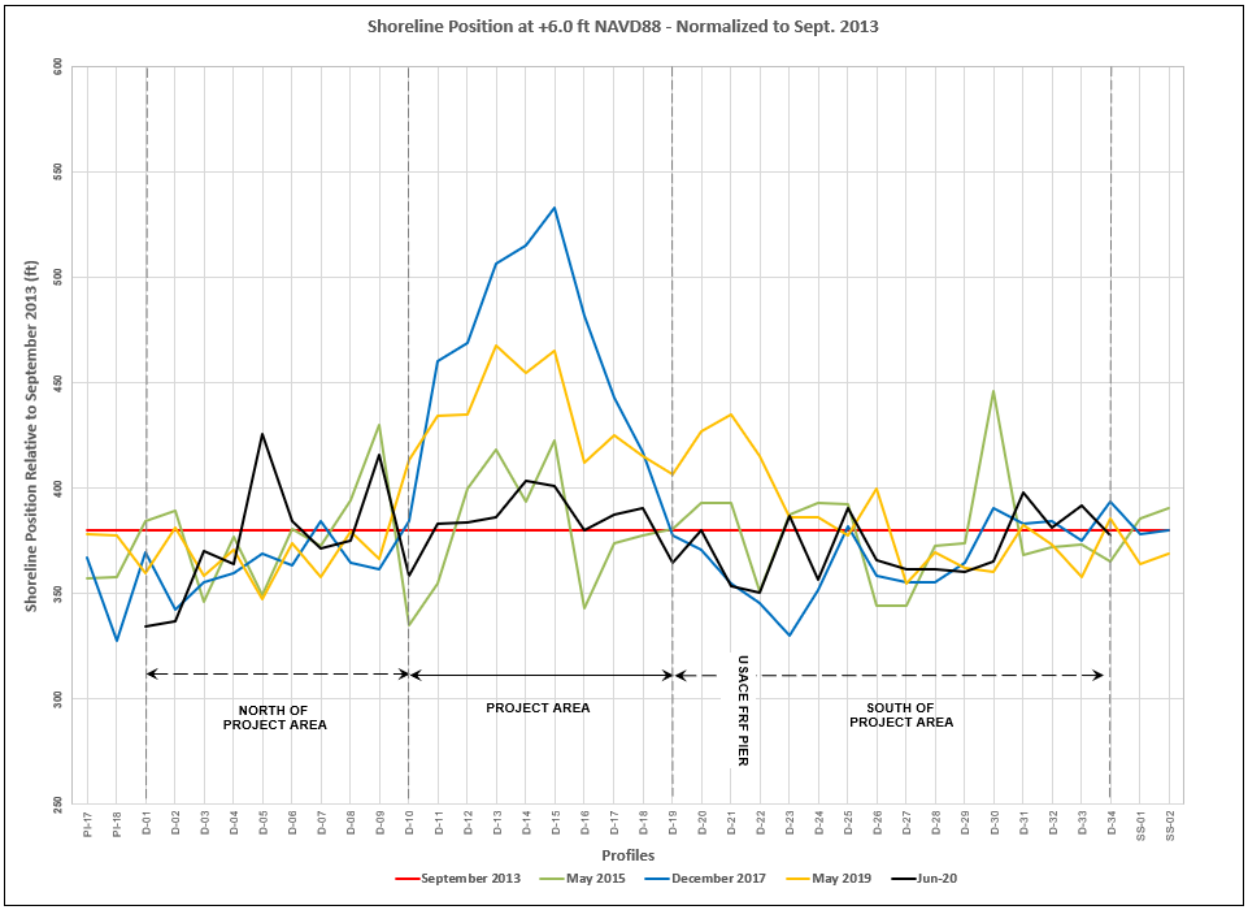

Figure 3. Historical +6.0 FT NAVD88 position relative to the September 2013 +6.0 FT NAVD88 position.

Project Shoreline Changes

Project Area. With the construction of the beach nourishment project in 2017, the +6 ft. NAVD88 contour was extended seaward +183 ft. based on comparisons of the before dredge (BD) and after dredge (AD) surveys. However, these numbers reflect the change based on the placement of the unequilibrated beach fill construction template. Between April 2017 and December 2017, the beach fill underwent immediate post-fill adjustments which reduced the initial advancement of the +6.0 ft. NAVD88 contour to an average of +89.5 feet. Note, this average does not include D-19 as this profile was not surveyed during the April 2017 pre-construction survey. The project average includes D-10 through D-18. This seaward advance of the +6.0 ft. NAVD88 contour is more reflective of the effective advance as a result of the project.

Beach profile data indicated that between December 2017 and June 2020, the average shoreline change of the +6 ft. NAVD88 contour within the project area was -74.8 feet, which is equivalent to a rate of change of 29.9 ft./yr. A profile-by-profile comparison shows a wide range of rates of change in the position of the +6.0 ft. NAVD88 contour (Table 3). The greatest shoreline changes measured appear to be taking place in the central portion of the project between Station D-13 (Sea Tern Dr.) and D-16 (Pintail Dr.). The average shoreline change along those 4 profiles was -116.2 ft. The average shoreline change between December 2017 and June 2020, in the northern portion of the project area from D-12 (Sound Sea Ave.) to D-10 (Skimmer Way) was -62.5 ft.; whereas, the average shoreline change in the southern part of the project

area from D-17 (located at the south end of Buffell Head Rd.) to D-19 (northern USACE FRF boundary) was -31.9 ft. Table 2 includes measured shoreline change for each profile as well as the average shoreline change for the beach nourishment project and the monitored areas outside the project. Table 3 includes rates of change of the +6.0 ft. NAVD88 contour for each profile as well as the average rate of change for the beach nourishment project and the monitored areas outside the project.

Figure 4 depicts the average cumulative change in the position of the +6.0 ft. NAVD88 contour within the project area (i.e. average change of stations D-10 to D-19) between September 2013 and June 2020. The large increase in the cumulative average shoreline change in the Project Area between May 2015 and December 2017 reflects the 89-foot seaward advancement of the average shoreline associated with the beach fill project completed in July 2017. After an initial shoreline recession measured between December 2017 and June 2018, the shoreline change appeared to stabilize somewhat and even advance seaward on average, between June 2018 and May 2019. Between May 2019 and June 2020, the average position of the +6.0 ft. NAVD88 contour moved -49.0 ft. (landward) along the project area. Note that the shoreline position measured in December 2019, during the Post-Dorian data collection, is also included in Figure 4 for the Project Area.

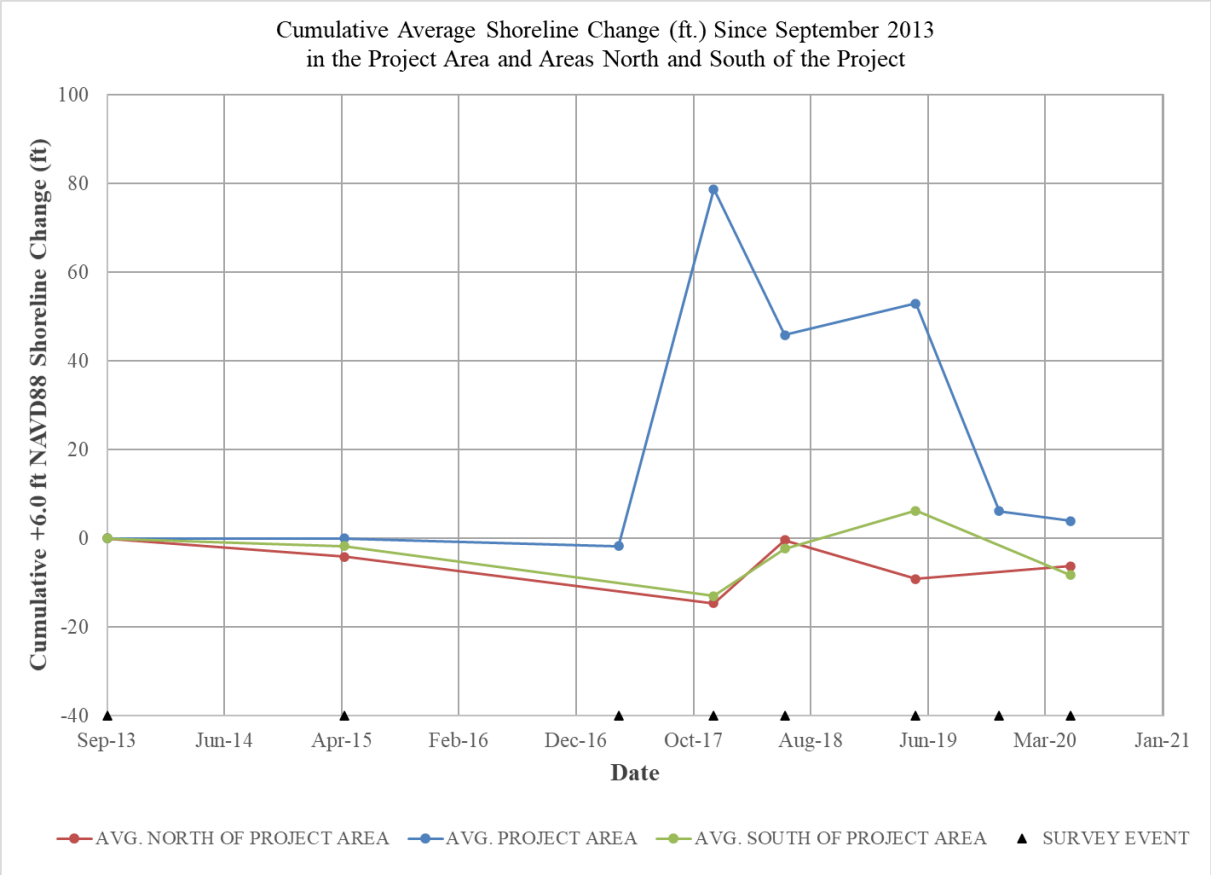

Figure 4. Average cumulative changes in the +6.0 ft. NAVD88 contour position since September 2013 in the Project Area and in the areas north and south of the Project Area.

Areas North and South of Project Area

Area North of Project. The average shoreline change measured along the +6.0 ft. NAVD88 contour between September 2013 and June 2020, north of the beach nourishment project (stations D-01 to D-10), was -6.3 ft. (landward movement). This is equivalent to a rate of -0.9 ft./yr. when annualized over the 6.75-year period. As shown in Figure 4, between September 2013 and December 2017, the Area North of the Project experienced negative shoreline change. Between December 2017 and June 2018, the shoreline position experienced a positive change, and since that time, the +6.0 ft. NAVD88 contour has remained relatively stable on average.

As seen in Table 2, the individual measurements from profile to profile vary considerably. The shoreline change at station D-05 (S Station Bay Dr) has experienced the greatest positive change of +45.6 ft. whereas the greatest negative change of -45.5 ft. was measured at station D-01 (Station 1 Ln).

During the recent survey interval from May 2019 to June 2020, the average shoreline change was 2.8 feet. Although the average change was positive (seaward movement), the measured shoreline change varied throughout the area. In general, the northernmost profiles at stations D-01 and D-02 had an average shoreline change of -34.9 feet (landward). The average shoreline change measured from station D-03 to D-09 (south end of S. Baum Trail to Pelican Way) was +21.7 feet (seaward). Station D-10, located at Skimmer Way, which is considered the boundary between the Project Area and the Area North of Project, experienced the greatest negative (landward) shoreline change between May 2019 and June 2020 (-54.5 feet.)

Area South of Project. The average shoreline change of the +6.0 ft. NAVD88 contour south of the project area (stations D-19 to D-34) between September 2013 and June 2020 was -8.3 ft. (landward movement). This is equivalent to a rate of -1.2 ft./yr. when annualized. As shown in Figure 4, between September 2013 and December 2017, the Area South of the Project experienced negative shoreline change. Between December 2017 and May 2019, the area experienced an average positive shoreline change. However, between May 2019 and June 2020, the average shoreline change has been negative.

As seen in Table 2 and Table 3, the individual measurements from profile to profile vary considerably. The average shoreline change measured from D-19 (northern boundary of FRF property) and D-26 (Cook Dr.) between May 2019 and June 2020 was -35.5 feet. This includes profiles at stations D-21 and D-22, both of which fall within the FRF, which showed shoreline change of -81.0 feet and -64.2 feet, respectively. South of Cook Dr., between stations D-27 (Wampum Dr.) and the southern end of Town (D-34), the average shoreline change between May 2019 and June 2020 was +6.4 feet.

V. VOLUMETRIC CHANGE RESULTS

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.). Volume change rates were evaluated for the periods from September 2013 to May 2015, December 2017 (Post-construction) to June 2020, and May 2019 to June 2020. The September 2013 to May 2015 rates represent trends occurring prior to construction of the project. The December 2017 to June 2020 surveys show changes occurring since the beach nourishment project was completed whereas the May 2019 to June 2020 surveys present the recent volume changes measured between the last two monitoring events.

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 5 graphically depicts the volumetric changes calculated above -24 ft. NAVD88 between September 2013 and June 2020 as well as changes measured from May 2019 to June 2020 and between December 2017 and June 2020.

Initial Beach Fill Volumes

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 stations D-10 and D-19 (APTIM, 2018A). However, the performance of the 2017 project along the Town of Duck is based on changes that occur relative to the conditional monitoring survey conducted in December 2017. For purposes of monitoring 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 (APTIM, 2018B). Based on volume changes computed between the April 2017 and December 2017, a volume change of approximately 963,100 cubic yards were measured on the active profile (above the -24-foot NAVD88 contour) from station D-10 to station D-19 (APTIM, 2018C). For more information on why this method of assessing volume is used, please refer to the 2018 Shoreline and Volume Change Monitoring Report (APTIM, 2018C).

Project Area (D-10 to D-19)

Beach profile monitoring surveys indicate a volume change within the project area of approximately -271,000 cubic yards between December 2017 (Post-construction) and June 2020. This equates to a rate of -12.4 cy/ft./yr. when annualized. **As of June 2020, the analysis indicates that the Town of Duck beach nourishment project had approximately 72% of the initial fill volume remaining as measured above the -24-foot NAVD88 contour.** Figure 6. Figure 6 shows the cumulative volumetric changes for the Town of Duck measured since the initial design survey conducted in September 2013. Cumulative volumetric changes are displayed for the Project Area, North of Project Area and South of Project Area. The large increase in the Project Area curve (blue line) between April 2017 and December 2017 reflects the addition of volume due to the project construction. Since then a relatively linear trend in erosion has been measured from December 2017 to June 2020. Figure 6 also illustrates the volumetric changes between May 2019 and June 2020, specifically the negative volumetric losses attributed to Hurricane Dorian, which impacted the beach in September 2019, and the recovery of the active beach profile between the December 2019 survey and the June 2020 survey.

Table 4. Volumetric Changes (CY/FT./YR.) along Duck above -24 FT NAVD88.

	PROFILE	September 2013 to May 2015 (Baseline Surveys)	December 2017 (Post-Con) to June 2020 (Year-3)	May 2019 (Year-2) to June 2020 (Year-3)
Area North of Project	D-01	-10.5	4.4	22.3
	D-02	0.3	6.2	-17.8
	D-03	-33.2	6.4	33.8
	D-04	-16.0	9.5	22.6
	D-05	-52.4	17.3	56.4
	D-06	-18.3	8.8	-3.7
	D-07	-28.4	8.4	29.0
	D-08	-37.2	4.8	0.8
	D-09	25.1	14.9	30.9
Project Area	D-10	-44.6	2.1	-5.9
	D-11	-69.9	-6.9	-1.0
	D-12	30.3	-5.4	-4.8
	D-13	33.1	-13.6	-31.9
	D-14	1.5	-12.8	16.4
	D-15	12.3	-24.9	-26.8
	D-16	-19.5	-17.8	7.5
	D-17	19.5	-10.5	4.4
	D-18	5.2	-18.9	-2.6
	D-19	-4.4	-15.8	-3.6
Area South of Project	D-20	3.9	-3.7	-3.2
	D-21	27.1	8.1	35.8
	D-22	-9.4	13.9	-1.5
	D-23	67.1	9.1	26.8
	D-24	38.0	-4.6	-6.6
	D-25	-1.1	2.0	28.1
	D-26	-28.2	-5.0	-16.4
	D-27	-30.6	1.1	31.5
	D-28	-10.9	6.7	5.6
	D-29	-55.3	2.0	9.5
	D-30	80.2	-0.7	11.1
	D-31	-7.1	13.0	18.1
	D-32	-2.8	7.4	21.8
	D-33	-12.9	22.0	51.6
	D-34	-35.1	0.8	-20.0
AREA NORTH OF PROJECT (D-01 TO D-10)		-21.5	8.3	16.8
PROJECT AREA (D-10 TO D-19)		-3.7	-12.4	-4.8
AREA SOUTH OF PROJECT (D-19 TO D-34)		1.1	3.5	11.8

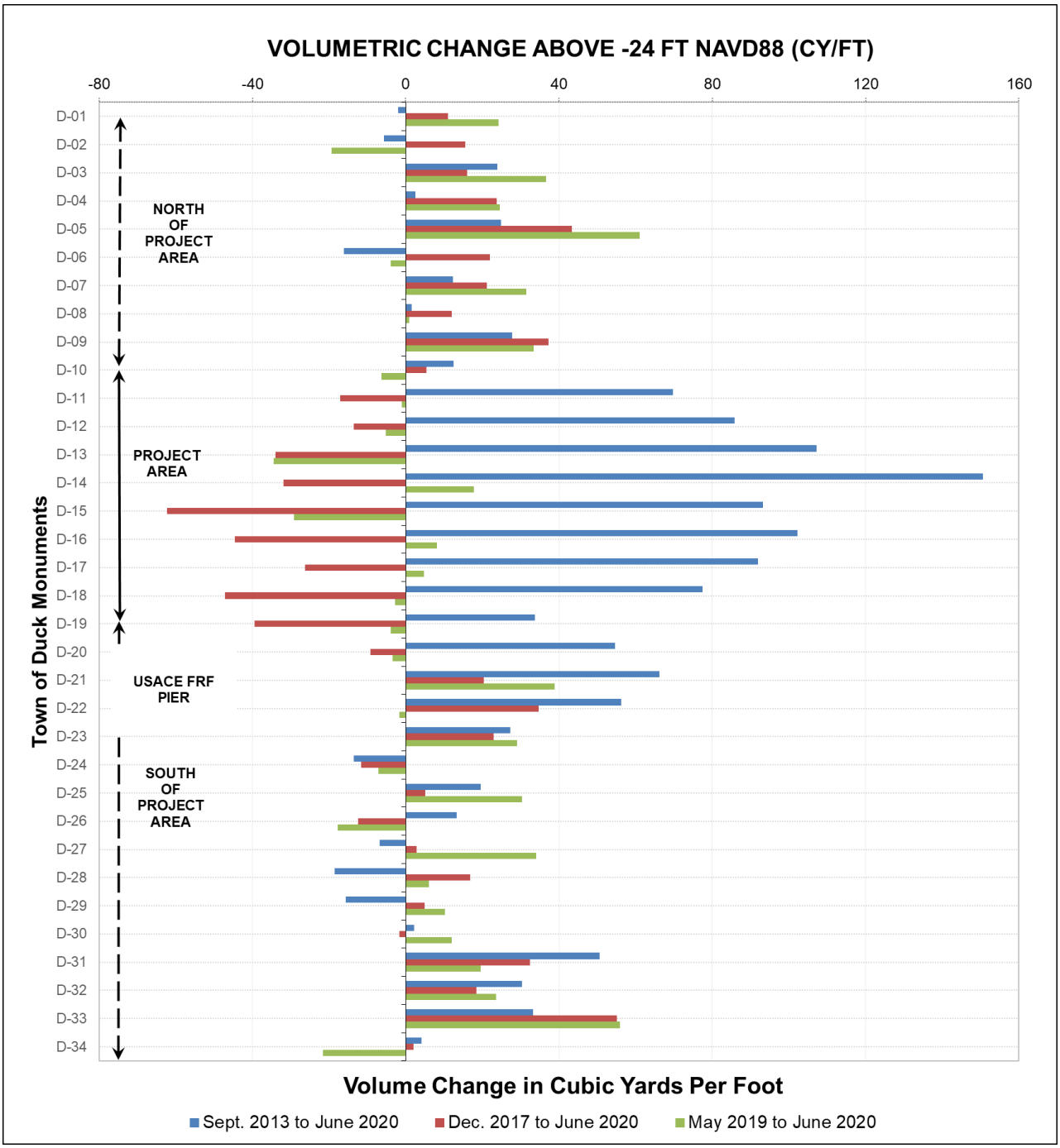

Figure 5. Volume Changes (cubic yards/foot) measured between Sept. 2013 to June 2020, Dec. 2017 to June 2020, and May 2019 to June 2020.

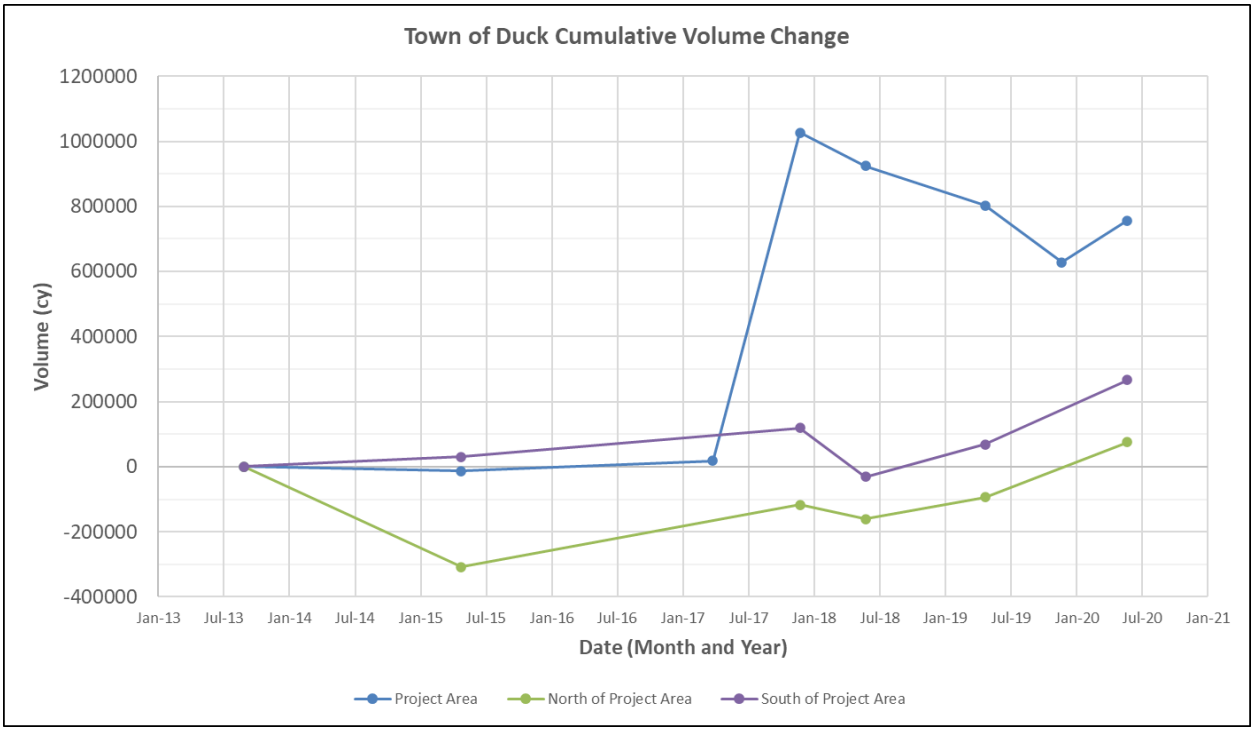

Figure 6. Average cumulative volumetric changes above the -24 ft. NAVD88 contour since September 2013 in the Project Area and in the areas north and south of the Project Area.

The net volumetric change measured from May 2019 to June 2020, was a negative volumetric change of approximately 45,000 cubic yards. This is equivalent to an average loss of approximately -4.8 cy/ft./yr. and equates to approximately 17% of the volumetric change measured between December 2017 and June 2020. The greatest negative volumetric changes were measured along station D-13 (-34.5 cy/ft.), located at Sea Tern Drive E., and station D-15 (-29.1 cy/ft), located along Bufflehead Road between Springtail and Canvasback Drive. The largest positive volumetric change was measured between these two stations at station D-14 (+17.8 cy/ft), located at Diane St. The four southern profiles within the Project Area (D-16 to D-19) measured an average volume change of approximately +1.6 cy/ft. over the 13-month period. Figure 5 illustrates both the individual short-term volumetric change trends along each profile as well as changes that have occurred since December 2017 and September 2013.

Area North of Project (D-01 to D-10). Volumetric changes in the monitoring Area North of the Project, prior to the construction of the beach nourishment project (September 2013 to May 2015), indicated an average volume change rate of -21.5 cy/ft./yr. Since the project was constructed (December 2017 to June 2020), the average volumetric change rate measured within the area North of the Project was +8.3 cy/ft./yr. The recent period between May 2019 to June 2020 (13-months) measured an average gain of 16.8 cy/ft./yr. within the area. In Figure 6, the curve representing the cumulative volumetric changes north of the Project Area (green) shows the relatively steep erosional trend observed between September 2013 and May 2015, prior to the construction of the project. The next data point for the Area North of the Project is the cumulative volume measured in December 2017, which shows an increase in volume between May 2015 and December 2017. It is noteworthy to report that even after the project, the cumulative volumetric change curve shows less volume in the area north of the project than what was present in September 2013. Between December 2017 and June 2018, the Area North of the Project experienced a modest reduction in volume followed by a 2-year period (June 2018 to June 2020) of

volumetric increase. As of June 2020, the Area North of the Project experienced a net positive volumetric change of approximately 80,000 cy compared to the area in September 2013. Since the project was constructed in 2017, the Area North of the Project experienced a positive volumetric change of approximately 190,000 cy.

In the previous monitoring report (APTIM, 2019), the analysis of the changes along the 4,000 ft. of shoreline immediately north of the Project Area between Martin Ln. and Skimmer Way (stations D-06 and D-10) measured a positive volumetric change of 3.5 cy/ft. between June 2018 and May 2019. The more recent volumetric change trend measured between May 2019 and June 2020 show this 4,000 ft. section gained an average 11.1 cy/ft., equivalent to approximately 60,000 cy.

The area along the northern approximately 5,000-foot section of the monitoring area from D-06 through D-01, experienced a positive average volumetric change of 20.5 cy/ft. between May 2019 and June 2020. This equates to a gain of approximately 111,000 cy.

Area South of Project (D-19 to D-34). Volumetric changes in the monitoring Area South of the Project, prior to the construction of the beach nourishment project (September 2013 to May 2015), were relatively stable indicating modest positive volumetric changes at a rate of 1.1 cy/ft./yr. However, a review of the changes from station to station indicates the behavior of the shoreline 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. During the 30-month period from December 2017 to June 2020, since the construction of the beach nourishment project, this area gained an average of 3.5 cy/ft./yr. During the recent 13-month period, from May 2019 to June 2020, this area accreted at an average rate of 11.8 cy/ft./yr. In Figure 6, the curve representing the cumulative volumetric changes south of the Project Area (purple) illustrates the relatively modest accretional trend observed between September 2013 and May 2015, prior to the construction of the project. The next data point for the area South of the Project is the cumulative volume measured in December 2017, which shows an increase in volume between May 2015 and December 2017. Similar to the trend observed in the area North of the Project, between December 2017 and June 2018, the area South of the Project experienced negative volumetric changes followed by a 2-year period (June 2018 to June 2020) of volumetric increase. As of June 2020, the area South of the Project as a whole experienced a net positive volumetric change of approximately 270,000 cy compared to the area in September 2013. Since the project was constructed in 2017, the area South of the Project experienced a positive volumetric change of approximately 150,000 cy.

During the recent survey interval from May 2019 to June 2020, the 3,000-foot section south of the Project, between stations D-20 and D-23, gained an average of 14.5 cy/ft./yr. An examination of volume changes measured station to station shows the highest volumetric gains of 35.8 cy/ft./yr. and 51.6 cy/ft./yr. at stations D-21 and D-33, respectively while stations D-26 and D-34 to the south exhibited the greatest negative volumetric changes of 16.4 cy/ft./yr. and 20.0 cy/ft./yr., respectively (Table 4). Figure 5 illustrates both the individual short-term volumetric change trends along each profile as well as changes that have occurred since December 2017 and September 2013.

VI. DISCUSSION

This monitoring report evaluated shoreline and volumetric changes along the portions of shoreline nourished in 2017 within the Town of Duck as well as portions of the adjacent shorelines to the north and south. The monitoring area extends south from station D-01, located at the northern limits of the Town of Duck, to 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 (D-01 to D-10), and the Area South of the Project (D-19 to D-34). Data collected in June 2020 was used to evaluate shoreline and volumetric changes that have occurred since the baseline survey was conducted in 2013, since the construction of the 2017 beach nourishment project, and over the past year between the 2019 and 2020 monitoring surveys.

Shoreline Change Analysis:

Project Area. Surveys conducted in April 2017 and December 2017 indicated that the beach fill effectively relocated the +6.0 ft NAVD88 contour an average of +89.5 feet seaward (from D-10 to D-18). D-19 was not surveyed during the April 2017 pre-construction survey and therefore, is not included in the project average. The construction of the project widened the beach considerably more; however, since the project was completed in June 2020 and the post-construction survey was conducted in 2017, the project experienced considerable equilibration over that time and therefore the December 2017 +6.0 ft. design contour is assumed to be equilibrated. The average shoreline change measured within the Project Area from December 2017 to June 2020 along the same section of the project from D-10 to D18 was -81.6. As shown in Figure 7, in some areas, particularly along the northern part of the project from 140 Skimmer Way (D-10) to Sound Sea Ave. (D-12) the current +6.0 ft. contour is landward of the pre-project (April 2017) +6.0 ft. NAVD88 contour. Along the southern portion of the project, where the pre-project condition was most severely eroded, the +6.0 ft. NAVD88 contour is still seaward of the pre-project condition. The average shoreline change rate along the project area measured between December 2017 and June 2020 was -29.9 ft./yr. However, over the 13-month period between May 2019 and June 2020 the rate was -45.2 ft/yr.

Much of the negative change in the +6.0 ft. contour is attributed to the impacts of Hurricane Dorian, which impacted the project in September 2019. Between May 2019 and December 2019 (Post-Storm Survey) the +6.0 ft. contour retreated an average of 46.8 ft. Between December 2019 (Post-Storm Survey) and the June 2020 survey, the +6.0 ft. NAVD88 Contour moved an average of -2.2 ft. (landward). In comparison, the MHW contour, which is at +1.18 ft. NAVD88 experienced negative shoreline change on average in the project area of -13.1 ft., between May 2019 and December 2019; whereas over the next 6 months from December 2019 to June 2020 the average shoreline change for the MHW contour advanced seaward 10.5 ft., indicating some recovery. This pattern is typical of beach response to storms. The migration of sand from the MHW contour offshore during a storm followed by recovery of the MHW contour following a storm is well documented. If the storm is large enough to impact the upper part of the profile, in this case the +6.0 ft. contour, it is more difficult for the upper beach to recover quickly as the processes that move sand from the nearshore up the foreshore and allow for recovery along the MHW line, do not move sediments so far up the profile to allow for recovery of the +6.0 ft. contour.

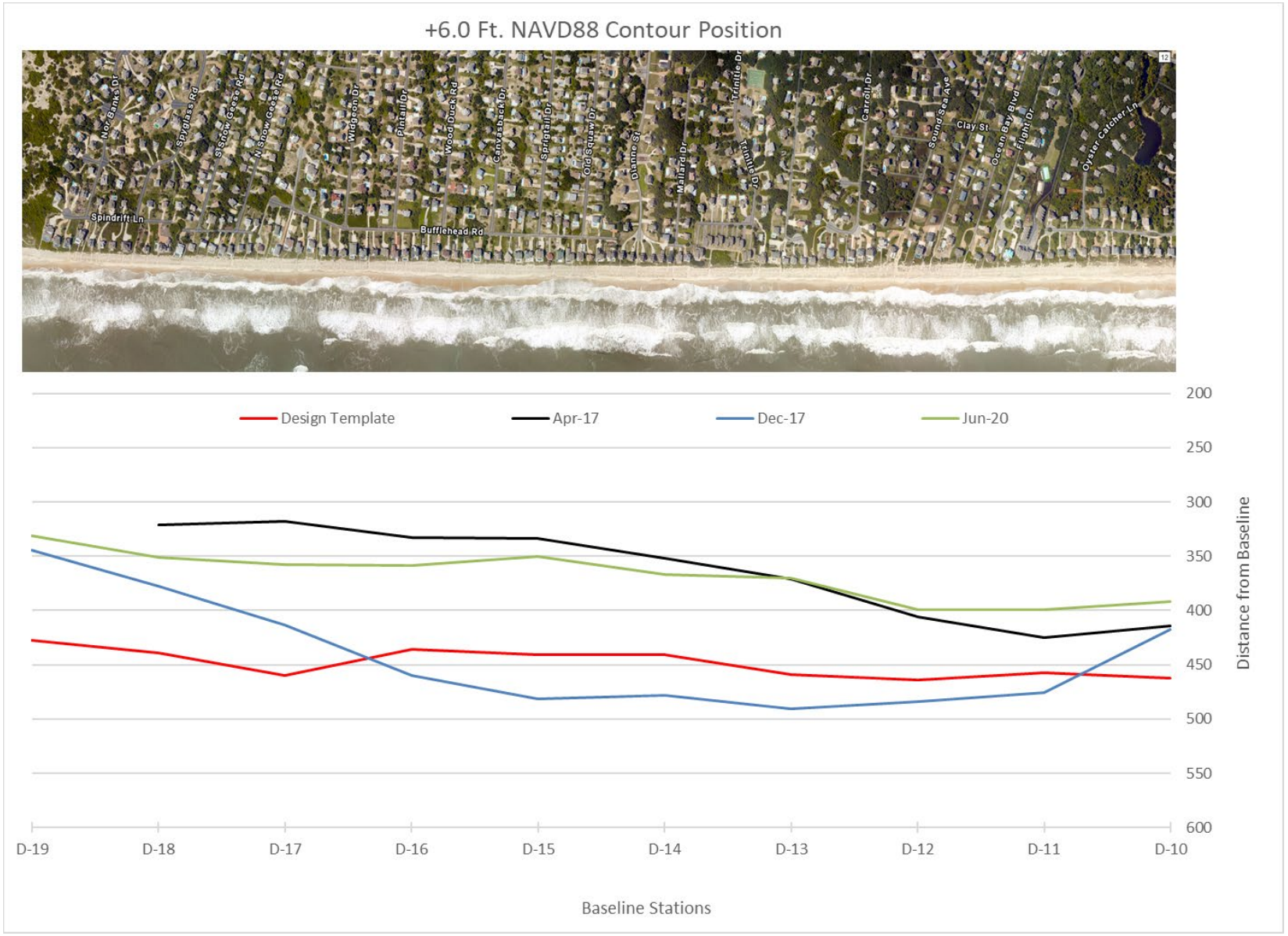

Figure 7. +6.0 ft. NAVD88 contour position throughout the Project Area compared to the +6.0 ft. NAVD88 contour for the project design.

The average position of the +6.0 ft. NAVD88 shoreline is only 3.9 ft. seaward of the September 2013 baseline survey as of June 2020. In comparison, the average MHW shoreline position is 51.0 ft. seaward of the September 2013 baseline position suggesting the beach slope is considerably less steep than it was in September 2013. As discussed in the previous paragraphs, the steepness of the beach is influenced by storm events, but it is also influenced by the grain size of the sand. When the beach fill project was constructed, the material used to construct the southern 2,500 feet of the project came from a combination of sand from Borrow Area A and C at a ratio of 2 loads from A for every 1 load from C; whereas, the material used to construct the rest of the project to the north all came from Borrow Area C. The mean grain sizes of the sand in Borrow Areas A and C were determined to have an average mean grain size of 0.36 mm and 0.26 mm, respectively (CPE-NC, 2015B). The fact that Borrow Area C was known to be finer than Borrow Area A and finer than the native beach led to the directive that additional sand was required to be placed along sections constructed with sand from Borrow Area C alone. Samples taken along the beach following construction of the project showed the average mean grain size of the samples collected in areas constructed with material from Borrow Area A had a mean grain size of approximately 0.39 mm, compared to the mean grain size of samples collected along the portion of the project constructed with material from Borrow Area C, which had a mean grain size of 0.29 mm. This data may help explain some of the beach fill performance and should be evaluated in the design of the next renourishment project.

Area North of the Project. The average long-term shoreline changes computed along the Area North of the Project (D-01 to D-10), was -6.3 ft (landward movement), between September 2013 and June 2020. This time period includes the construction of the beach nourishment project. This is equivalent to a rate of -0.9 ft/yr. The average rate between D-01, located near the northern Town Boundary and D-04, located at the Sanderling Resort, was -4.2 ft./yr. (landward movement); whereas the average long-term shoreline change from the Sanderling south to the Project Area (D-04 to D-10) was a positive 0.7 ft./yr. (seaward movement).

Recent surveys (May 2019 and June 2020) indicate an overall average change in the +6.0 ft. NAVD88 contour of +2.8 ft. (Seaward). However, there is a clear distinction between the trend directly north of the project from the Project Area (D-10) to D-04, located at the Sanderling Resort, and the portion of the Town's beach north of the Sanderling Resort. The average change in the +6.0 ft. contour position from D-10 to D-04 was +12.2 ft. (seaward), and from D-04 to D-01 the average change was -16.1 ft. (landward).

Area South of the Project. Long-term shoreline changes computed between September 2013 and June 2020, which includes the construction of the beach nourishment project, averaged -8.3 ft. (landward movement), equivalent to a rate of -1.2 ft/yr. However, one section of the shoreline located between Plover Dr. and Bias Ln E. (stations D-31 and D-33) has experienced a positive trend of seaward movement, with an average shoreline change of +10.5 ft., or a rate of +1.6 ft./yr. when annualized.

Recent surveys (May 2019 and June 2020) indicate an overall average change in the +6.0 ft. NAVD88 contour of -14.5 ft. However, there is a clear distinction between the trend directly south of the project from the northern boundary of the FRF property (D-19) to Sea Colony Drive (D-25), and the trend from Sea Colony Drive (D-25) south to the Town southern boundary (D-34). In the area directly south of the project, the average change was -35.7 ft. over the approximate 13-month period from May 2019 to June 2020. In contrast, the average shoreline change measured from Sea Colony Drive south was +3.0 ft. Within this area, the +6.0 ft. NAVD88 contour between the end of Christopher Dr. (D-29) and Bias Ln. E. (D-33) experienced a seaward movement of +12.1 ft. on average.

Volumetric Change Analysis:

Project Area Beach profile surveys indicate that during the most recent survey interval (May 2019 to June 2020), a volumetric loss of approximately 45,000 cubic yards was measured. The highest losses occurred between Ocean Pines Dr. and Dianne St. (D-12 to D-15). Since the completion of Town of Duck beach nourishment project, the Project Area has lost a total of 271,000 cubic yards (December 2017 to June 2020). This equates to approximately 28% of the fill measured in the Project Area in December 2017. As of June 2020, the analysis indicates that the Town of Duck beach nourishment project had 72% of the initial fill volume remaining as measured above the -24-foot NAVD88 contour.

As discussed in the Shoreline Change portion of this Section, survey data suggests the slope of the beach between the design berm contour of +6.0 ft. NAVD88 and the MHW contour has flattened over the life to the project. This appears to be more pronounced in the northern portion of the project constructed with sand from Borrow Area C. This flattening of the beach appears to have occurred as the +6.0 ft. contour retreated landward while the MHW line moved slightly seaward. The +6.0 ft. contour position at every profile within the project area is landward of the designed berm position. In other words, in terms of the design berm, the project has eroded back into the project design at the berm elevation. In fact, on average, the +6.0 ft. contour is approximately 81.0 ft. landward of where it was designed to be between D-10 and D-19. That said, as mentioned above, approximately 72% of the material placed along the project area as measured in December 2017 is still located within the project area. This suggests that a considerable amount of sand is being stored in the offshore portion of the profile. This may be a function of the mean grain size of the material used to build the northern 5,700 feet of the project being of relatively finer grain size than the pre-project beach mean grain size. This is something that is being evaluated as part of the design of the proposed 2022 renourishment project.

The portion of the project remaining in place continues to provide vital storm protection to the Town as well as recreational benefits. CPE is continuing to evaluate project performance and adapt to conditions that are better understood through the evaluation of the project monitoring data. More information on this topic is provided in the Recommendations Section.

Area North of the Project The long-term average volumetric change rate in the area North of the Project, measured between September 2013 and June 2020, was +1.2 cy/ft./yr. Individual rates range from -2.4 cy/ft./yr. at station D-06 near Martin Lane to +4.1 cy/ft./yr. at station D-09 located at the south end of Pelican Way.

Since the project was constructed, the average volumetric change in the Area North of the Project was +8.3 cy/ft./yr. This is significantly higher than the long-term average of +1.2 cy/ft./yr. This rate is also significantly higher than the rate documented in the 2019 Monitoring report for the period from December 2017 to May 2019, which was +1.7 cy/ft./yr. (APTIM, 2019). This is reflective of the recent positive volumetric change measured between May 2019 and June 2020. The average volumetric change along this area over that 13-month period was 18.2 cy/ft. or 16.8 cy/ft./yr. Some of these gains to the area North of the Project over this 13-month period may be related to volumetric losses to the project attributed to Hurricane Dorian (CPE, 2020). For instance, the 4,000-foot area immediately north of the Project Area between Martin Ln. and Skimmer Way had a positive volumetric change of +11.1 cy/ft., equivalent to approximately 60,000 cy. However, some of the highest volumetric gains measured on individual profiles occurred over a mile north of the project area, which may be associated with other coastal processes.

Area South of the Project The long-term average volumetric change rate in the area south of the project, measured between September 2013 and June 2020, was +3.1 cy/ft./yr. Individual rates range from -2.8 cy/ft./yr. at station D-28 at the end of Duck Landing Lane to +9.8 cy/ft./yr. at station D-21 located directly north of the Field Research Facility Pier (Figure 5).

Since the project was constructed (Dec. 2017 to June 2020), the average volumetric change south of the project area was +3.5 cy/ft./yr. This is comparable to the long-term average of +3.1 cy/ft./yr. calculated from Sept. 2013 to June 2020. However, this is a reversal of the post-project volumetric change rate reported along the area South of the Project between December 2017 and May 2019 (-2.8 cy/ft./yr.) (APTIM, 2019). The reversal in the post-project trend is due to significant positive volumetric changes measured between May 2019 and June 2020, which can be seen in Figure 5. The average volumetric change along this area over that 13-month period was 12.8 cy/ft. or 11.8 cy/ft./yr. Some of these gains to the Area South of the Project over this 13-month period may be related to volumetric losses to the project attributed to Hurricane Dorian (CPE, 2020). For instance, the 3,000-foot area immediately south of the Project Area along the FRF property (D-19 to D-23) had a positive volumetric change of +10.9 cy/ft., equivalent to approximately 38,000 cy. However, some of the highest volumetric gains measured on individual profiles occurred over a mile south of the project area, which may be associated with other coastal processes.

When comparing the December 2017 survey to June 2020, there does not appear to be a significant increase of volume to the area directly south of the project as is typically observed adjacent to beach nourishment projects. With the relatively short beach fill project constructed along the Town of Duck, combined with the fact that the project did not include a typical taper section to the South, due to restrictions on placing material along the FRF, one might expect end losses and volumetric gains to the area south of the project to be even more obvious along this project.

In June 2018, an anomalous wide and deep trough was identified just offshore at station D-21. The volumetric change measured at station D-21 between December 2017 and June 2018 was a negative 55.4 cy/ft. Between June 2018 and May 2019, a positive volumetric change of 36.9 cy/ft. was measured along D-21; however, the net volumetric change that occurred between December 2017 and May 2019 was still negative. Most recently, between May 2019 and June 2020, a positive volumetric change of 38.8 cy/ft was measured along D-21, bringing the net volumetric change measured since December 2017 at station D-21 to a +20.4 cy/ft. This is significant, because. The development of the anomalous trough offshore of D-21 shortly after the construction of the project may have obscured the volumetric gains experienced along the area directly south of the project related to the spreading of the beach fill.

VII. RECOMMENDATIONS

CPE recommends the Town continue to monitor the beach along the entire Town oceanfront in order to assess long-term shoreline and volumetric changes. Within the Project Area, the continued annual monitoring not only provides a pre-storm condition survey that can be used to estimate storm damages as was the case following the impact of Hurricane Dorian, but it also allows for the continued assessment of volume trends, which are being used to design the renourishment project, currently proposed for 2022. Outside the Project Area, continued monitoring is instrumental for the Town to evaluate future areas of concerns and longshore transport trends, and to develop successful shoreline management strategies to deal with issues as they arise.

Since construction of the project in 2017, the volumetric trend along the Town's beaches has been positive change (accretion) both north of and south of the Project Area. It is not uncommon to see positive volumetric changes adjacent to a beach nourishment project due to the spreading of material that serves to feed the adjacent beaches. However, some of the volumetric changes appear to be occurring outside the expected influence of the project and may be caused by other coastal processes. Continued monitoring of the areas outside the project will detect any changes in this trend, which may render other portions of the Town vulnerable.

The monitoring program serves as the basis for determining how frequently additional nourishment is needed and how much volume is required to maintain the project design over the long term. In this regard, initial monitoring of the project over the first 3 years following construction indicates a volumetric change rate higher than estimated in the initial project design, which may be related to a number of factors. The Town's maintenance plan calls for an estimated nourishment fill density of approximately 30 cy/ft., every 5 years, which translates to an annual average loss of approximately 6 cy/ft. The actual rate of volumetric change measured since 2017, in the first three years pos-construction, has been 12.4 cy/ft., which is twice the rate programed in the beach management plan. It must be considered, however, that the loss of material from a beach nourishment project typically does not occur in a linear pattern; rather the trend is to observe higher losses immediately following construction of the project followed by a tapering off of rates over time as the project equilibrates with the surroundings and fill diffusion losses decrease. Given the 2017 project was the initial construction of the Town's project and beach profile data along the Project Area was limited prior to the construction of the 2017 project, the monitoring program is revealing the true erosion rate. The true erosion rate is influenced by the construction of the project itself, recent impacts of storms, alongshore variability, and other factors that may be contributing to the erosion rate beyond the initial estimate.

While the post-project volumetric change rate may decrease over the next two years, prior to the 2022 project, the Town may need to place additional material on the project in excess of the 30 cy/ft. fill density prescribed in the beach maintenance plan to re-establish and maintain the present design objectives. CPE is currently working on updating these numbers as part of the design of the 2022 project, which can be re-evaluated as additional monitoring data become available.

Following the impact of Hurricane Dorian on the project, the Town contracted with CPE to conduct post-storm surveys to determine storm impacts. CPE completed a volume analysis and design report stating that Hurricane Dorian caused the loss of approximately 170,800 cy of sand (~20 cy/ft.) that should be eligible for FEMA Public Assistance funding. While CPE is working on updating the design for the 2022 project to account for the higher observed erosion rates as discussed previously, it is recommended that the Town plan to at least replace the 170,800 cy of material lost as a result of Hurricane Dorian in addition to the programed placement of 254,000 cy of sand. In the report prepared for FEMA, CPE estimated the additional cost to replace the 170,800 cy of sand to be approximately $2,972,000 (CPE. 2020).

VIII. REFERENCES

APTIM, 2020. Aptim Coastal Planning & Engineering of North Carolina, Inc., *Town of Duck Shore Protection Project Beach Maintenance Plan*. Prepared for Town of Duck. Wilmington, NC.

APTIM, 2018B. Aptim Coastal Planning & Engineering of North Carolina, Inc., *Town of Duck North Carolina 2017 Shoreline & Volume Change Monitoring Report.* Prepared for Town of Duck. Wilmington, NC.

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

CPE, 2020. Coastal Protection Engineering of North Carolina, Inc. Post-Storm Design Report: Hurricane Dorian Town of Duck Shore Protection Project Repair Dare County, NC. Prepared for Town of Duck. Wilmington, NC.

CPE-NC, 2015B. Coastal Planning & Engineering of North Carolina, Inc., *Comprehensive Marine Sand Search and Borrow Areas Design Report.* Prepared for the Towns of Duck, Kitty Hawk, and Kill Devil Hills. Wilmington, NC.

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

APPENDIX A

2020 TOWN OF DUCK TOPOGRAPHIC AND HYDROGRAPHIC SURVEY REPORT

2020 Town of Duck
Topographic and Hydrographic Survey Report

Prepared for:

Town of Duck

Prepared by:

Aptim Environmental & Infrastructure, LLC
2481 N.W. Boca Raton Blvd.
Boca Raton, FL 33431

July 2020

APTIM

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List of Appendices

ABSTRACT

Aptim Environmental & Infrastructure, LLC (APTIM) was contracted by Duck, North Carolina to provide a topographic and hydrographic survey. The 2020 topographic and hydrographic survey consisted of thirty-four (34) profile stations spanning across the Town of Duck, NC. APTIM surveyors conducted the beach and hydrographic surveys from June 7, 2020 through June 25, 2020.

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. 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 is expected to occur.

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 Topographic and Hydrographic 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** (digital format only). 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 within a virtual reference station (VRS) network to locate and confirm survey control for this project. The North Carolina Geodetic Survey Continuously Operating Reference Station (CORS) Network stations used for this project included NCDU (Duck 3), NCBI (Bodie Island), NCBX (Buxton), NCEL (Elizabeth), and NCCR (Creswell). 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 2nd order monuments, specifically WAY, KITTY, CAFFEY, X254, and

Y254 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 2nd 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 2nd 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.

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 and R10 RTK GPS rovers 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 250 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.* S*takeout point* allows surveyors to maintain the profile azimuth without relying on a 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 200kHz with an Odom Hydrotrac II single frequency sounder connected to a centrally located, hull-mounted transducer on APTIM's twenty-eight (28) foot Parker survey vessel. These soundings were then reduced to 25' spacing, sufficient to provide an accurate depiction of the seafloor.

Data was digitally stored using HYPACK 2020 Software. A Trimble R8 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 2020 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 2020 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 two (2) weeks 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 2020, 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 2020'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.

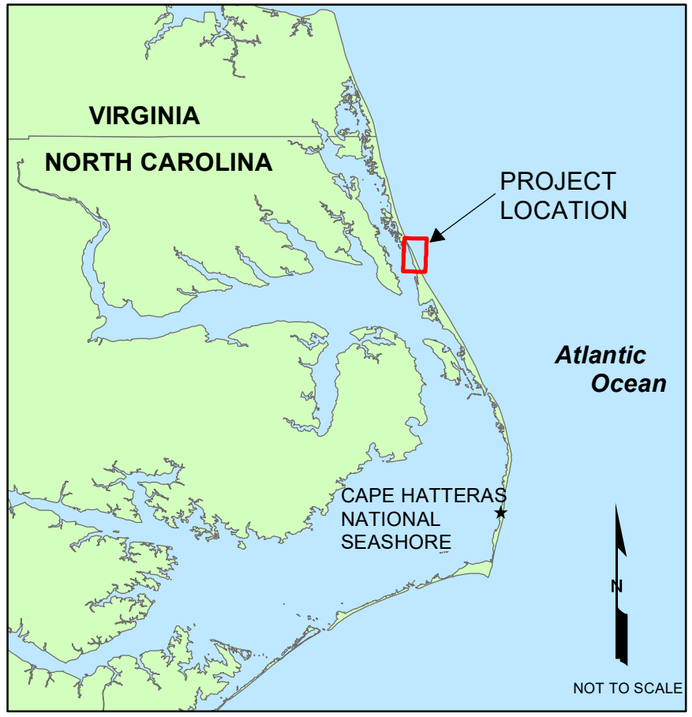
Map Preparation:

Upon completion of the surveys and data reduction, the survey maps were prepared in ArcGIS 10.7.1. In order to avoid congestion, the survey maps do not show all 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 Esri's background aerial imagery from March, 2018.

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.

2020 TOWN OF DUCK
TOPOGRAPHIC AND HYDROGRAPHIC SURVEY REPORT



INDEX TO SHEETS

TOWN OF DUCK STATION INFORMATION JUNE 2020			
DATUMS: NAD83(2011) / NAVD88 (U.S. SURVEY FEET)			
STATION	NORTHING	EASTING	AZIMUTH
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
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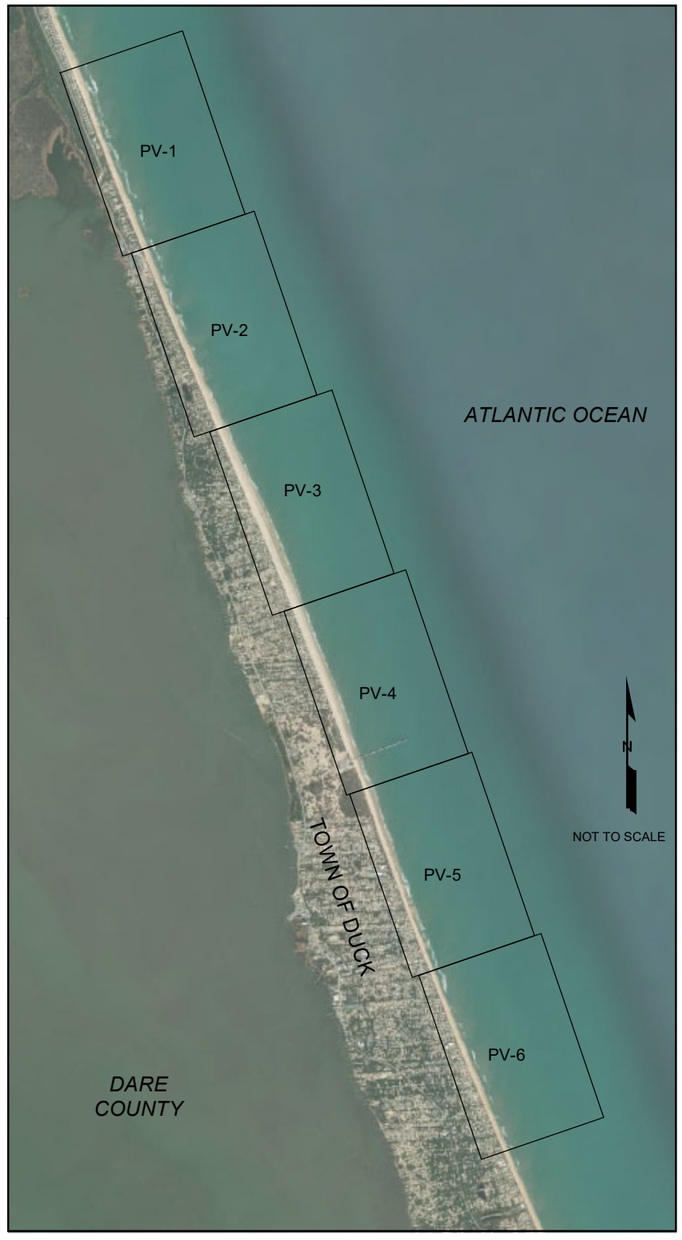
D-32	891379.40	2962078.10	70.00
D-33	890553.20	2962439.40	70.00
D-34	889616.10	2962839.60	70.00

TOWN OF DUCK A-MON CONTROL			
MONUMENT	NORTHING	EASTING	M. ELEV.
CAFFEY	915308.87	2952084.11	1.99
KITTY	859358.84	2977204.86	9.17
WAY	924642.81	2948590.66	4.88
X 254	876428.61	2968761.03	9.93
Y 254	880716.27	2966184.93	12.15

LEGEND

⊕	PROFILE STATION
⊞	CONTROL MONUMENT
PV	PLAN VIEW
CS	COVER SHEET
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
LLC	LIMITED LIABILITY COMPANY
Dr	DRIVE
BLVD	BOULEVARD
Ln	LANE



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No.	Description	Date

Designed by: M. Lowiec
Drawn by: T. Shahan
Date: July 2020
Plot Scale: AS NOTED
Checked by: M. Lowiec
Reviewed by: R. Hart
Submitted by: M. Lowiec
Comm. No.: 631014677

Reference Files:

2020 TOWN OF DUCK
TOPOGRAPHIC AND HYDROGRAPHIC
SURVEY REPORT

COVER SHEET

DRAWING NO.

CS

SHEET 1 OF 7

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NOTES:

1. DATES OF SURVEY: JUNE 7, 2020 - JUNE 25, 2020
2. COORDINATES SHOWN ARE IN FEET BASED ON THE NORTH CAROLINA STATE PLANE COORDINATE SYSTEM, ZONE 3200 NORTH AMERICAN DATUM 1983/2011 (NAD83/2011).
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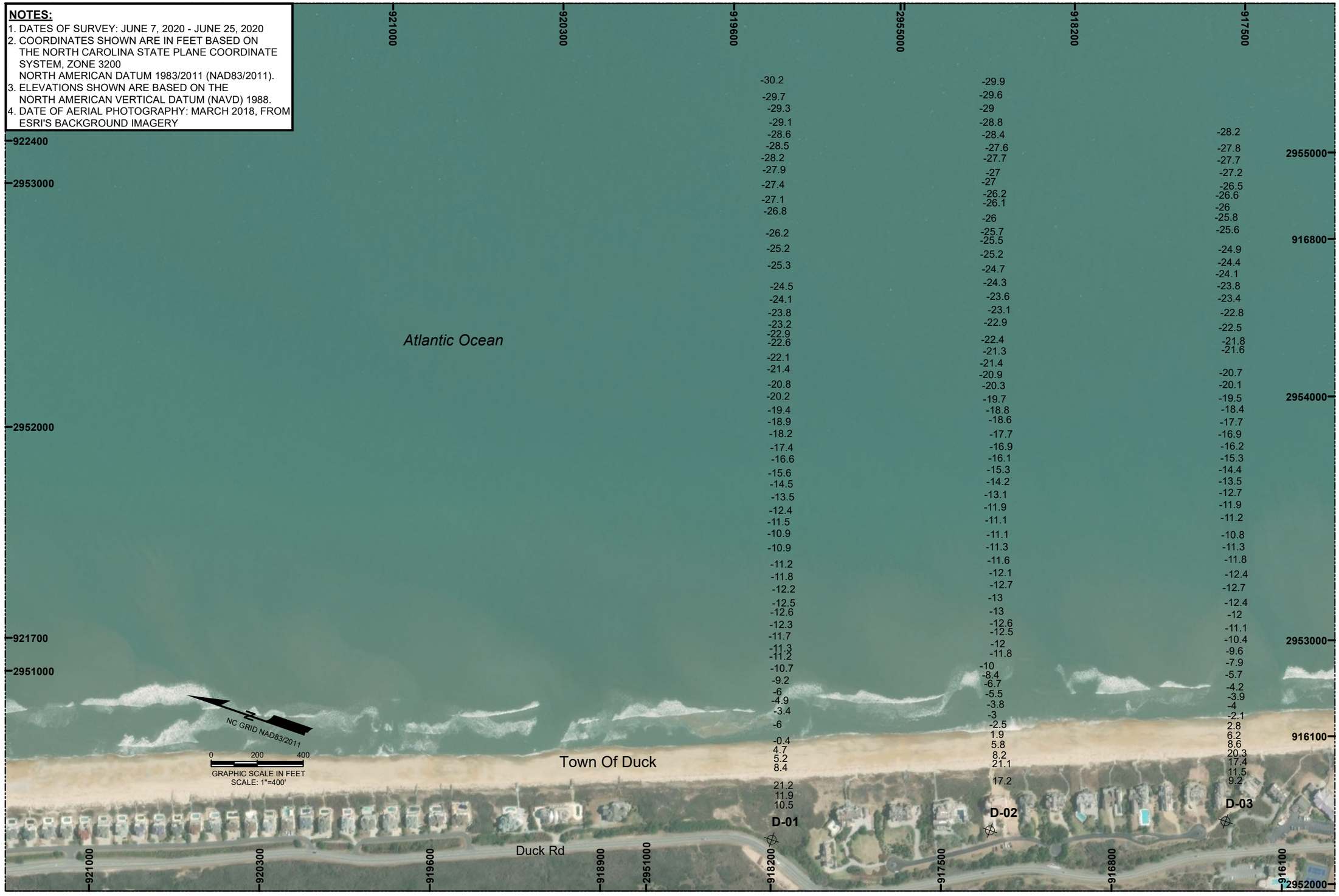

MATCHLINE SHEET 3 OF 7

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2020 TOWN OF DUCK
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PLAN VIEW

DRAWING NO.

PV-1

SHEET 2 OF 7

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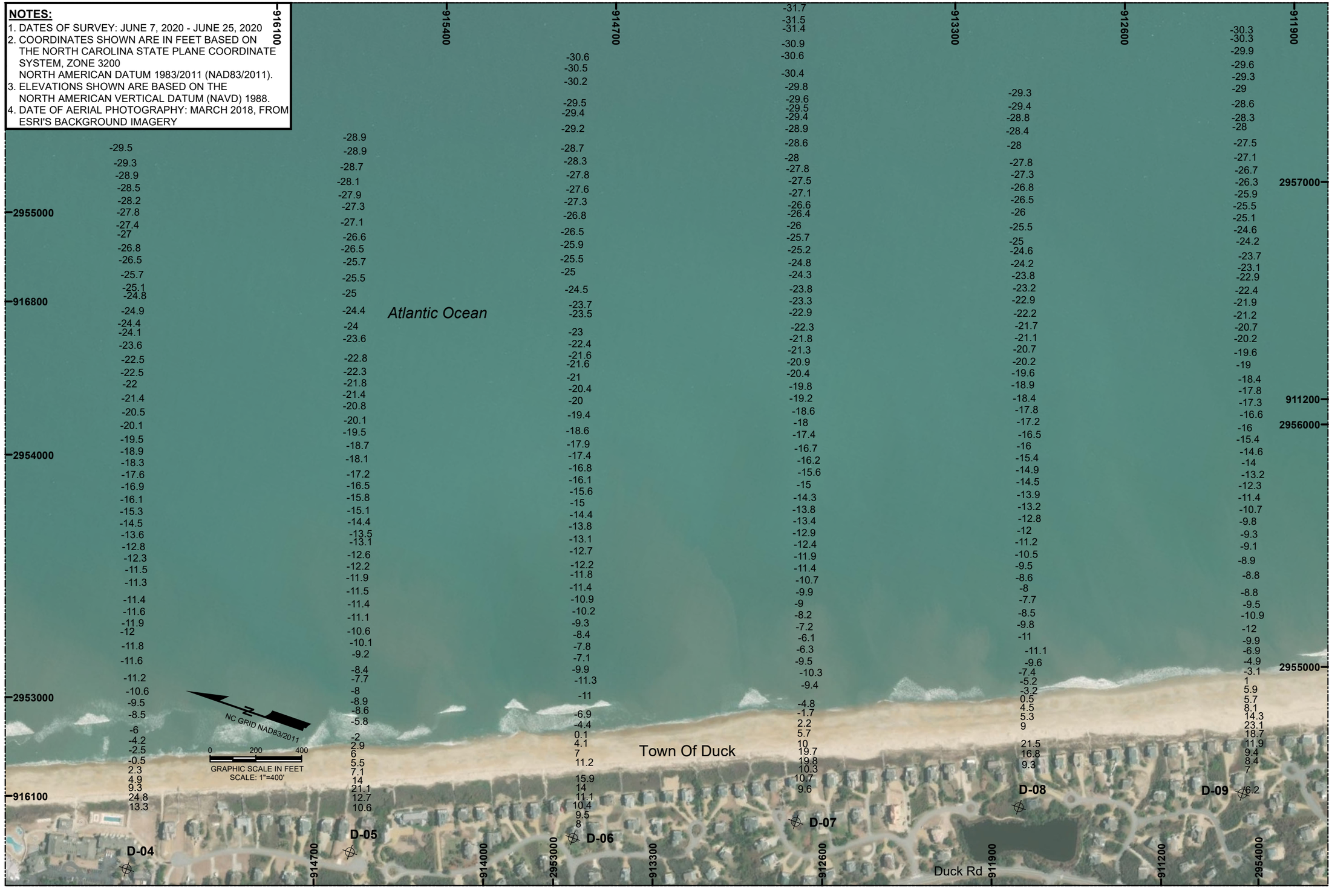

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TOPOGRAPHIC AND HYDROGRAPHIC
SURVEY REPORT

PLAN VIEW

DRAWING NO.

PV-2

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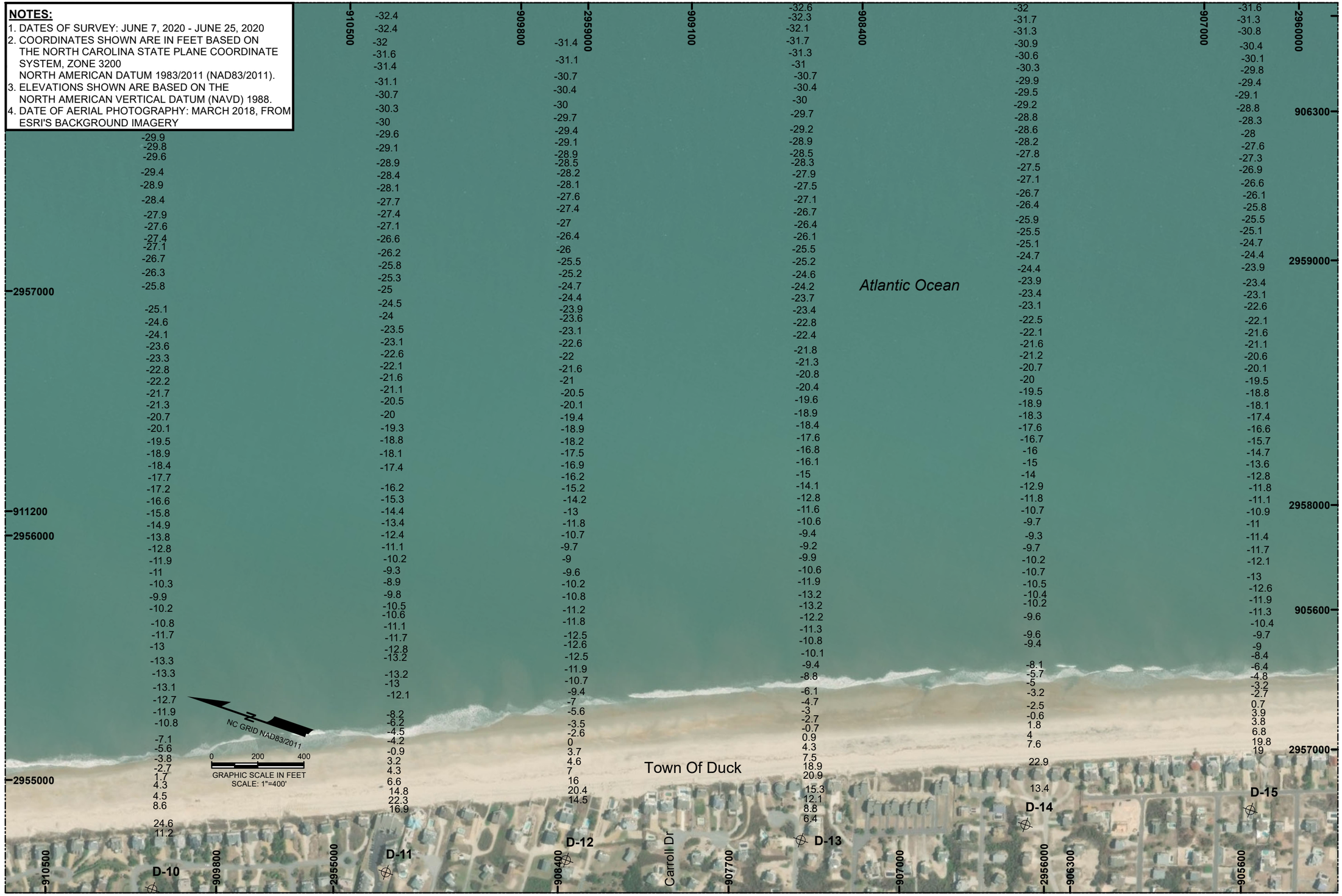

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PV-3

SHEET 4 OF 7

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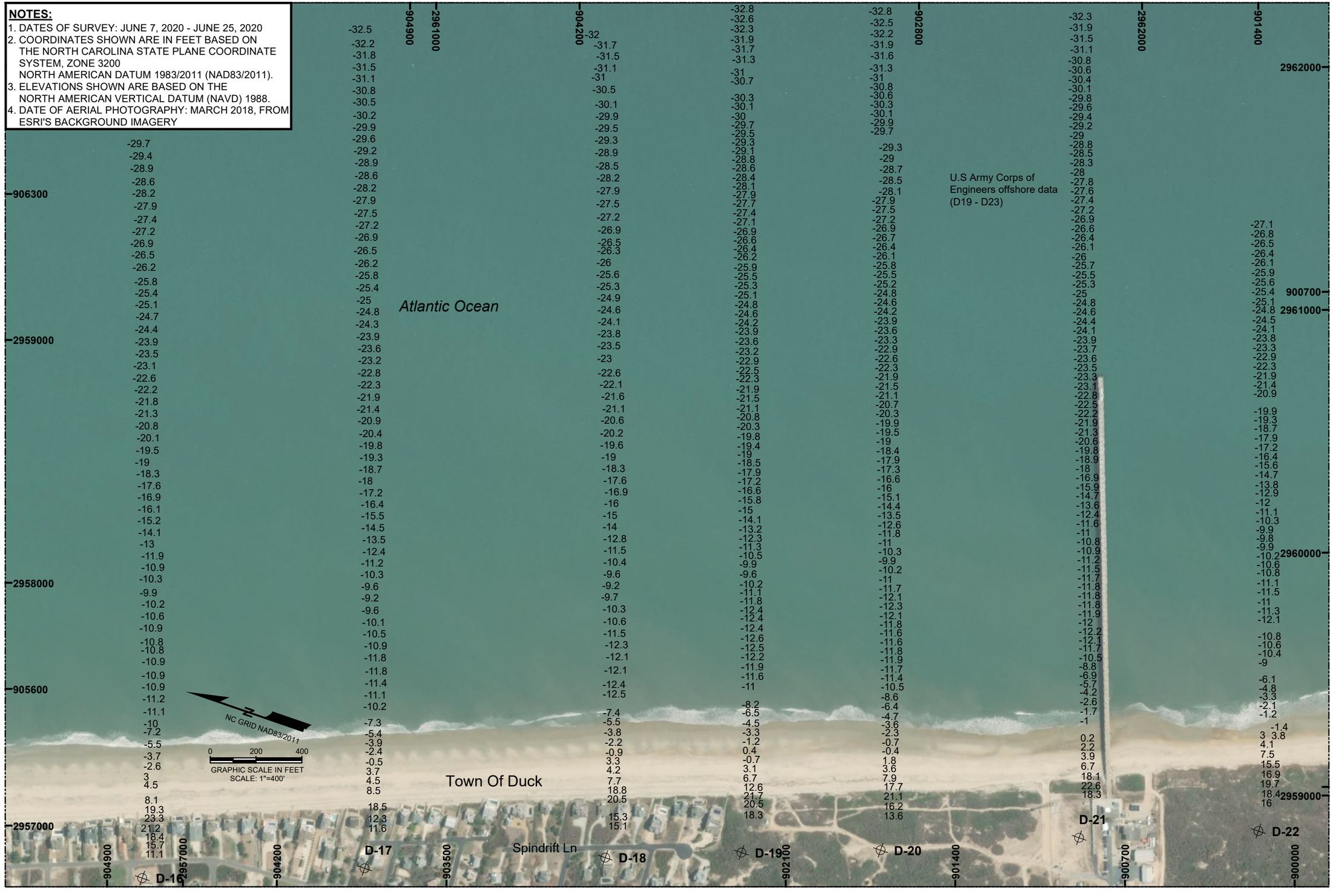

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PLAN VIEW

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PV-4

SHEET 5 OF 7

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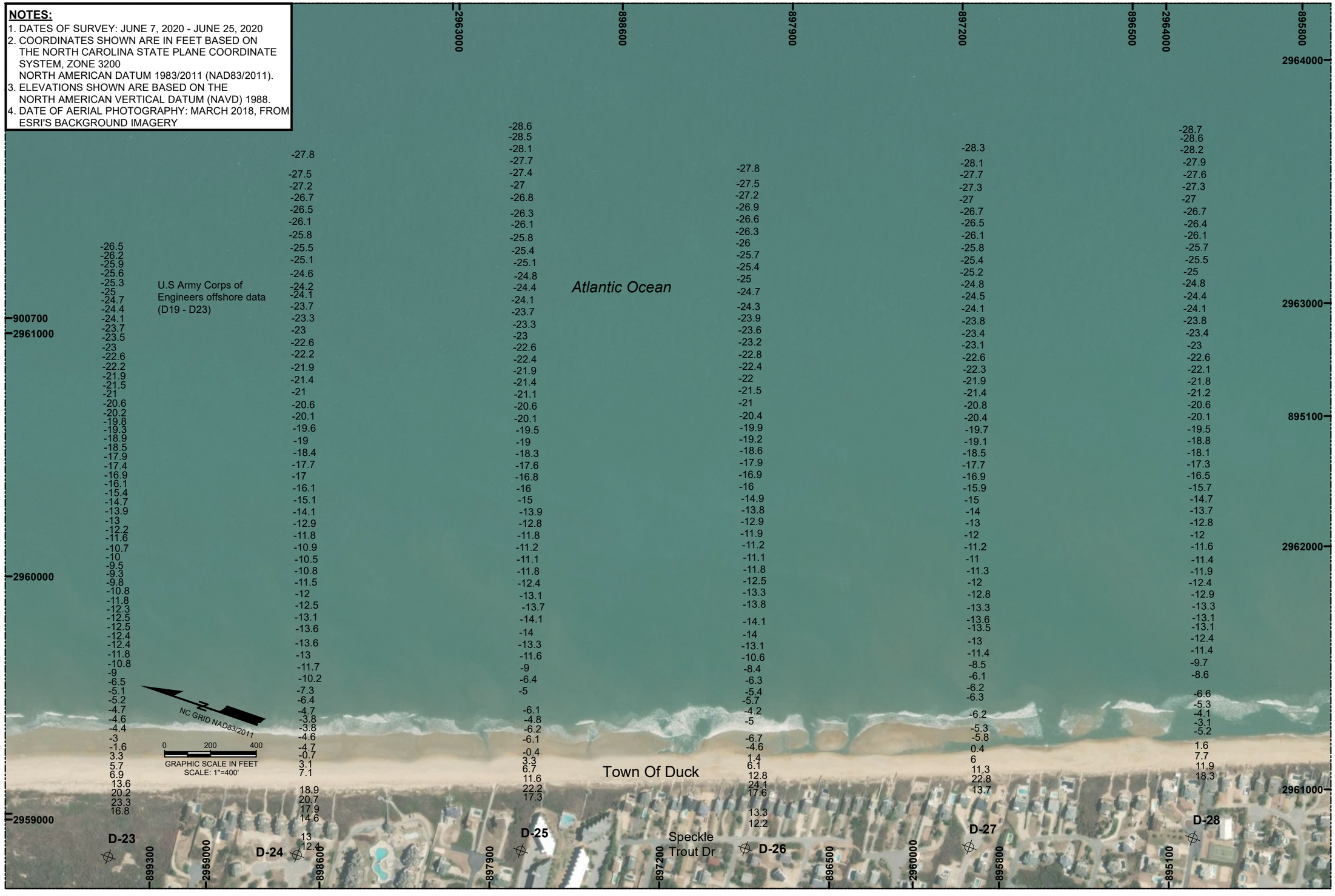

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PLAN VIEW

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PV-5

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MATCHLINE SHEET 6 OF 7

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2020 TOWN OF DUCK
TOPOGRAPHIC AND HYDROGRAPHIC
SURVEY REPORT

PLAN VIEW

DRAWING NO.

PV-6

SHEET 7 OF 7

Survey Report Notes

Survey Title:	2020 Town of Duck Topographic and Hydrographic Survey Report
Prepared Date:	July 2020
Prepared For:	Duck, NC
Prepared By:	Aptim Environmental & Infrastructure, LLC
Dates of Survey:	June 7, 2020 through June 25, 2020
Survey Location:	Town of Duck D-01 through D-34

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 KITTY, WAY, CAFFEY, X254, and Y254 per published NGS coordinates.

5. Bearings are based on a bearing of South 24° 10’ 46” East between NGS second order monuments KITTY and CAFFEY 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 No. 520 and NC field book No. 252 for swims and the onshore portion, and navigation book No. 57 for the offshore portion.

8. Aids to navigation were not located during this survey.

9. Soundings were collected using an Odom Hydrotrac II, 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 the 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, entered in 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.

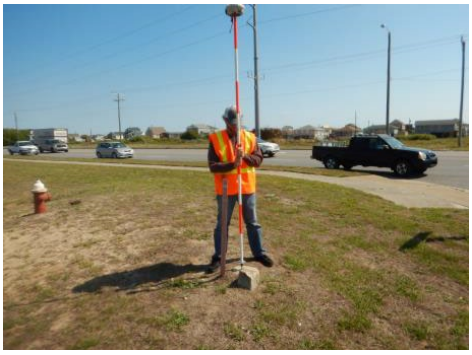
5) Field Book Pages (digital only)
This appendix includes copies of the field book pages used for the survey. Refer to APTIM field book No. 520 and NC field book No. 252 for the swims and the onshore portion, and navigation field book No. 57 for the offshore survey.

APPENDIX 1

MONUMENT INFORMATION REPORT

CONTROL MONUMENT USED BY APTIM FOR 2020 TOWN OF DUCK TOPOGRAPHIC AND HYDROGRAPHIC SURVEY REPORT JUNE 2020	
DATUMS: NAD83(2011) - NAVD1988 (US SURVEY FEET)	
Designation	KITTY
Stamping	KITTY 1962
Northing	859358.84
Easting	2977204.86
Horizontal Root Mean Square Error	0.11
Elevation	9.17
Vertical Root Mean Square Error	0.23
Description	Station is located about 0.65 miles east of the post office in Kitty Hawk. The station is a standard disk set in a 12x12 inch concrete monument. It is 126 feet east-southeast of the intersection, 17 feet east of a power line pole and 2.7 feet northeast of a metal witness post with sign. The mark is flush with the ground.

Monument: KITTY



Location Verification: KITTY

Mean of Inverse Shots – Published Versus APTIM Found				
Monument	No. of Shots	ΔN	ΔE	ΔZ
KITTY	33	0.00	-0.02	0.15

CONTROL MONUMENT USED BY APTIM FOR 2020 TOWN OF DUCK TOPOGRAPHIC AND HYDROGRAPHIC SURVEY REPORT JUNE 2020	
DATUMS: NAD83(2011) - NAVD1988 (US SURVEY FEET)	
Designation	Way
Stamping	Way
Northing	924642.81
Easting	2948590.66
Horizontal Root Mean Square Error	0.11
Elevation	4.88
Vertical Root Mean Square Error	0.05
Description	The mark is 18.9 MI SE of Currituck and 5.6 Mi. NE of Jarvisburg along NC 12 for 1.4 Mi. N from the Currituck/Dare county line on the centerline prolongation of an asphalt runway. Mark is about 3 Ft. lower than NC 12 and recessed 3 In. below the ground. Located 175.5 Ft. W of the centerline of NC 12, 168 Ft. S-SE of the S end of the private runway.

Mean of Inverse Shots – Published Versus APTIM Found				
Monument	No. of Shots	ΔN	ΔE	ΔZ
WAY	6	0.07	0.04	-0.04

CONTROL MONUMENT USED BY APTIM FOR 2020 TOWN OF DUCK TOPOGRAPHIC AND HYDROGRAPHIC SURVEY REPORT JUNE 2020	
DATUMS: NAD83(2011) - NAVD1988 (US SURVEY FEET)	
Designation	CAFFEY
Stamping	CAFFEY 1935
Northing	915308.87
Easting	2952084.11
Horizontal Root Mean Square Error	0.09
Elevation	1.99
Vertical Root Mean Square Error	0.05
Description	Station is about 350 feet W of Caffey Inlet Coast Guard Station, on a small sand neck which extends into the marsh on the E shore of Currituck Sound. This neck is just S of an old can buoy lying in the marsh and is just N of a small gut which the road crosses on a small bridge. The station is about 225 feet W of a flagpole at the fence line W of the coast guard station, a point in line with the S fence, and 179 feet NW of the center of the bridge.

Monument: CAFFEY

NO IMAGE

Location Verification: CAFFEY

Mean of Inverse Shots – Published Versus APTIM Found				
Monument	No. of Shots	ΔN	ΔE	ΔZ
CAFFEY	31	-0.05	-0.02	0.04

CONTROL MONUMENT USED BY APTIM FOR 2020 TOWN OF DUCK TOPOGRAPHIC AND HYDROGRAPHIC SURVEY REPORT JUNE 2020	
DATUMS: NAD83(2011) - NAVD1988 (US SURVEY FEET)	
Designation	X 254
Stamping	X 254
Northing	876428.61
Easting	2968761.03
Horizontal Root Mean Square Error	0.08
Elevation	9.93
Vertical Root Mean Square Error	0.02
Description	Proceed along NC 12 for 1.1 mi. N from the intersection of US 154 in Kitty Hawk to house number 92. The mark is in the NW corner of the property level with the centerline of NC 12 and flush with the ground. It is located 35.8 Ft. E of the centerline of NC 12, 54.0 Ft. S of the S edge of concrete drive to the house and 1 Ft. W of a witness post.

Mean of Inverse Shots – Published Versus APTIM Found				
Monument	No. of Shots	ΔN	ΔE	ΔZ
X 254	4	-0.01	0.06	0.00

CONTROL MONUMENT USED BY APTIM FOR 2020 TOWN OF DUCK TOPOGRAPHIC AND HYDROGRAPHIC SURVEY REPORT JUNE 2020	
DATUMS: NAD83(2011) - NAVD1988 (US SURVEY FEET)	
Designation	Y 254
Stamping	Y 254
Northing	880716.27
Easting	2966184.93
Horizontal Root Mean Square Error	0.10
Elevation	12.15
Vertical Root Mean Square Error	0.05
Description	Proceed along NC 12 for 2.1 mi. N from the intersection of US 154 in Kitty Hawk to house number 160. Station is level with the centerline of NC 12 and flush with the ground. Located 31.5 Ft. E of the centerline of NC 12, 30 Ft. S-SW of the center of concrete drive to house, 8.4 Ft. S of a water meter, 1.2 SW of a witness sign, and 3.3 Ft. W-SW of a power pole with 2 guy wires and a reference tag.

Mean of Inverse Shots – Published Versus APTIM Found				
Monument	No. of Shots	ΔN	ΔE	ΔZ
Y 254	27	-0.02	-0.03	0.03

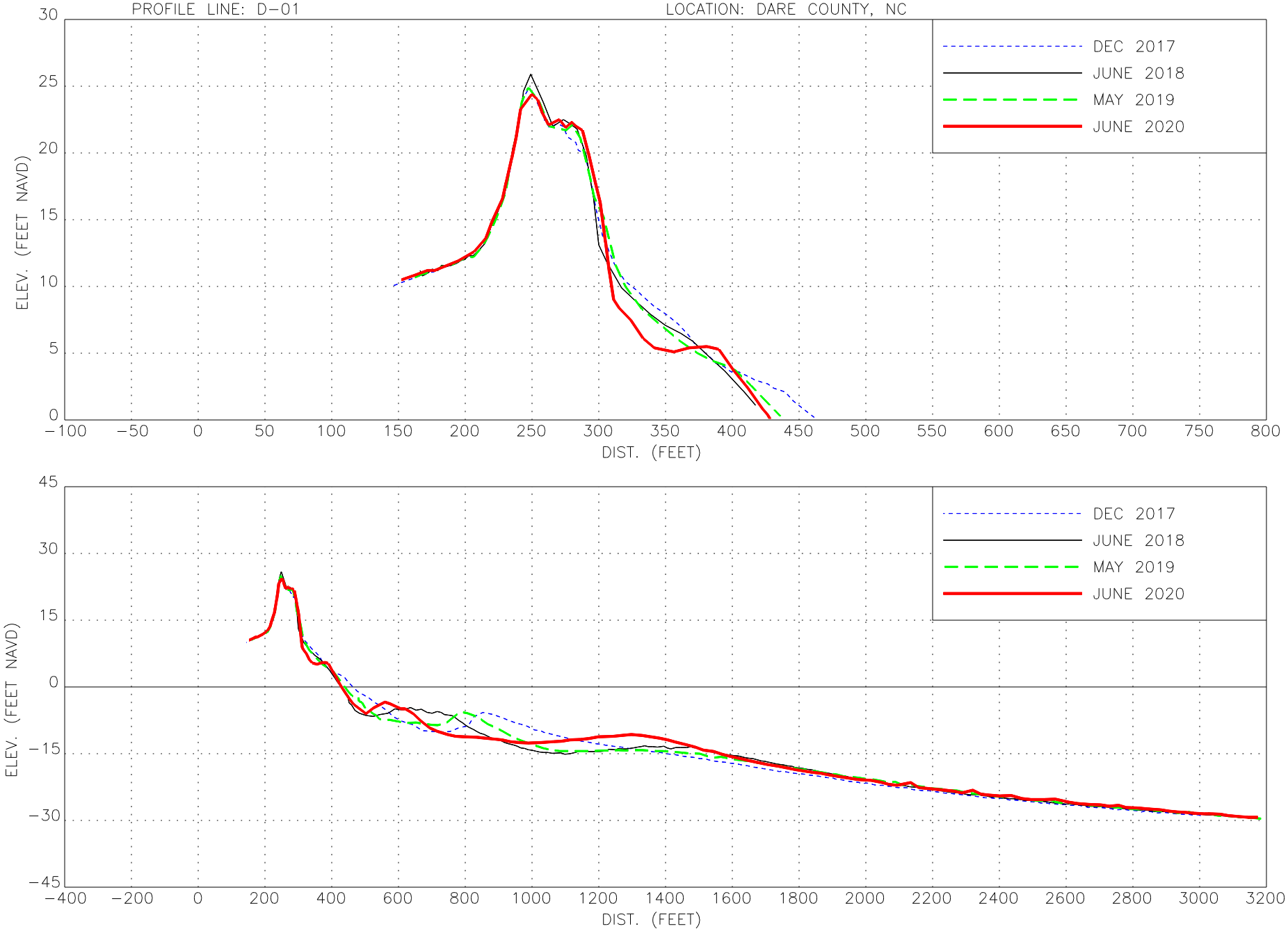
TOWN OF DUCK STATION INFORMATION JUNE 2020			
DATUMS: NAD83(2011) / NAVD88 (US SURVEY FEET)			
STATION	**NORTHING**	**EASTING**	**AZIMUTH**
D-01	918267.70	2951387.50	70.00
D-02	917384.40	2951733.80	70.00
D-03	916429.40	2952103.00	70.00
D-04	915495.30	2952464.00	70.00
D-05	914598.00	2952849.30	70.00
D-06	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/-197+12	889616.10	2962839.60	70.00

APPENDIX 2: Profile XYZ Data

PROFILE XYZ DATA
(Available in digital format only)

APPENDIX 3

PROFILE PLOTS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MAY 2019
JUNE 2020
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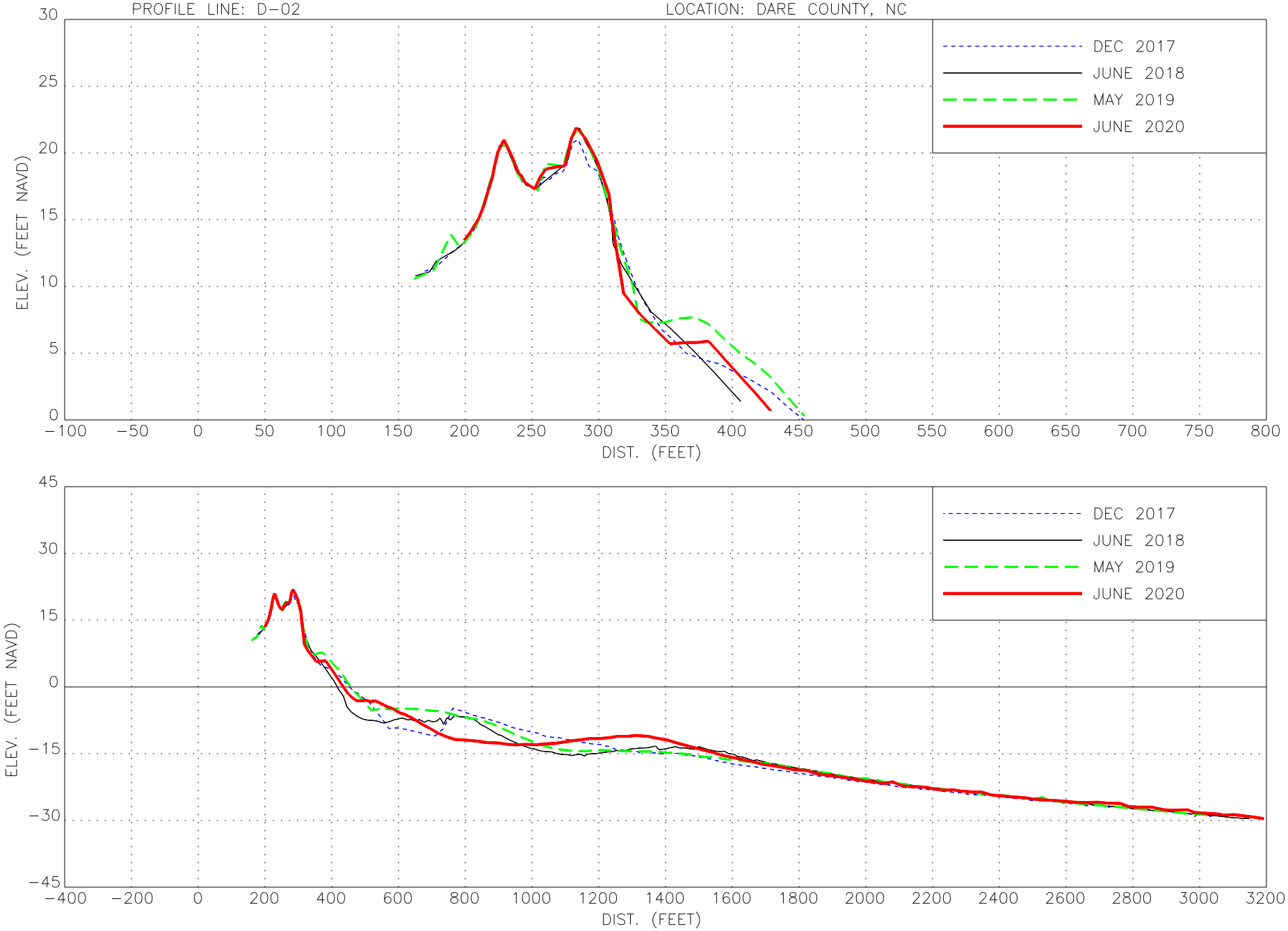
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MAY 2019
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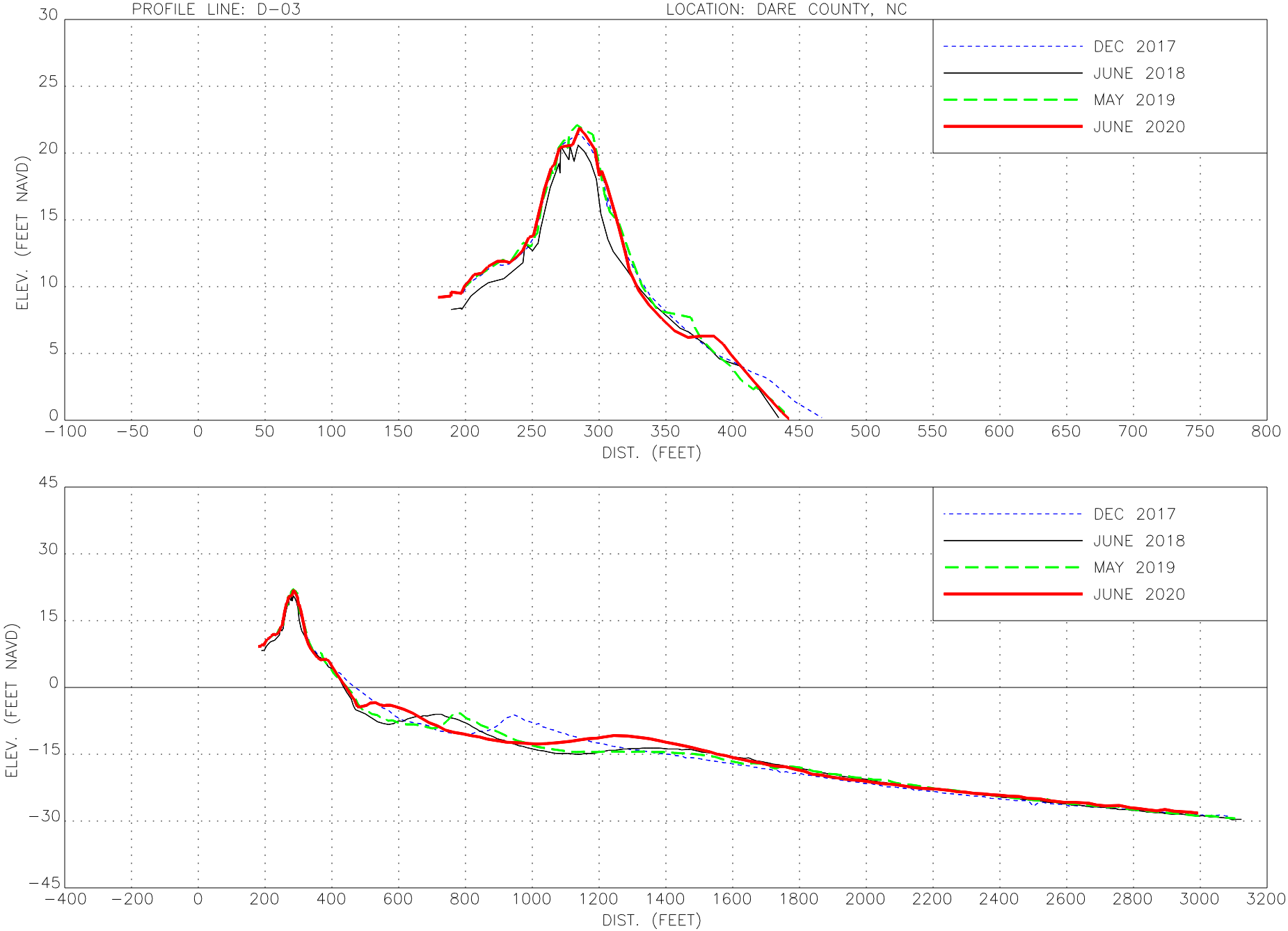
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MAY 2019
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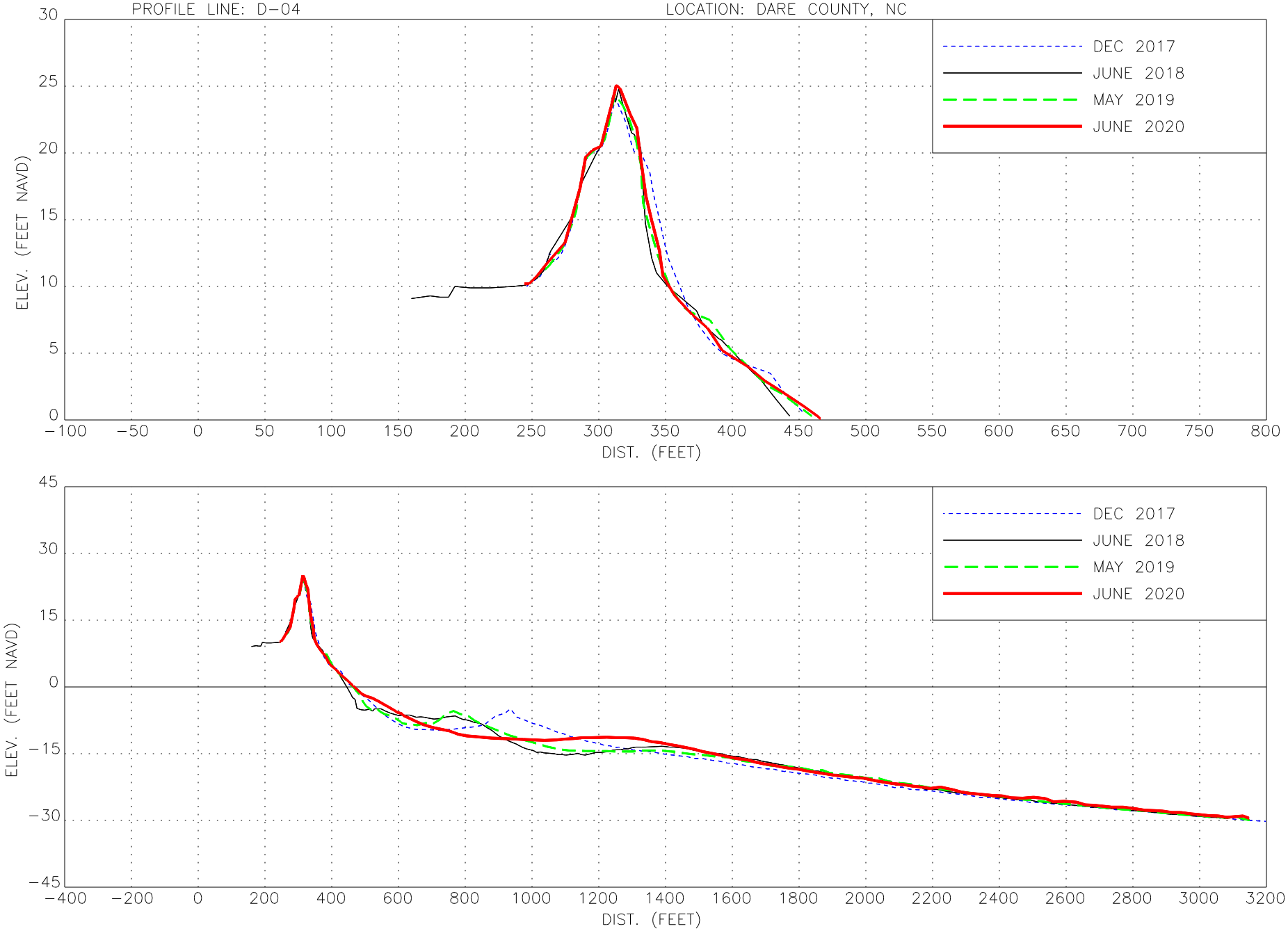
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MAY 2019
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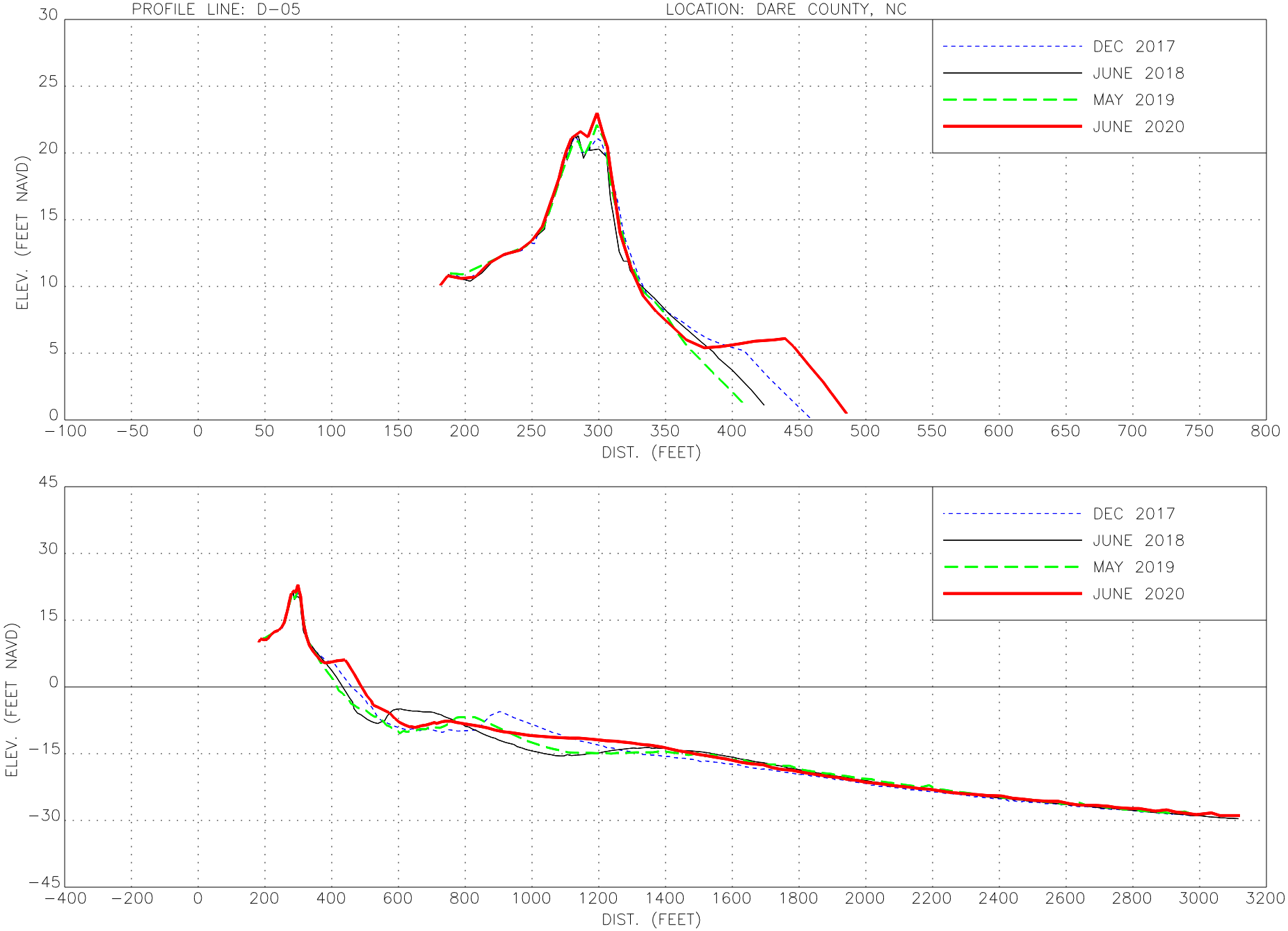
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MAY 2019
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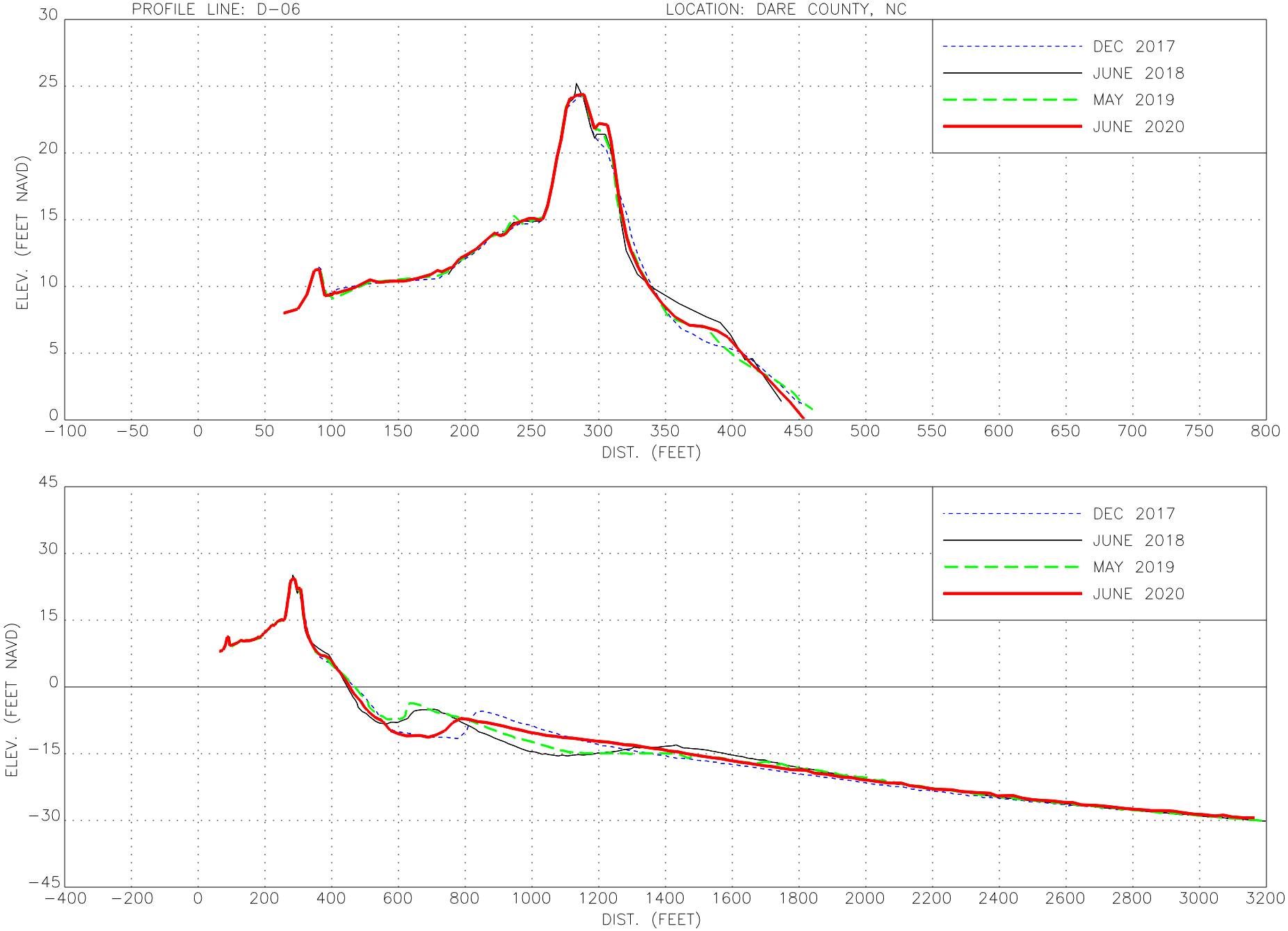
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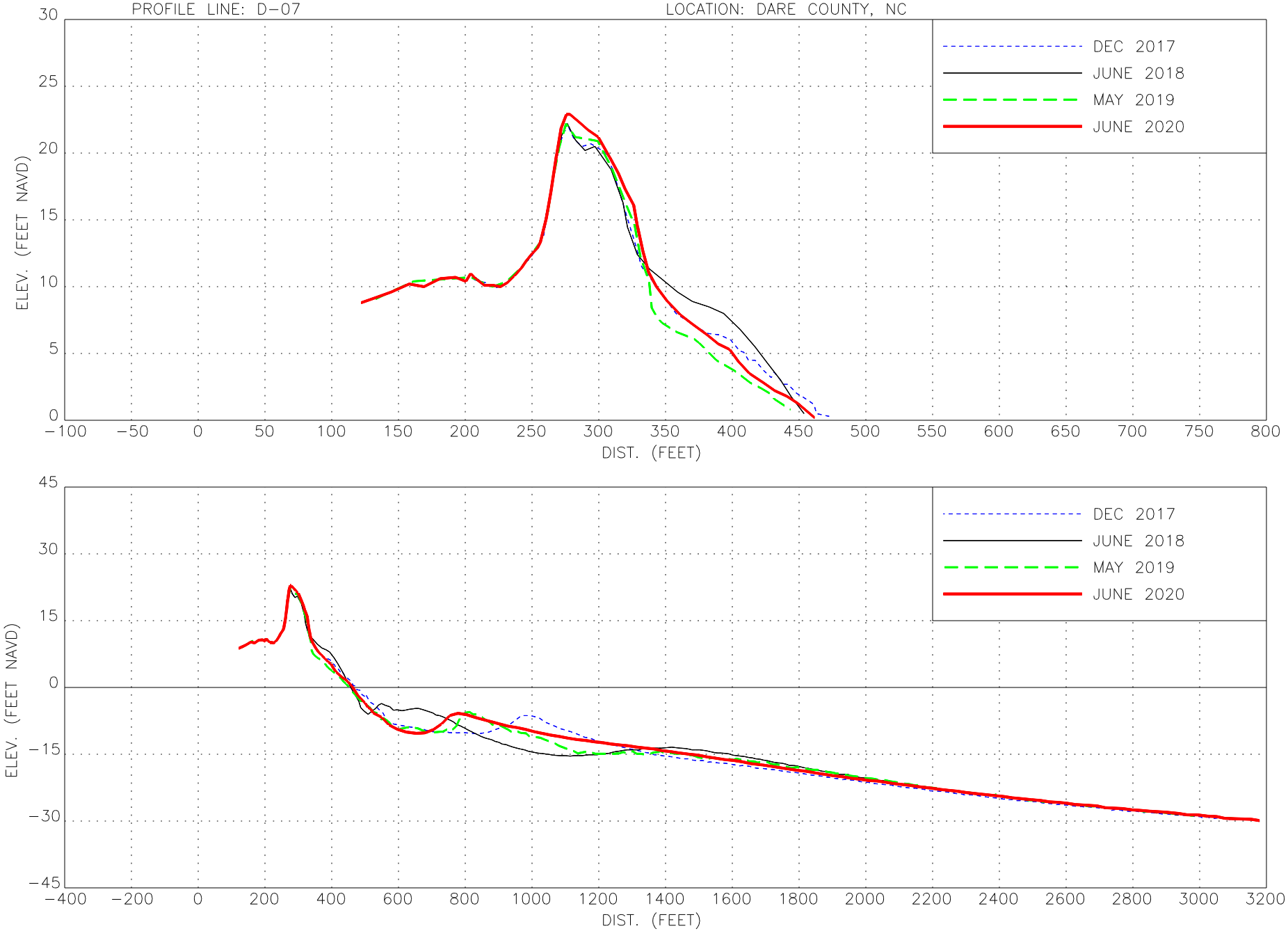
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MAY 2019
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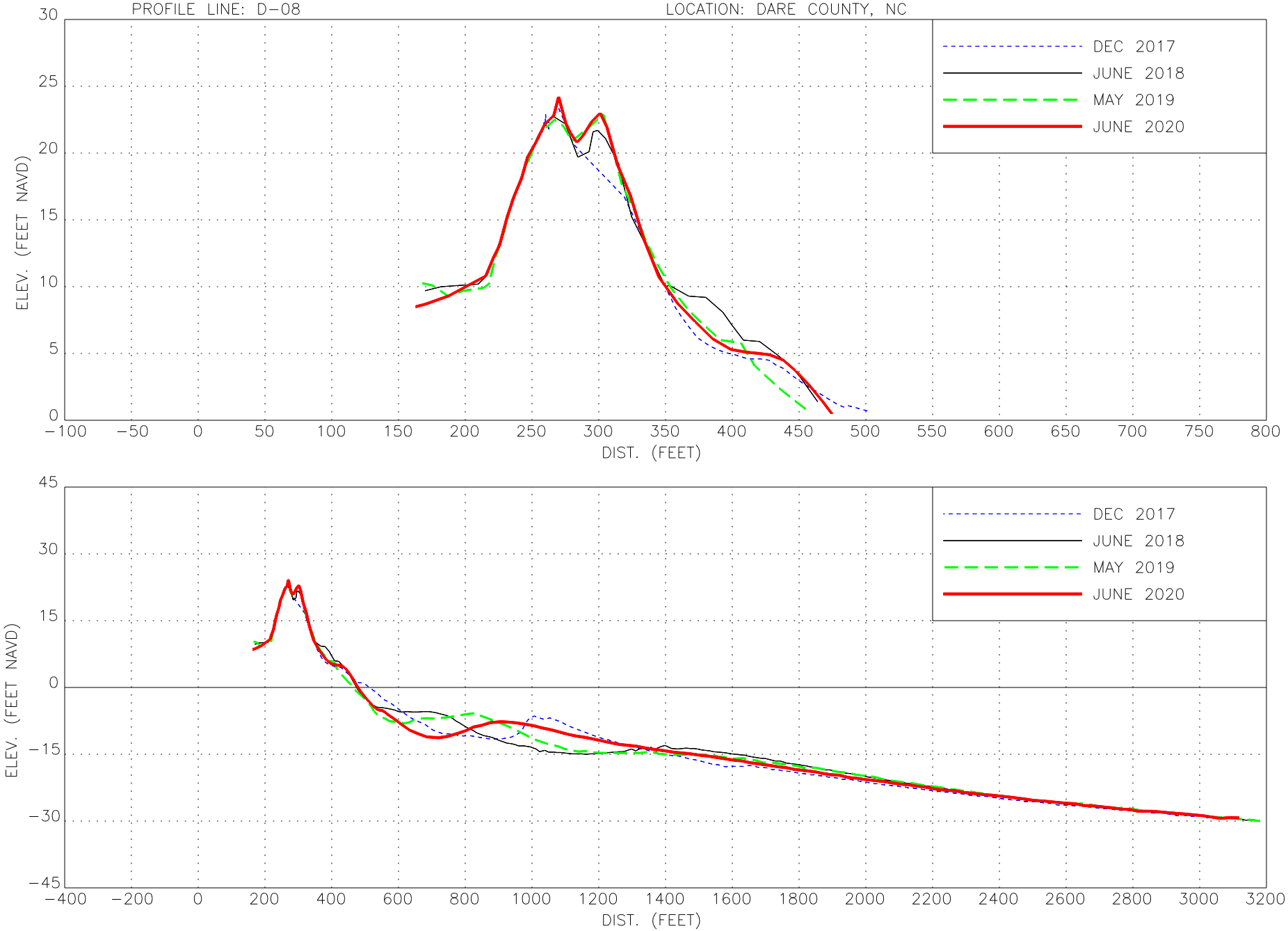
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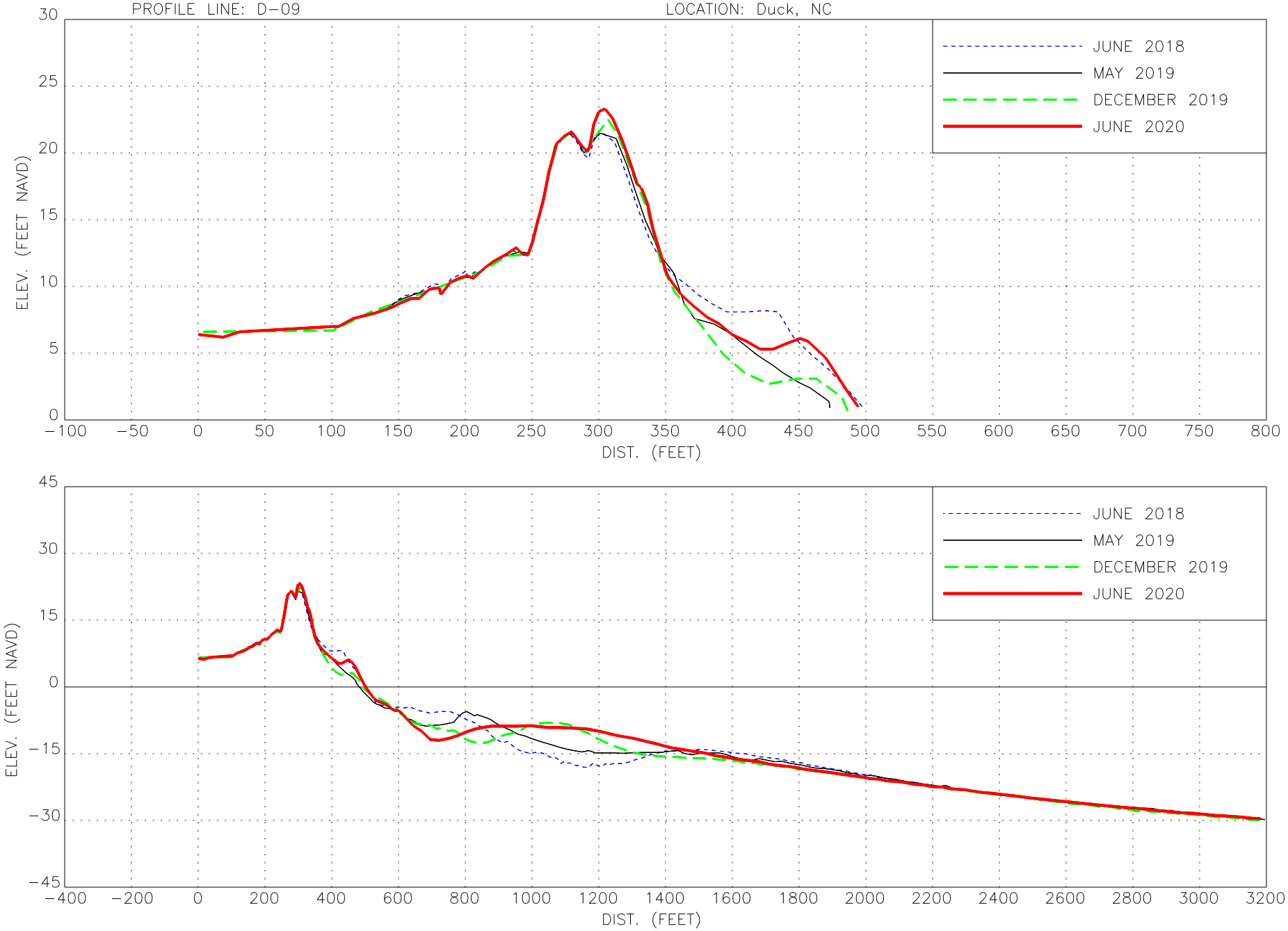
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DECEMBER 2019
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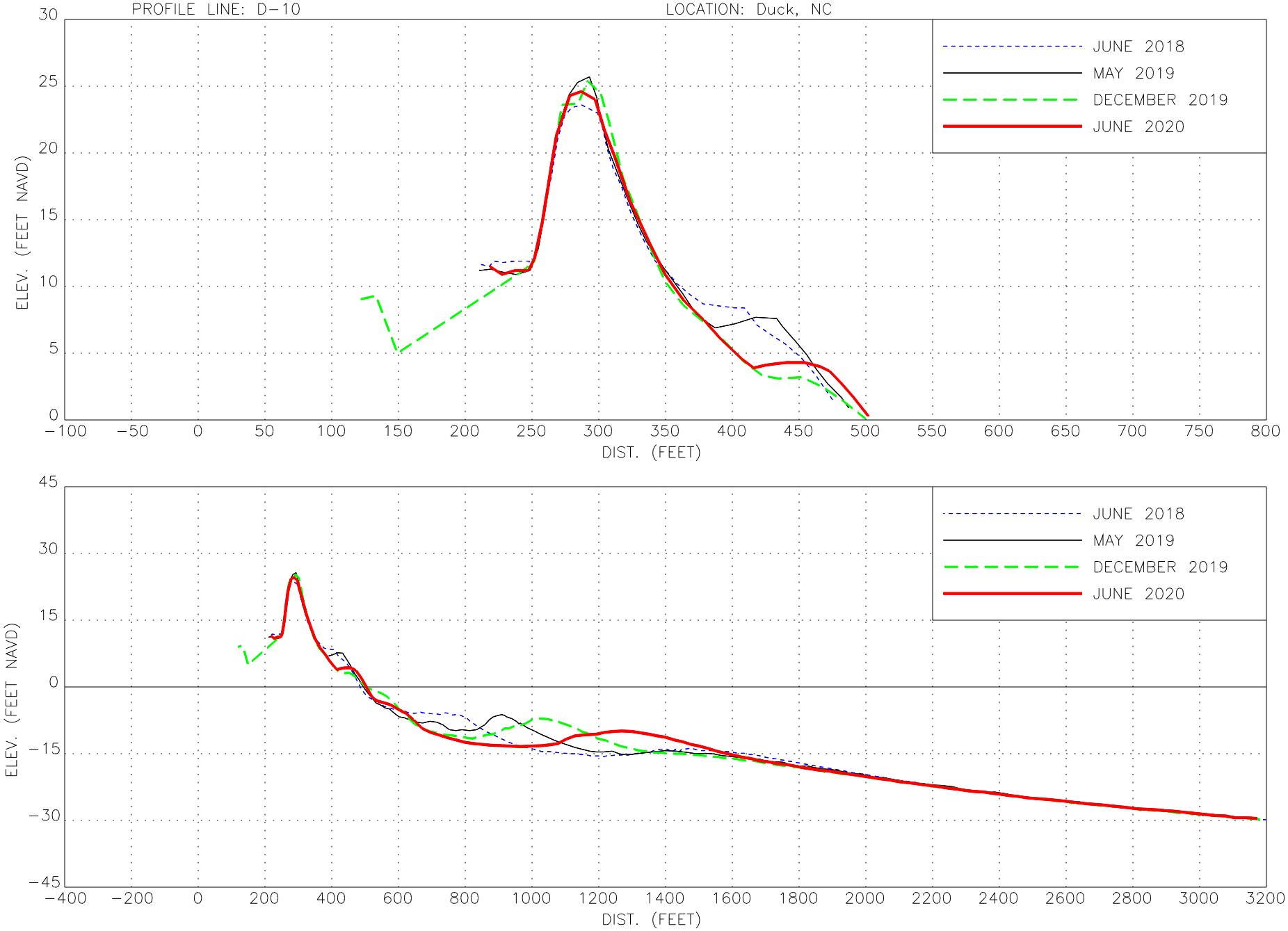
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DECEMBER 2019
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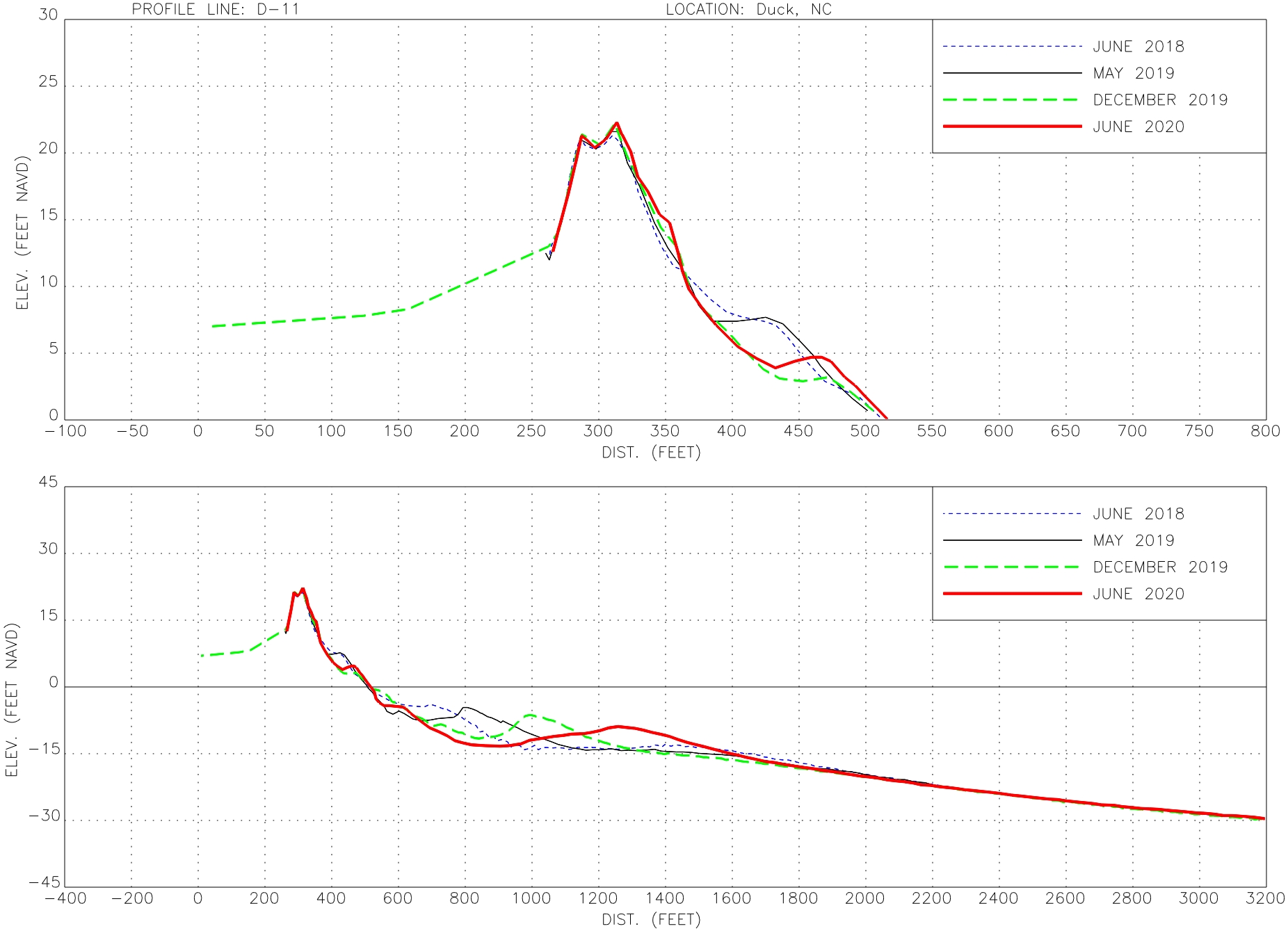
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MAY 2019
DECEMBER 2019
JUNE 2020
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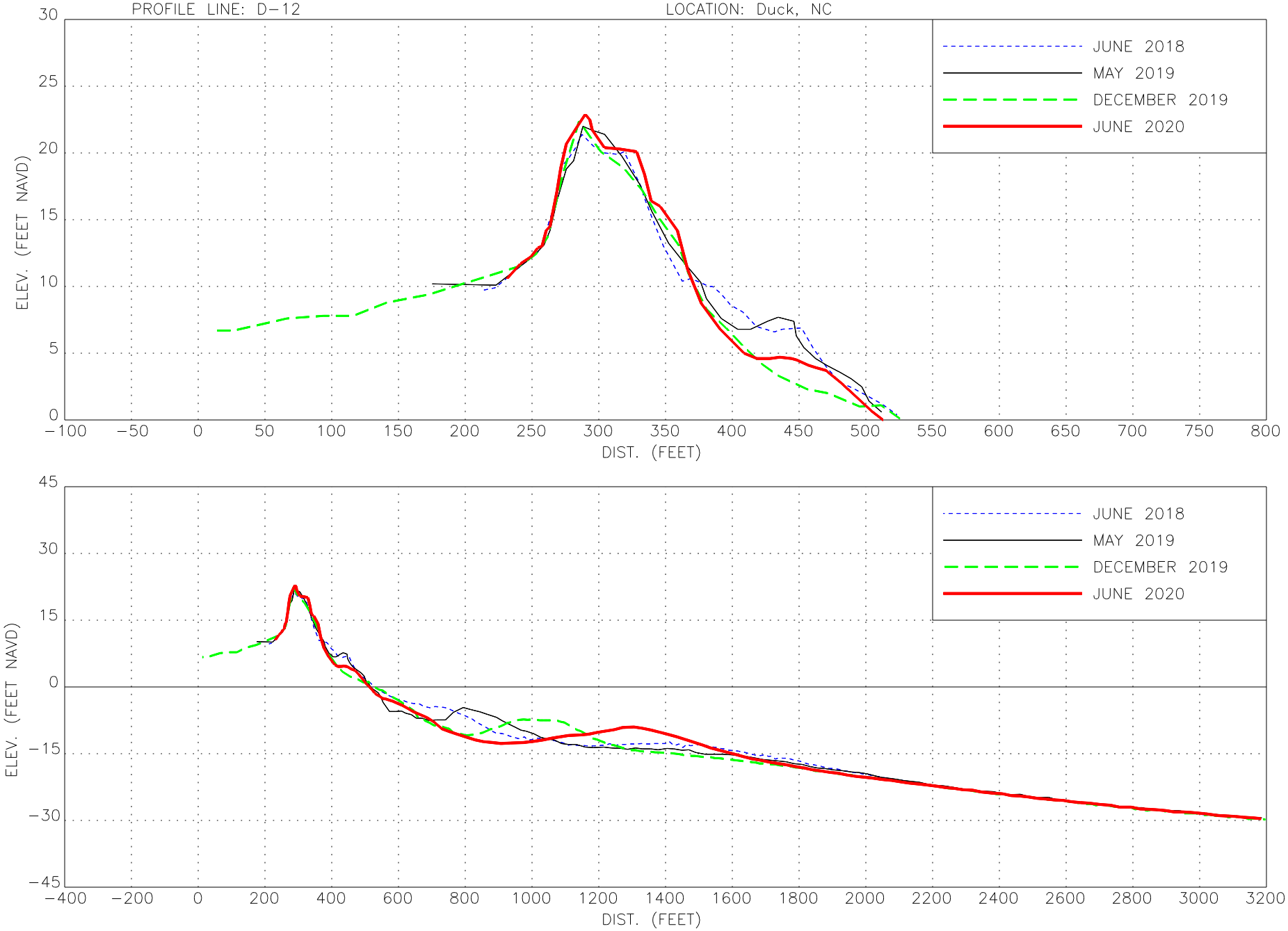
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DECEMBER 2019
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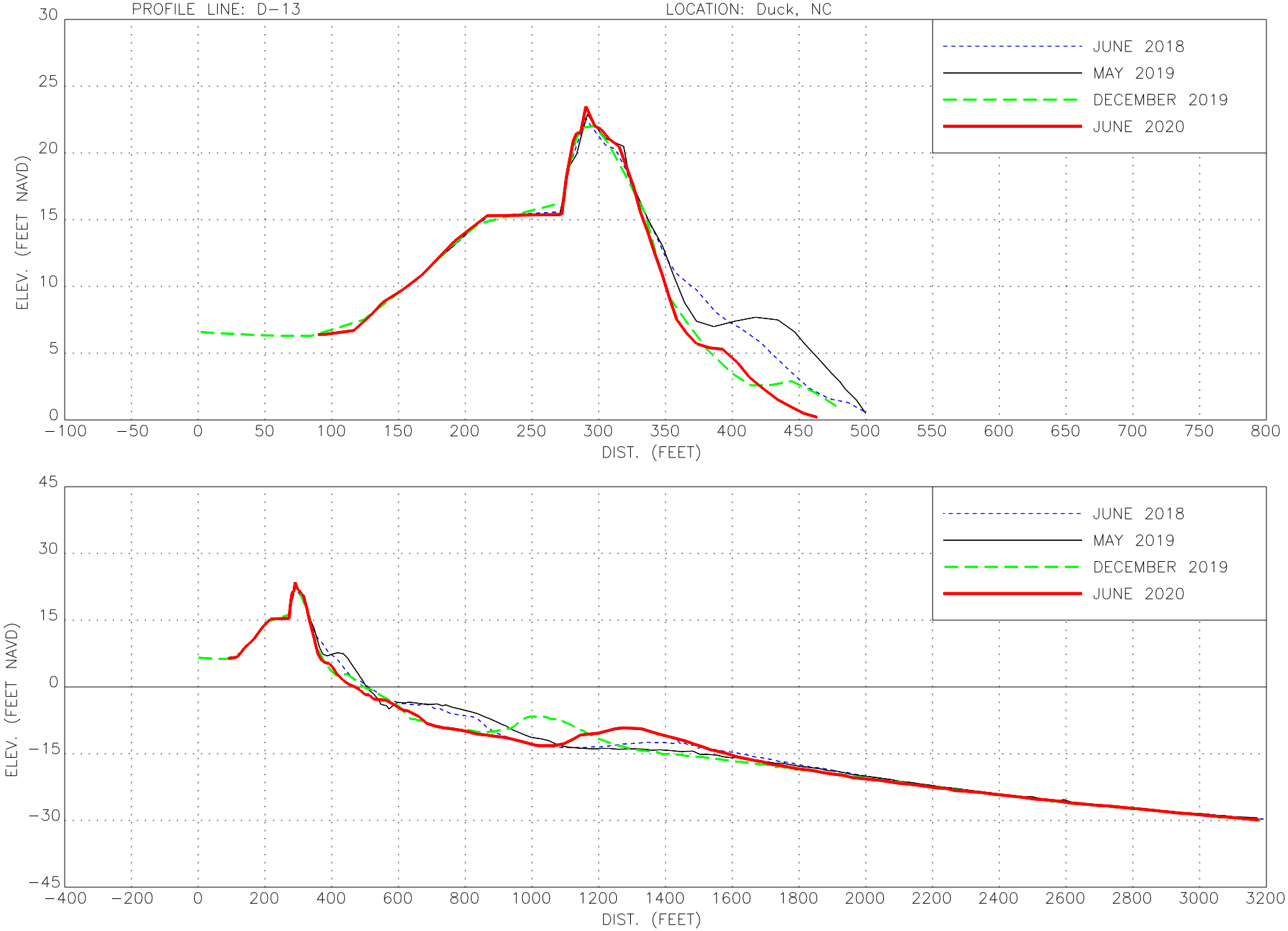
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MAY 2019
DECEMBER 2019
JUNE 2020
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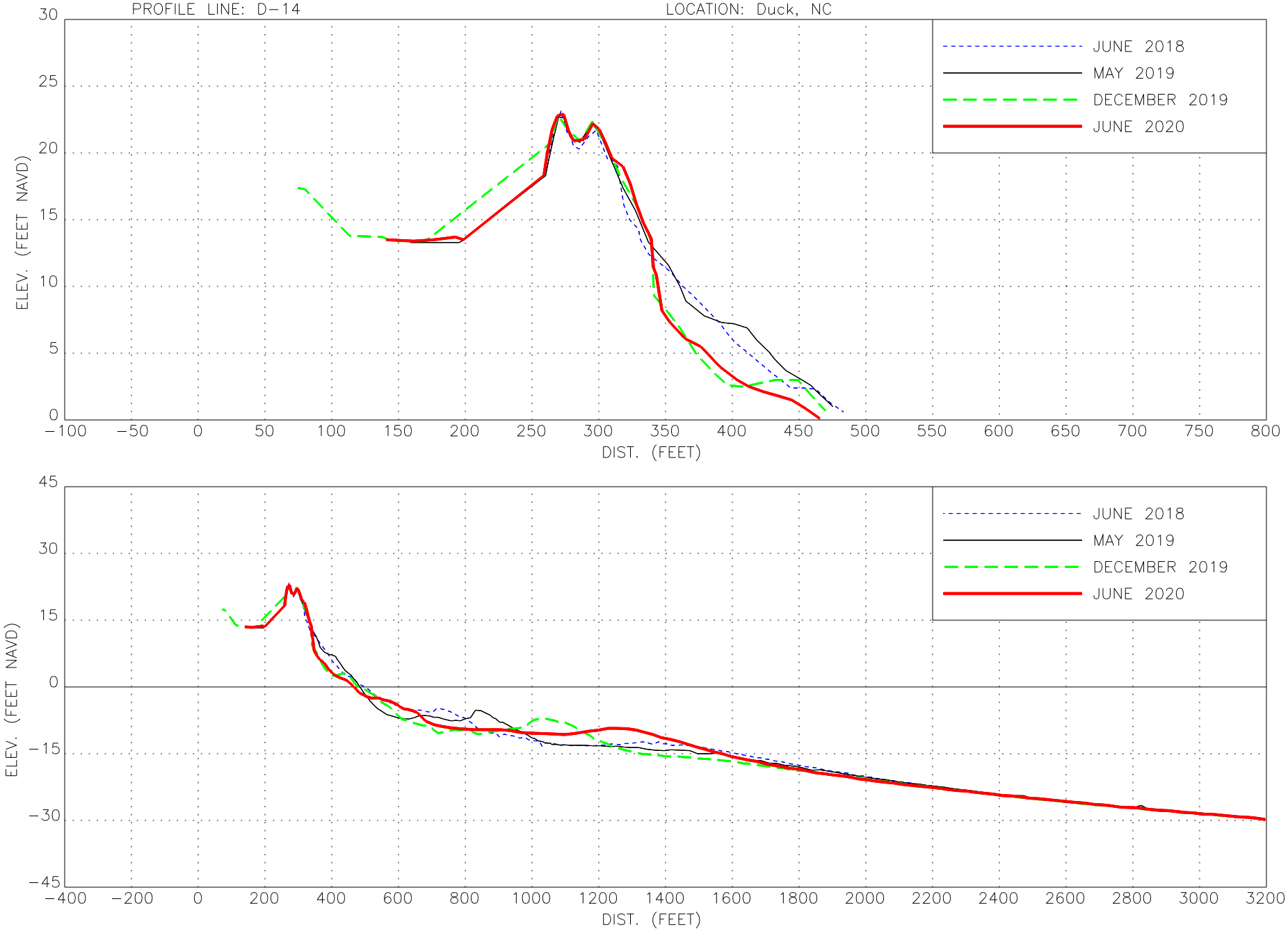
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MAY 2019
DECEMBER 2019
JUNE 2020
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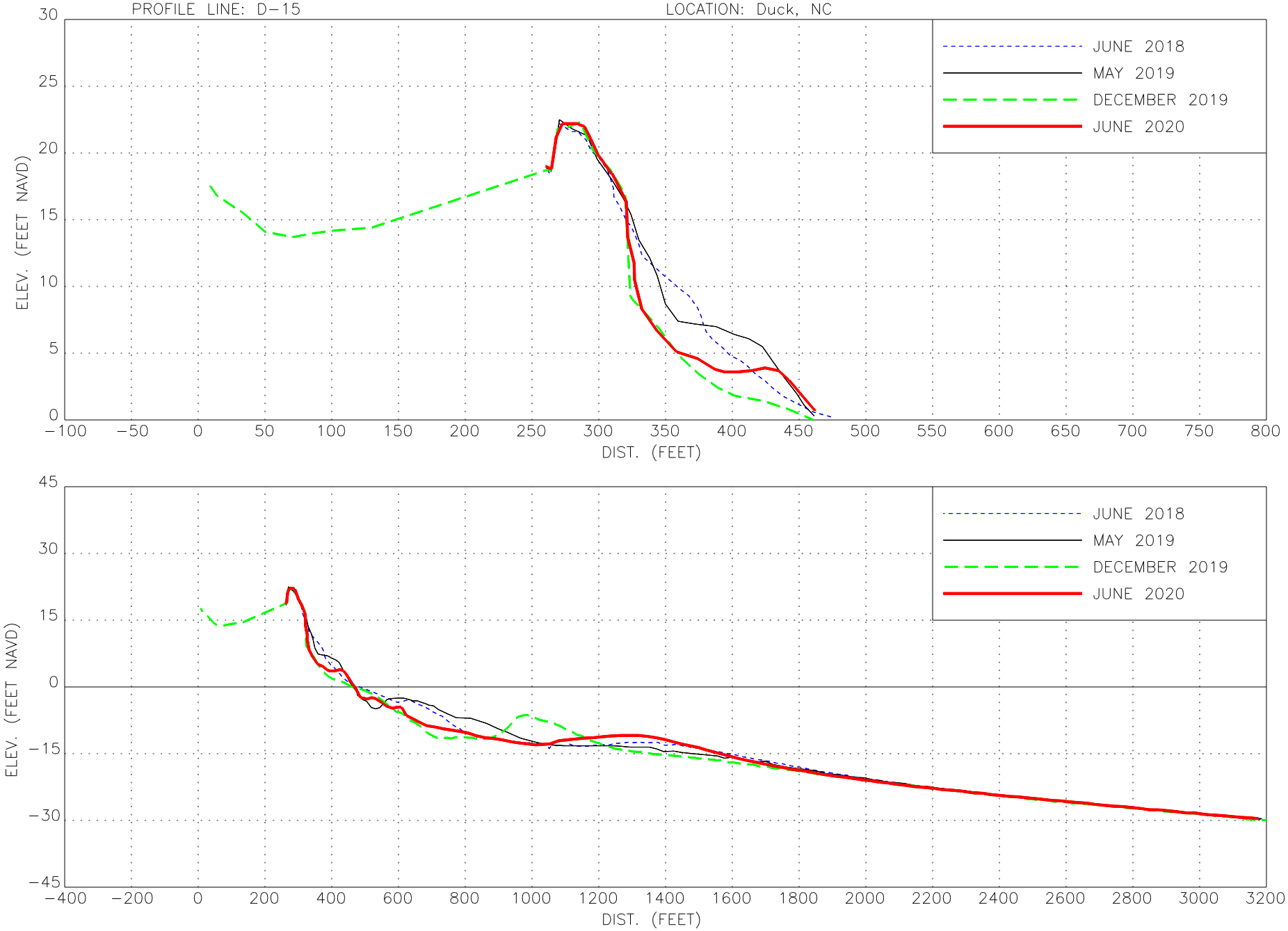
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DECEMBER 2019
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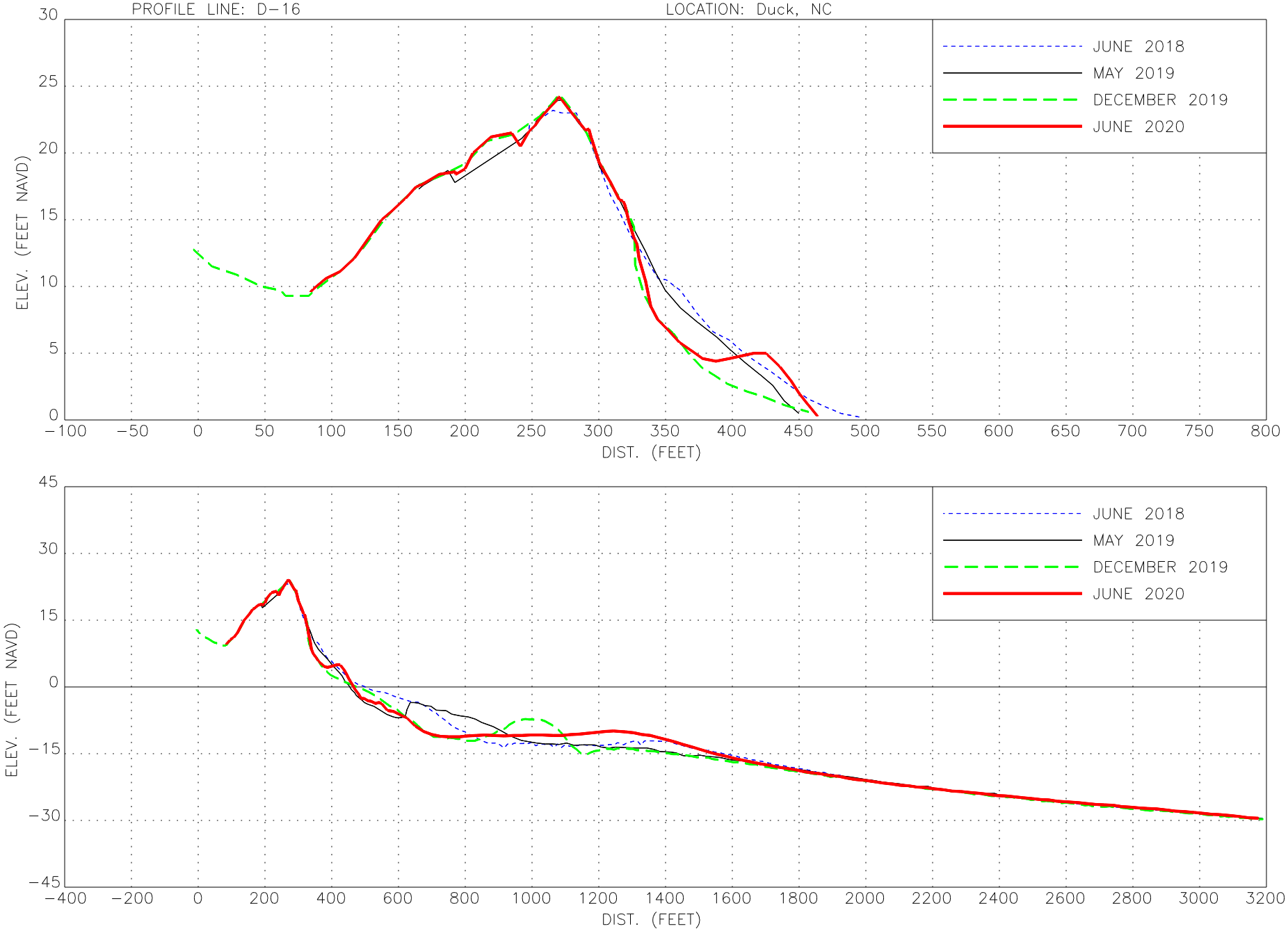
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DECEMBER 2019
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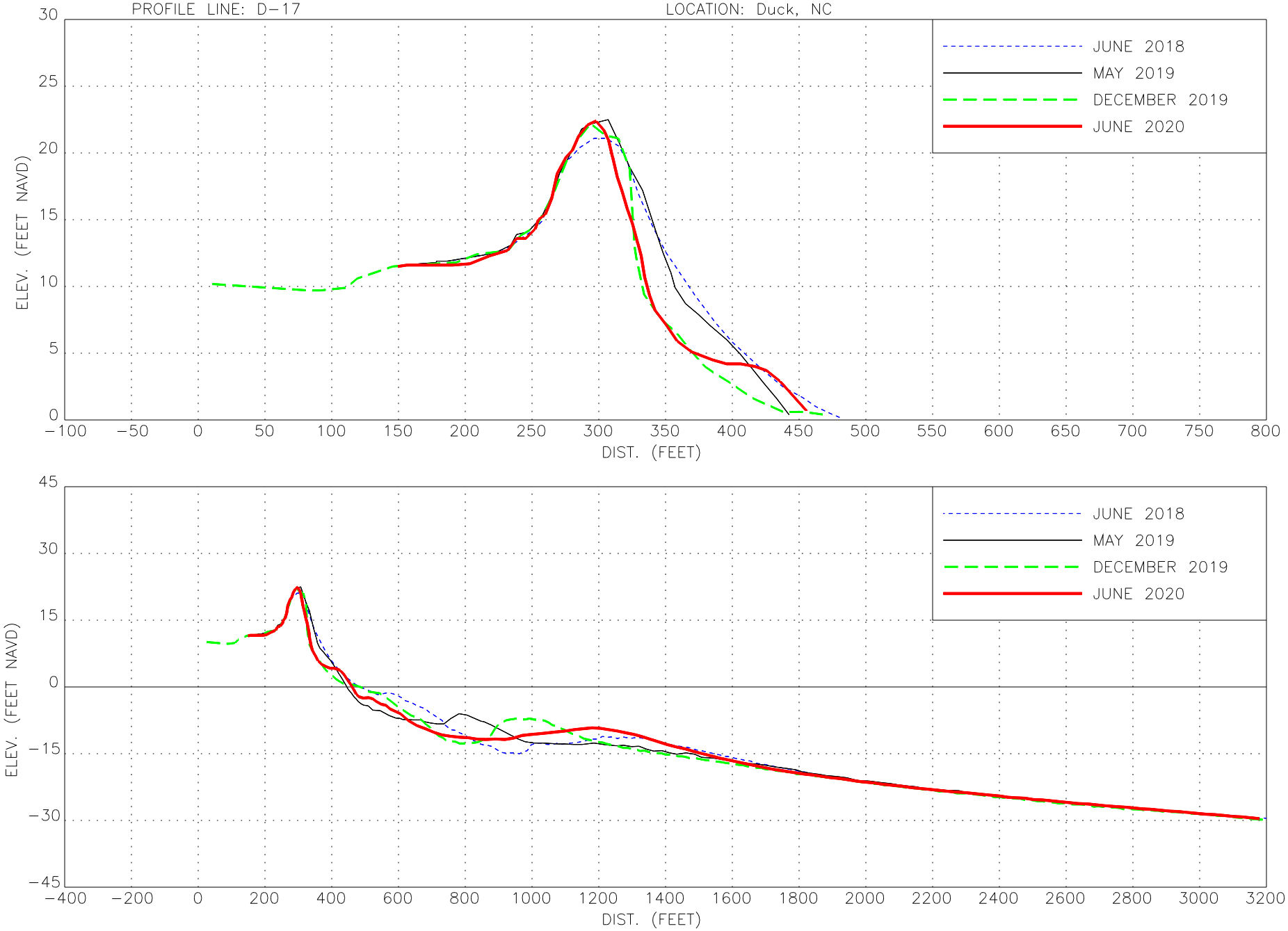
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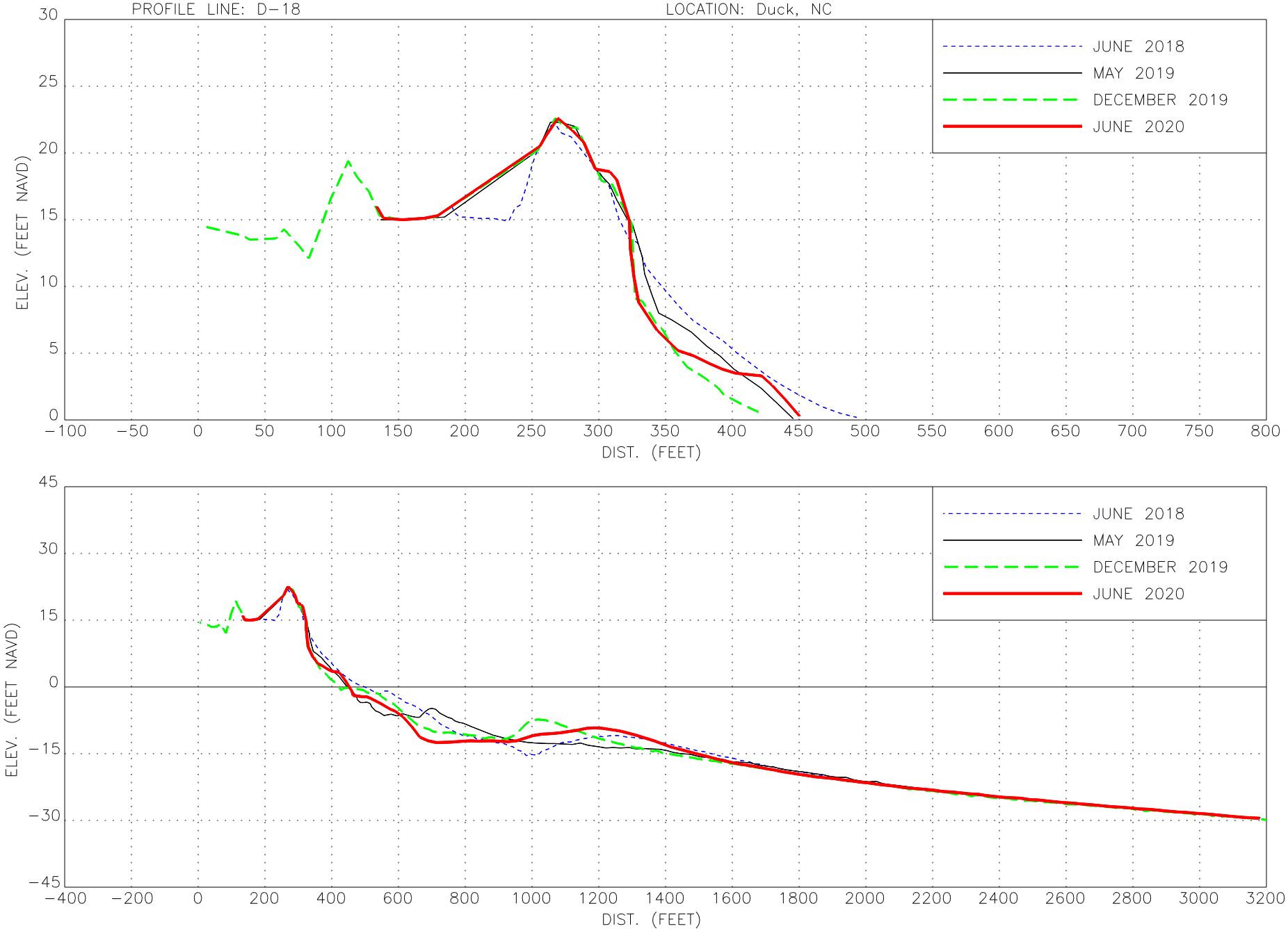
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DECEMBER 2019
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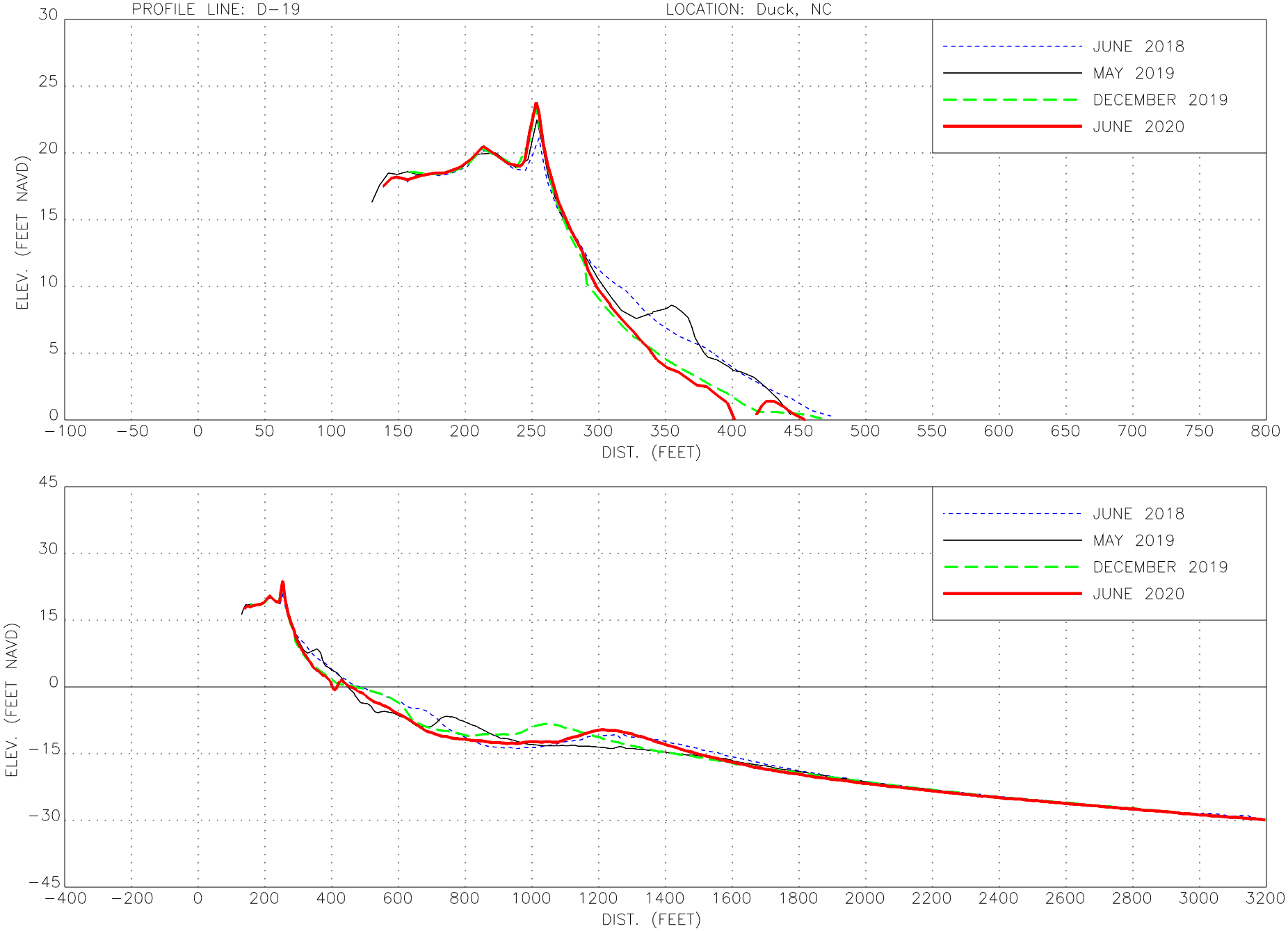
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DECEMBER 2019
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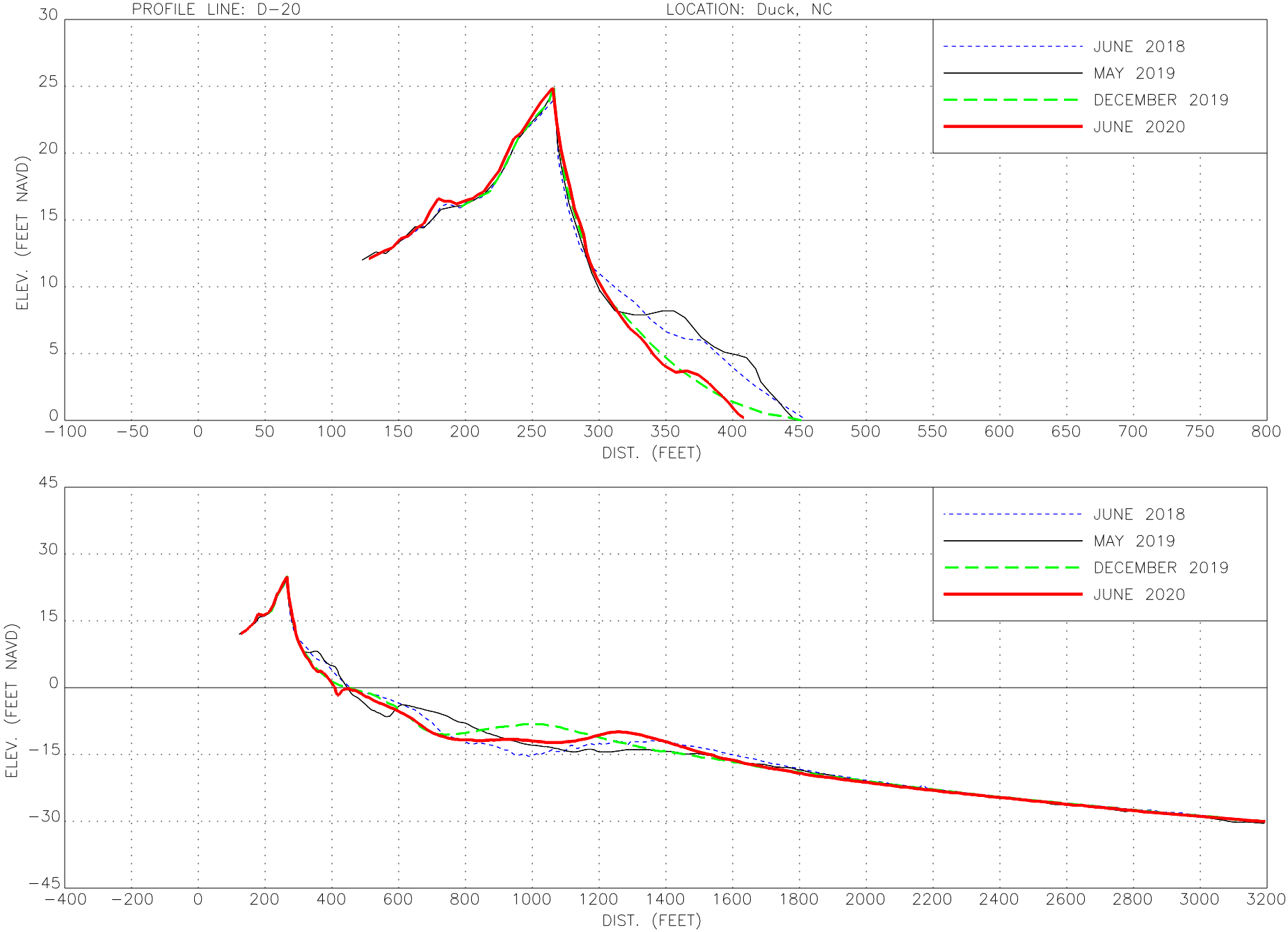
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DECEMBER 2019
JUNE 2020
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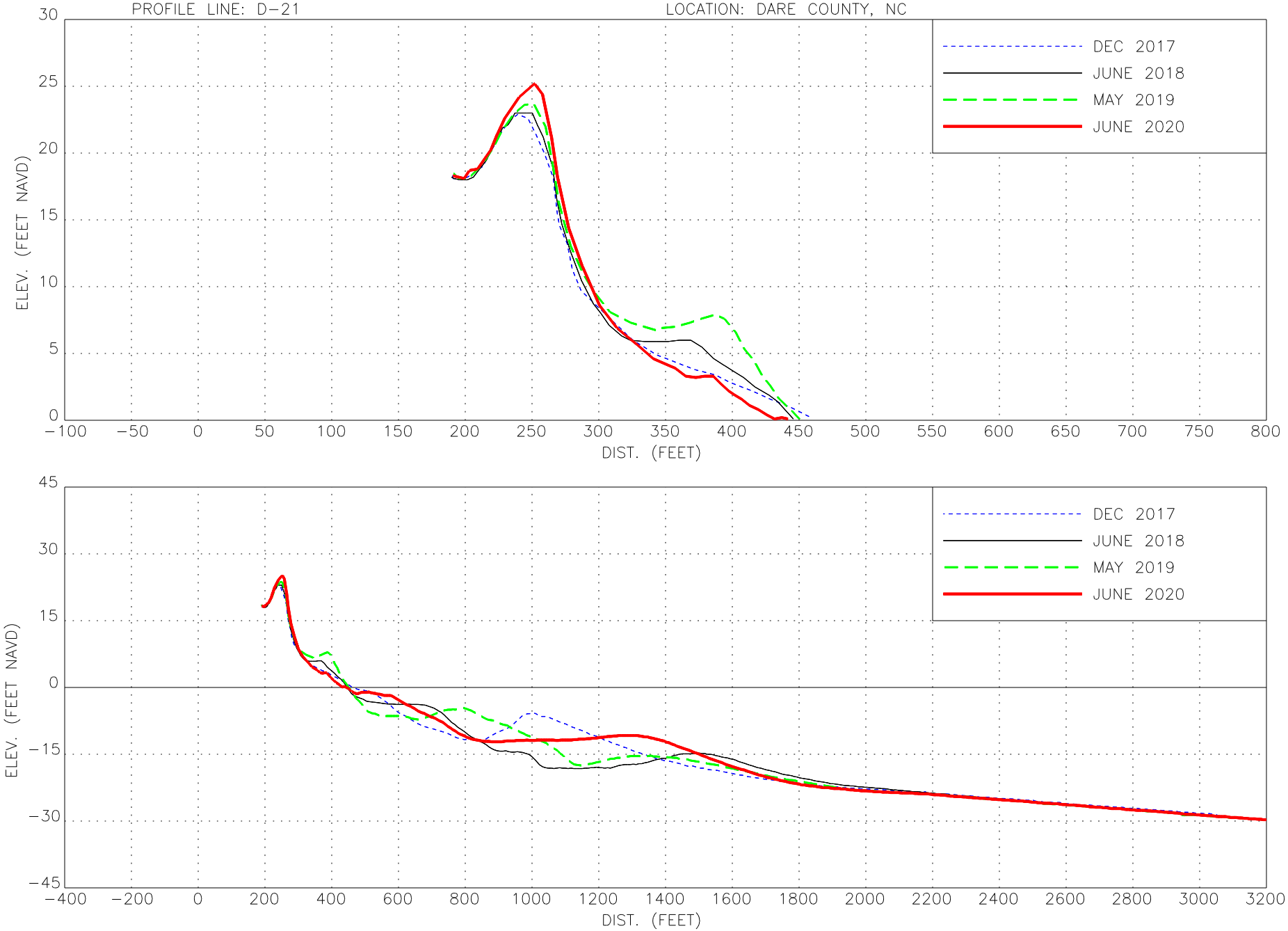
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MAY 2019
JUNE 2020
ELEV. (FEET NAVD)
DIST. (FEET)
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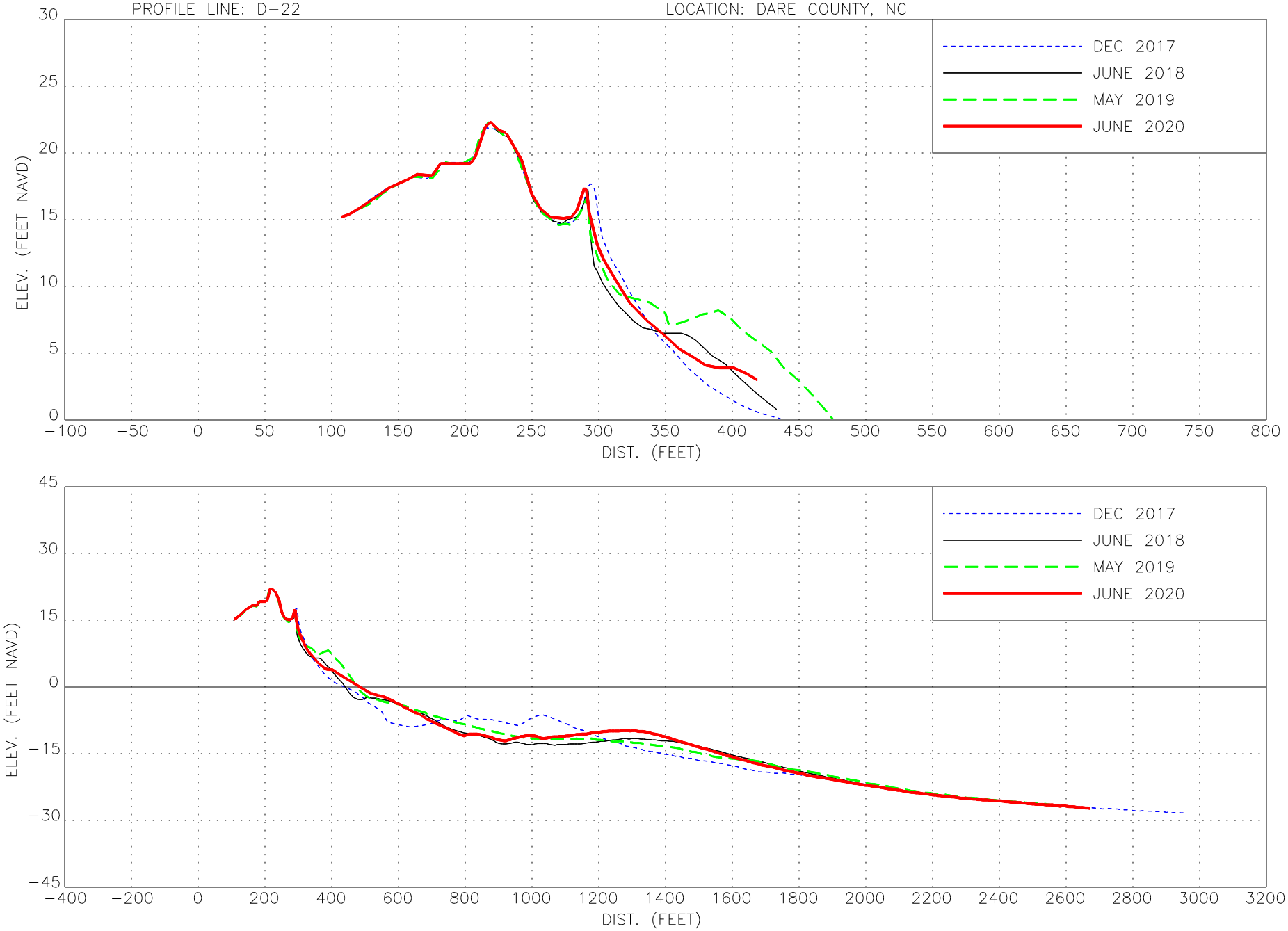
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LOCATION: DARE COUNTY, NC
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MAY 2019
JUNE 2020
ELEV. (FEET NAVD)
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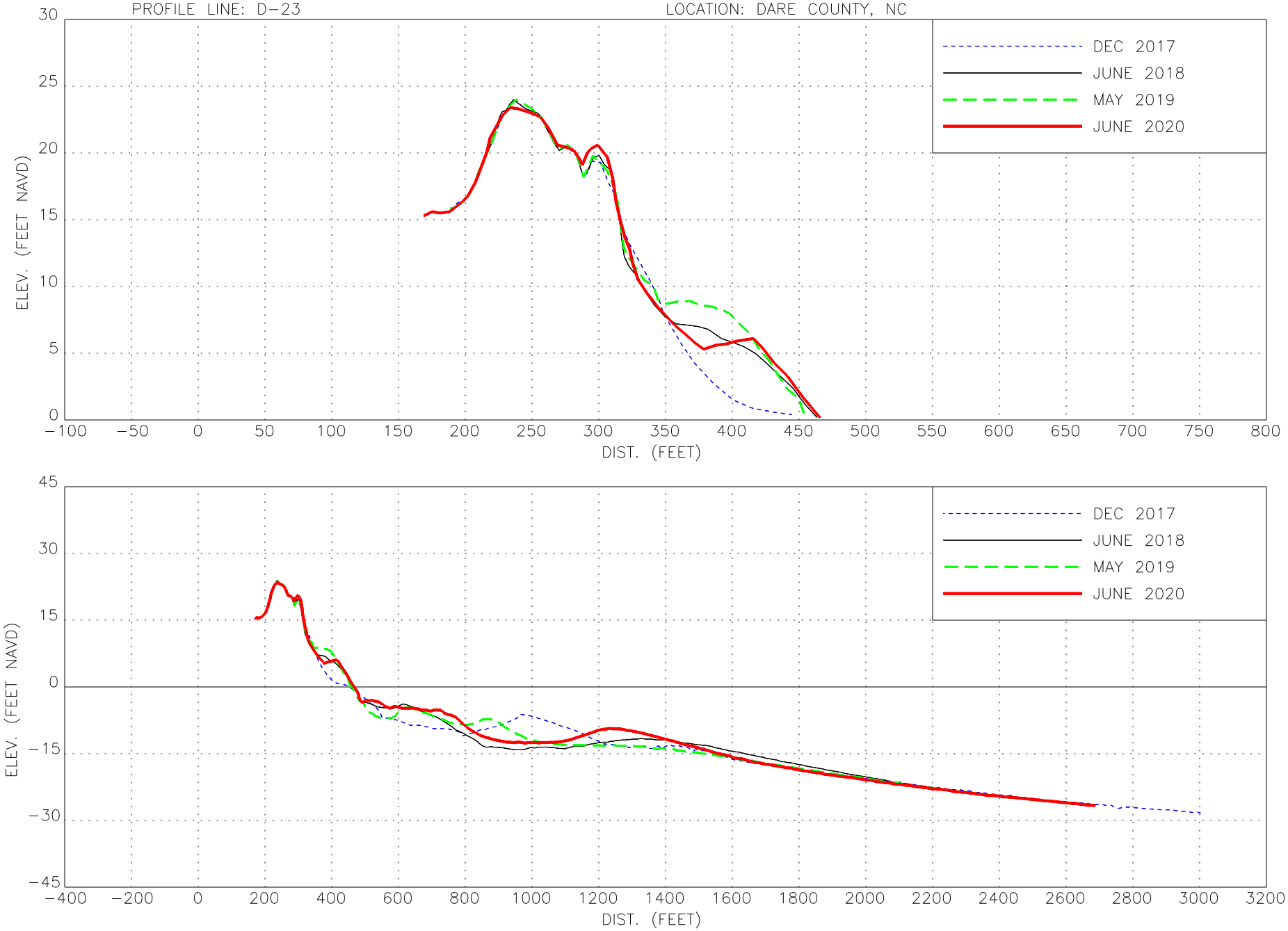
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LOCATION: DARE COUNTY, NC
DEC 2017
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MAY 2019
JUNE 2020
ELEV. (FEET NAVD)
DIST. (FEET)
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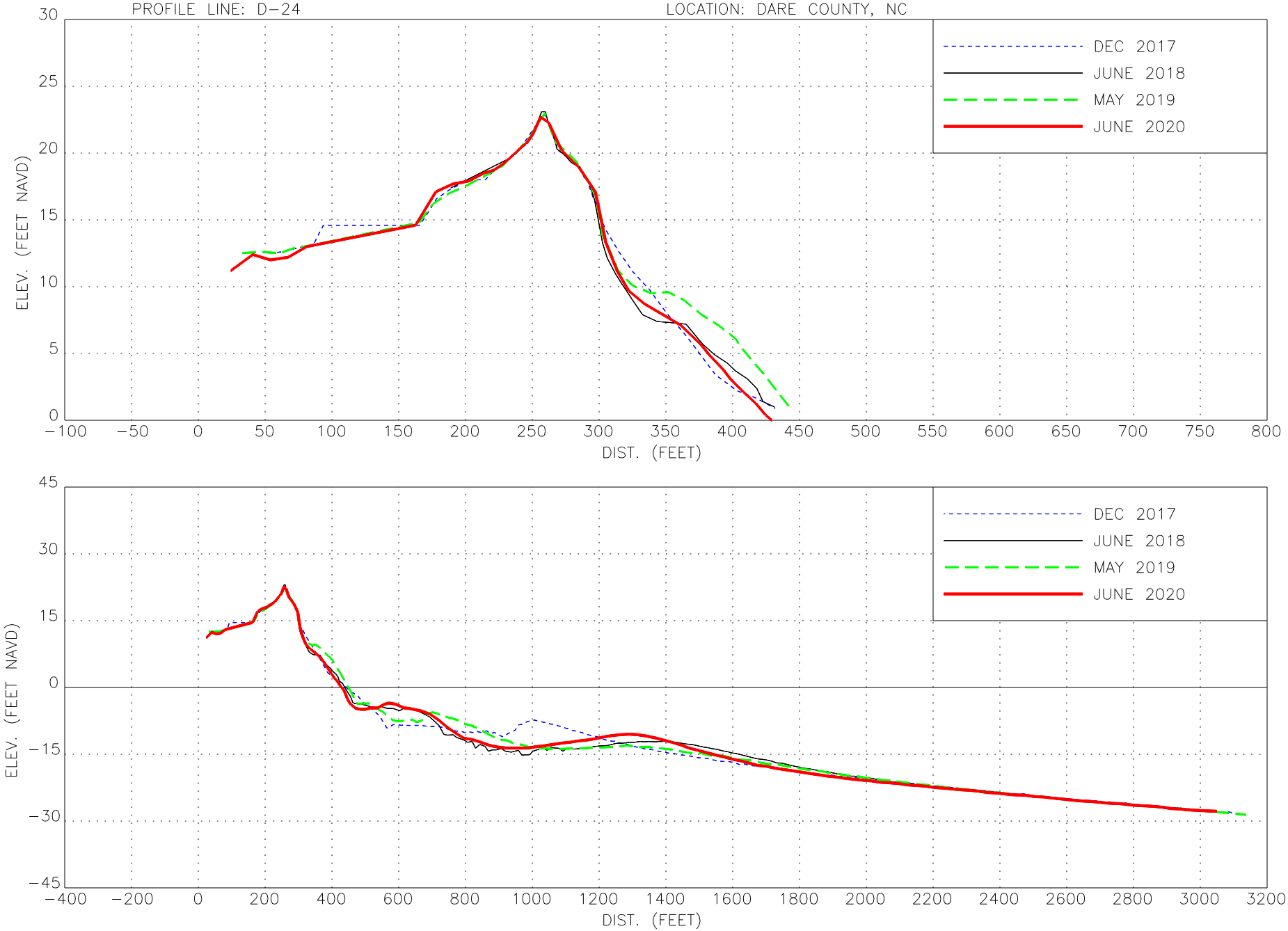
PROFILE LINE: D-24
LOCATION: DARE COUNTY, NC
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JUNE 2018
MAY 2019
JUNE 2020
ELEV. (FEET NAVD)
DIST. (FEET)
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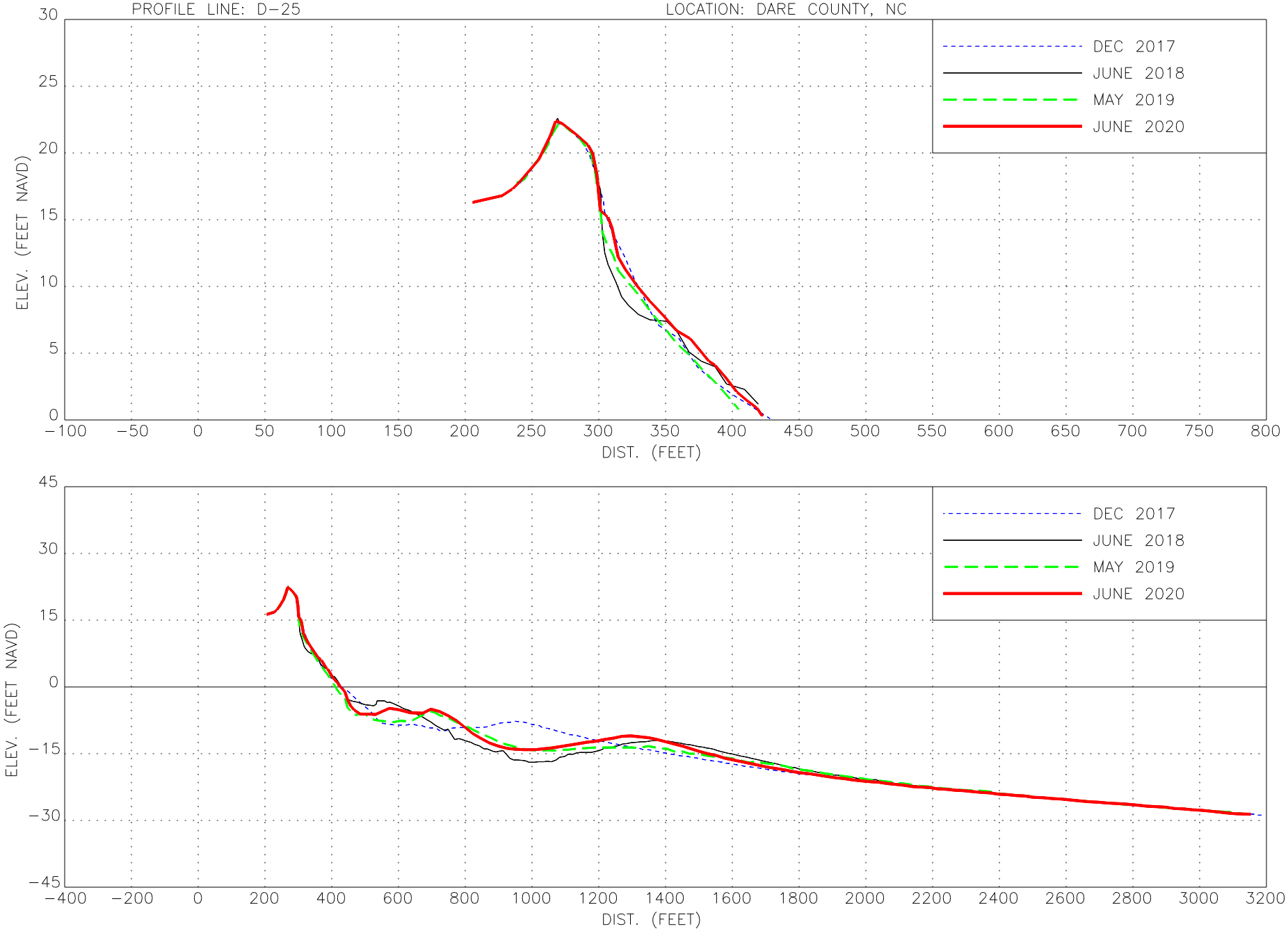
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MAY 2019
JUNE 2020
ELEV. (FEET NAVD)
DIST. (FEET)
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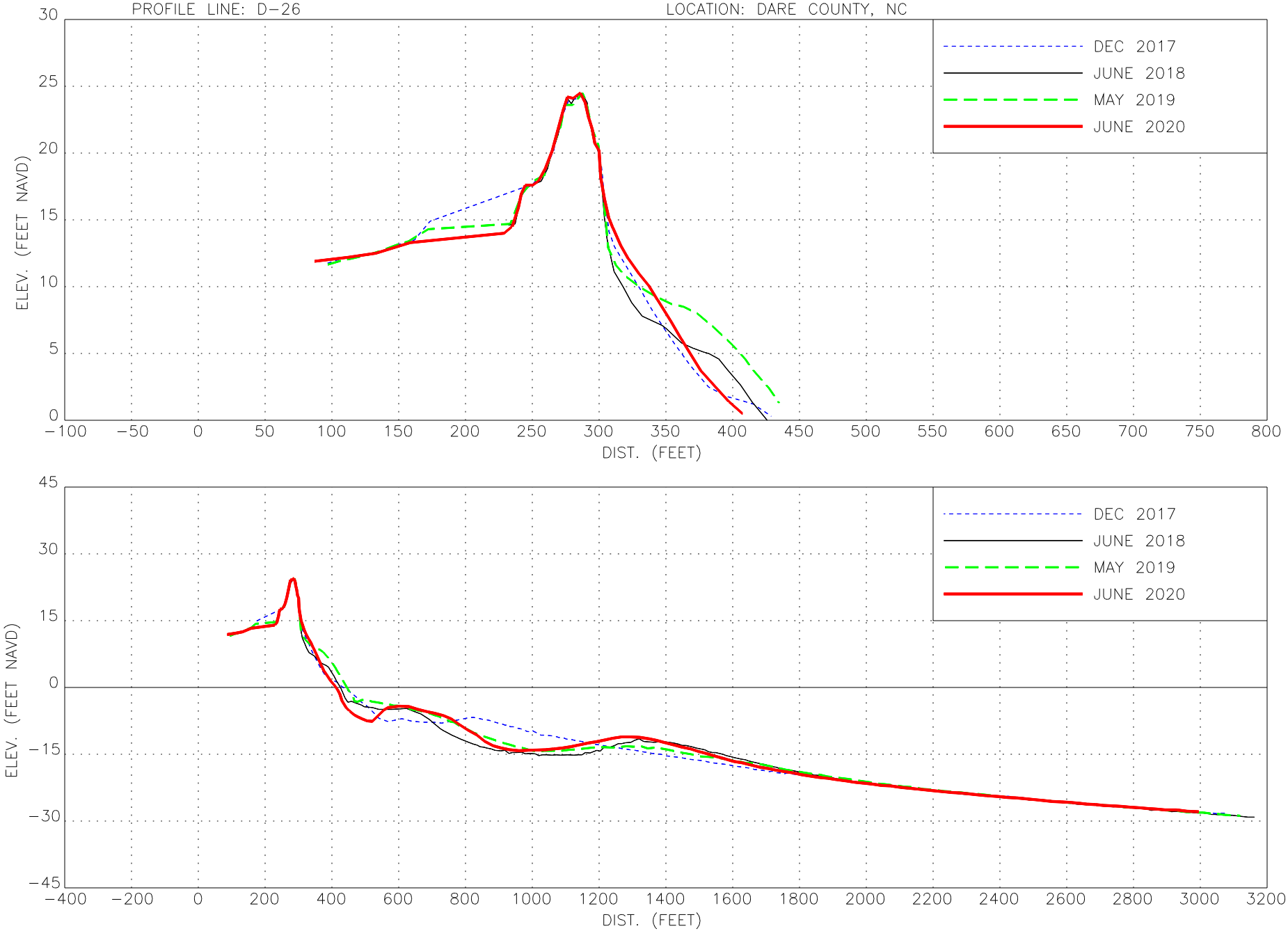
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LOCATION: DARE COUNTY, NC
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MAY 2019
JUNE 2020
ELEV. (FEET NAVD)
DIST. (FEET)
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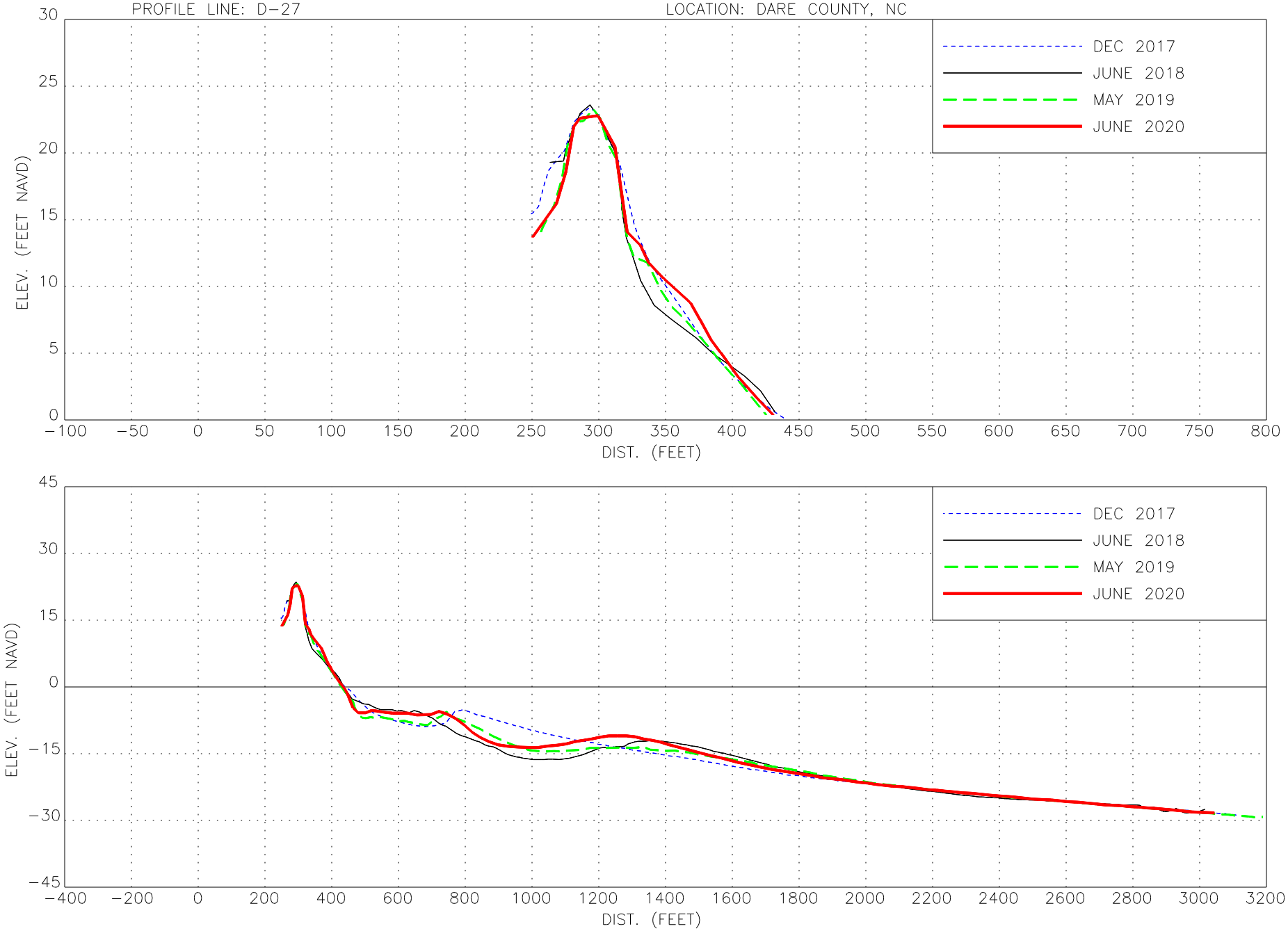
PROFILE LINE: D-27
LOCATION: DARE COUNTY, NC
DEC 2017
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MAY 2019
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ELEV. (FEET NAVD)
DIST. (FEET)
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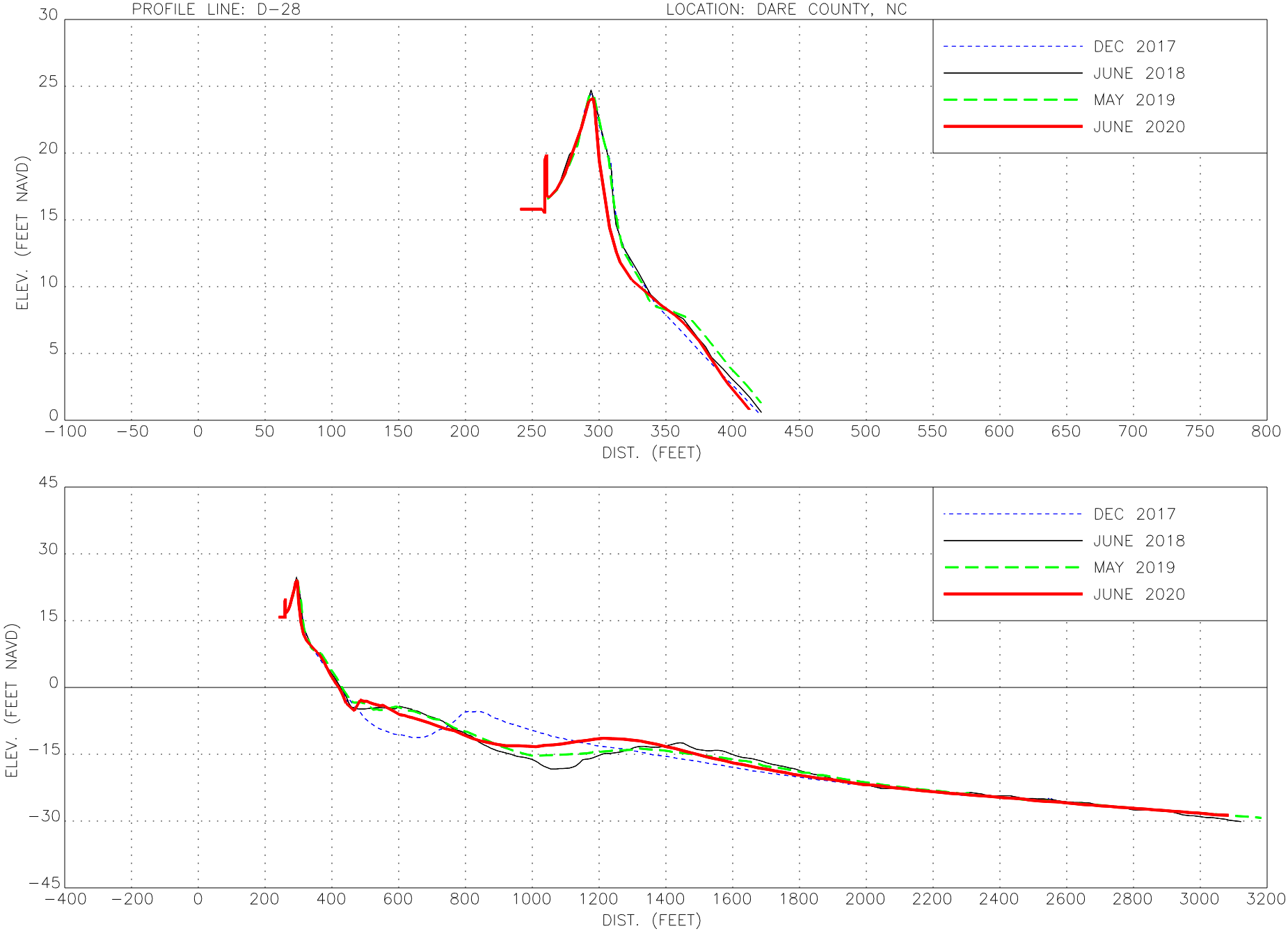
PROFILE LINE: D-28
LOCATION: DARE COUNTY, NC
DEC 2017
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MAY 2019
JUNE 2020
ELEV. (FEET NAVD)
DIST. (FEET)
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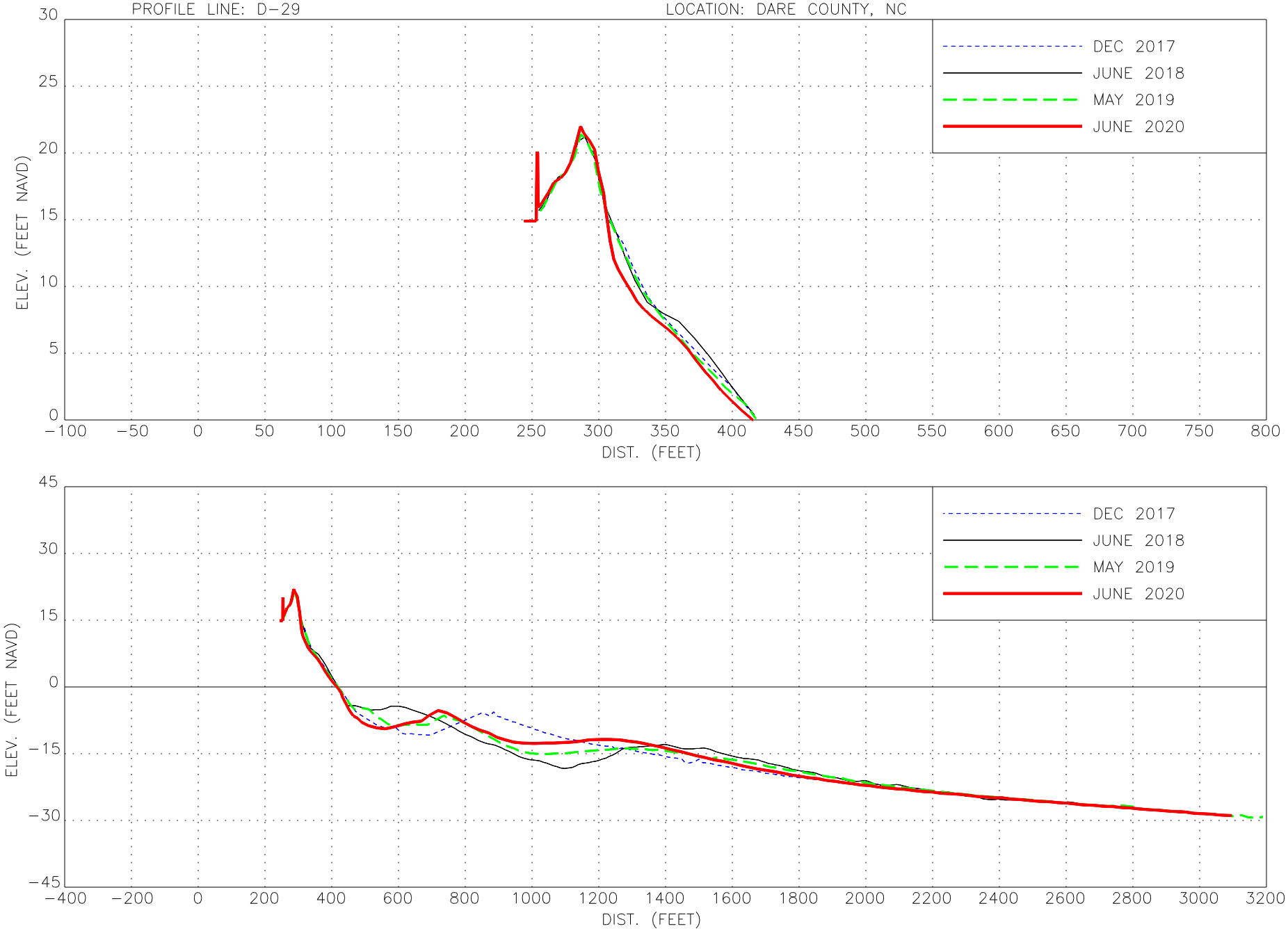
PROFILE LINE: D-29
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DEC 2017
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MAY 2019
JUNE 2020
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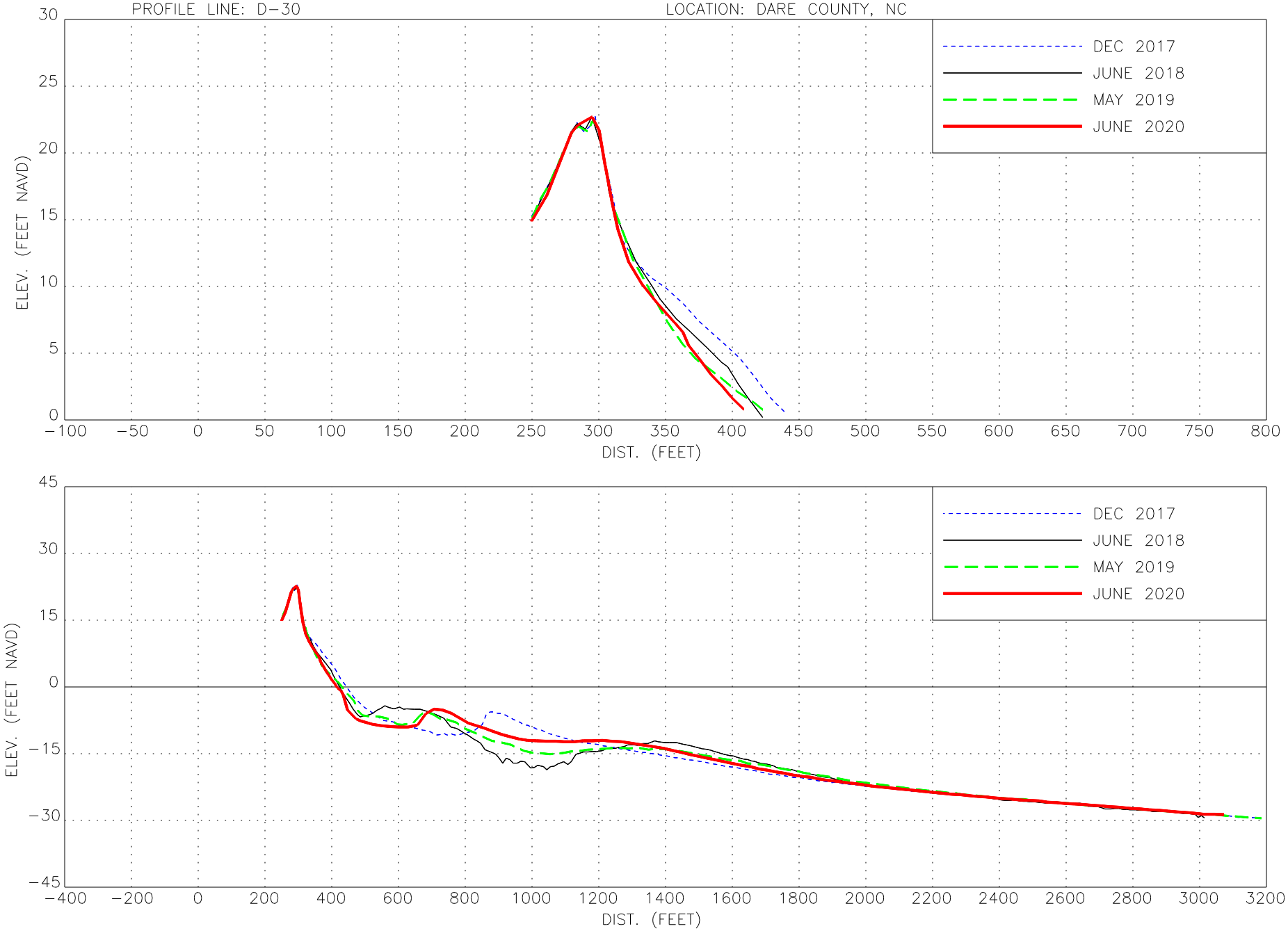
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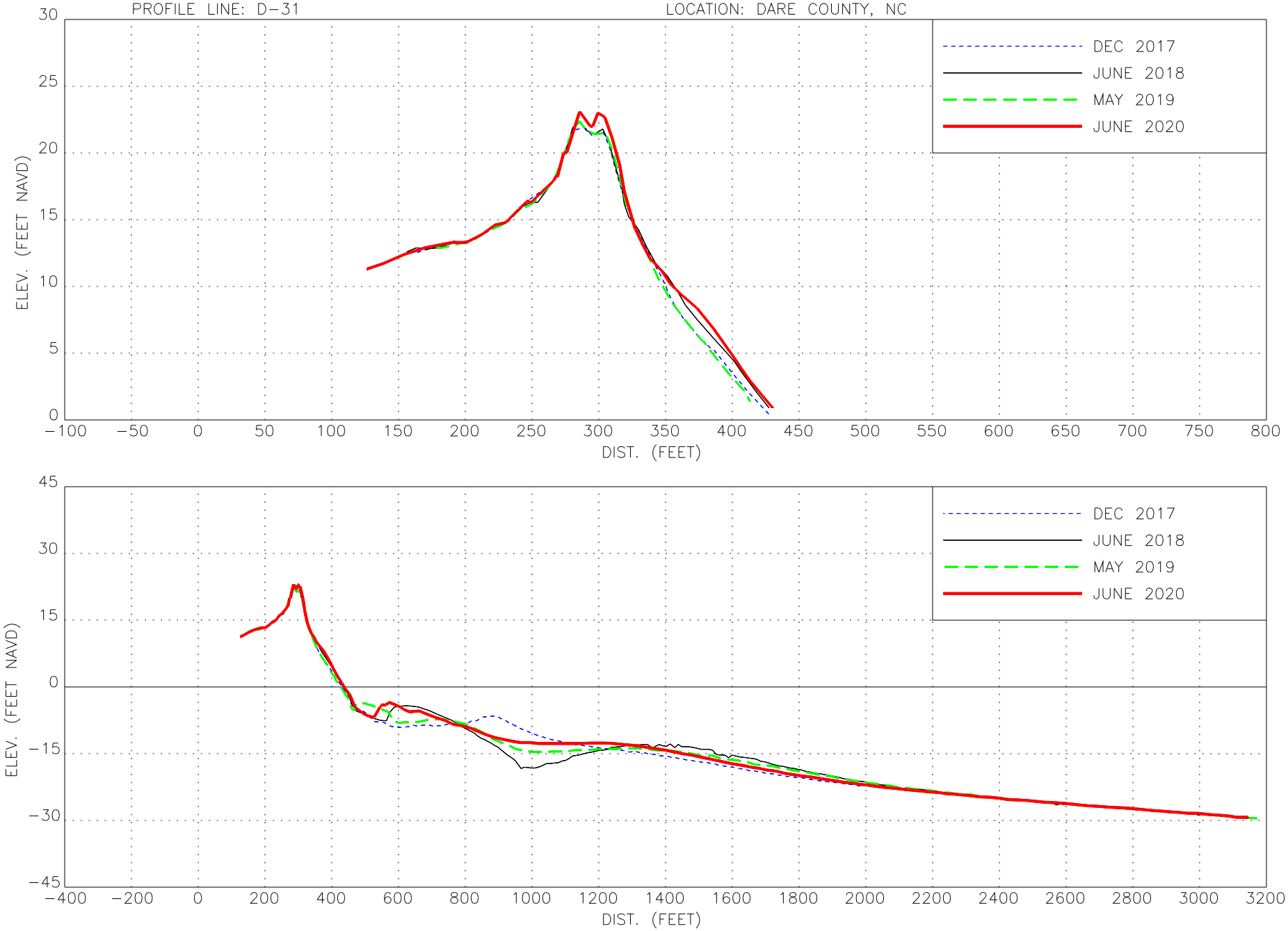
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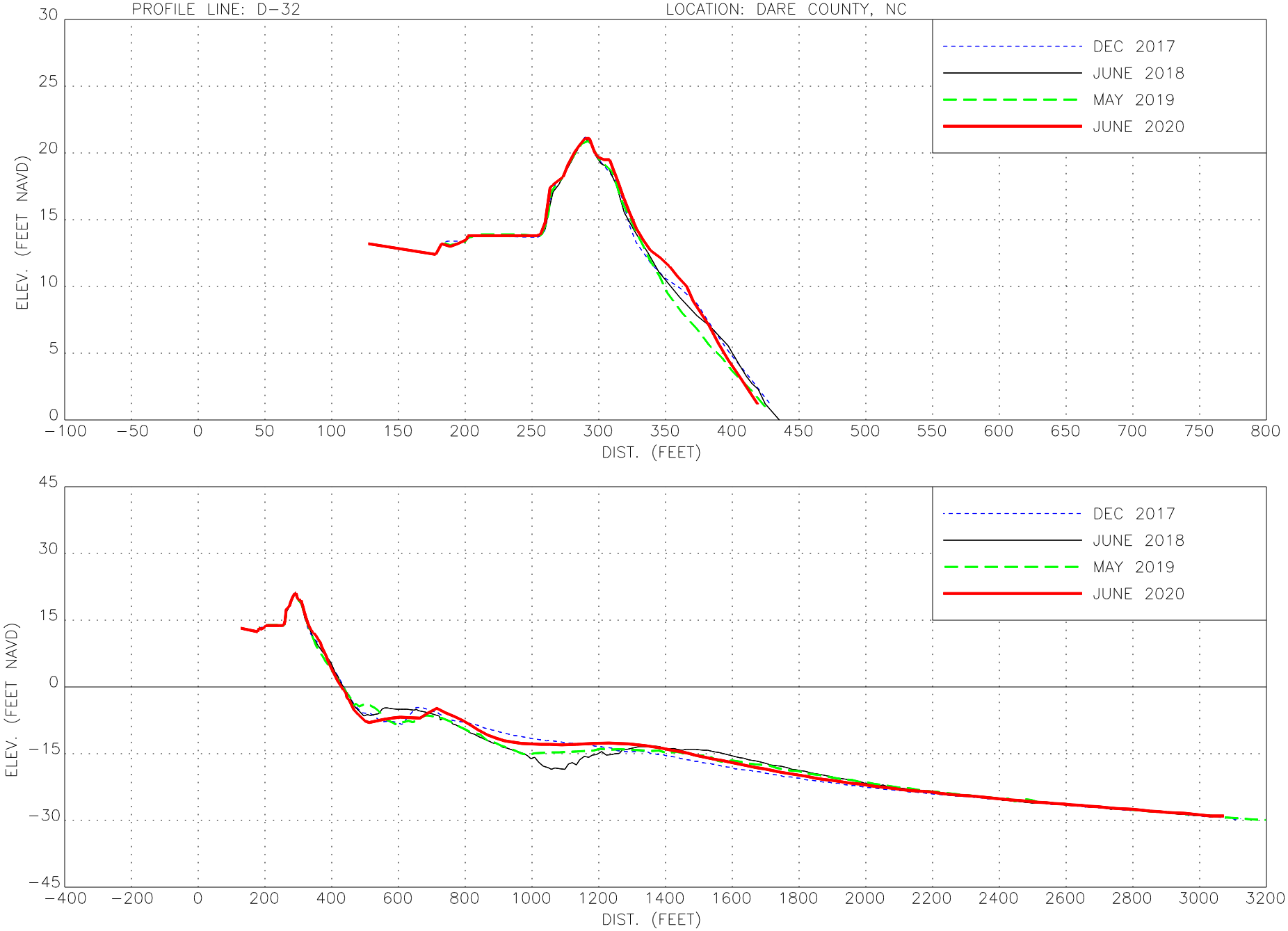
PROFILE LINE: D-32
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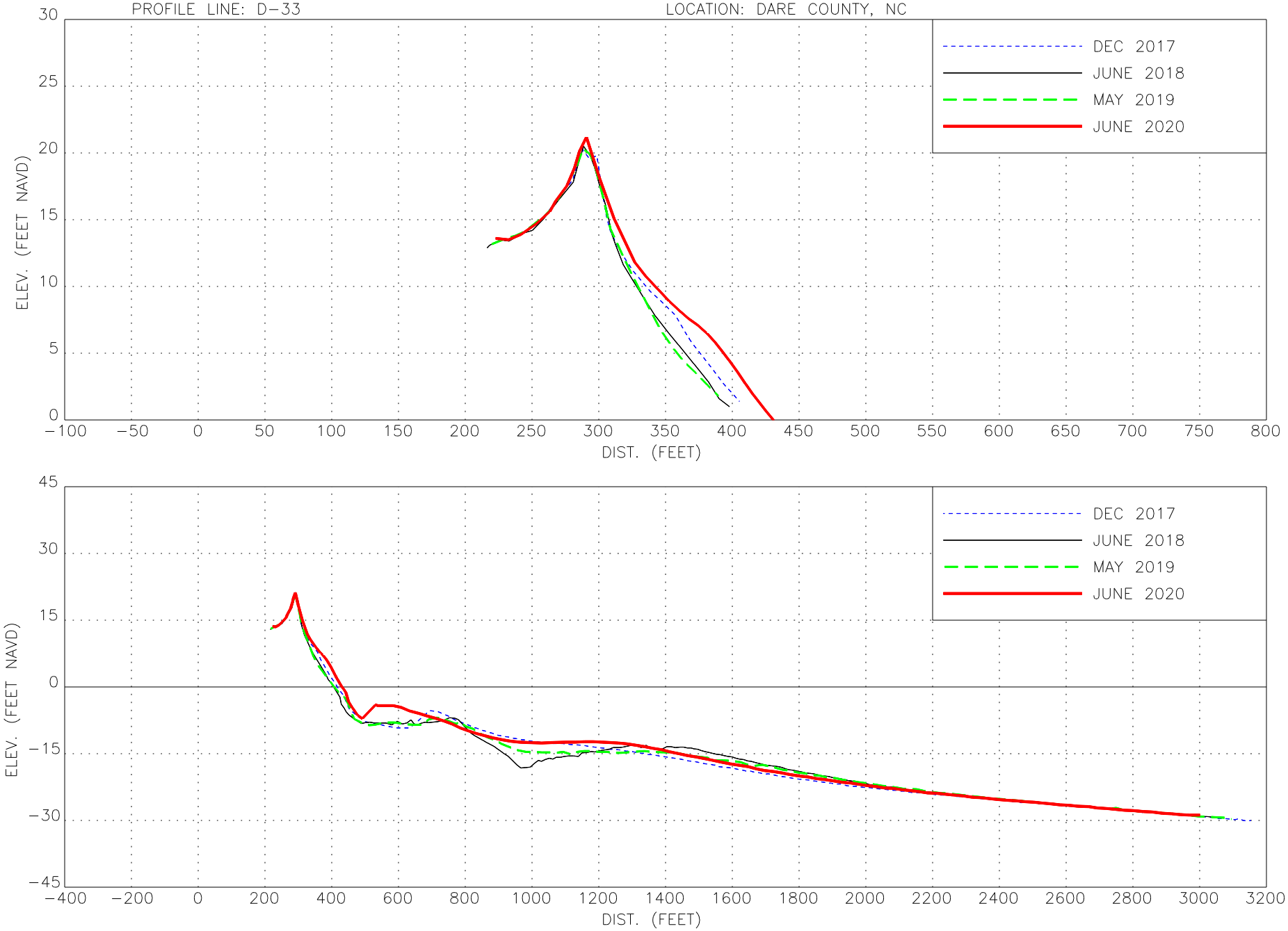
PROFILE LINE: D-33
LOCATION: DARE COUNTY, NC
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MAY 2019
JUNE 2020
ELEV. (FEET NAVD)
DIST. (FEET)
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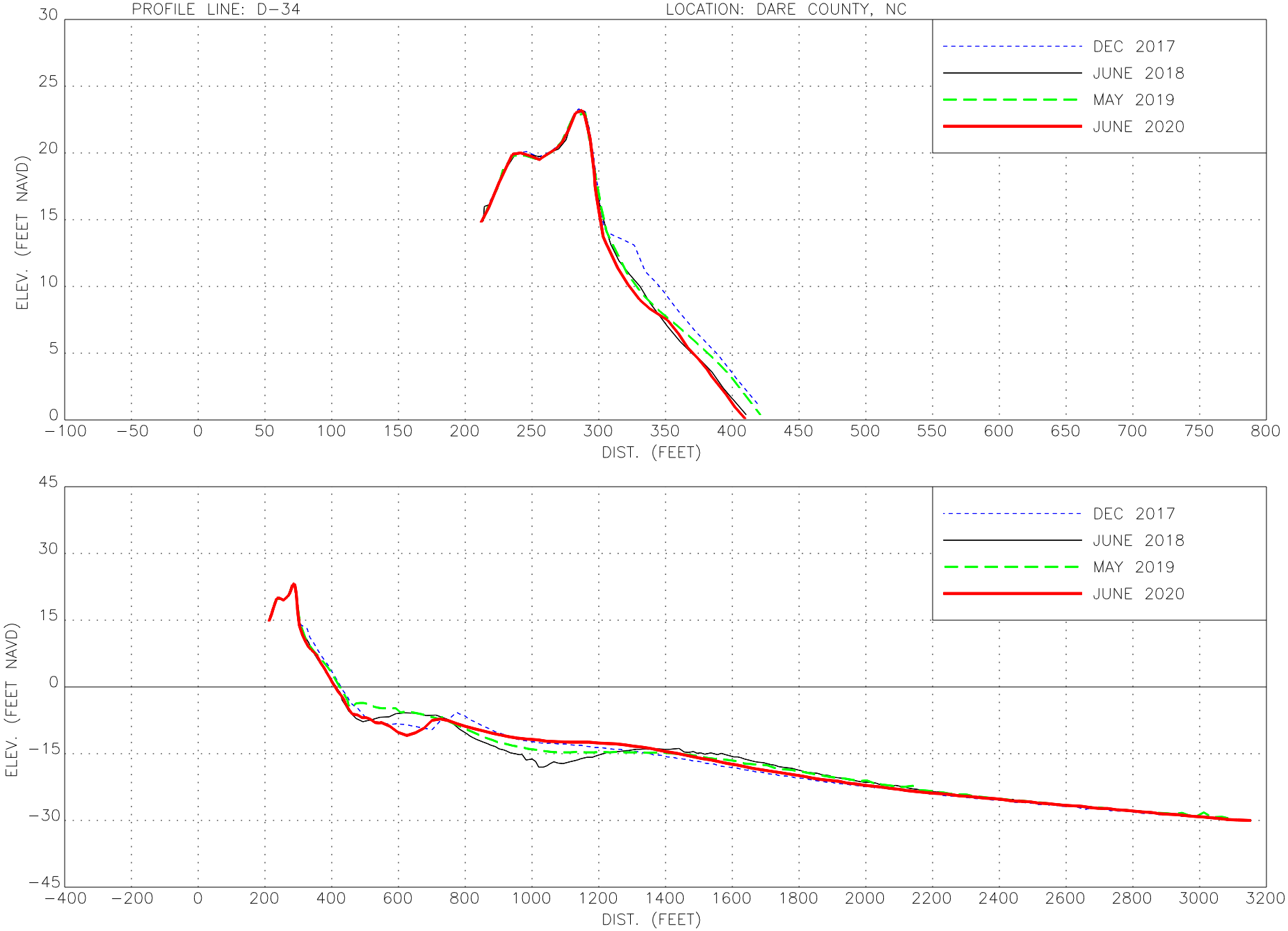
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APPENDIX 4

GROUND DIGITAL PHOTOGRAPHY

Ground Digital Photography
Monument

D-01

North View

South View

Landward View

Ground Digital Photography
Monument

D-02

North View

South View

Landward View

Ground Digital Photography
Monument

D-03

North View

South View

Landward View

Ground Digital Photography
Monument

D-04

North View

South View

Landward View

Ground Digital Photography
Monument

D-05

North View

South View

Landward View

Ground Digital Photography
Monument

D-06

North View

South View

Landward View

Ground Digital Photography
Monument

D-07

North View

South View

Landward View

Ground Digital Photography
Monument

D-08

North View

South View

Landward View

Ground Digital Photography
Monument

D-09

North View

South View

Landward View

Ground Digital Photography
Monument

D-10

North View

South View

Landward View

Ground Digital Photography
Monument

D-11

North View

South View

Landward View

Ground Digital Photography
Monument

D-12

North View

South View

Landward View

Ground Digital Photography
Monument

D-13

North View

South View

Landward View

Ground Digital Photography
Monument

D-14

North View

South View

Landward View

Ground Digital Photography
Monument

D-15

North View

South View

Landward View

Ground Digital Photography
Monument

D-16

North View

South View

Landward View

Ground Digital Photography
Monument

D-17

North View

South View

Landward View

Ground Digital Photography
Monument

D-18

North View

South View

Landward View

Ground Digital Photography
Monument

D-19

North View

South View

Landward View

Ground Digital Photography
Monument

D-20

North View

South View

Landward View

Ground Digital Photography
Monument

D-21

North View

South View

Landward View

Ground Digital Photography
Monument

D-22

North View

South View

Landward View

Ground Digital Photography
Monument

D-23

North View

South View

Landward View

Ground Digital Photography
Monument

D-24

North View

South View

Landward View

Ground Digital Photography
Monument

D-25

North View

South View

Landward View

Ground Digital Photography
Monument

D-26

North View

South View

Landward View

Ground Digital Photography
Monument

D-27

North View

South View

Landward View

Ground Digital Photography
Monument

D-28

North View

South View

Landward View

Ground Digital Photography
Monument

D-29

North View

South View

Landward View

Ground Digital Photography
Monument

D-30

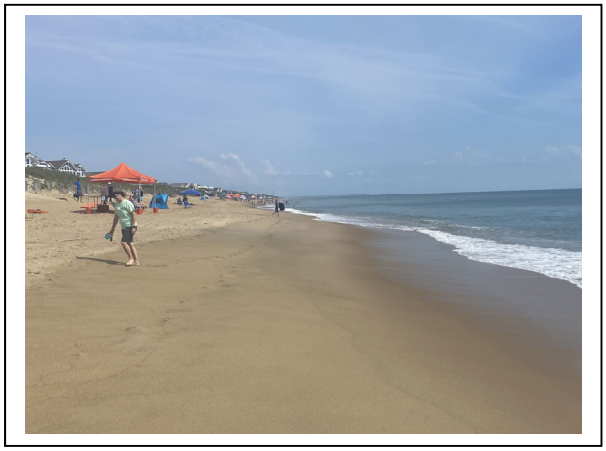
North View

South View

Landward View

Ground Digital Photography
Monument

D-31



North View

South View

Landward View

Ground Digital Photography
Monument

D-32

North View

South View

Landward View

Ground Digital Photography
Monument

D-33

North View

South View

Landward View

Ground Digital Photography
Monument

D-34/-197+12

North View

South View

Landward View

APPENDIX 5

FIELD BOOK PAGES
(Available in digital format only)