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Via Email

June 4, 2021
File No. 04.0190838.04

Mr. Tobey Reynolds, P.E.
Bureau of Highway Design – Roadway Design
New Hampshire Department of Transportation
5 Hazen Drive, P.O. Box 483
Concord, New Hampshire 03302-0483

RE: Conceptual Design Report
North Hampton-Rye 42312
NH 1A Coastal Revetment Resilience/Conceptual Design
New Hampshire Department of Transportation (NHDOT)
Geotechnical Services Contract: Statewide 41773

Dear Mr. Reynolds:

This report presents the results of the coastal revetment resilience study performed by GZA GeoEnvironmental, Inc. (GZA) for nine seawall/revetment sections along NH Route 1A between North Hampton and Rye (Sites). This study was completed in accordance with the conditions of engagement as described in our Geotechnical Services Statewide Agreement Number 41773 dated March 2, 2018; our Scope and Budget Estimate for Geotechnical Engineering Services dated May 16, 2019; and our Scope and Fee Amendment dated December 14, 2020. The contents of this report are subject to the *Limitations* set forth in **Appendix A**.

BACKGROUND, OBJECTIVES AND SCOPE OF SERVICES

NH Route 1A is a coastal roadway with multiple types of shoreline protection treatments ranging from concrete seawalls, mortar rubble masonry walls, and shale piles with stone facing (revetments). The focus of the study herein are nine sections of revetment, along 2.5 miles of coastline, between Odiorne Point and Little Boars Head. (See **Figure 1** below.) The revetment sections include:

Section 1.........	1,242 linear feet	beginning just south of Odiorne Point
Section 2.........	609 linear feet	continuing from Section 1
Section 3.........	1,750 linear feet	near Pulpit Rock to just north of Seal Rock
Section 4.........	846 linear feet	near Concord Point (south of Wallis Sands)
Section 5.........	1,813 linear feet	continuing from Section 4 to approx. Washington Rd/north of Foss Beach
Section 6.........	3,806 linear feet	continuing from Section 5 along Foss Beach
Section 7.........	959 linear feet	Philbrick's Beach to just north of Rye Ledge
Section 10.......	1,230 linear feet	Bass Beach (near Philbrick Pond)
Section 13.......	1,020 linear feet	south of Fox Hill Point to north of Little Boars Head

Figure 1: Shoreline Sections within the Project Scope

NH Rt 1A is identified as "the transportation asset most vulnerable to coastal flooding and disruption from sea-level rise" and "highly vulnerable…to storms" in the 2016 NH Coastal Risk and Hazards Commission's report, *Preparing New Hampshire for Projected Storm Surge, Sea-Level Rise, and Extreme Precipitation*. During coastal storm events, storm surge, wave and wave overtopping cause damage to the revetments resulting in road closures and post-storm cleanup operations. During the series of nor'easters in March 2018, wave overtopping of the revetments resulted in nearly four hours to 37.5 cumulative hours of road closures along the various revetment sections due to flooding and cleanup of stone displaced onto the roadway. **See Table 1** below.

TABLE 1: MARCH 2018 NH ROUTE 1A CUMULATIVE FULL ROADWAY CLOSURES ALONG REVETMENT SECTIONS*

Revetment Section	1	2	3	4	5	6	7	10	13
Cumulative Full Roadway Closure Time (Hours: Minutes)	3:52	3:52	3:52	23:52	23:52	16:56	15:55	37:36	37:36
Number of Full Roadway Closure Periods	1	1	1	4	4	4	4	8	8

* Data provided by NHDOT.

The damage resulting from the March 2018 storms led to an emergency declaration by the Federal Emergency Management Agency (FEMA). FEMA conducted site inspections of the revetments with NHDOT after the storms and issued their findings In November 2018. Subsequently, NHDOT engaged GZA for a coastal revetment resilience study to assess the vulnerability of the revetments and develop conceptual improvement recommendations with associated construction cost estimates. The focus of the conceptual recommendations was to limit post-storm roadway cleanup operations.

GZA's work effort for completing the coastal revetment resilience study included the following scope of work. GZA:

- Conducted site reconnaissance to document existing conditions at each revetment section including typical stone size, visual damage to the revetments, and coastal features of influence to the vulnerability assessment.
- Conducted field visits during the April 9th, 2020 storm event to observe wave conditions and overtopping.

Photograph 1: Revetment Section 5 During April 9, 2020 Storm

- Completed coastal flood hazards characterization through metocean data analysis and numerical wave modeling for the revetment sections.
- Completed risk-based vulnerability assessments of the existing revetment geometries and the 1978 record revetment geometries for current tidal conditions and storm recurrence intervals, projected sea level rise, and storm recurrence intervals.
- Developed conceptual revetment improvement recommendations and associated cost estimates.
- Completed milestone meetings with NHDOT's project team to discuss the project development and interim results.
- Supported the NHDOT project team with presenting the study results and recommendations to NHDOT's management team.
- Prepared this report summarizing the evaluation and recommendations.

EXISTING REVETMENT GEOMETRY

GZA developed base plans using NHDOT's survey data from November 2019. The NHDOT data was used to create contours from NH Route 1A to the approximate toe of the revetment on the ocean side. GZA supplemented this data with publicly available topographic LiDAR (2014 CMGP Post Sandy liDAR DEM published by USGS and downloaded from NH GRANIT) and bathymetric data (1998 NOAA Coastal Relief Model). Using the merged contours, approximate Mean Higher High Water, Mean Sea Level, and Mean Lower Low Water contours were incorporated into the base plans.

The base plans were interfaced with GZA's ArcGIS web application, The Coastal Engineering GeoTool™ (GeoTool), in order to provide access to geospatial data layers and real-time data collection and management during our field reconnaissance. The GeoTool allowed for collection of elevation spot shots and geo-referenced photographs and field notes with respect to a real-time view of the location on the base plans. To provide GZA with the capability to collect elevation data while in the field, the GeoTool™ was used in conjunction with Collector for ArcGIS, an ESRI (Environmental Systems Research Institute)-based mobile data collection application. A handheld Trimble R1 GNSS (Global Navigation Satellite System) receiver provided positioning information to a Bluetooth-connected mobile device, allowing the Collector application to provide positioning data with a three-foot to five-foot vertical accuracy.

Using the above-described data collection method, GZA completed field reconnaissance with a two-person field crew over three days between 18 February 2020 and 5 March 2020. GZA observed and documented existing slope conditions along the revetments. Specific data collected included revetment stone size and variation, apparent damage locations, and nearshore features that would likely influence storm surge, waves, and runup at each site. Georeferenced photographs were taken to document our observations. See **Attachment A** for a general summary of observed conditions for each revetment section.

Based on GZA's review of 1978 record drawings of the revetment sections and GZA's field observations, the existing revetment cross sections consist of a shale stone core with armor stone on the ocean side and exposed shale on the roadway side. At some of the sections, the armor stone extends across the crest. Where armor stone does not extend across the crest, the core shale stone is exposed. Armor stone sizes were visually approximated and visible damage was documented during the site reconnaissance.

Over the nine revetment sections, the crest elevation and armor stone sizes vary between revetments and within revetements. Crest elevations vary from +12 feet NAVD 88 to +21.7 feet NAVD 88. The estimated D_{50} stone sizes range between 14 inches and 8 feet depending on the revetment. **See Table 2** below for a general overview of the 1978 revetment sections. **Attachment A** provides the summary of the estimated D_{50} stone sizes.

TABLE 2: EXISTING REVETMENT CREST ELEVATIONS*

Revetment Section	Linear Feet		Crest EL Range	Average Crest EL
	Along NH RT 1A Stationing	Along Revetment Crest		
1	1,242	1,378	12.2–15.7	14.5
2	609	649	14.8–15.0	14.9
3	1,750	1,821	13.3–18.5	15.4
4	846	879	14.6-16.0	15.2
5	1,813	1,883	15.0-16.4	15.9
6	3,806	3,760	14.5 -17.6	16.4
7	959	941	17.0–17.7	17.2
10	1,230	1,187	19.0-20.6	20.1
13	1,020	1,000	13.7-21.7	18.3

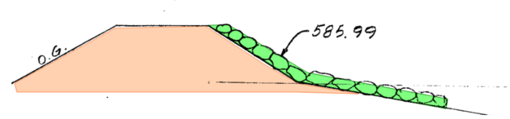
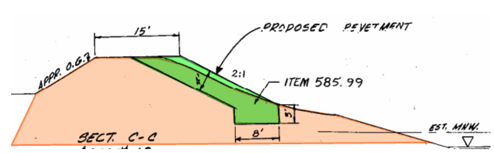
* Elevations in feet referenced to NAVD88.

1978 REVETMENT GEOMETRY

The revetment geometry for the 1978 conditions was based on available drawings for the "Emergency Relief – Storm of Feb 6-7, 1978." The drawings provided cross sections with information related to the crest and toe elevation. Not all elevations were explicitly called out in the archive drawings. Therefore, relative scaling was required to estimate some data. In addition, the stone size was not explicitly identified in the archive drawings and the archive project specifications are not available. Therefore, the 1978 conditions were based on the cross sections, estimated crest and toe elevations, and armor stone sizes assumed consistent with the existing stone observed during our site reconnaissance.

Based on the 1978 archive drawings, four of the shoreline sections were "stone blankets" with a single layer of facing stone over a shale stone core and a crest elevation of approximately 11.6 feet NAVD 88. The remaining five shoreline sections were "shale piles with treatment" consisting of a thicker layer of facing stone over a shale stone core, a keyed toe, and crest elevations between 15.0 and 21.5 feet NAVD88. **See Table 3** below for a general overview of the 1978 revetment sections.

TABLE 3: 1978 SHORELINE SECTIONS

Revetment Section	1978 Crest EL*	Total Linear Feet	1978 Revetment Section Type	Example 1978 Revetment Sections
1	11.6	1,242	Stone Blanket	
2	11.6	609	Stone Blanket	
3	16.0	1,750	Shale Pile Treatment	
4	11.8	846	Stone Blanket	Example Stone Blanket
5	11.8	1,813	Stone Blanket	
6	17.3	3,806	Shale Pile Treatment	
7	15.0	959	Shale Pile Treatment	
10	21.5	1,230	Shale Pile Treatment	
13	16.9	1,020	Shale Pile Treatment	Example Shale Pile Treatment

* Elevation in feet referenced to NAVD88.

OVERVIEW OF EVALUATION METHODS

GZA completed metocean data analysis and wave modeling for representative transects at each revetment section (See **Attachment B**). Using the analysis and modeling data, each revetment section was evaluated for five flood event annual exceedance probabilities including recurrence intervals: 1-year, 2-year, 10-year, 50-year, and 100-year. The annual exceedance probability flood (aka recurrence interval in years) represents the chance that the associated flood conditions (water levels and waves) will be met or exceeded at least once in any given year. A 1-year recurrence interval flood event has a near 100% chance of being met or exceeded in any given year. A 100-year recurrence interval flood event has a 1 in 100 (1%) chance of being met or exceeded at least once in any given year. GZA assumed for this study that flood water levels and waves are highly correlated; therefore, flood water level and wave probabilities are consistent. The water level and wave conditions associated with a recurrence interval today will change in the future due to sea level rise.

Applying the annual exceedance flood risk over a 25-year design life for a revetment provides the chance that flood water levels will be exceeded at least once over the service life. **Table 4** below summarizes the occurrence probabilities for a 25-year service life. Note that the effects of sea level rise will increase the probabilities of flood water levels and waves, which is not explicitly included in **Table 4**.

TABLE 4: FLOOD ENCOUNTER PROBABILITY - 25 YEAR DESIGN LIFE

Flood Recurrence Interval	Occurrence Exceedance Probability (over 25 years)
1-year	100 %
2-year	100 %
10-year	93 %
50-year	40 %
100-year	22 %

Numerical wave model simulations using the SWAN model were performed to evaluate nearshore and onshore wave transformation along the entire project site. Simulations were performed for representative flood scenarios (i.e., water levels, boundary condition waves and local wind fields). For each flood event recurrence interval, each revetment section was evaluated using the metocean data and numerical model results for both the existing revetment geometry and the 1978 revetment geometry. It should be noted that the shoreline morphology varies from bedrock promontories to pocket beaches along the various revetment sections. Within the surf zone, wave set-up, a condition where breaking wave momentum can increase stillwater elevations within the breaker zone, will vary along the different shoreline features and can locally affect breaking wave heights, wave run-up and overtopping. FEMA has predicted wave set-up for the 100-year recurrence interval flood event but not for other recurrence intervals. Wave set-up was considered in GZA's revetment evaluation where applicable.

Backwater flooding (floodwaters entering into the estuary and flooding the roadway from the estuary side) was also evaluated using non-hydrodynamic, GIS-based flood inundation simulations.

The revetment evaluations considered stability of the revetment slope, wave runup, wave overtopping, shale displacement potential, and roadway use impacts as highlighted below:

- Slope Stability: Based on comparison of the existing stone size with the minimum D_{50} stone size required for stability of the revetment slope (ocean side) for the incoming wave characteristics for the flood recurrence interval, in accordance with *Engineer Manual 1110-2-1100 - Coastal Engineering Manual* (U.S. Army Corps of Engineers, September 2011);
- Wave Runup: Based on comparison of the crest elevation with the wave run-up height above the stillwater flood elevation for the flood recurrence intervals, in accordance with the *Manual on Wave Overtopping of Sea Defences and Related Structures* (EurOtop Manual, 2018) and *Guidance for Flood Risk Analysis and Mapping Coastal Wave Runup and Overtopping* (FEMA, 2018);
- Wave Overtopping Impact: Based on the relationship between overtopping flowrate and impact to vehicular and pedestrian uses along NH Route 1A, in accordance with EurOtop Manual (2018), FEMA guidance; and the Coastal Engineering Manual; and

- Shale Displacement Potential: Based on recommended limits for wave overtopping flowrates for structural safety in the design of breakwaters, seawalls and grass sea-dikes per the EurOtop Manual (2018) and on the flowrates for structural safety of embankment seawalls and grass sea-dikes per Engineer Manual 1110-2-1100.

Consideration of these characteristics for each of the flood event recurrence intervals establishes the likely performance and susceptibility of the geometries for the revetment sections. Given the smaller shale stone size that comprises the existing revetment slope on the roadway side, flowrate of wave overtopping provides a predictor of the likelihood that the roadway will need post-event cleanup of the displaced smaller shale stone.

OVERVIEW OF THE RELATIVE SEA LEVEL RISE EVALUATION METHOD

Sea level rise is highly uncertain with several available sea level rise projections that are reflective of different assumptions around greenhouse gas emissions and other factors. The State of New Hampshire has developed guidance for the selection of a sea level rise projection based on the facility's risk tolerance. For this project, in consideration of the roadway use, the project team established that NH Route 1A is considered to have a low to medium tolerance for flood risk. With a low risk tolerance and a 25-year design service life for reconstruction of the revetments, the NH Coastal Flood Risk Summary Part II recommends +2-foot relative sea level rise (RSLR) by the year 2050. Therefore, the RSLR evaluation for the revetment sections reflect a sea level rise of 2 feet by the year 2050.

To evaluate the effects of storm flood events on the revetment (including environmental loads, wave run-up and wave overtopping), the 2050 antecedent water levels were linearly superimposed to the current flood stillwater levels (tidal water levels plus storm surge). These revised antecedent water levels were used with the SWAN numerical wave model to simulate wave heights for three flood recurrence intervals: 10-year, 50-year and 100-year. These three flood recurrence intervals were determined to be the most relevant for evaluating the potential impacts to the revetment and post-storm cleanup requirements anticipated along NH Route 1A.

For each of the flood recurrence intervals, the existing geometry and the 1978 geometry of each revetment section were evaluated for potential damage to the revetment and potential use impacts to the roadway. For a comparative analysis, the following evaluations were completed:

- Comparison of existing D_{50} stone size on the ocean side to the calculated D_{50} estimated stone size required for the revised wave height. The calculated D_{50} was based on both the Hudson (CERC, 1984) and Van der Meer (1988) approaches to estimate the maximum D_{50} and minimum D_{50}, respectively. The larger size D_{50} estimated from Hudson was carried forward for conceptual evaluations.
- Occurrence of wave overtopping and flowrate impacts to vehicular use along NH Route 1A.
- Occurrence of wave overtopping and flowrate impacts to pedestrian use along NH Route 1A.
- Occurrence of wave overtopping and flowrate impacts resulting in displacement of shale stone from the crest and roadway slope of the revetment.
- Potential for backwater flooding and impacts to NH Route 1A.

The RSLR evaluation used the same approach and methods as were used for the evaluations of the existing geometry and the 1978 geometry without sea level rise.

SUMMARY OF EVALUATION RESULTS

NH Route 1A, along the revetment sections evaluated, is vulnerable to flooding and/or revetment damage from storm events. This includes:

- Incident waves impacting armor stone stability;
- Wave runup and overtopping, causing:
  - Piping and erosion along the revetment crest;
  - Erosion and displacement of the small diameter stone shale;
  - Piping at the backside splash zone; and
  - Overwash deposition of the stone shale (predominantly) and armor stone (rarely), resulting in significant storm and post-storm deposition of shale in the roadway.
- Backwater roadway flooding from the estuary side, as noted above. In addition, flood water can reach the roadway through access breaks in the revetment. These two vulnerabilities were not specifically within the scope of the evaluations but were noted by GZA during elevation-based flood inundation simulations and review of photographs and videos from storm events.

The degree of revetment vulnerability varies for each section of revetment, and within each section, based on the exposure conditions and revetment geometry. However, each revetment section has similar conditions which have affected their integrity and performance. Multiple storm events have displaced the armor stone on the ocean side of the existing revetments. Displaced armor stone reduces the stability and effectiveness of the revetment and increases its vulnerability to subsequent storms/wave loads. The revetment stability is further compromised by the lack of filtration beneath the existing armor stone. The lack of a filtration layer contributes to piping and erosion of the revetment material which deteriorates the foundation for the armor stone. Further, at certain locations, the existing armor stone is undersized relative to the wave loads.

In terms of roadway impact, the most significant vulnerability is the erosion and displacement of the shale material on the revetment crest and backslope (roadway side). Wave runup and overtopping result in flow velocities that exceed the stability of the shale material, which leads to erosion of the crest and backslope, scour, and deposition of the shale as overwash in the roadway. Evidence of each of these vulnerabilities existed after the March 2018 storms. See **Photographs 2 through 4** below.

Photograph 2: Evidence of Revetment Damage After March 2018 Storms

Photograph 3: Evidence of Shale Damage from Wave Overtopping After March 2018 Storms

Photograph 4: Stone Overwash Cleanup After March 2018 Storms

In general, the existing revetment geometries provide marginally better performance than the 1978 geometries with respect to armor stone size and overtopping impacts for current water levels and the flood recurrence intervals. The existing crest elevation combined with the slope of the ocean side slope of the revetments offer more protection of NH Route 1A than the 1978 geometries at all of the revetment sections except for Section 6 and Section 10. The 1978 crest elevations at Section 6 and Section 10 are approximately 1-foot and 1.5-feet higher, respectively, than the average existing crest elevation (See **Table 5**), which reduces wave overtopping impacts. However, under RSLR conditions, the existing geometries and the 1978 geometries have similar performances with overtopping impacts over essentially 100% of the revetment lengths for each flood recurrence interval with few exceptions. See **Attachment C**, **Attachment D**, and the summaries below for the assessment parameters.

TABLE 5: COMPARISON OF REVETMENT CREST ELEVATIONS

Revetment Section	1978 Crest EL	Average Existing Crest EL	Ave. Exist. Crest EL Higher than 1978 Crest EL?
1	11.6	14.5	Yes
2	11.6	14.9	Yes
3	16.0	15.4	No
4	11.8	15.2	Yes
5	11.8	15.9	Yes
6	17.3	16.4	No
7	15.0	17.2	Yes
10	21.5	20.1	No
13	16.9	18.3	Yes

* Elevation in feet referenced to NAVD88.

Slope Stability Evaluation: Revetment stability for the existing geometries and the 1978 geometries was evaluated for the wave conditions and ocean side slope of each revetment section. The estimated design D_{50} stone size varies by section and by flood event recurrence interval for both the current water levels and the RSLR water levels. See **Table 6** for comparisons for the existing revetment geometries and **Table 7** for comparisons for the 1978 revetment geometries. Overall, the average existing D_{50} stone is undersized for current water levels with the 50-year and 100-year flood recurrence intervals and for RSLR with the 10-year through 100-year flood recurrence intervals. Calculated D_{50} stone larger than existing D_{50} stone are shaded blue in the table. Note that the calculated average D_{50} stone size for the 1978 geometries is generally larger than or the same as for the existing geometries, as identified by italicized values in Table 7.

TABLE 6: ESTIMATED EXISTING D_{50} STONE SIZE COMPARED TO CALCULATED DESIGN D_{50} STONE SIZE FOR EXISTING GEOMETRY

Revetment Section	Est. Average Exist. D_{50} (ft) *	Flood Recurrence Interval & Average Calculated Design D_{50} (ft)†					
		10-year	50-year	100-year	10-year + RSLR	50-year + RSLR	100-year + RSLR
1	3	2.5	3.0	3.5	4.0	4.5	4.5
2	3	3.0	3.5	4.0	4.5	5.0	5.5
3	4	5.0	5.0	5.0	6.0	8.0	8.0
4	6	3.5	4.0	4.5	5.5	6.0	6.5
5	3	4.5	5.0	5.5	6.5	7.0	7.5
6	4	4.0	4.0	4.5	5.5	6.0	6.5
7	4	4.0	4.5	4.5	5.5	6.0	6.0
10	5	5.0	5.5	6.0	6.5	7.5	8.0
13	2	4.5	4.5	5.0	6.0	6.0	6.5

* Existing estimated D_{50} stone sized based on visual observations.
† Average calculated D50 stone size based on Hudson (CERC, 1984) and round to nearest 0.5 foot.

TABLE 7: ESTIMATED EXISTING D_{50} STONE SIZE COMPARED TO CALCULATED DESIGN D_{50} STONE SIZE FOR 1978 GEOMETRY

Revetment Section	Est. Average Exist. D_{50} (ft) *	Flood Recurrence Interval & Average Calculated Design D_{50} (ft)†					
		10-year	50-year	100-year	10-year + RSLR	50-year + RSLR	100-year + RSLR
1	3	*3.0*	*4.0*	*4.0*	*5.0*	*5.5*	*6.0*
2	3	*4.0*	*4.5*	*5.0*	*6.0*	*6.5*	*7.0*
3	4	*6.0*	*5.5*	*6.0*	*7.0*	*9.0*	*9.0*
4	6	*3.5*	*4.0*	4.0	*5.5*	*6.0*	*6.5*
5	3	*4.5*	*5.0*	5.5	*6.5*	*7.0*	*7.5*
6	4	3.5	*4.0*	4.0	5.0	5.5	6.0
7	4	*4.0*	*4.5*	*5.0*	*5.5*	*6.0*	*6.5*
10	5	4.5	5.0	5.0	6.0	6.5	6.5
13	2	*4.5*	*5.0*	*5.5*	*6.0*	*6.5*	*7.0*

* Existing estimated D_{50} stone sized based on visual observations.
† Average calculated D50 stone size based on Hudson (CERC, 1984) and round to nearest 0.5 foot. Italicized entries indicate the stone size is larger than or equal to the corresponding condition in Table 6 for the existing revetment geometries.

Wave Runup Evaluation: The wave runup elevations for the flood recurrence intervals evaluated generally are higher than both the existing crest elevations and the 1978 crest elevations over a greater percentage of the revetment length for the northern revetment sections under current water levels. However, under RSLR conditions, the wave runup elevations exceed the existing and the 1978 crest elevations over essentially 100% of the revetment lengths for each flood recurrence interval with few exceptions. See **Table 8** and **Table 9** below. Where the wave runup elevation exceeds the revetment crest elevation, overtopping occurs with potential for erosion of the exposed shale stone and roadway use impacts.

TABLE 8: WAVE RUNUP ELEVATION VS REVETMENT CREST ELEVATIONS - FOR EXISTING GEOMETRY

Revetment Section	Percentage of Linear Feet of Revetment with Wave Runup Elevation Greater than Crest Elevation*					
	Flood Recurrence Interval					
	10-yr	50-yr	100-yr	10-year + RSLR	50-year + RSLR	100-year + RSLR
1	-	40	40	91	100	100
2	-	55	79	100	100	100
3	66	66	66	92	100	100
4	14	14	14	100	100	100
5	68	85	85	100	100	100
6	11	19	60	100	100	100
7	-	-	81	100	100	100
10	20	20	20	80	100	100
13	11	11	11	64	100	100

* Where the overtopped length of revetment is 50% or greater, the percentage is shaded.

TABLE 9: WAVE RUNUP ELEVATION VS REVETMENT CREST ELEVATIONS - FOR 1978 GEOMETRY

Revetment Section	Percentage of Linear Feet of Revetment with Wave Runup Elevation Greater than Crest Elevation*					
	Flood Recurrence Interval					
	10-yr	50-yr	100-yr	10-year + RSLR	50-year + RSLR	100-year + RSLR
1	100	100	100	100	100	100
2	100	100	100	100	100	100
3	75	92	92	92	100	100
4	100	100	100	100	100	100
5	100	100	100	100	100	100
6	-	-	52	100	100	100
7	100	100	100	100	100	100
10	-	-	-	-	80	100
13	-	100	100	100	100	100

* Where the overtopped length of revetment is 50% or greater, the percentage is shaded.

Overtopping Impacts to NH Route 1A: Overtopping impacts to vehicular and pedestrian uses along NH Route 1A were evaluated based on wave overtopping flowrates. Note that NH Route 1A impacts resulting from backwater flooding are not considered because they are not within the scope of this project. Based on the evaluation of the overtopping flowrates, when overtopping occurs it results in unsafe driving conditions along NH Route 1A. Unsafe driving conditions includes driving at any speed and driving at high speed (for consideration of emergency response vehicles) as defined by the Coastal Engineering Manual.

For the 10-year, 50-year and 100-year flood recurrence intervals and current water levels, the existing revetment geometry has less overtopping impacts than the 1978 revetment geometry at all revetment sections except for Section 10. (Section 10 is the only revetment section for which the 1978 crest elevation is higher than the minimum existing crest elevation over the revetment length.) Unsafe driving occurs along all of the revetment sections except for Sections 1, 2, 7 and 10 for the 10-year flood recurrence interval. Driving conditions become unsafe at Sections 1, 2 and 10 with the 50-year flood recurrence interval and unsafe at Section 7 with the 100-year flood recurrence interval. Under RSLR conditions, roadway use becomes unsafe over the majority of the revetments for the 10-year flood recurrence interval and over 100% of the revetement lengths for the 50-year and 100-year flood recurrence intervals. See **Attachments C and D**.

Shale Displacement Potential: With all of the revetment sections having exposed shale stone on the backside slope (roadway side) and exposed shale stone over at least part of the crest, wave overtopping has potential to displace the shale stone and require post-event roadway clean-up. Based on the evaluation criteria for overtopping flowrates for which likely displacement of the exposed shale will occur, the existing revetment geometries under current water levels for the 10-year flood recurrence interval would be expected to perform well. Only Section 3 and Section 13 had results suggesting shale displacement. However, the results show increasing shale displacement for the 50-year and 100-year flood recurrence intervals for the current water levels and significantly greater potential under RSLR. The results suggest the majority of the existing revetment geometries have shale stone displace over their full lengths under the RSLR flood recurrence intervals. See **Attachment D**.

CONCEPTUAL IMPROVEMENT RECOMMENDATIONS

Based on the results of the coastal vulnerability evaluation and site reconnaissance for each of the revetment sections, GZA recommends reconstruction of the revetments to mitigate overtopping impacts and improve armor stone stability. With the expectation that significantly elevating the crest elevation is not practical or feasible, it is GZA's opinion that the reconstructed revetment should have a crest elevation of at least the maximum existing crest elevation at each section, or the 1978 crest elevation where the 1978 elevation is higher. In addition, it is recommended that the revetment sections be modified such that the shale stone core is not exposed on the crest or backslope (roadway side) to avoid material loss due to overtopping.

A conceptual revetment cross-section for each revetment section is included in **Attachment E**. The conceptual cross-sections represent engineered revetments consisting of core stone, geotextile, filter stone, and armor stone on the ocean side, crest, and backslope (roadway side). The development of the cross-sections considered the following parameters:

- Crest elevation set at the greater of the existing crest elevation and the 1978 crest elevation.
- Crest width similar to existing conditions, including a pedestrian walkway if one currently exists.
- Ocean side slope of 2.0 to 2.5 horizontal to 1 vertical with a toe location approximately similar to existing conditions to limit additional regulatory permitting considerations.

- Ocean side armor stone sized for wave conditions and stability based on the 100-year flood occurrence interval + 2 feet of sea level rise. Armor stone specifically placed for interlocking and roughness to dissipate wave energy.
- Backslope of 1.5 to 2.0 horizontal to 1 vertical with a toe location approximately similar to existing locations to maintain NH Route 1A shoulder width and drainage provisions.
- Backslope stone equivalent to NHDOT Class III riprap to protect the shale core from displacement from wave overtopping flow rates.

While the conceptual revetment cross-sections will reduce the duration of roadway closures and post-storm cleanup-up/maintenance, they will not reduce the frequency of roadway flooding. Flooding would occur during storm events with wave overtopping and backwater flooding (floodwaters entering into the estuary and flooding the roadway from the estuary side). The intent of the revetment reconstruction is to mitigate erosion and displacement of the shale core, and improve the armor stone stability to provide increased resiliency of the overall revetment structure and decreased maintenance requirements including restoration following storm events.

CONCEPTUAL CONSTRUCTION COST ESTIMATE

Conceptual construction cost estimates were developed assuming 70% of the existing armor stone and 70% of the existing shale core are suitable for reuse in the revetment reconstruction. Material costs were based on GZA's database of revetment and breakwater construction projects and NHDOT's weighted average unit price data. The cost estimates carry a provision for access which is intended to consider construction access via a temporary access road on/adjacent to the revetment and/or traffic control for work zone safety and access. For the conceptual status of the recommendation, a 25% contingency is included in the construction cost estimates. The cost estimates do not include design related field services, engineering fees, regulatory permitting, or coordination with FEMA. **Table 10** below provides the overall conceptual construction costs summary. See **Attachment F** for a cost estimate breakdown by revetment section.

In consideration of FEMA cost recovery for the March 2018 declaration, construction cost estimates for reconstructing the revetment to in-kind conditions were also developed. In-kind conditions were considered as the conceptual reconstruction cross sections with the shale core exposed on the backslope and the crest similar to the 1978 as-built record drawings. Where armor stone extends over the existing crest, the in-kind cross section includes crest armor stone. The total project conceptual construction cost for all nine revetment sections is approximately $17,000,000 less than the recommended full reconstruction revetment concept. **Table 10** below provides an overall conceptual construction costs summary. See **Attachment E** for an example in-kind replacement cross section. See **Attachment F** for a cost estimate breakdown by revetment section.

TABLE 10: REVETMENT RECONSTRUCTION – CONCEPTUAL CONSTRUCTION COST ESTIMATES*

Revetment Section	Full Reconstruction with Crest and Backslope Armor Stone	Full Reconstruction with Exposed Shale on the Crest and Backslope Similar to 1978
1	$5.5M to $6.5M	$3.5M to $4.5M
2	$2.5M to $3.5M	$1.5M to $2.5M
3	$10.5M to $11.5M	$7.5M to $8.5M
4	$3.5M to $4.5M	$2.0M to $3.0M
5	$8.5M to $9.5M	$6.5M to $7.5M
6	$17.5M to $18.5M	$13.5M to $14.5M
7	$3.5M to $4.5M	$2.5M to $3.5M
10	$7.0M to $8.0M	$5.5M to $6.5M
13	$4.5M to $5.5M	$3.5M to $4.5M
Total	**$63M to $72M**	**$46M to $55M**

* This conceptual cost estimate is for general planning purposes for reconstruction of revetment sections along NH Route 1A. Actual cost may vary depending on the project phasing, when the work is completed, labor and material costs and the waterfront marine construction bid environment. See Appendix A for limitations.

CLOSING

We appreciate the opportunity to work with you on this project, and we would be pleased to work with you as the department coordinates with FEMA and moves towards final design. In the meantime, if you have any questions regarding the information contained in this report or require additional information, please contact us.

Very truly yours,
GZA GEOENVIRONMENTAL, INC.

Cheryl W. Coviello, P.E., D.PE
Senior Project Manager

David G. Lamothe, P.E.
Associate Principal

Daniel C. Stapleton, P.E.
Consultant/Reviewer

CWC/DGL/DCS:
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Attachments:

Appendix A - Limitations
Attachment A – Revetment Sections Observed Conditions February – March 2020
Attachment B – Metocean Data Analysis and Wave Modeling
Attachment C – Summary Tables: Existing Revetments Wave Runup & Roadway Use Impacts
Attachment D – Summary Tables: Existing and 1978 Revetments Compiled Impacts for Current Water Levels and Projected Relative Sea Level Rise
Attachment E – Conceptual Revetment Reconstruction Cross Sections with Crest and Backslope Armor Stone
Attachment F – Conceptual Construction Cost Estimates

Appendix A – Limitations

LIMITATIONS

Use of Report

1. GZA GeoEnvironmental, Inc. (GZA) prepared this report on behalf of, and for the exclusive use of our Client for the stated purpose(s) and location(s) identified in the Proposal for Services and/or Report. Use of this report, in whole or in part, at other locations, or for other purposes, may lead to inappropriate conclusions; and we do not accept any responsibility for the consequences of such use(s). Further, reliance by any party not expressly identified in the agreement, for any use, without our prior written permission, shall be at that party's sole risk, and without any liability to GZA.

Standard of Care

2. GZA's findings and conclusions are based on the work conducted as part of the Scope of Services set forth in GZA's Proposal for Services and/or Report, and reflect our professional judgment. These findings and conclusions must be considered not as scientific or engineering certainties, but rather as our professional opinions concerning the limited data gathered during the course of our work. If conditions other than those described in this report are found at the subject location(s), or the design has been altered in any way, GZA shall be so notified and afforded the opportunity to revise the report, as appropriate, to reflect the unanticipated changed conditions.

3. GZA's services were performed using the degree of skill and care ordinarily exercised by qualified professionals performing the same type of services, at the same time, under similar conditions, at the same or a similar property. No warranty, expressed or implied, is made.

Cost Estimates

4. Unless otherwise stated, our opinions of cost are only for comparative and general planning purposes. These opinions are based on the limited data and the conditions and assumptions described in the Report. The cost estimates may involve approximate quantity evaluations and are not intended to be sufficiently accurate to develop construction bids, or to predict the actual cost of work addressed in the Report. Further, since we have no control over when the work will take place nor the labor and material costs required to plan and execute the anticipated work, our cost opinions were made by relying on our experience, the experience of others, and other sources of readily available information. Actual costs may vary over time and could be significantly more, or less, than stated in the Report.

5. Cost opinions presented in the Report are based on a combination of sources and may include published RS Means Cost Data; past bid documents; cost data from federal, state or local transportation agency web sites; discussions with local experienced contractors; and GZA's experience with costs for similar projects at similar locations. GZA did not attempt to independently verify the accuracy or completeness of all information reviewed or received during the course of this evaluation. Actual costs will likely vary depending on the quality of materials and installation; manufacturer of the materials or equipment; field conditions; geographic location; access restrictions; phasing of the work; subcontractors mark-ups; quality of the contractor(s); project management exercised; and the availability of time to thoroughly solicit competitive pricing. In view of these limitations, the costs presented in the Report should be considered "order of magnitude" and used for budgeting and comparison purposes only. Detailed quantity and cost estimating should be performed by experienced professional cost estimators to evaluate actual costs. The opinions of cost in the Report should not be interpreted as a bid or offer to perform the work. Unless stated otherwise, all costs are based on present value.

6. The opinion of costs is based only on the quantity and/or cost items identified in the Report, and should not be assumed to include other costs such as legal, administrative, permitting or others. The estimate also does not include any costs with respect to third-party claims, fines, penalties, or other charges which may be assessed against any responsible party because of either the existence of present conditions or the future existence or discovery of any such conditions.

<u>Additional Services</u>

7. GZA recommends that we be retained to provide services during any future: site observations, design, implementation activities, construction and/or property development/redevelopment. This will allow us the opportunity to: i) observe conditions and compliance with our design concepts and opinions; ii) allow for changes in the event that conditions are other than anticipated; iii) provide modifications to our design; and iv) assess the consequences of changes in technologies and/or regulations.

Attachment A
Revetment Sections – Observed Conditions
February – March 2020

SECTION 1

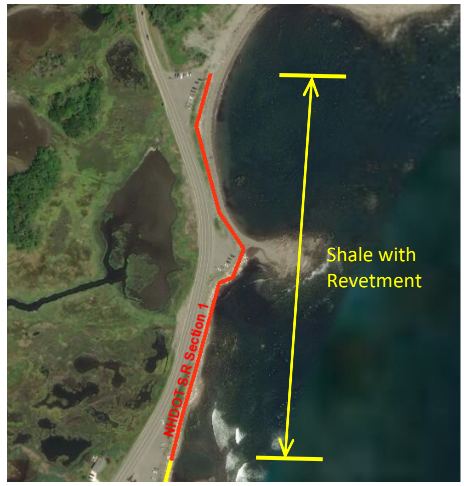
Begin STA 806+33 End STA 818+75

Length 1,242 LF

Stone type: 1,242 LF Shale pile with revetment

Revetment Stone:
D_{min} = ranges from 12” to 3’
D_{50} = ranges from 2.5’ to 5’
D_{max} = ranges from 4’ to 11’

Slope: Ranges from 25% to 44%



Photographs:


North End of Section 1
Looking Northwest


Loosely Placed Revetment Stone Facing
Looking Southwest


Shale Pile; Loosely Placed Revetment Stone Facing
Looking Southeast (±Sta. 813)


Shale Pile
Looking Northwest

SECTION 1: Photographs Cont'd:

Shale Pile; Loosely Placed Revetment Stone Facing
Looking Northeast (±Sta. 813)

Top of Revetment
Looking Northeast (±Begin Sect.)

SECTION 2

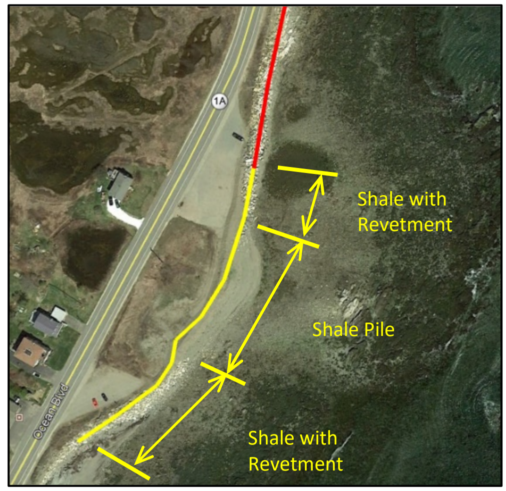
Begin STA 800+24 End STA 806+33

Length 609 LF

Stone type: 250 LF Shale pile
133 LF Shale Pile with revetment at north limits
226 LF Shale Pile with revetment south limits

Revetment Stone: D_{min} = ranges from 12" to 2'
D_{50} = ranges from 3' to 4'
D_{max} = ranges from 5' to 7'

Slope: Ranges from 30% to 44%



Photographs:

Revetment Stone Facing; Potential Displaced Stone
Looking Northeast towards Section 1

End of Revetment/Beginning of Beach Access
Looking Northwest

Shale Pile; Evidence of Erosion
Looking West

Beginning of Revetment/End of Beach Access
Looking Southwest

SECTION 2: Photographs Cont'd:

Loosely Placed Revetment Stone Facing
Looking Southwest

Loosely Placed Revetment Stone Facing
Looking Northeast

Top of Revetment
Looking Southwest

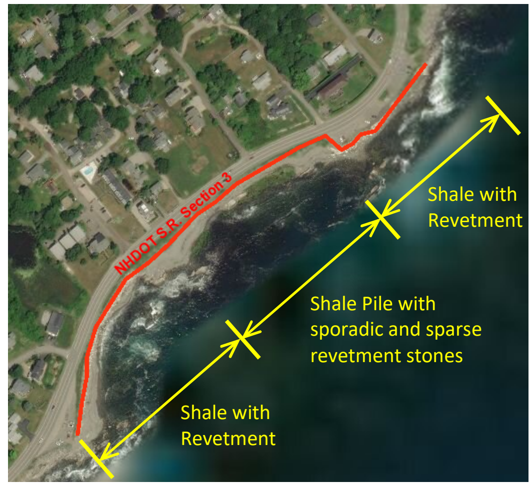
Top of Revetment; Voids
Looking Northeast

SECTION 3

Begin STA 767+06 End STA 784+56

Length 1,750

Stone type: 750 LF Shale pile with sporadic and sparse revetment stones
406 LF Shale Pile with revetment at north limits
594 LF Shale Pile with revetment south limits



Revetment Stone:
D_{min} = ranges from 12” to 3’
D_{50} = ranges from 2.5’ to 5’
D_{max} = ranges from 5’ to 12’

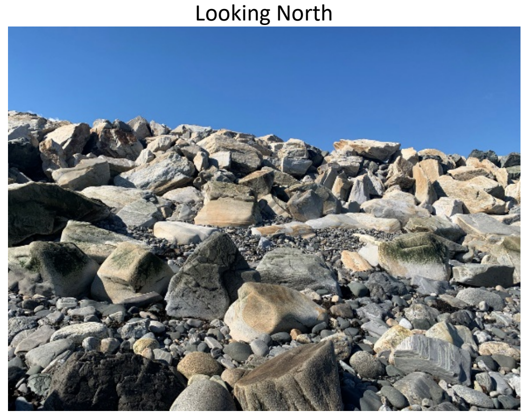
Slope: Ranges from 30% to 44%

Photographs:


Loosely Placed Revetment Stone Facing
Looking West (±Begin Sect.)


Loosely Placed Revetment Stone Facing
Looking North


Revetment Stone Facing; Evidence of Subsidence
Looking South


Loosely Placed Revetment Stone Facing; Possible
Damage - Looking West (±Sta. 770)

SECTION 3: Photographs Cont'd:

End Revetment/Beginning Beach Access & Shale Pile Looking Northeast (±Sta. 773)

Begin Revetment/End Beach Access; Sparse Revetment Stone - Looking Northeast (±Sta. 776)

Shale Pile; Sporadic and Sparse Revetment Stone Looking West (±Sta. 773 – Sta. 780+50)

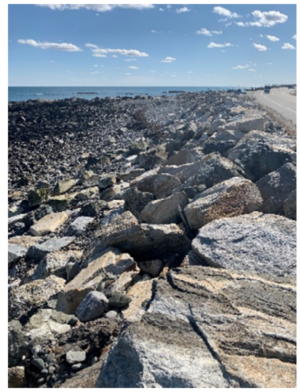
Shale Pile; Sporadic and Sparse Revetment Stone Looking Southwest (±Sta. 773 – Sta. 780+50)

Shale Pile; Loosely Placed Revetment Stone Facing; Possible Damage - Looking West (±Sta.781 - 783)

Revetment Stone Facing; Variable Size; Possible Subsidence - Looking Northeast (±. Sta. 783-End Sect.)

SECTION 3: Photographs Cont'd:

End Revetment/Beginning Bedrock Outcrop; Large Voids Evident - Looking Northeast (±Sta 783+50)



Top of Revetment; Voids Between Stone Looking Southeast

SECTION 4

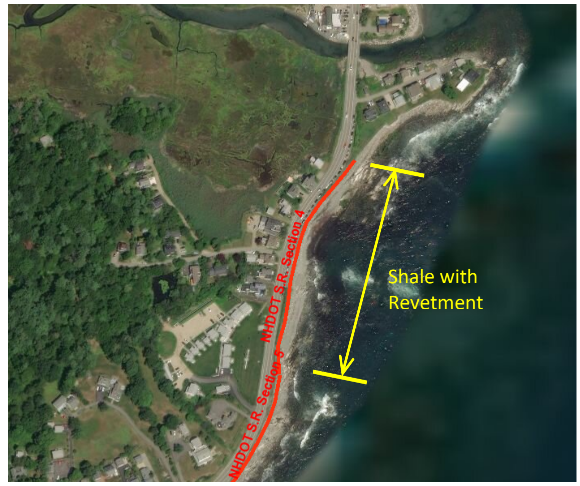
Begin STA 687+83 End STA 696+29

Length 846LF

Stone type: 846 LF Shale pile with revetment

Revetment Stone:
D_{min} = ranges from 12" to 2'
D_{50} = ranges from 3' to 8'
D_{max} = ranges from 5' to 12'

Slope: Ranges from 31% to 142"



Photographs:

Revetment Stone Facing & Beach Bench
Looking North (±Begin Sect.)

Revetment Stone Facing
Looking Southwest (±Sta. 693+50)

Revetment Stone Facing
Looking Southwest (±Sta. 694)

Revetment Stone Facing
Looking Southwest (±Sta. 695+80)

SECTION 4: Photographs Cont'd:

Typical Revetment
Looking Southwest (±End Sect.)

Top of Revetment
Looking Southwest (±End Sect.)

SECTION 5

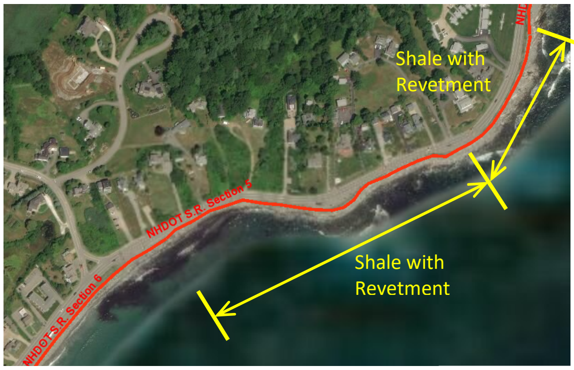
Begin STA 669+70 End STA 687+83

Length 1,813 LF

Stone type: 1,813 LF Shale Pile with revetment

Revetment Stone:
D_{min} = ranges from 6” to 4’
D_{50} = ranges from 18” to 6’
D_{max} = ranges from 3’ to 12’

Slope: Ranges from 43% to 100%

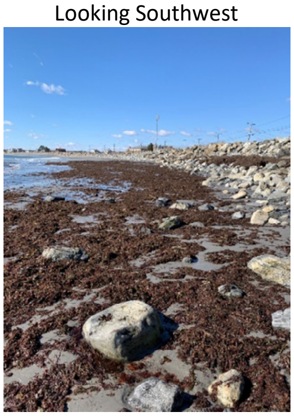


Photographs:


Revetment Stone Facing
Looking Northeast (±Begin Sect.)


Revetment Stone Facing
Looking Southwest


Revetment Stone Facing
Looking Northeast (±Sta. 672)


Beginning of Sandy Beach
Looking Southwest (±Sta. 673)


Loosely Place Revetment Stone Facing; Variable Stone Size/Gap in Revetment - Looking West (±Sta. 676+50)


Revetment
Looking Northeast

SECTION 5: Photographs Cont'd:


Loosely Placed Revetment Stone Facing
Looking Southwest (±Sta. 683)


Typical Revetment
Looking Southwest (±Sta. 677 – Sta. 680+50)


Top of Revetment
Looking South (±End Sect.)


Top of Revetment; Gap in Revetment
Looking Northeast (±Begin Sect.)


Top of Revetment
Looking Southwest (±Sta 677+60)


Top of Revetment
Looking Northeast (±Sta 676)

<u>SECTION 6</u>

Begin STA 631+64 End STA 669+70

Length 3,806 LF

Stone type: 3,306 LF Shale pile with revetment
500 LF Shale pile with sporadic and sparse revetment stones

Revetment Stone: D_{min} = ranges from 12” to 3’
D_{50} = ranges from 3’ to 6’
D_{max} = ranges from 6’ to 12’

Slope: Ranges from 43% to 60%

Photographs:

Revetment Stone Facing
Looking North (±Begin Sect.)

Loosely Placed Revetment Stone/Possible Damage
Looking Northwest (±Sta. 637)

Erosion/Revetment Stone Subsidence
Looking West (±Sta. 639+25)

Loosely Placed Revetment Stone/Possible Damage
Looking Northwest (±Sta. 641)

SECTION 6: Photographs Cont'd:

Shale Pile with Sporadic and Sparse Revetment Stone
Looking Southwest (±Sta. 646)

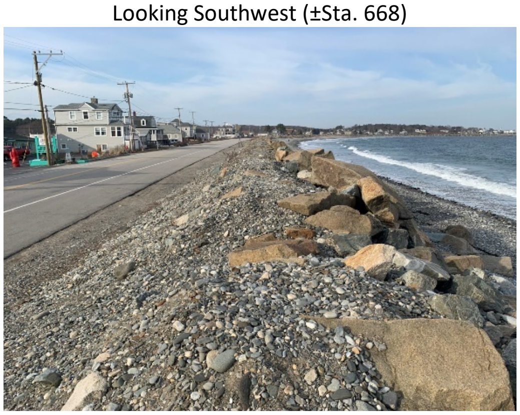
Loosely Placed Revetment Stone
Looking North (±Sta. 659+30)

Loosely Placed Revetment Stone
Looking North (±Sta. 664+10)

Loosely Placed Revetment Stone
Looking Southwest (±Sta. 668+80)

Top of Revetment; Loosely Placed Revetment Stone
Looking Southwest (±Sta. 668)

Top of Revetment; Sporadic and Sparse Revetment
Stone - Looking South (±Sta. 650+50)



Top of Revetment; Loosely Placed Revetment Stone;
Evidence of Revetment Subsidence - Looking North (±Sta. 639)

Top of Revetment
Looking South Towards Begin Section 6

SECTION 7

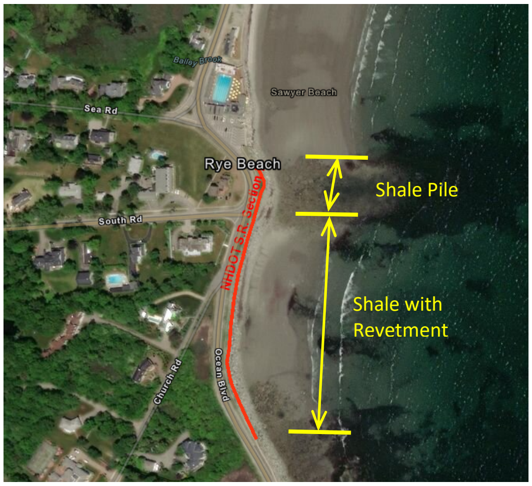
Begin STA 336+19 End STA 345+78

Length 959 LF

Stone type: 93 LF Shale pile
866 LF Shale Pile with revetment

Revetment Stone:
D_{min} = ranges from 18” to 3’
D_{50} = ranges from 3’ to 6’
D_{max} = ranges from 6’ to 12’

Slope: Ranges from 40% to 48%



Photographs:


Shale Pile at Beach Access
Looking West (±End Sect.)


Loosely Placed revetment Stone Near Top of Slope
Looking Southwest (±334+50)


Loosely Placed Revetment Stone; Possible Revetment
Damage - Looking West (±341+50)


Revetment Stone
Looking South

SECTION 7: Photographs Cont'd:

Revetment Stone
Looking Southwest (±Sta. 340+20)

Revetment stone
Looking West towards ±Begin Sect.

Top of Revetment; Defined Walking Path
Looking Northwest (±Begin Sect.)

Top of Revetment; Defined Walking Path
Looking Southwest (±344+40)

SECTION 10

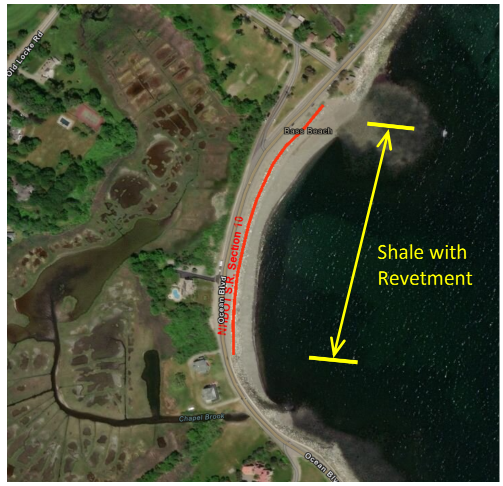
Begin STA 297+51 End STA 309+81

Length 1,230 LF

Stone type: 1,230 LF Shale pile with revetment

Revetment Stone: D_{min} = ranges from 3' to 4'
D_{50} = ranges from 5' to 6'
D_{max} = ranges from 7' to 10'

Slope: Ranges from 31% to 77%



Photographs:

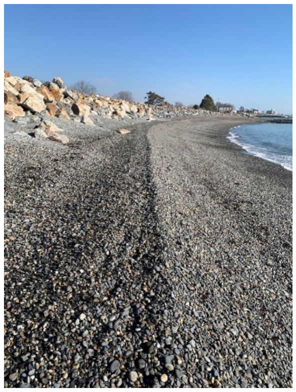

Revetment Stone; Evidence of Revetment Damage – Looking North (±Begin Sect.)


Revetment Stone; Evidence of Revetment Damage - Looking South (±Sta. 300+75)


Revetment Stone; Evidence of Revetment Damage – Looking East (±Sta. 301+50)


Revetment Stone; Evidence of Revetment Damage – Looking Southwest

SECTION 10: Photographs Cont'd:



Revetment Stone and Cobble Berm
Looking Northeast (±Sta. 303)

Revetment Stone
Looking North (±Sta. 304+60)

Revetment Stone; Possible Revetment Subsidence
Looking Northwest (±Sta. 307)

Revetment Stone
Looking Northeast towards ±End Sect.

Top of Revetment
Looking North towards ±End Sect

Top of Revetment
Looking Southwest

SECTION 13

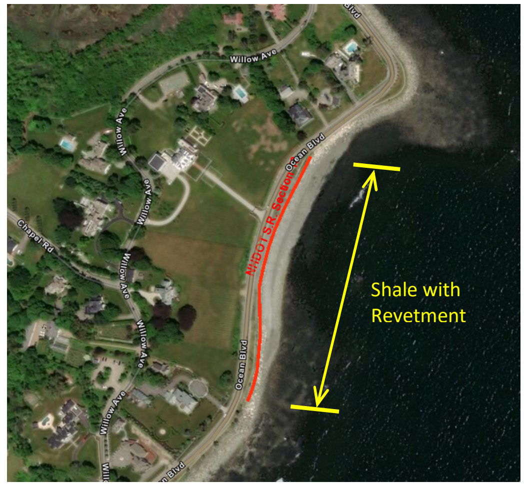
Begin STA 272+25 End STA 282+45

Length 1,020 LF

Stone type: 1,020 LF Shale pile with revetment

Revetment Stone: D_{min} = ranges from 6” to 2’
D_{50} = ranges from 14” to 4’
D_{max} = ranges from 4’ to 8’

Slope: Ranges from 29% to 50%



Photographs:

Revetment Stone; Evidence of Revetment Damage – Looking Northwest (±Begin Sect.)

Revetment Stone; Evidence of Revetment Damage – Looking Northwest (±Begin Sect.)

Revetment Stone; Evidence of Revetment Damage – Looking East (±Sta. 275)

Loosely Placed Revetment Stone Looking North (±End Sect.)

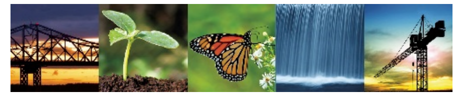
SECTION 13: Photographs Cont'd:

Revetment Stone
Looking South (±End Sect.)

Top of Revetment; Possible Damage
Looking North (±Begin Sect.)

Top of Revetment Defined Walking Path
Looking North (±Sta. 280+30)

Attachment B
Metocean Data Analysis and Wave Modeling



MEMORANDUM

To: Internal Project Memorandum

From: Tianyi Liu, Ph.D., P.E.
Daniel C. Stapleton, P.E.

Date: April 2, 2020

File No.: 04.0190838.04

Re: Metocean Data Analysis
NH Route 1A Coastal Revetment Resilience Study

NHDOT has requested that GZA develop conceptual alternatives for incorporating coastal resilience into the shale pile and shale pile with revetment-facing structures along select portions of NH Route 1A. The current study focus is on the road sections from immediately south of Odiorne Point State Park to 0.25 mile north of Little Boars Head, including approximately 0.12 mile of shale pile structure (Shale) and 2.4 miles of shale pile with revetment facing (S.R.) (See **Table 1** and **Figures 1** and **2**).

This memorandum presents the results of GZA's metocean data analysis, which was performed to characterize the topography and bathymetry and environmental conditions (water levels and waves) for use in evaluation of the existing structures and engineering and design of proposed structures.

Coastal Site Setting

New Hampshire Route 1A, located along the ocean shoreline of New Hampshire, is exposed to the Atlantic Ocean (**Figure 1**) and vulnerable to the effects of coastal flooding. The project shoreline, effectively, has an open fetch to the Atlantic Ocean. A small complex of islands is located across a portion of the project shoreline, approximately 6 miles offshore.

Along the seaward side, the roadway is bordered by a revetment that varies between shale pile (Shale) and shale pile with stone rip rap revetment (S.R.). During coastal storms, the storm surge, waves, and wave overtopping result in revetment damage, and overwash into the roadway.

Coastal flooding of the New Hampshire coast predominantly occurs due to extratropical storms (nor'easters) and post-tropical cyclones. Occasionally, tropical cyclones (including hurricanes) track within Massachusetts Bay.

Topographic and Bathymetric Data

GZA compiled available topographic and bathymetric data. Supplemental field survey is planned along defined transects to provide greater topographic accuracy of the existing structures, and NHDOT will provide the supplemental topo survey for the project.

GZA created a Digital Elevation Model (DEM) of the project area based on available Lidar, specifically the 2014 CMGP Post Sandy LiDAR DEM published by USGS and downloaded from NH GRANIT (3-foot horizontal resolution, Reference 1) - see **Figure 3**. The vertical datum of the 2014 CMGP Post Sandy LiDAR DEM is NAVD88. Preliminary elevation profiles were developed by GZA along three transects at each NHDOT section – see **Figures 7** through **60**. Bathymetric features at NH coast and Atlantic Ocean based on 3-second resolution 1998 NOAA Coastal Relief Model (Reference 2) – see **Figure 61**, and the vertical datum for the source bathymetric data was generally mean lower low water (MLLW) (0 ft MLLW = -5.0 ft NAVD88 at the project site).

Metocean Data

A metocean data analysis was performed to characterize the environmental site conditions (combined wind, tide, storm surge and waves), including:

- Tidal elevations;
- Coastal flood-frequency;
- Storm surge hydrographs,
- Sea level rise projections;
- Wind speed; and
- Wave heights.

Supplemental, numerical wave modeling and wave overtopping calculations are planned to further characterize the wave effects on the project structures.

Tides

The tidal datums in the vicinity of the NHDOT project sections are based on the NOAA Fort Point Tidal Station located to the north of the project site (Reference 3, see **Figure 2** for location):

- Mean Higher High Water (MHHW): 4.39 feet NAVD88
- Mean High Water (MHW): 3.97 feet NAVD88
- Mean Sea Level (MSL): -0.31 feet NAVD88
- Mean Low Water (MLW): -4.66 feet NAVD88
- Mean Lower Low Water (MLLW): -5.00 feet NAVD88

Coastal Flood Elevations

The coastal stillwater flood elevations (i.e., coastal flood frequency data) include storm surge plus astronomical tide, and represents the storm flood elevation in the absence of wave effects. The storm surge is the elevated change in water level above predicted tide levels. Total Water Levels include the stillwater plus wave set-up. The wave crest elevation is the elevation of the Total Water Level plus a portion of the wave height. The water levels vary over time during a storm event due to changes in tidal elevation, storm surge height and wave height. The wave crest elevation also varies over time due to local variability in wind speed and direction, bathymetric features, changes in the storm tide elevation and effects of currents. Stillwater and Total Water Levels are typically characterized in terms of peak conditions associated with an annual probability of occurrence (the annual recurrence interval or annual exceedance probability [AEP]).

The coastal flood elevations were developed from available public data including: 1) FEMA; 2) the USACE; and 3) NOAA extreme water level analysis at representative tidal stations.

FEMA

The effective and preliminary FEMA Flood Insurance Study (FIS) (Reference 4) and effective Flood Insurance rate Maps (FIRMs) present: 1) peak stillwater and Total Water elevations; 2) predicted wave set-up; 3) flood hazard zones; and 4) the Base Flood Elevations (BFEs). The Base Flood is the flood associated with the 100-year recurrence interval flood. **Tables 2** and **3** present FEMA-predicted flood elevations at representative coastal transects. **Table 2** presents the 10-year and 100-year stillwater elevations at coastal transects (see **Figure 5**) along NH Route 1A based on the effective FEMA FIS (2005). **Table 3** presents the 10-year, 50-year, 100-year and 500-year stillwater elevations at coastal transects (see **Figure 6**) based on the revised preliminary FEMA FIS (2016). The effective (2005) and revised preliminary (2016) FEMA FIS are generally consistent relative to the predicted stillwater elevations at coastal transects located near NHDOT sections: the 10-year stillwater elevation ranges from about 7.2 to 7.5 feet NAVD88 and 100-year stillwater elevation is 8.4 feet NAVD88 (**Table 4**). FEMA water levels are developed based on interpolation of historical NOAA tide gage data.

The FEMA-predicted wave set-up during the 100-year recurrence interval flood at the coastal transects (**Table 3**) near the NHDOT sections is approximately 3.2 feet, with the 100-year Total Water elevation in the range of 11.4 to 11.8 feet NAVD88 (**Table 3**). The FEMA flood hazard zones in the vicinity of the NHDOT sections are presented in **Figures 9** to **58**, and are generally classified VE, indicating high flow velocity conditions due to peak wave heights greater than 3 feet. The FEMA Base Flood Elevation (BFE), which approximately represents the peak wave crest elevation associated with the 100-year recurrence interval flood, ranges between 13 feet and 23 feet NAVD88 at the NHDOT sections based on FEMA effective FIS (2005) from FEMA National Flood Hazard Layer (NFHL). FEMA wave-set up is estimated using empirical correlation methods (i.e., Direct Integration Method).

USACE NACCS

Predicted storm surge and total water level data are also available from the US Army Corps of Engineers (USACE) North Atlantic Coast Comprehensive Study (NACCS) (Reference 5). The USACE performed extensive regional coastal flood hazard analyses after Hurricane Sandy (i.e., the North Atlantic Coast Comprehensive Study). These analyses utilized interpretation of meteorological parameters, numerical computer modeling of storm surge and waves, and statistical analysis (e.g., Joint Probability Method-Optimum Sampling, Empirical Simulation Technique) to characterize regional flood hazards. **Figure 4** presents the locations of the NACCS save points (i.e., study output stations) in the vicinity of NHDOT sections, and the mean NACCS-predicted total water elevations associated with the 10-year, 50-year, 100-year and 500-year recurrence interval flood are presented in **Table 4** and **Figure 62**.

Note that the NACCS points are typically located outside the limit of wave set-up and are generally reflective of stillwater elevations. The NACCS save points are located in offshore coastal water, as shown in **Figure 4**, and the wave setup is unlikely to contribute much to the total water level due to minor wave breaking in offshore deep water outside the surf zone. Therefore, the 100-year total water levels (8.2 to 8.3 feet NAVD88) at the NACCS save points in **Table 4** are generally consistent with the FEMA stillwater elevation (i.e., 8.4 feet NAVD88), while the relatively higher total water levels (9.0 to 9.2 feet NAVD88) at save points that are closer to the coast (i.e., save points 18974, 51 and 18972) may indicate a larger contribution from wave setup.

NOAA

Statistical analyses of extreme water levels have been performed by NOAA on most NOAA tide gages. While these analyses are not available at nearby tide stations (NOAA Fort Point, NH and Wells, ME tide stations), extreme water level frequency curves are developed for the NOAA Boston and Portland gages (see **Figure 2** for locations), which are located approximately 50 miles in the north and south of the NHDOT sections. NOAA stillwater flood elevation-frequency data are presented in **Figure 63.** The NOAA stillwater elevations are summarized in **Table 4**. The 100-year stillwater elevation at Portland, ME (i.e., 8.6 feet NAVD88) is consistent with FEMA FIS and NACCS estimates, while the 100-year stillwater elevation at Boston (i.e., 9.4 feet NAVD88) is higher.

The highest observed water levels at the NOAA Boston and Portland gages are presented in **Table 5**, indicating that most historical extreme water levels at Boston and Portland were caused by extratropical nor'easters. **Figure 64** presents the observed water level hydrograph during a recent nor'easter in March 2018 at the NOAA Fort Point, NH gage which is the closest NOAA gage to the NHDOT sections (note that the peak water level at approximately 12:00 3/2/2018 EST at this gage is not recorded but was greater than 7.5 feet NAVD88). **Figure 65** presents the observed time series water level data at NOAA Boston, Fort Point, Wells and Portland gages during the March 2018 nor'easter. Based on the peak flood elevations observed at these stations, the March, 2018 flood resulted in stillwater elevations reflective of coastal flood events with a 10-year to 50-year recurrence interval.

Sea Level Rise

Sea Level Rise (SLR) is the rise of global ocean waters. Relative sea level change (RSLC) is the change of sea level relative to the adjacent land mass and is unique to a given geographic location. RSLC is caused by several factors, including: 1) ground settlement due to post-glacial isostatic adjustment; 2) warming of ocean waters, resulting in volume expansion; 3) increase in ocean volumes due to melting Arctic and land ice; 4) ocean density gradients due to the infusion of lower density fresh water; and 5) changes to global ocean circulation patterns (e.g., the Gulf Stream and Labrador Current).

<u>NOAA Observation Gage</u>

The observed RSLC at the NOAA Boston, Portland and Seavey Island (see **Figure 66** for location) tide stations (Reference 6), over the last approximately 100 years for Boston and Portland tide stations and 60 years for Seavey Island Gage, indicates a historical mean sea level rise trend of 2.83 mm/year (Boston), 1.88 mm/year (Portland), 1.76 mm per year (Seavey Island); 95% confidence intervals are +/- 0.15 mm, +/- 0.14 mm and +/- 0.30 mm per year, respectively. Observed sea level rise trends are not available for the NOAA Fort Point and Wells tide stations. The difference between the observed sea level trends from Boston to Seavey Island is due principally to the differences between observed post-glacial isostatic adjustment (vertical land movement), which is settling at Boston, neutral at Portland and rising at Seavey Island.

<u>NOAA et al. (2017)</u>

While the sea level at New England coast is rising, predicting the future rate of sea level rise is complex, highly uncertain, and dependent on many unknown factors (such as future emissions of greenhouse gases, rate and amount of ice melt, etc.). NOAA et al. (2017) projections (Reference 7, also referred to as Sweet et al. 2017) are provided in vicinity of NHDOT sections at a NOAA tide gage Seavey Island, ME (**Figure 67**, **Table 6**), relative to the year 2000. Corrected values representing sea level rise from current (year 2020) sea levels are presented in **Table 7**. These projections were developed using the USACE Sea Level Change Curve Calculator (version 2019.21) (Reference 8) and are based on NOAA et al. (2017) projections. NOAA et al. (2017) utilizes six descriptive categories: VLM (representing vertical land movement); Low; Intermediate-Low; Intermediate; Intermediate-High; High; and Extreme, and these categories correspond to different greenhouse-gas emission levels (NOAA et al. 2017). In GZA's opinion based on NOAA et al. (2017), the median "Intermediate-Low" is generally considered appropriate as an "analysis and planning lower bound" and either the median "Intermediate" or median "Intermediate-High" is appropriate as an "analysis and planning upper bound". **Table 8** presents estimated exceedance probabilities associated with the six NOAA et al. (2017) projections (shown in **Figure 67**) for several possible future climate scenarios (Representative Concentration Pathways RCP 2.6, RCP 4.5, RCP 8.5) adopted by the Intergovernmental Panel on Climate Change (IPCC) for its fifth Assessment Report (AR5).

The variance between the NOAA et al. (2017) projections increases significantly by mid-century. The NOAA et al. (2017) Intermediate-Low projection has a high (possible to certain) likelihood of occurrence (49% to 96% by 2100). The NOAA et al. (2017) Intermediate projection has low to moderate (possible to certain) likelihood of occurrence (2% to 17% by 2100). The NOAA et al. (2017) Extreme GMSL scenario is a worst case scenario. At NOAA Seavey Island, ME gage in vicinity of the NHDOT sections, the Extreme RSLC scenario for the year 2100 is about 10 feet. Note that the probabilities presented here are approximate; however, they are appropriate for use in understanding the risk of different sea level rise scenarios and planning.

New Hampshire Coastal Flood Risk Science and Technical Advisory Panel (2020) (NHCFR Guidance)

The New Hampshire Coastal Flood Risk Science and Technical Advisory Panel provided guidance in 2020 to help decision makers assess and incorporate best available projections for relative sea-level rise (RSLR) (Reference 10, referred to as NHCFR Guidance). The NHCFR Guidance is based on the study of *2019 New Hampshire Coastal Flood Risk Summary, Part I: Science* (Reference 9, referred to as NHCFR Science) which used scenario-based probabilistic projections based on different global greenhouse gas concentration scenarios represented by different RCPs. The RCPs represent a broad range of climate outcomes, consistent with a range of different socioeconomic and policy futures, including an ambitious mitigation scenario (RCP 2.6), two intermediate stabilization scenarios (RCP 4.5 and RCP 6.0), and a growing greenhouse gas concentration scenario (RCP 8.5).

The NHCFR Guidance recommends use of RCP 4.5 RSLR estimates, while project proponents may be justified in using RSLR estimates for alternative RCPs. The recommended RSLR Estimates for Coastal New Hampshire under the stabilized greenhouse gas concentration scenario (RCP 4.5), and using 2000 sea levels as the baseline, are (**Table 9**, References 9 and 10):

- Coastal New Hampshire is likely (67% probability) to experience RSLR of 0.5 to 1.3 feet between 2000 and 2050. There is a 1-in-20 chance that RSLR will exceed 1.6 feet, a 1-in-100 chance that RSLR will exceed 2.0 feet, a 1-in-200 chance that RSLR will exceed 2.3 feet, and a 1-in-1000 chance that RSLR will exceed 2.9 feet by 2050.

- Coastal New Hampshire is likely (67% probability) to experience RSLR of 1.0 to 2.9 feet between 2000 and 2100. There is a 1-in-20 chance that RSLR will exceed 3.8 feet, a 1-in-100 chance that RSLR will exceed 5.3 feet, a 1-in-200 chance that RSLR will exceed 6.2 feet, and a 1-in-1000 chance that RSLR will exceed 8.7 feet by 2100.

- Coastal New Hampshire is likely (67% probability) to experience RSLR of 1.2 to 4.6 feet between 2000 and 2150. There is a 1-in-20 chance that RSLR will exceed 6.4 feet, a 1-in-100 chance that RSLR will exceed 9.9 feet, a 1-in-200 chance that RSLR will exceed 11.7 feet, and a 1-in-1000 chance that RSLR will exceed 18.1 feet by 2150.

The NHCFR Science compared RSLR estimates with NOAA et al. (2017) (Reference 7) discussed in the above section, which indicate that the 2050 RSLR projections from NHCFR Science for coastal New Hampshire under the stabilized greenhouse gas concentration scenario (RCP 4.5) are consistent with NOAA et al. (2017), but the 2100 RSLR projections are lower under a stabilized greenhouse gas concentration scenario (RCP 4.5) and very similar under the growing greenhouse gas concentration scenario (RCP 8.5) when compared to the NOAA et al. (2017).

Additional Sea Level Rise Information

GZA noted multiple sources on sea level rise estimates and analyses for New Hampshire coast. For instance, in 2015, the Rockingham Planning Commission assessed the influences of sea level rise on vulnerability of New Hampshire coastal municipalities including Portsmouth, New Castle, Rye, North Hampton, Hampton, Hampton Falls and Seabrook (Reference 11), and a "highest" sea level rise scenario is 6.3 feet for the year 2100, which can be found in several other studies (Reference 12, 13, 14). In 2014, the New Hampshire Coastal Risk and Hazards Commission Science and Technical Advisory Panel published a summary of sea-level rise projections, which stated that, using 1992 as a baseline, coastal New Hampshire's sea levels would rise between 0.6 and 2.0 feet by 2050 and between 1.6 and 6.6 feet by 2100 (Reference 15). This study had been cited in multiple analysis (e.g., Reference 16, 17), but was updated in the 2019 NHCFR Science and Guidance discussed in the above section.

Summary

In consideration of the information presented above, it is recommended that the most up-to-date study of 2020 NHCFR Guidance by the New Hampshire Coastal Flood Risk Science and Technical Advisory Panel (2020) be used for planning purposes. Multiple project sections presented in **Figure 2** are located along evacuation route for Town of Seabrook (Reference 14), and thus may be considered as "Low Risk Tolerance" facilities described in NHCFR Guidance. "Low Risk Tolerance" refers to a 1 in 100 exceedance probability. For an assumed typical 30 to 50 years project design life for roadways (year 2050 to 2070 relative to current year of 2019), the sea level rise relative to 2000 sea level for low risk tolerance projects is 2 feet and 3.3 feet for year 2050 and 2070, respectively (Table 3 in Reference 10, RSLR of 3.3 feet for year 2070 was linearly interpolated based on 2 feet RSLR in 2050 and 5.3 feet RSLR in 2100). For more information on RSLR in coastal New Hampshire, it is recommended to refer to the comprehensive studies in NHCFR Science and Guidance (Reference 9, 10). These approximately correspond to NOAA 2017 Intermediate-High sea level rose projections.

The effect of sea level rise, at a minimum, is to increase the elevation and associated probability of coastal flood levels. It is reasonable to linear superimpose (i.e., add) the projected sea level rise to the current stillwater elevation-frequency data to predict future flood stillwater elevations.

Wind Climate Analysis

To analyze the local wind patterns at NHDOT sections, GZA conducted statistical analyses of historical wind data from the nearby Pease International Tradeport and Isle of Shoals (**Figure 68**) for the prevailing and extreme conditions. GZA also reviewed ASCE 7 design gusts.

Wind Observations

The Pease International Tradeport airport has a 63 year record (1956 to 2019) of hourly wind data (speed and direction) (Reference 17). The site at Isle of Shoals has a 35 year record (1985 to 2019) (Reference 18). The observed wind data at the two observation sites during the March 2018 nor'easter is presented in **Figure 69**, which indicates the wind is generally from the northeast direction during the storm. The wind speed at Pease International Tradeport located approximately 6 miles from the coast is lower than that at Isle of Shoals which is located in the open ocean, which may be due to the land reduction effects by vegetation in the coastal region.

Prevailing Wind Analysis

"Prevailing" winds refers to the dominant, non-storm winds. The cumulative probabilities of the complete wind data set at Pease International Tradeport and Isle of Shoals in 22.5-degree directional bins are presented in **Figures 70** and **71**, respectively, and the data are also plotted as a wind rose which shows wind frequency and magnitude throughout the historical record coming from 32 different directional bins (**Figure 72**). To determine the direction from which the strongest winds impact the project site (and therefore the biggest storms), these data were also divided into six categories of magnitude from winds 0 to10 mph to winds greater than 50 mph, and a wind rose was plotted for each category (**Figures 73** and **74**). The results of that analysis indicate the following:

- The prevailing, low velocity, winds are generally from the western quadrant. At Pease International Tradeport, wind is primarily westerly between southwest and northwest, while at Isle of Shoals, wind is westerly and southerly between northwest and southeast.
- At Pease International Tradeport, about 60% of the 1-minute sustained wind speeds are less than 10 miles per hour (mph); about 30% of the sustained wind speeds are between 10 mph and 20 mph and about 4% are between 20 mph and 30 mph.

- At Isle of Shoals, about 20% of the 1-minute sustained wind speeds are less than 10 miles per hour (mph); about 40% of the sustained wind speeds are between 10 mph and 20 mph; about 32 % are between 20 mph and 30 mph and about 8% are above 30 mph.
- For high wind speeds which are greater than 50 mph, only one record was observed at Pease International Tradeport (i.e., 52 mph at 07/18 20:36 1997 UTC), while at Isle of Shoals, most of the high winds with speed greater than 50 mph are from northeast direction (**Figure 74**) which may represent a typical wind feature during nor'easter.

Extreme Wind Analysis

ASCE 7-16 presents wind speeds (3-second gust) for the project area for 10-Year, 25-Year, 50-Year and 100-Year recurrence intervals (**Figure 75**) (Reference 19). The 3-second gust is converted to a 1-minute sustained wind speed at 10 meters height with the conversion factor of 1.23 (Reference 20) based on assumed condition "onshore winds at a coastline", and the converted ASCE 1-minute sustained wind speed is presented in **Table 10**.

GZA performed statistical analysis on wind data records (1-minute averaging duration) at Pease International Tradeport and Isle of Shoals. GZA's statistical analysis was based on Generalized Extreme Value (GEV) analysis which produces a frequency curve corresponding to a series of recurrence intervals. The wind frequency curves for Pease International Tradeport and Isle of Shoals are presented in **Figures 76** to **84** and **Figures 85** to **93**, respectively. The wind speeds at 10-year, 50-year, 100-year and 500-year recurrence intervals from GZA statistical analysis are summarized in **Table 10**.

The comparison of the ASCE wind and GZA wind statistical analysis at Pease International Tradeport in **Table 10** and **Figures 76** to **84** indicate that the GZA wind statistical analysis based on data is quite lower than ASCE winds for all-direction wind and each directional bin. This is probably because the wind data from Pease International Tradeport is influenced by land reduction due to vegetation and topographic features in the coastal region. The GZA wind statistics based on data at Isle of Shoals compare well with ASCE wind speeds, as shown in **Table 10** and **Figures 85** to **93**: the GZA wind statistics are in good agreement with ASCE wind speeds for all-direction records (**Figure 85**), as well as west (**Figure 86**), south (**Figure 88**) and east (**Figure 90**) directional bins. Therefore, the ASCE 7-16 wind speeds presented in **Figure 85** and **Table 10** are supported by the site specific-statistical analysis based on wind data at Isle of Shoals in the vicinity of the NHDOT sections, and are therefore recommended to use for the wind climatology at the project site.

Wave Climate Analysis

Wave climate is defined as the distribution of wave parameters (e.g., wave height, wave period and wave direction) averaged over a defined time interval at a particular location. Nearshore waves play a significant role in raising stillwater elevation by wave setup and causing inland flooding by wave runup and overtopping. Waves are also the principal mechanism for causing structural damage.

Wave Observation

Wave observation data is not available at the coastline near the NHDOT sections but is available at wave buoys that are located 10 to 20 miles offshore from the project site. The wave buoys include USACE WIS (Wave Information Studies) buoys 63042, 63043, 63044, 63045 (**Figure 2**, about 10 to 15 miles to the east of the NHDOT sections, data record: 1980 to 2014) and the NERACOOS (Northeastern Regional Association of Coastal Ocean Observing Systems) B01 buoy (**Figure 2**, located about 20 miles to the northeast of the NHDOT sections, data record: 2002 to 2019). The offshore waves recorded at the WIS and NERACOOS buoys are deep water waves (water depth presented in **Table 11**) and can differ significantly from the nearshore waves at the coast due to wave shoaling over complex shoreline and bathymetric features near the coast. However, the deep water waves can still present similar characteristics (e.g., dominant wave direction, wave period) as nearshore waves which evolved from deep water waves under influence of local wind. Therefore, the wave observations at the WIS and NERACOOS buoys are assessed for the wave climate at the NHDOT sections at the coast.

The wave rose at the WIS wave buoys is presented in **Figure 94**, indicating that waves are predominantly from the southeast direction, and the extreme wave frequency curves are presented in **Figure 95**, indicating the 100-year wave height at the WIS buoys is approximately 27 feet (about 8 meters). Wave direction is not provided in NERACOOS buoy records; therefore no directional analysis can be performed with such data. The wave height and wave period during the March 2018 nor'easter observed at the NERACOOS B01 buoy are presented in **Figure 96**, indicating that wave heights reached approximately 28 feet at this buoy which is located about 8.5 miles off the coast of Maine and about 20 miles from the NHDOT sections (generally consistent with the 100-year recurrence interval wave height).

USACE NACCS

The USACE NACCS also developed wave height statistics for the U.S. North Atlantic coast (Chesapeake Bay to New Hampshire) using numerical, coupled storm surge and wave modeling (ADCIRC+STWAVE) and the Joint Probability Method (JPM) statistical methodology. The wave height statistics at NACCS save points (see **Figure 3** for location) in the vicinity of NHDOT sections are summarized in **Table 12**. The water depths at the NACCS save points are presented in **Table 11**. High resolution numerical modeling of wave generation and propagation is recommended for more detailed and accurate assessment of the wave characteristics at the NHDOT sections at the coast.

Depth-Limited Wave Heights

The immediate vicinity of the project revetments and adjacent roadway are submerged during coastal flood events. Wave heights at the seaward toe of the revetments will be depth-limited and can be estimated using the following equation:

Depth-limited wave height = (Total Water elevation – ground surface elevation) * 0.78

Wave Modeling

Utilizing input from the metocean data analysis, GZA performed a numerical wave analysis using the SWAN (Simulating WAves Nearshore) model to evaluate waves generated by wind and deep-water waves at the NHDOT sections for 100-year recurrence interval. SWAN is a third-generation wave model developed by the Delft University of Technology. SWAN calculates random, short-crested wind-generated waves in coastal regions and inland waters. The model results present wave vectors. The simulated wave heights presented here represent significant wave heights, Hs and breaking wave heights, H_b (where depth limited wave conditions exist).

GZA's SWAN model, with variable resolution, is built based on the 2014 CMGP Post Sandy LiDAR DEM (**Figure 3**) and 1998 NOAA Coastal Relief Model (**Figure 61)**. The metocean inputs to the SWAN model for the 100-year recurrence interval are summarized in **Table 13**. The simulated wave heights are presented in **Figures 12** through **60,** and are summarized in **Table 13** for the transects of each section.

Flood Inundation Mapping

GZA created inundation maps based on the DEM with flood elevations from 6 to 12 ft NAVD88 with 0.5-foot increment. The flood maps with flood elevation of 8.5 ft NAVD88 which is similar as the 100-Year stillwater elevation (i.e., 8.4 ft NAVD88 from FEMA) are presented in **Figures 10** to **58** for each section. The inundation maps indicate back water flooding on the landward side of the NH Route 1A, which is generally due to low elevation grounds along the shoreline and brings flood risk to the road, although the total water level is below the top of the revetment. The back water flooding conditions at representative transects of each section are summarized in **Tables 14** – **16** for 100-year, 50-year and 10-year recurrence intervals.

Wave Runup and Overtopping

Wave runup at the revetments along Routh 1A was calculated using EurOtop Manual (Reference 25). This approach is consistent with the latest FEMA guidance for runup and overtopping (Reference 26). This method uses the significant deep water wave height, H_{m0}, and the slope angle, α, to estimate the wave runup on slopes with armored rubble slopes and mounds, as shown in **Figure 97**. The wave runup height exceeded by 2% of incoming waves is calculated using Equation 6.2 of the EurOtop Manual:

$$\frac{R_{u2\%}}{H_{m0}} = 1.75 * \gamma_b * \gamma_f * \gamma_\beta * \xi_{m-1,0}$$

where:

$R_{u2\%}$ = wave runup height exceeded by 2% of the incoming waves (feet);

H_{m0} = significant deep water wave height (feet);

γ_b = influence factor for a berm (dimensionless);

γ_f = influence factor for roughness elements on a slope (dimensionless);

γ_β = influence factor for oblique wave attack (dimensionless);

$\xi_{m-1,0}$ = breaker parameter (dimensionless):

$$\xi_{m-1,0} = \frac{\tan\alpha}{\sqrt{s_{m-1,0}}}$$

where:

α = angle of the slope relative to horizontal direction (degree);

$s_{m-1,0}$ = wave steepness (dimensionless): $s_{m-1,0} = \frac{H_{m0}}{L_{m-1,0}}$, where $L_{m-1,0}$ is the wave length.

The overtopping discharge rate is then estimated using Equation 6.6 and 5.12 as presented in the EurOtop Manual for the scenario of wave overtopping on slopes with armored rubble slopes and mounds, as shown in **Figure 97**. The equations to estimate the overtopping discharge rate for slopes with armored rubble slopes and mounds are indicated below:

$$\frac{q}{\sqrt{gH_{m0}^3}} = \frac{0.026}{\sqrt{tan\alpha}}\gamma_b\xi_{m-1,0}\exp\left[-\left(2.5\frac{R_c}{\xi_{m-1,0}H_{m0}\gamma_b\gamma_f\gamma_\beta}\right)^{1.3}\right]$$

with a maximum of: $\frac{q}{\sqrt{gH_{m0}^3}} = 0.1035\exp\left[-\left(1.35\frac{R_c}{H_{m0}\gamma_f\gamma_\beta}\right)^{1.3}\right]$ for steep slopes 1:2 to 1:4/3

where:

q = overtopping flowrate (feet^2/sec);

α = slope angle (degree);

R_c = freeboard (feet).

GZA performed survey at the NHDOT sections and developed the revetment stone characteristics and slope features. Based on the surveyed information and metocean analysis described in above sections, the wave runup and wave overtopping flowrate were calculated at multiple transects at each NHDOT section for 10-Year, 50-Year and 100-Year recurrence intervals. The incoming wave heights for calculating wave runup and overtopping were selected at deep water locations which are approximately 50 – 100 feet off the coast. The calculated wave runup and overtopping are presented in **Tables 14** – **16**, and the revetment condition and the influences on traffic safety were assessed by the overtopping discharge rate for multiple transects based on USACE Coastal Engineering Manual (Reference 27).

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Table 1. Conceptual design focus areas.

NHDOT IDENTIFICATION*	CONSTRUCTION TYPE†	APPROX. LENGTH ALONG COASTLINE‡
Section 1	S.R.	1,400 LF
Section 2	Shale	625 LF
Section 3	S.R.	1,800 LF
Section 4	S.R.	825 LF
Section 5	S.R.	1,925 LF
Section 6	S.R.	3,720 LF
Section 7	S.R.	1,050 LF
Section 10	S.R.	1,160 LF
Section 13	S.R.	1,020 LF

* Based on Northern, Central and Southern Location Maps provided by NHDOT.
† Shale = shale pile. S.R. = shale pile with stone revetment facing.
‡ The approximate length is based on measurement using Google Earth, and is subject to revision based on supplemental survey from NHDOT.

Table 2. Transect data from Effective FEMA FIS (2005), Rockingham County, NH.

TABLE 7 – TRANSECT DATA

FLOODING SOURCE	STILLWATER ELEVATION (feet NGVD 29) 10-YEAR	STILLWATER ELEVATION (feet NGVD 29) 100-YEAR	ZONE	BASE FLOOD ELEVATION[1] (feet NGVD 29)
ATLANTIC OCEAN				
Transects 1-2	8.2	9.2	VE	11-18
			AE	9-13
Transects 3-10	8.3	9.2	VE	12-22
			AE	9-12
			AO	1'-2' (Depth)
Transects 11-12	8.3	9.2	VE	14-23
			AE	9
			AO	1' (Depth)
Transects 13-14	8.2	9.2	VE	12-14
			AE	9

[1]Because of map scale limitations, base flood elevations shown on the FIRM represent average elevations for the zones depicted

Note:

The datum conversion between NGVD29 and NAVD88 is based on NOAA VDatum (Reference 22) for the project site (longitude/latitude: -70.728743/43.008696): 0 ft NAVD88 = 0.78 ft NGVD29, so the flood elevations in NGVD29 are converted to NAVD88 as follows:

8.2 ft NGVD29 = 7.4 ft NAVD88
8.3 ft NGVD29 = 7.5 ft NAVD88
9.2 ft NGVD29 = 8.4 ft NAVD88

Table 3. Transect data corresponding to NHDOT sections from Revised Preliminary FEMA FIS (2016), Rockingham County, NH

Transect	Stillwater Elevation (feet NAVD88*)				Total Water Elevation 1-Percent Annual Chance[1]	Zone	Base Flood Elevation* (feet NAVD88**)	NHDOT Section
	10-Percent Annual Chance	2-Percent Annual Chance	1-Percent Annual Chance	0.2-Percent Annual Chance				
16	7.24	7.98	8.36	9.43	11.53	VE	16[2]-18	1
						AE	16[2]	
						AO	3	
						AE	8-9	
17	7.24	7.98	8.36	9.43	11.61	VE	17[2]-18	2
						AE	17[2]	
						AO	3	
19	7.24	7.98	8.36	9.43	11.76	VE	16[2]-18	3
						AE	16[2]	
						AO	3	
20	7.24	7.98	8.36	9.43	11.63	VE	20[2]	
						AE	20[2]	
						AO	3	
26	7.24	7.98	8.36	9.43	11.72	VE	19	4
						AE	19[2]	
						AO	3	
						AE	8-10	
27	7.24	7.98	8.36	9.43	11.51	VE	17[2]-18	5
						AE	17[2]	
						AO	3	
28	7.24	7.98	8.36	9.43	11.57	VE	19[2]	6
						AE	19[2]	
						AO	3	
						AE	8-9	
29	7.24	7.98	8.36	9.43	11.64	VE	20[2]	
						AO	3	
						AE	8-9	

Note:

*Due to map scale limitations, base flood elevations shown on the FIRM represent average elevations for the zones depicted.

**North American Vertical Datum of 1988

[1]Including stillwater elevation and effects of wave setup

[2]Wave runup elevation.

Table 3 cont. Transect data corresponding to NHDOT sections from Revised Preliminary FEMA FIS (2016), Rockingham County, NH – continued

Transect	Stillwater Elevation (feet NAVD88*)				Total Water Elevation 1-Percent Annual Chance[1]	Zone	Base Flood Elevation* (feet NAVD88**)	NHDOT Section
	10-Percent Annual Chance	2-Percent Annual Chance	1-Percent Annual Chance	0.2-Percent Annual Chance				
30	7.24	7.98	8.36	9.43	11.67	VE	21[2]	6
						AE	21[2]	
						AO	3	
						AE	8-10	
31	7.24	7.98	8.36	9.43	11.66	VE	20[2]	
						AE	20[2]	
						AO	3	
						AE	8-10	
43	7.24	7.98	8.36	9.43	11.47	VE	16[2]-18	7
						AE	16[2]	
						AO	3	
44	7.24	7.98	8.36	9.43	11.53	VE	18[2]	
						AE	18[2]	
46	7.24	7.98	8.36	9.43	11.66	VE	20[2]	10
						AE	20[2]	
						AO	3	
						AE	8-9	
47	7.24	7.98	8.36	9.43	11.21	VE	24[2]	
						AE	24[2]	
						AO	3	
						AE	8-9	
48	7.24	7.98	8.36	9.43	11.82	VE	22[2]	13
						AE	22[2]	
49	7.24	7.98	8.36	9.43	11.7	VE	18[2]	
						AE	18[2]	

Note:

*Due to map scale limitations, base flood elevations shown on the FIRM represent average elevations for the zones depicted.

**North American Vertical Datum of 1988

[1]Including stillwater elevation and effects of wave setup

[2]Wave runup elevation.

Table 4. Coastal flood elevations in vicinity of NHDOT sections based on publicly available sources.

Recurrence Interval	FEMA Stillwater Elevation (ft, NAVD88)		FEMA Total Water Elevation (ft, NAVD88)	NACCS Stillwater Water Elevation (ft, NAVD88)[4]							NOAA Stillwater Elevation (ft, NAVD88)	
	Effective FIS (2005)[1]	Revised Preliminary FIS (2016)[2]	Revised Preliminary FIS (2016)[3]	NHDOT Sections 7 through 13		NHDOT Sections 1 through 6		Not recommended for project sites[7]				
				2025	2032	18974	51	2045	2046	18972	Boston[5]	Portland[6]
1-year				5.9	5.9	5.9	6.0	5.8	5.8	5.9	6.5	6.4
2-year				6.4	6.4	6.6	6.6	6.4	6.4	6.6	7.4	7.1
5-year				7.0	7.0	7.2	7.3	6.9	7.0	7.2	7.7	7.5
10-year	7.5	7.2		7.3	7.3	7.6	7.8	7.3	7.3	7.7	8.3	7.8
50-year		8.0		8.0	8.0	8.6	8.9	8.0	8.1	8.8	9.1	9.3
100-year	8.4	8.4	11.6	8.2	8.3	9.0	9.2	8.2	8.3	9.1	9.4	8.6
500-year		9.4		8.7	8.8	9.7	10.0	8.7	8.8	10.0		

Note:

1. Based on representative Transects 3 through 10 in Table 2.
2. Based on all transects presented in Table 3.
3. See Table 3 for specific transect locations relative to NHDOT revetment sections. The total water elevation of 11.6 ft NAVD88 for the 100-year recurrence interval listed here is for transect 28 in Table 3 and is approximately the median total water elevation for all transects in Table 3. Total water elevation equals to stillwater elevation plus wave setup (footnote 1 for Table 3), so the wave setup at transect 28 in 100-year recurrence interval = 11.6 – 8.4 = 3.2 ft.
4. Locations of NACCS save points are indicated in Figure 2.
5. Converted from MHHW to NAVD88 based on datum at NOAA Boston gage (Reference 23).
6. Converted from MHHW to NAVD88 based on datum at NOAA Portland gage (Reference 24).
7. NACCS save point 2045, 2046 and 18972 water levels are in deeper water and also reflective of estuary effects and may not be representative of conditions at NHDOT section 1, 2 and 3.

Table 5. Top Ten Highest Water Levels[1] at NOAA Boston and Portland Gage.

Boston, MA			Portland, ME		
Time	**Water Level[2] (ft, NAVD88)**	**Storm Type**	**Time**	**Water Level[2] (ft, NAVD88)**	**Storm Type**
1/4/2018	9.66	Nor'Easter	2/7/1978	8.87	Nor'Easter
2/7/1978	9.59	Nor'Easter	1/9/1978	8.68	Nor'Easter
3/2/2018	9.13	Nor'Easter	1/4/2018	8.26	Nor'Easter
1/2/1987	8.69	Nor'Easter	3/16/1976	8.01	Nor'Easter
10/30/1991	8.63	Nor'Easter	12/4/1990	8.00	Nor'Easter
1/25/1979	8.53	Nor'Easter	11/20/1945	7.99	Nor'Easter
12/12/1992	8.52	Nor'Easter	11/30/1944	7.99	Nor'Easter
12/29/1959	8.47	Nor'Easter	3/2/2018	7.91	Nor'Easter
2/19/1972	8.39	Nor'Easter	4/16/2007	7.91	Nor'Easter
1/3/2014	8.33	Nor'Easter	1/2/1987	7.88	Nor'Easter

Note:

1. Source data provided by NOAA, available at http://tidesandcurrents.noaa.gov/est/Top10_form_ft.pdf.
2. Water levels were converted to NAVD88 from source data.

Table 6. Sea Level Rise Projections (using the USACE Relative Sea Level Change Calculator for NOAA et. al. 2017 projections; relative to the year 2000) for Seavey Island, ME, NOAA2017 VLM (vertical land movement): -0.00092 feet/yr, all values are expressed in feet.

Year	NOAA2017 VLM	NOAA2017 Low	NOAA2017 Int-Low	NOAA2017 Intermediate	NOAA2017 Int-High	NOAA2017 High	NOAA2017 Extreme
2019	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08
2040	-0.11	0.38	0.55	1.00	1.50	1.99	2.25
2050	-0.12	0.51	0.71	1.37	2.05	2.84	3.27
2070	-0.14	0.74	1.04	2.22	3.37	4.74	5.76
2100	-0.17	0.94	1.37	3.66	5.86	8.55	10.65

Table 7. Sea Level Rise Projections (using the USACE Relative Sea Level Change Calculator for NOAA et. al. 2017 projections; relative to the year 2019) for Seavey Island, ME, NOAA2017 VLM (vertical land movement): -0.00092 feet/yr, all values are expressed in feet.

Year	NOAA2017 VLM	NOAA2017 Low	NOAA2017 Int-Low	NOAA2017 Intermediate	NOAA2017 Int-High	NOAA2017 High	NOAA2017 Extreme
2019	--	--	--	--	--	--	--
2040	-0.01	0.24	0.34	0.64	0.95	1.29	1.48
2050	-0.02	0.37	0.50	1.01	1.50	2.14	2.50
2070	-0.04	0.60	0.83	1.86	2.82	4.04	4.99
2100	-0.07	0.80	1.16	3.30	5.31	7.85	9.88

Table 8. Probability of Exceeding Global Mean Sea Levels in 2100 for Several Representative Concentration Pathways (RCP) Scenarios.

GMSL Rise Scenario	RCP 2.6	RCP 4.5	RCP 8.5
Low (0.3 m)	94%	98%	100%
Intermediate-Low (0.5 m)	49%	73%	96%
Intermediate (1.0 m)	2%	3%	17%
Intermediate-High (1.5 m)	0.4%	0.5%	1.3%
High (2.0 m)	0.1%	0.1%	0.3%
Extreme (2.5 m)	0.05%	0.05%	0.1%

Table 9. NHCFR recommended RSLR Estimates for Coastal New Hampshire under the stabilized greenhouse gas concentration scenario (RCP 4.5).

Year	Likely Range	1-in-20 Chance	1-in-100 Chance	1-in-200 Chance	1-in-1000 Chance
	67% probability SLR is between	5% probability SLR meets or exceeds	1% probability SLR meets or exceeds	0.5% probability SLR meets or exceeds	0.1% probability SLR meets or exceeds
2050	0.5 – 1.3	1.6	2.0	2.3	2.9
2100	1.0 – 2.9	3.8	5.3	6.2	8.7
2150	1.2 – 4.6	6.4	9.9	11.7	18.1

Table 10. Wind Speed Statistics (1-min, 10-meter) based on ASCE 7-16 and GZA wind statistical analysis.

Analysis	Wind Direction	Wind Speed (mph) Statistics			
		10-year	50-year	100-year	500-year
ASCE 7-16	All Direction	60	72	78	--
GZA Statistical Analysis on Pease Intl Tradeport	All Direction	42	49	53	62
	North	33	39	42	50
	Northeast	36	41	43	46
	East	34	38	39	41
	Southeast	36	41	43	47
	South	31	36	37	41
	Southwest	32	39	41	47
	West	37	43	46	52
	Northwest	36	39	39	41
GZA Statistical Analysis on Isle of Shoals	All Direction	65	76	81	96
	North	57	62	64	68
	Northeast	59	63	64	66
	East	59	69	73	82
	Southeast	57	60	61	62
	South	50	59	64	76
	Southwest	47	52	54	59
	West	54	62	65	73
	Northwest	52	55	55	57

Table 11. Wave depth under mean sea level (MSL) at WIS and NERACOOS wave buoys and NACCS save points.

Stations	Station ID	Water Depth (ft)
WIS Buoys	63042	236
	63043	223
	63044	148
	63045	282
NERACOOS Buoy	B-01	203
NACCS Save Points	2025	33
	2032	35
	51	9
	2045	32
	2046	34

Table 12. Wave height statistics at NACCS save points in vicinity of NHDOT sections.

Return Period	Wave height (ft) at NACCS save points[1]				
	2025	2032	51	2045	2046
1-year	11.0	10.0	8.4	10.3	10.4
2-year	15.6	14.0	9.9	14.9	14.9
5-year	19.5	18.3	10.5	18.6	18.6
10-year	21.4	20.6	10.9	20.6	20.7
50-year	23.5	23.9	11.5	23.8	24.8
100-year	23.8	24.8	11.8	24.8	26.4
500-year	24.4	26.1	12.3	26.3	29.5

Note:

1. Wave height statistics are unavailable for NACCS save points 18972and 18974 (see Figure 2 for location).

Table 13. SWAN Wave Modeling for 100-year recurrence interval.

SWAN Model Input	Stillwater Elevation[1] (ft, NAVD88)		8.4
	Wave Input at eastern open boundary	Significant Wave Height[2] (ft)	26.9
		Wave Period[2] (sec)	12
		Wave Direction	From due east
	Wind	Speed[3] (mph)	78
		Direction	From due east
SWAN Model Output of Significant Wave Height[4] (ft)	Section 1	Transect 1	2.6
		Transect 2	2.8
		Transect 3	3.1
	Section 2	Transect 1	1.5
		Transect 2	2.8
		Transect 3	3.5
	Section 3	Transect 1	4.6
		Transect 2	4.6
		Transect 3	4.0
	Section 4	Transect 1	2.8
		Transect 2	3.0
		Transect 3	3.3
	Section 5	Transect 1	3.2
		Transect 2	3.8
		Transect 3	2.0
	Section 6	Transect 1	3.0
		Transect 2	3.5
		Transect 3	3.3
	Section 7	Transect 1	3.5
		Transect 2	3.4
		Transect 3	3.3
	Section 10	Transect 1	4.1
		Transect 2	3.9
		Transect 3	4.0
	Section 13	Transect 1	4.1
		Transect 2	4.1
		Transect 3	4.2

Note:

1. Based on FEMA Preliminary FIS (2016) (see **Table 4**);
2. Based on wave data at WIS buoy 63044 (see **Figure 2**);
3. 1-min sustained wind speed, based on ASCE 7-16 (see **Table 10**).
4. The output location for each transect is approximately at the intersection point between the section line and the transect line shown in **Figures 7** through **60**.

Table 14. Assessment of wave runup, overtopping and revetment conditions for 100-Year storm condition.

NHDOT Section	NH RT 1A Coastal Revetment Survey					Metocean Characteristics				Revetment Condition				Wave Runup		Wave Overtopping	Risk Assessment		
	Approx. Station[1]	Distance to North Transect	Crest EL.	Toe EL.	Slope	Stillwater Level	Total Water Level[2]	Incident Wave Height	Peak Wave Period	Free board	Revetment Inundated?	Back Water Flood?	RT 1A Flood?	Runup $R_{2\%}$	Wave Runup EL.	Flowrate per foot	Wave Runup Impact	Wave Overtopping Impact[3]	
		ft	ft, NAVD88	ft, NAVD88	%	ft, NAVD88	ft, NAVD88	ft	sec	ft				ft	ft, NAVD88	cfs	Above/Below Revetment Crest	Traffic	Pedestrians
1			-	-	-														
Transect 1	806+33	0	15	9	33	8.4	11.53	2.6	13.5	6.6	No	Yes	Yes	6.0	14.4	1.61E-04	Below	Unsafe parking	Uncomfortable but not dangerous
Transect 2	818+0.0	70	15.7	9.6	31	8.4	11.53	2.6	13.5	7.3	No	Yes	Yes	5.8	14.2	4.18E-05	Below	Unsafe driving at high speed	Wet but not uncomfortable
Transect 3	817+30	110	14	6.5	43	8.4	11.53	2.5	13.5	5.6	No	Yes	Yes	6.4	14.8	6.45E-04	Above	Unsafe parking	Dangerous
Transect 4	816+20	325	12.2	6	25	8.4	11.53	3.2	13.5	3.8	No	Yes	Yes	6.3	14.7	9.29E-02	Above	Unsafe at any speed	Very dangerous
Transect 5	812+95	145	13.8	2.8	42	8.4	11.53	3.1	13.5	5.4	No	Yes	Yes	7.4	15.8	8.74E-03	Above	Unsafe at any speed	Dangerous
Transect 6	811+50	225	15.5	5.3	44	8.4	11.53	3.5	13.5	7.1	No	Yes	Yes	7.8	16.2	2.88E-03	Above	Unsafe parking	Dangerous
Transect 7	809+25	225	15.5	4.3	36	8.4	11.53	4.0	13.5	7.1	No	Yes	Yes	8.7	17.1	1.11E-02	Above	Unsafe at any speed	Very dangerous
2																			
Transect 1	800+24	0	15	4	44	8.4	11.61	4.7	13.5	6.6	No	Yes	Yes	10.5	18.9	6.90E-02	Above	Unsafe at any speed	Very dangerous
Transect 2	805+50	310	15	7.5	30	8.4	11.61	4.7	13.5	6.6	No	Yes	Yes	9.0	17.4	6.90E-02	Above	Unsafe at any speed	Very dangerous
Transect 3	802+40	216	14.8	10	30	8.4	11.61	4.0	13.5	6.4	No	Yes	Yes	8.1	16.5	2.38E-02	Above	Unsafe at any speed	Very dangerous
3																			
Transect 1	767+06	0	13.5	4.7	40	8.4	11.7	6.8	13.5	5.1	No	No	No	14.0	22.4	1.45E+00	Above	Unsafe at any speed	Very dangerous
Transect 2	782+75	175	13.3	5.6	43	8.4	11.7	7.1	13.5	4.9	No	No	No	14.9	23.3	1.89E+00	Above	Unsafe at any speed	Very dangerous
Transect 3	781+0.0	480	14	8.3	81	8.4	11.7	6.8	13.5	5.6	No	No	No	18.1	26.5	1.12E+00	Above	Unsafe at any speed	Very dangerous
Transect 4	776+20	370	17	9.4	40	8.4	11.7	5.3	13.5	8.6	No	No	No	10.9	19.3	3.29E-02	Above	Unsafe at any speed	Very dangerous
Transect 5	772+50	350	18.5	9	44	8.4	11.7	4.8	13.5	10.1	No	No	No	10.4	18.8	3.25E-03	Above	Unsafe parking	Dangerous
Transect 6	769+0.0	150	15.9	8.8	45	8.4	11.7	4.9	13.5	7.5	No	No	No	10.4	18.8	4.33E-02	Above	Unsafe at any speed	Very dangerous
4																			
Transect 1	687+83	0	15	10	31	8.4	11.72	4.7	13.5	6.6	No	Yes	No	9.0	17.4	6.90E-02	Above	Unsafe at any speed	Very dangerous
Transect 2	695+50	350	16	10	47	8.4	11.72	3.9	13.5	7.6	No	Yes	No	8.8	17.2	4.88E-03	Above	Unsafe at any speed	Dangerous
Transect 3	692+0.0	340	14.6	7.5	142	8.4	11.72	5.1	13.5	6.2	No	No	No	16.4	24.8	1.67E-01	Above	Unsafe at any speed	Very dangerous
5																		Safe driving at all speeds	Wet but not uncomfortable
Transect 1	669+70	0	16.4	10	100	8.4	11.51	4.7	13.5	8	No	No	No	14.1	22.5	1.94E-02	Above	Unsafe at any speed	Very dangerous
Transect 2	686+40	340	15.6	9.8	76	8.4	11.51	4.6	13.5	7.2	No	No	No	12.5	20.9	3.40E-02	Above	Unsafe at any speed	Very dangerous
Transect 3	683+0.0	275	16	6.5	43	8.4	11.51	4.6	13.5	7.6	No	No	No	10.0	18.4	2.34E-02	Above	Unsafe at any speed	Very dangerous
Transect 4	680+25	355	16.2	7.4	93	8.4	11.51	4.1	13.5	7.8	No	No	No	12.4	20.8	6.49E-03	Above	Unsafe at any speed	Dangerous
Transect 5	676+70	100	15	4.4	61	8.4	11.51	3.8	13.5	6.6	No	No	No	9.6	18.0	1.21E-02	Above	Unsafe at any speed	Very dangerous
Transect 6	675+70	470	16	4.5	51	8.4	11.51	3.1	13.5	7.6	No	No	No	7.4	15.8	3.21E-04	Below	Unsafe parking	Uncomfortable but not dangerous
6																			
Transect 1	631+64	0	14.5	4	60	8.4	11.65	3.1	13.5	6.1	No	Yes	No	7.9	16.3	3.17E-03	Above	Unsafe parking	Dangerous
Transect 2	669+0.0	225	16.7	6.6	46	8.4	11.65	3.3	13.5	8.3	No	Yes	No	7.5	15.9	2.59E-04	Below	Unsafe parking	Uncomfortable but not dangerous
Transect 3	666+75	475	16.4	6.8	56	8.4	11.65	3.2	13.5	8	No	Yes	No	8.0	16.4	2.66E-04	Below	Unsafe parking	Uncomfortable but not dangerous
Transect 4	662+0.0	250	17.4	10	43	8.4	11.65	3.5	13.5	9	No	Yes	No	7.7	16.1	2.14E-04	Below	Unsafe parking	Uncomfortable but not dangerous
Transect 5	659+50	650	17.6	11.5	50	8.4	11.65	4.4	13.5	9.2	No	Yes	No	10.3	18.7	3.04E-03	Above	Unsafe parking	Dangerous
Transect 6	653+0.0	1540	17.3	8.6	49	8.4	11.65	3.9	13.5	8.9	No	Yes	Yes	9.2	17.6	1.03E-03	Above	Unsafe parking	Dangerous

NHDOT Section	NH RT 1A Coastal Revetment Survey					Metocean Characteristics				Revetment Condition				Wave Runup		Wave Overtopping	Risk Assessment		
	Approx. Station[1]	Distance to North Transect	Crest EL.	Toe EL.	Slope	Stillwater Level	Total Water Level[2]	Incident Wave Height	Peak Wave Period	Free board	Revetment Inundated?	Back Water Flood?	RT 1A Flood?	Runup $R_{2\%}$	Wave Runup EL.	Flowrate per foot	Wave Runup Impact	Wave Overtopping Impact[3]	
		ft	ft, NAVD88	ft, NAVD88	%	ft, NAVD88	ft, NAVD88	ft	sec	ft				ft	ft, NAVD88	cfs	Above/Below Revetment Crest	Traffic	Pedestrians
Transect 7	637+60	160	14.9	4	47	8.4	11.65	3.7	13.5	6.5	No	Yes	Yes	8.6	17.0	1.07E-02	Above	Unsafe at any speed	Dangerous
Transect 7	636+0.0	160	14.9	4	86	8.4	11.65	3.7	13.5	6.5	No	Yes	Yes	11.1	19.5	1.07E-02	Above	Unsafe at any speed	Dangerous
7																			
Transect 1	336+19	0																	
Transect 2	345+44	132	17.7	5.3	40	8.4	11.5	4.5	13.5	9.3	No	No	No	9.7	18.1	3.52E-03	Above	Unsafe parking	Dangerous
Transect 3	344+12	312	17	5	44	8.4	11.5	4.8	13.5	8.6	No	No	No	10.6	19.0	1.35E-02	Above	Unsafe at any speed	Very dangerous
Transect 4	341+0.0	358	17	6	46	8.4	11.5	4.5	13.5	8.6	No	No	No	10.2	18.6	7.18E-03	Above	Unsafe at any speed	Dangerous
10																			
Transect 1	297+51	0	20.2	7.6	65	8.4	11.4	4.7	13.5	11.8	No	No	No	12.0	20.4	4.49E-04	Above	Unsafe parking	Dangerous
Transect 2	307+0.0	100	20.6	12.5	55	8.4	11.4	4.1	13.5	12.2	No	No	No	9.9	18.3	3.50E-05	Below	Unsafe driving at high speed	Wet but not uncomfortable
Transect 3	306+0.0	262	20.5	6.6	44	8.4	11.4	4.2	13.5	12.1	No	No	No	9.5	17.9	5.91E-05	Below	Unsafe driving at high speed	Uncomfortable but not dangerous
Transect 3	303+38	262	20.5	6.6	77	8.4	11.4	4.2	13.5	12.1	No	No	No	11.9	20.3	5.91E-05	Below	Unsafe driving at high speed	Uncomfortable but not dangerous
Transect 4	303+38	453	19	6	73	8.4	11.4	4.2	13.5	10.6	No	No	No	11.6	20.0	3.56E-04	Above	Unsafe parking	Dangerous
Transect 4	298+85	453	19	6	31	8.4	11.4	4.2	13.5	10.6	No	No	No	8.4	16.8	3.56E-04	Below	Unsafe parking	Dangerous
13																			
Transect 1	272+25	0	17.5	12	37	8.4	11.76	4.4	13.5	9.1	No	No	No	9.3	17.7	3.38E-03	Above	Unsafe parking	Dangerous
Transect 2	281+05	295	20.5	12.5	50	8.4	11.76	4.5	13.5	12.1	No	No	No	10.5	18.9	1.74E-04	Below	Unsafe parking	Uncomfortable but not dangerous
Transect 3	278+10	275	18.3	10.9	52	8.4	11.76	4.6	13.5	9.9	No	No	No	10.8	19.2	2.44E-03	Above	Unsafe parking	Dangerous
Transect 4	275+35	145	13.7	6.4	29	8.4	11.76	4.9	13.5	5.3	No	No	No	9.3	17.7	2.65E-01	Above	Unsafe at any speed	Very dangerous
Transect 5	273+90	175	21.7	7.2	44	8.4	11.76	5.0	13.5	13.3	No	No	No	10.9	19.3	2.35E-04	Below	Unsafe parking	Uncomfortable but not dangerous

Notes:

1. Refer to drawings for location of stations;
2. Total water level includes stillwater level plus wave setup, which was provided by FEMA only for 100-Year return period.
3. Based on USACE Coastal Engineering Manual (Reference 27) for safety assessment based on overtopping discharge.

Table 15. Assessment of wave runup, overtopping and revetment conditions for 50-Year storm condition.

NHDOT Section	NH RT 1A Coastal Revetment Survey					Metocean Characteristics				Revetment Condition				Wave Runup		Wave Overtopping	Risk Assessment		
	Approx. Station[1]	Distance to North Transect	Crest EL.	Toe EL.	Slope	Stillwater Level	Total Water Level[2]	Incident Wave Height	Peak Wave Period	Free board	Revetment Inundated?	Back Water Flood?	RT 1A Flood?	Runup $R_{2\%}$	Wave Runup EL.	Flowrate per foot	Wave Runup Impact	Wave Overtopping Impact[3]	
		ft	ft, NAVD88	ft, NAVD88	%	ft, NAVD88	ft, NAVD88	ft	sec	ft				ft	ft, NAVD88	cfs	Above/Below Revetment Crest	Traffic	Pedestrians
1			-	-	-														
Transect 1	806+33	0	15	9	33	8.0	NA	2.3	13.3	7	No	Yes	Yes	5.4	13.4	1.03E-05	Below	Safe driving at all speeds	Wet but not uncomfortable
Transect 2	818+0.0	70	15.7	9.6	31	8.0	NA	2.3	13.3	7.7	No	Yes	Yes	5.2	13.2	2.07E-06	Below	Safe driving at all speeds	Wet but not uncomfortable
Transect 3	817+30	110	14	6.5	43	8.0	NA	2.2	13.3	6	No	Yes	Yes	5.7	13.7	4.89E-05	Below	Unsafe driving at high speed	Uncomfortable but not dangerous
Transect 4	816+20	325	12.2	6	25	8.0	NA	3.0	13.3	4.2	No	Yes	Yes	5.9	13.9	3.58E-02	Above	Unsafe at any speed	Very dangerous
Transect 5	812+95	145	13.8	2.8	42	8.0	NA	2.8	13.3	5.8	No	Yes	Yes	6.8	14.8	1.69E-03	Above	Unsafe parking	Dangerous
Transect 6	811+50	225	15.5	5.3	44	8.0	NA	3.3	13.3	7.5	No	Yes	Yes	7.4	15.4	8.37E-04	Below	Unsafe parking	Dangerous
Transect 7	809+25	225	15.5	4.3	36	8.0	NA	3.8	13.3	7.5	No	Yes	Yes	8.3	16.3	4.19E-03	Above	Unsafe parking	Dangerous
2																			
Transect 1	800+24	0	15	4	44	8.0	NA	4.5	13.3	7	No	Yes	Yes	10.1	18.1	3.43E-02	Above	Unsafe at any speed	Very dangerous
Transect 2	805+50	310	15	7.5	30	8.0	NA	4.5	13.3	7	No	Yes	Yes	8.6	16.6	3.43E-02	Above	Unsafe at any speed	Very dangerous
Transect 3	802+40	216	14.8	10	30	8.0	NA	3.8	13.3	6.8	No	Yes	Yes	7.7	15.7	9.61E-03	Above	Unsafe at any speed	Dangerous
3																			
Transect 1	767+06	0	13.5	4.7	40	8.0	NA	6.6	13.3	5.5	No	No	No	13.6	21.6	1.03E+00	Above	Unsafe at any speed	Very dangerous
Transect 2	782+75	175	13.3	5.6	43	8.0	NA	6.9	13.3	5.3	No	No	No	14.4	22.4	1.39E+00	Above	Unsafe at any speed	Very dangerous
Transect 3	781+0.0	480	14	8.3	81	8.0	NA	6.7	13.3	6	No	No	No	17.8	25.8	8.47E-01	Above	Unsafe at any speed	Very dangerous
Transect 4	776+20	370	17	9.4	40	8.0	NA	5.1	13.3	9	No	No	No	10.5	18.5	1.67E-02	Above	Unsafe at any speed	Very dangerous
Transect 5	772+50	350	18.5	9	44	8.0	NA	4.6	13.3	10.5	No	No	No	10.0	18.0	1.31E-03	Below	Unsafe parking	Dangerous
Transect 6	769+0.0	150	15.9	8.8	45	8.0	NA	4.7	13.3	7.9	No	No	No	10.0	18.0	2.13E-02	Above	Unsafe at any speed	Very dangerous
4																			
Transect 1	687+83	0	15	10	31	8.0	NA	4.5	13.3	7	No	Yes	No	8.6	16.6	3.43E-02	Above	Unsafe at any speed	Very dangerous
Transect 2	695+50	350	16	10	47	8.0	NA	3.6	13.3	8	No	Yes	No	8.1	16.1	1.21E-03	Above	Unsafe parking	Dangerous
Transect 3	692+0.0	340	14.6	7.5	142	8.0	NA	4.9	13.3	6.6	No	No	No	15.7	23.7	9.30E-02	Above	Unsafe at any speed	Very dangerous
5																		Safe driving at all speeds	Wet but not uncomfortable
Transect 1	669+70	0	16.4	10	100	8.0	NA	4.5	13.3	8.4	No	No	No	13.5	21.5	8.77E-03	Above	Unsafe at any speed	Dangerous
Transect 2	686+40	340	15.6	9.8	76	8.0	NA	4.4	13.3	7.6	No	No	No	12.0	20.0	1.58E-02	Above	Unsafe at any speed	Very dangerous
Transect 3	683+0.0	275	16	6.5	43	8.0	NA	4.4	13.3	8	No	No	No	9.6	17.6	1.05E-02	Above	Unsafe at any speed	Dangerous
Transect 4	680+25	355	16.2	7.4	93	8.0	NA	3.9	13.3	8.2	No	No	No	11.8	19.8	2.40E-03	Above	Unsafe parking	Dangerous
Transect 5	676+70	100	15	4.4	61	8.0	NA	3.6	13.3	7	No	No	No	9.1	17.1	4.41E-03	Above	Unsafe parking	Dangerous
Transect 6	675+70	470	16	4.5	51	8.0	NA	2.9	13.3	8	No	No	No	6.9	14.9	6.32E-05	Below	Unsafe driving at high speed	Uncomfortable but not dangerous
6																			
Transect 1	631+64	0	14.5	4	60	8.0	NA	2.9	13.3	6.5	No	Yes	No	7.4	15.4	8.01E-04	Above	Unsafe parking	Dangerous
Transect 2	669+0.0	225	16.7	6.6	46	8.0	NA	3.1	13.3	8.7	No	Yes	No	7.1	15.1	5.48E-05	Below	Unsafe driving at high speed	Uncomfortable but not dangerous
Transect 3	666+75	475	16.4	6.8	56	8.0	NA	3.0	13.3	8.4	No	Yes	No	7.5	15.5	5.39E-05	Below	Unsafe driving at high speed	Uncomfortable but not dangerous
Transect 4	662+0.0	250	17.4	10	43	8.0	NA	3.4	13.3	9.4	No	Yes	No	7.5	15.5	7.78E-05	Below	Unsafe driving at high speed	Uncomfortable but not dangerous
Transect 5	659+50	650	17.6	11.5	50	8.0	NA	4.2	13.3	9.6	No	Yes	No	9.9	17.9	1.13E-03	Above	Unsafe parking	Dangerous
Transect 6	653+0.0	1540	17.3	8.6	49	8.0	NA	3.7	13.3	9.3	No	Yes	Yes	8.7	16.7	3.10E-04	Below	Unsafe parking	Uncomfortable but not dangerous

NHDOT Section	NH RT 1A Coastal Revetment Survey					Metocean Characteristics				Revetment Condition				Wave Runup		Wave Overtopping	Risk Assessment		
	Approx. Station[1]	Distance to North Transect	Crest EL.	Toe EL.	Slope	Stillwater Level	Total Water Level[2]	Incident Wave Height	Peak Wave Period	Free board	Revetment Inundated?	Back Water Flood?	RT 1A Flood?	Runup $R_{2\%}$	Wave Runup EL.	Flowrate per foot	Wave Runup Impact	Wave Overtopping Impact[3]	
		ft	ft, NAVD88	ft, NAVD88	%	ft, NAVD88	ft, NAVD88	ft	sec	ft				ft	ft, NAVD88	cfs	Above/Below Revetment Crest	Traffic	Pedestrians
Transect 7	637+60	160	14.9	4	47	8.0	NA	3.5	13.3	6.9	No	Yes	Yes	8.2	16.2	3.74E-03	Above	Unsafe parking	Dangerous
Transect 7	636+0.0	160	14.9	4	86	8.0	NA	3.5	13.3	6.9	No	Yes	Yes	10.5	18.5	3.74E-03	Above	Unsafe parking	Dangerous
7																			
Transect 1	336+19	0																	
Transect 2	345+44	132	17.7	5.3	40	8.0	NA	4.4	13.3	9.7	No	No	No	9.4	17.4	1.78E-03	Below	Unsafe parking	Dangerous
Transect 3	344+12	312	17	5	44	8.0	NA	4.6	13.3	9	No	No	No	10.2	18.2	6.03E-03	Above	Unsafe at any speed	Dangerous
Transect 4	341+0.0	358	17	6	46	8.0	NA	4.3	13.3	9	No	No	No	9.7	17.7	2.91E-03	Above	Unsafe parking	Dangerous
10																			
Transect 1	297+51	0	20.2	7.6	65	8.0	NA	4.5	13.3	12.2	No	No	No	11.5	19.5	1.55E-04	Below	Unsafe parking	Uncomfortable but not dangerous
Transect 2	307+0.0	100	20.6	12.5	55	8.0	NA	4.0	13.3	12.6	No	No	No	9.7	17.7	1.36E-05	Below	Unsafe driving at high speed	Wet but not uncomfortable
Transect 3	306+0.0	262	20.5	6.6	44	8.0	NA	4.0	13.3	12.5	No	No	No	9.0	17.0	1.55E-05	Below	Unsafe driving at high speed	Wet but not uncomfortable
Transect 3	303+38	262	20.5	6.6	77	8.0	NA	4.0	13.3	12.5	No	No	No	11.3	19.3	1.55E-05	Below	Unsafe driving at high speed	Wet but not uncomfortable
Transect 4	303+38	453	19	6	73	8.0	NA	4.1	13.3	11	No	No	No	11.3	19.3	1.56E-04	Above	Unsafe parking	Uncomfortable but not dangerous
Transect 4	298+85	453	19	6	31	8.0	NA	4.1	13.3	11	No	No	No	8.2	16.2	1.56E-04	Below	Unsafe parking	Uncomfortable but not dangerous
13																			
Transect 1	272+25	0	17.5	12	37	8.0	NA	4.2	13.3	9.5	No	No	No	8.8	16.8	1.27E-03	Below	Unsafe parking	Dangerous
Transect 2	281+05	295	20.5	12.5	50	8.0	NA	4.3	13.3	12.5	No	No	No	10.1	18.1	5.36E-05	Below	Unsafe driving at high speed	Uncomfortable but not dangerous
Transect 3	278+10	275	18.3	10.9	52	8.0	NA	4.4	13.3	10.3	No	No	No	10.4	18.4	9.30E-04	Above	Unsafe parking	Dangerous
Transect 4	275+35	145	13.7	6.4	29	8.0	NA	4.7	13.3	5.7	No	No	No	8.9	16.9	1.50E-01	Above	Unsafe at any speed	Very dangerous
Transect 5	273+90	175	21.7	7.2	44	8.0	NA	4.8	13.3	13.7	No	No	No	10.5	18.5	8.28E-05	Below	Unsafe driving at high speed	Uncomfortable but not dangerous

Notes:

1. Refer to drawings for location of stations;
2. Total water level includes stillwater level plus wave setup, which was provided by FEMA only for 100-Year return period.
3. Based on USACE Coastal Engineering Manual (Reference 27) for safety assessment based on overtopping discharge.

Table 16. Assessment of wave runup, overtopping and revetment conditions for 10-Year storm condition.

NHDOT Section	NH RT 1A Coastal Revetment Survey					Metocean Characteristics				Revetment Condition				Wave Runup		Wave Overtopping	Risk Assessment		
	Approx. Station[1]	Distance to North Transect	Crest EL.	Toe EL.	Slope	Stillwater Level	Total Water Level[2]	Incident Wave Height	Peak Wave Period	Free board	Revetment Inundated?	Back Water Flood?	RT 1A Flood?	Runup $R_{2\%}$	Wave Runup EL.	Flowrate per foot	Wave Runup Impact	Wave Overtopping Impact[3]	
		ft	ft, NAVD88	ft, NAVD88	%	ft, NAVD88	ft, NAVD88	ft	sec	ft				ft	ft, NAVD88	cfs	Above/Below Revetment Crest	Traffic	Pedestrians
1			-	-	-														
Transect 1	806+33	0	15	9	33	7.2	NA	2.0	12.8	7.8	No	Yes	Yes	4.8	12.0	8.11E-08	Below	Safe driving at all speeds	Wet but not uncomfortable
Transect 2	818+0.0	70	15.7	9.6	31	7.2	NA	2.0	12.8	8.5	No	Yes	Yes	4.6	11.8	1.11E-08	Below	Safe driving at all speeds	Wet but not uncomfortable
Transect 3	817+30	110	14	6.5	43	7.2	NA	1.9	12.8	6.8	No	Yes	Yes	5.0	12.2	4.45E-07	Below	Safe driving at all speeds	Wet but not uncomfortable
Transect 4	816+20	325	12.2	6	25	7.2	NA	2.7	12.8	5	No	Yes	Yes	5.4	12.6	4.36E-03	Above	Unsafe parking	Dangerous
Transect 5	812+95	145	13.8	2.8	42	7.2	NA	2.5	12.8	6.6	No	Yes	Yes	6.1	13.3	9.18E-05	Below	Unsafe driving at high speed	Uncomfortable but not dangerous
Transect 6	811+50	225	15.5	5.3	44	7.2	NA	2.9	12.8	8.3	No	Yes	Yes	6.5	13.7	3.74E-05	Below	Unsafe driving at high speed	Wet but not uncomfortable
Transect 7	809+25	225	15.5	4.3	36	7.2	NA	3.4	12.8	8.3	No	Yes	Yes	7.5	14.7	3.89E-04	Below	Unsafe parking	Dangerous
2																			
Transect 1	800+24	0	15	4	44	7.2	NA	4.1	12.8	7.8	No	Yes	Yes	9.2	16.4	6.49E-03	Above	Unsafe at any speed	Dangerous
Transect 2	805+50	310	15	7.5	30	7.2	NA	4.2	12.8	7.8	No	Yes	Yes	8.0	15.2	8.25E-03	Above	Unsafe at any speed	Dangerous
Transect 3	802+40	216	14.8	10	30	7.2	NA	3.5	12.8	7.6	No	Yes	Yes	7.1	14.3	1.48E-03	Below	Unsafe parking	Dangerous
3																			
Transect 1	767+06	0	13.5	4.7	40	7.2	NA	6.3	12.8	6.3	No	No	No	12.9	20.1	5.27E-01	Above	Unsafe at any speed	Very dangerous
Transect 2	782+75	175	13.3	5.6	43	7.2	NA	6.6	12.8	6.1	No	No	No	13.7	20.9	7.47E-01	Above	Unsafe at any speed	Very dangerous
Transect 3	781+0.0	480	14	8.3	81	7.2	NA	6.3	12.8	6.8	No	No	No	16.7	23.9	3.90E-01	Above	Unsafe at any speed	Very dangerous
Transect 4	776+20	370	17	9.4	40	7.2	NA	4.8	12.8	9.8	No	No	No	9.8	17.0	4.35E-03	Above	Unsafe parking	Dangerous
Transect 5	772+50	350	18.5	9	44	7.2	NA	4.2	12.8	11.3	No	No	No	9.1	16.3	1.55E-04	Below	Unsafe parking	Uncomfortable but not dangerous
Transect 6	769+0.0	150	15.9	8.8	45	7.2	NA	4.4	12.8	8.7	No	No	No	9.2	16.4	5.13E-03	Above	Unsafe at any speed	Dangerous
4																			
Transect 1	687+83	0	15	10	31	7.2	NA	4.1	12.8	7.8	No	Yes	No	7.8	15.0	6.49E-03	Above	Unsafe at any speed	Dangerous
Transect 2	695+50	350	16	10	47	7.2	NA	3.3	12.8	8.8	No	Yes	No	7.4	14.6	1.22E-04	Below	Unsafe parking	Uncomfortable but not dangerous
Transect 3	692+0.0	340	14.6	7.5	142	7.2	NA	4.5	12.8	7.4	No	No	No	14.4	21.6	2.34E-02	Above	Unsafe at any speed	Very dangerous
5																		Safe driving at all speeds	Wet but not uncomfortable
Transect 1	669+70	0	16.4	10	100	7.2	NA	4.1	12.8	9.2	No	No	No	12.3	19.5	1.33E-03	Above	Unsafe parking	Dangerous
Transect 2	686+40	340	15.6	9.8	76	7.2	NA	4.1	12.8	8.4	No	No	No	11.1	18.3	3.32E-03	Above	Unsafe parking	Dangerous
Transect 3	683+0.0	275	16	6.5	43	7.2	NA	4.1	12.8	8.8	No	No	No	8.9	16.1	2.11E-03	Above	Unsafe parking	Dangerous
Transect 4	680+25	355	16.2	7.4	93	7.2	NA	3.7	12.8	9	No	No	No	11.1	18.3	4.60E-04	Above	Unsafe parking	Dangerous
Transect 5	676+70	100	15	4.4	61	7.2	NA	3.4	12.8	7.8	No	No	No	8.5	15.7	7.91E-04	Above	Unsafe parking	Dangerous
Transect 6	675+70	470	16	4.5	51	7.2	NA	2.6	12.8	8.8	No	No	No	6.1	13.3	2.04E-06	Below	Safe driving at all speeds	Wet but not uncomfortable
6																			
Transect 1	631+64	0	14.5	4	60	7.2	NA	2.6	12.8	7.3	No	Yes	No	6.6	13.8	4.18E-05	Below	Unsafe driving at high speed	Wet but not uncomfortable
Transect 2	669+0.0	225	16.7	6.6	46	7.2	NA	2.8	12.8	9.5	No	Yes	No	6.4	13.6	2.18E-06	Below	Safe driving at all speeds	Wet but not uncomfortable
Transect 3	666+75	475	16.4	6.8	56	7.2	NA	2.8	12.8	9.2	No	Yes	No	6.9	14.1	3.88E-06	Below	Safe driving at all speeds	Wet but not uncomfortable
Transect 4	662+0.0	250	17.4	10	43	7.2	NA	3.1	12.8	10.2	No	Yes	No	6.8	14.0	4.41E-06	Below	Safe driving at all speeds	Wet but not uncomfortable
Transect 5	659+50	650	17.6	11.5	50	7.2	NA	4.0	12.8	10.4	No	Yes	No	9.3	16.5	2.27E-04	Below	Unsafe parking	Uncomfortable but not dangerous
Transect 6	653+0.0	1540	17.3	8.6	49	7.2	NA	3.5	12.8	10.1	No	Yes	Yes	8.2	15.4	4.39E-05	Below	Unsafe driving at high speed	Uncomfortable but not dangerous

NHDOT Section	NH RT 1A Coastal Revetment Survey					Metocean Characteristics				Revetment Condition				Wave Runup		Wave Overtopping	Risk Assessment		
	Approx. Station[1]	Distance to North Transect	Crest EL.	Toe EL.	Slope	Stillwater Level	Total Water Level[2]	Incident Wave Height	Peak Wave Period	Free board	Revetment Inundated?	Back Water Flood?	RT 1A Flood?	Runup $R_{2\%}$	Wave Runup EL.	Flowrate per foot	Wave Runup Impact	Wave Overtopping Impact[3]	
		ft	ft, NAVD88	ft, NAVD88	%	ft, NAVD88	ft, NAVD88	ft	sec	ft				ft	ft, NAVD88	cfs	Above/Below Revetment Crest	Traffic	Pedestrians
Transect 7	637+60	160	14.9	4	47	7.2	NA	3.3	12.8	7.7	No	Yes	Yes	7.6	14.8	6.26E-04	Below	Unsafe parking	Dangerous
Transect 7	636+0.0	160	14.9	4	86	7.2	NA	3.3	12.8	7.7	No	Yes	Yes	9.8	17.0	6.26E-04	Above	Unsafe parking	Dangerous
7																			
Transect 1	336+19	0						4.2											
Transect 2	345+44	132	17.7	5.3	40	7.2	NA	4.1	12.8	10.5	No	No	No	8.8	16.0	2.86E-04	Below	Unsafe parking	Uncomfortable but not dangerous
Transect 3	344+12	312	17	5	44	7.2	NA	4.3	12.8	9.8	No	No	No	9.5	16.7	1.21E-03	Below	Unsafe parking	Dangerous
Transect 4	341+0.0	358	17	6	46	7.2	NA	4.1	12.8	9.8	No	No	No	9.2	16.4	6.59E-04	Below	Unsafe parking	Dangerous
10																			
Transect 1	297+51	0	20.2	7.6	65	7.2	NA	4.2	12.8	13	No	No	No	10.7	17.9	1.95E-05	Below	Unsafe driving at high speed	Wet but not uncomfortable
Transect 2	307+0.0	100	20.6	12.5	55	7.2	NA	3.7	12.8	13.4	No	No	No	8.9	16.1	9.56E-07	Below	Safe driving at all speeds	Wet but not uncomfortable
Transect 3	306+0.0	262	20.5	6.6	44	7.2	NA	3.8	12.8	13.3	No	No	No	8.5	15.7	1.93E-06	Below	Safe driving at all speeds	Wet but not uncomfortable
Transect 3	303+38	262	20.5	6.6	77	7.2	NA	3.8	12.8	13.3	No	No	No	10.7	17.9	1.93E-06	Below	Safe driving at all speeds	Wet but not uncomfortable
Transect 4	303+38	453	19	6	73	7.2	NA	3.8	12.8	11.8	No	No	No	10.4	17.6	1.59E-05	Below	Unsafe driving at high speed	Wet but not uncomfortable
Transect 4	298+85	453	19	6	31	7.2	NA	3.8	12.8	11.8	No	No	No	7.5	14.7	1.59E-05	Below	Unsafe driving at high speed	Wet but not uncomfortable
13																			
Transect 1	272+25	0	17.5	12	37	7.2	NA	3.9	12.8	10.3	No	No	No	8.2	15.4	1.78E-04	Below	Unsafe parking	Uncomfortable but not dangerous
Transect 2	281+05	295	20.5	12.5	50	7.2	NA	4.0	12.8	13.3	No	No	No	9.3	16.5	5.37E-06	Below	Safe driving at all speeds	Wet but not uncomfortable
Transect 3	278+10	275	18.3	10.9	52	7.2	NA	4.1	12.8	11.1	No	No	No	9.6	16.8	1.38E-04	Below	Unsafe parking	Uncomfortable but not dangerous
Transect 4	275+35	145	13.7	6.4	29	7.2	NA	4.4	12.8	6.5	No	No	No	8.3	15.5	4.61E-02	Above	Unsafe at any speed	Very dangerous
Transect 5	273+90	175	21.7	7.2	44	7.2	NA	4.5	12.8	14.5	No	No	No	9.8	17.0	1.11E-05	Below	Unsafe driving at high speed	Wet but not uncomfortable

Notes:

1. Refer to drawings for location of stations;
2. Total water level includes stillwater level plus wave setup, which was provided by FEMA only for 100-Year return period.
3. Based on USACE Coastal Engineering Manual (Reference 27) for safety assessment based on overtopping discharge.

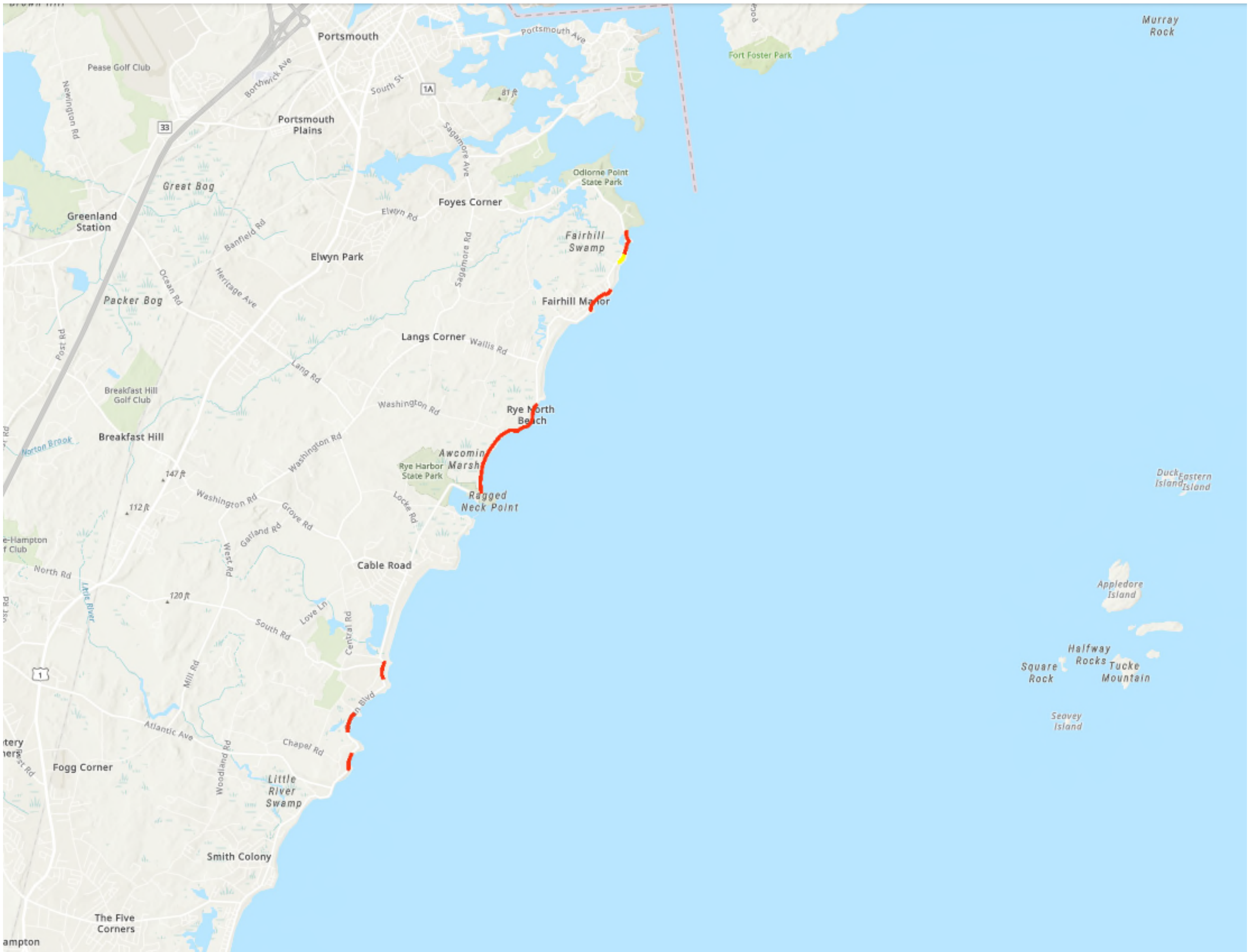


Figure 1. Location of NHDOT sections.

Figure 2. Location of NHDOT sections and observation sites for water level (NOAA gages), wave (WIS buoys and NDBC 44007) and wind (NDBC IOSN3 and NDBC 44073).

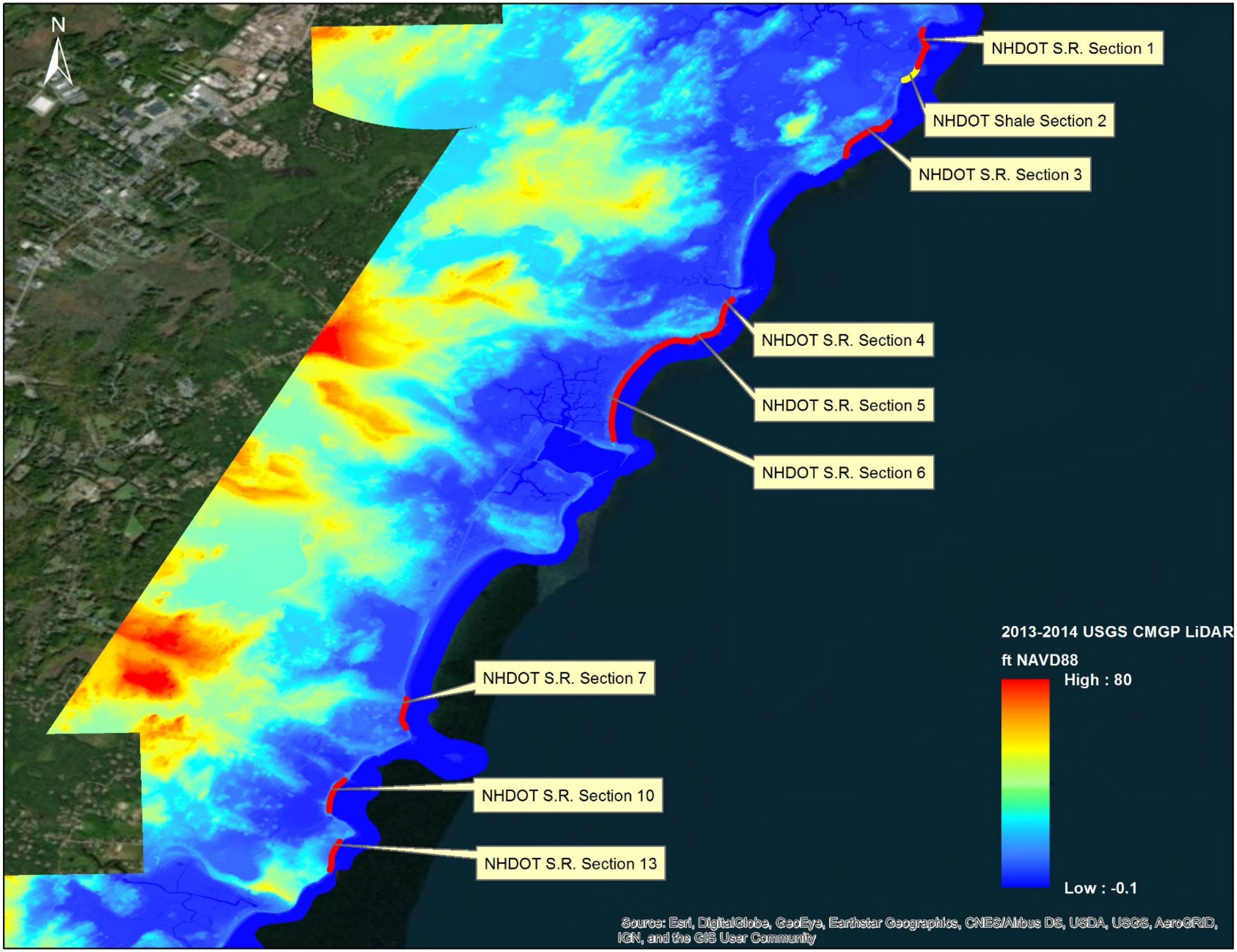


Figure 3. New England CMGP Sandy Lidar (2013-2014).

Figure 4. Location of NHDOT sections, nearby tide gage, WIS wave buoy and NACCS save points.

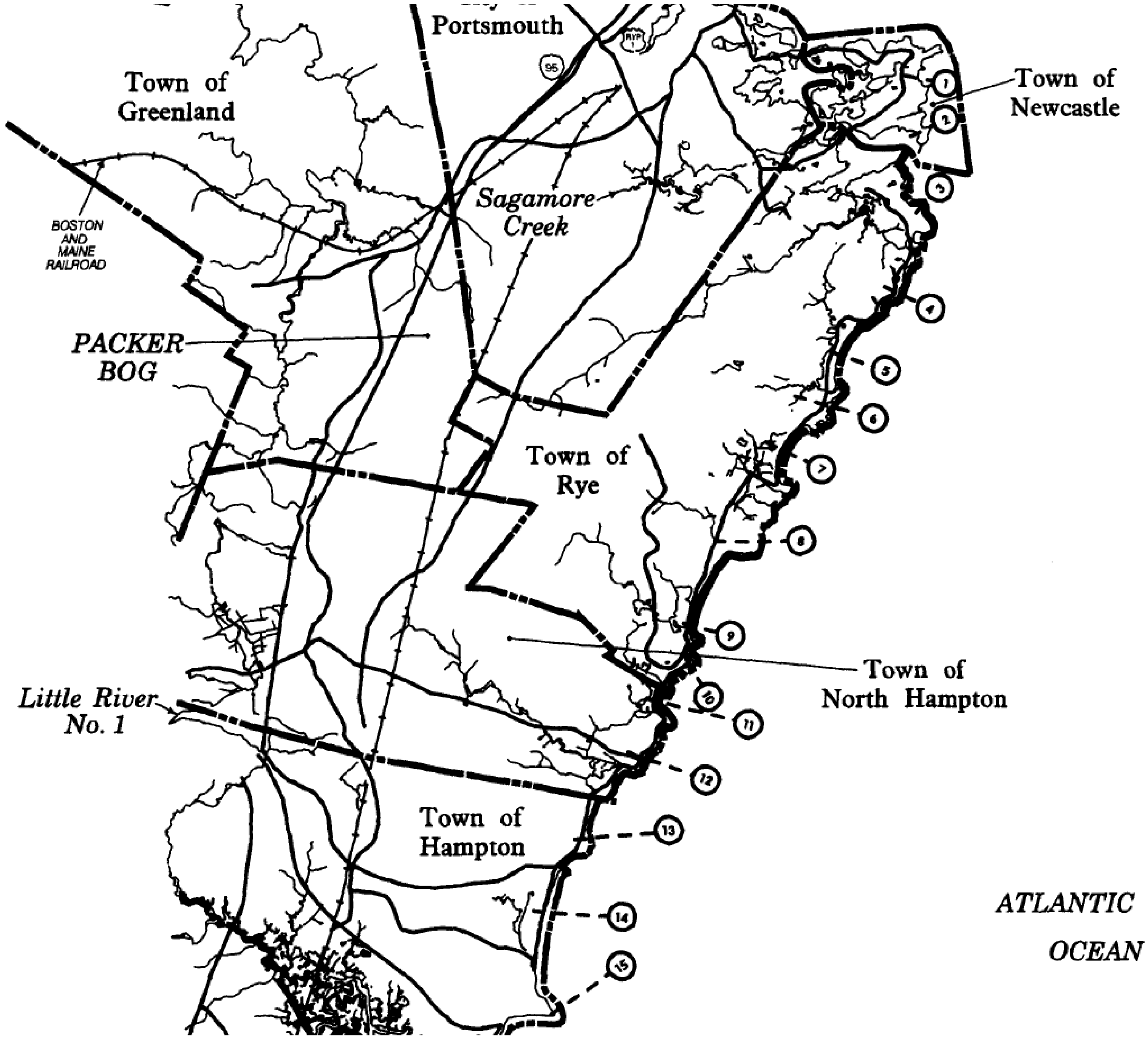


Figure 5. Coastal transects for Effective FEMA FIS (2005) at Town of Rye and Town of Hampton, NH.

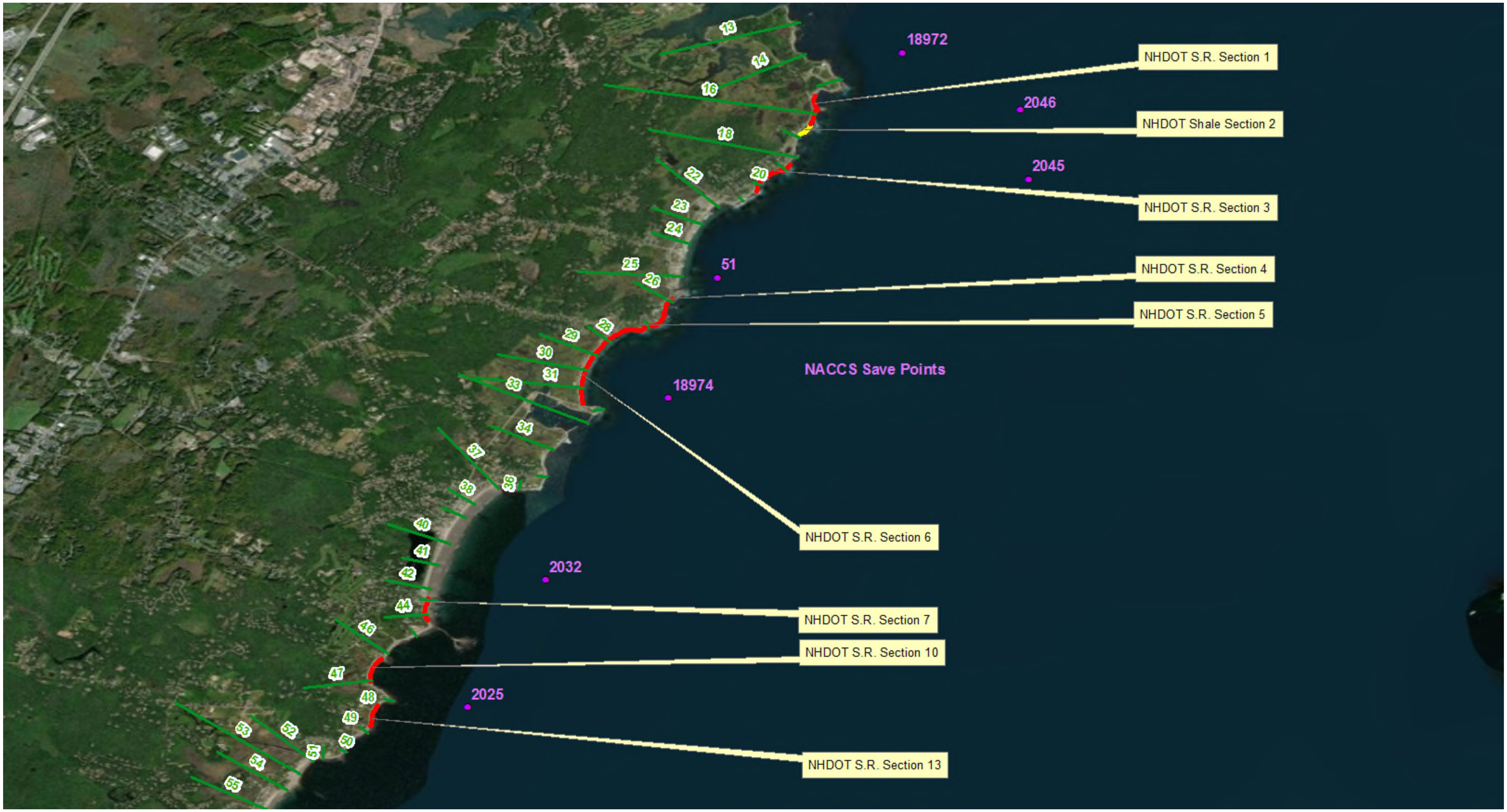


Figure 6. Coastal transects for Revised Preliminary FEMA FIS (2016) at Town of Rye and Town of Hampton, NH.

Figure 7. Transect Locations at NHDOT S.R. Section 1.

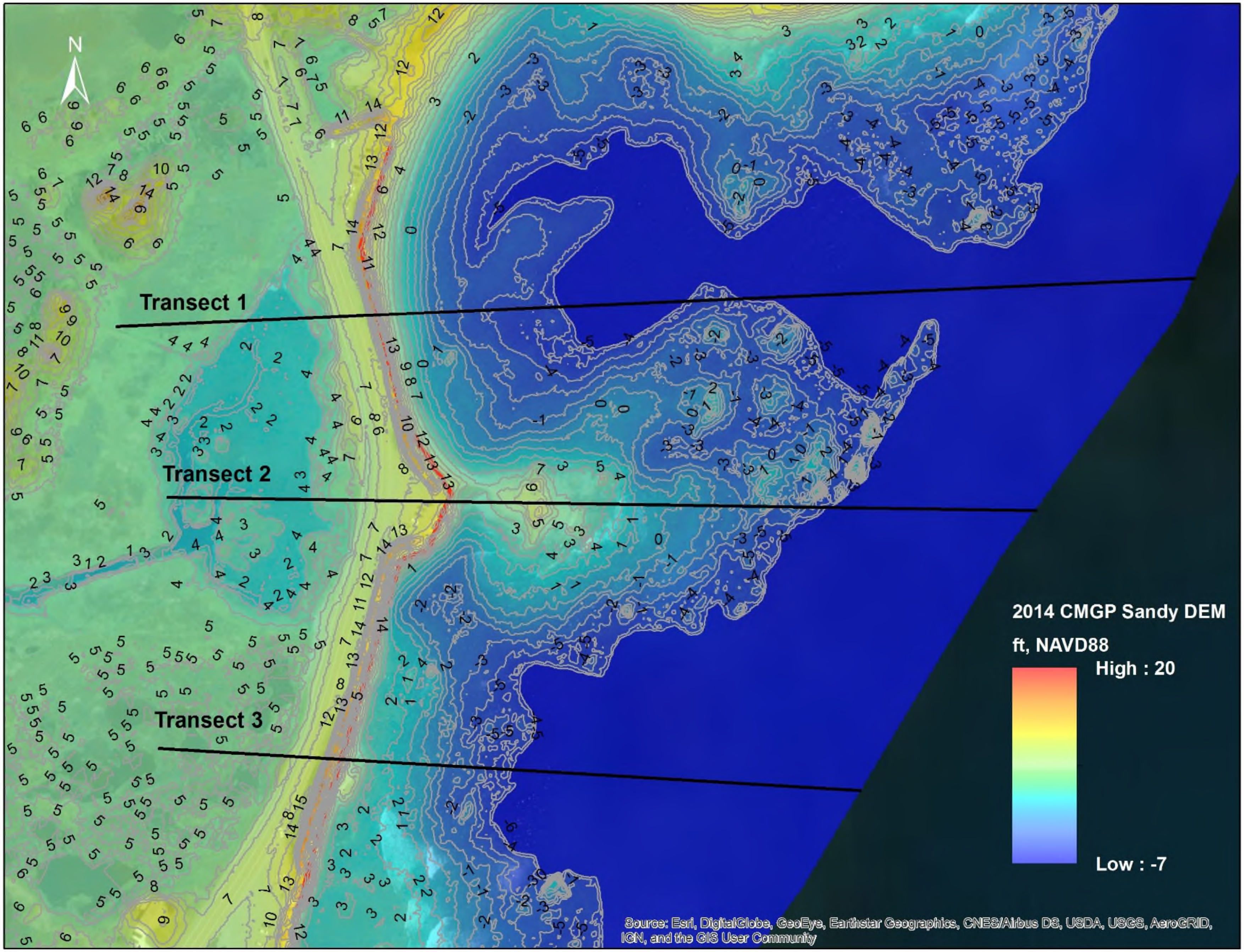


Figure 8. Transects and elevations at NHDOT S.R. Section 1.

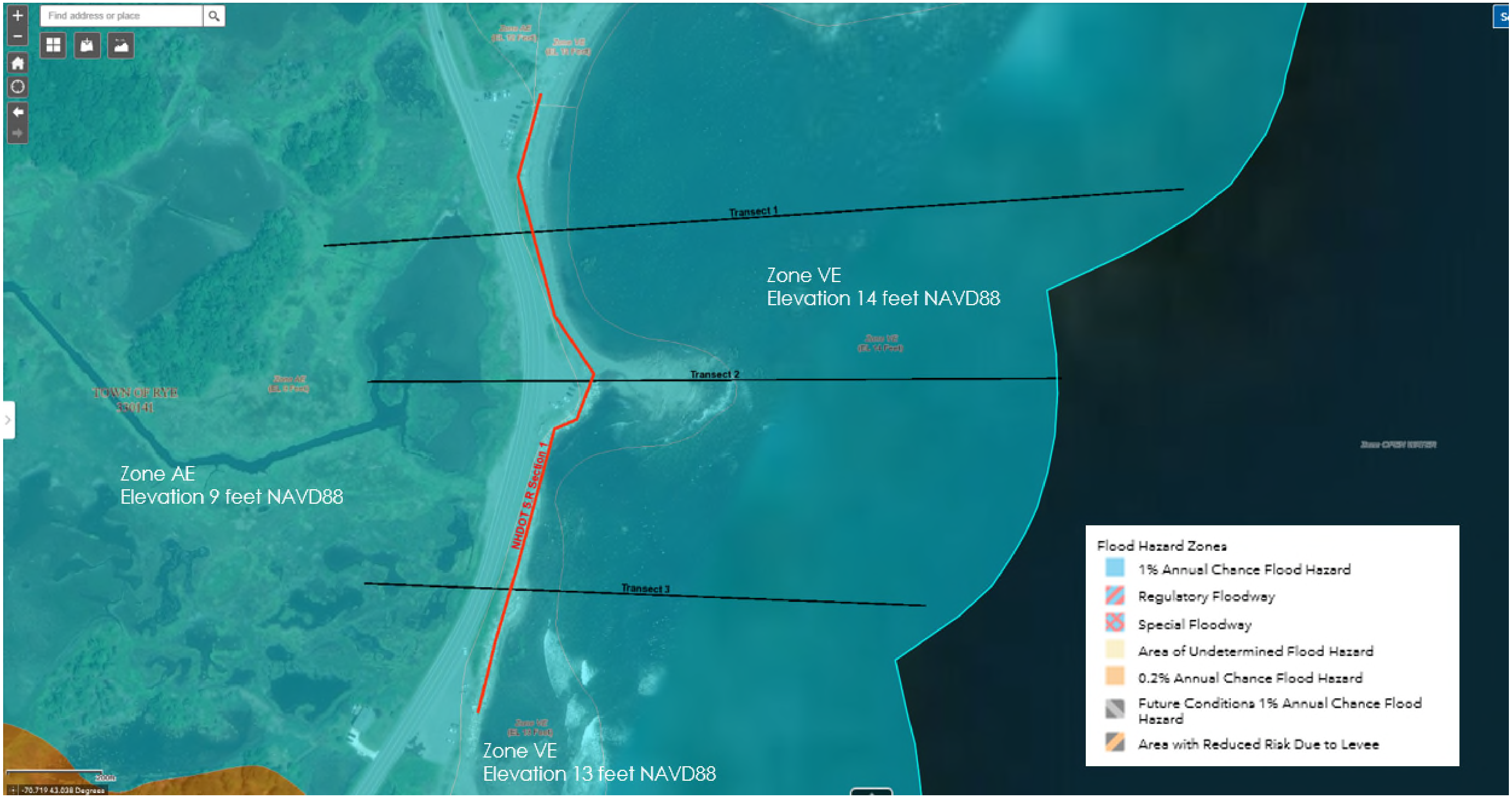


Figure 9. FEMA Flood Hazard Zones in vicinity of the NHDOT sections – Section 1.

Figure 10. Flood inundation at Stillwater Elevation 8.5 feet NAVD88 – Vicinity of Section 1.

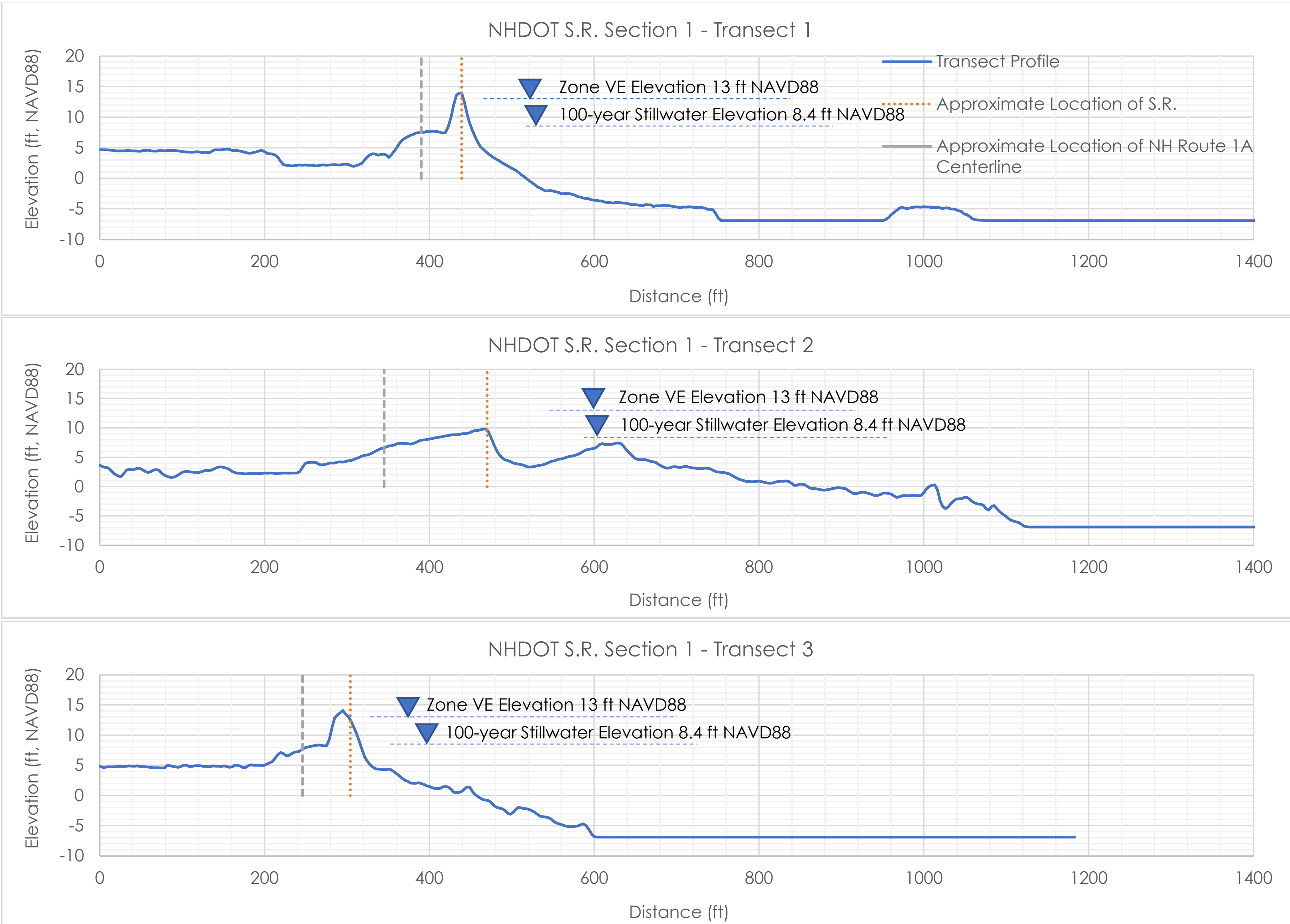


Figure 11. Elevation profile for Transect 1, 2, 3 at NHDOT S.R. Section 1.

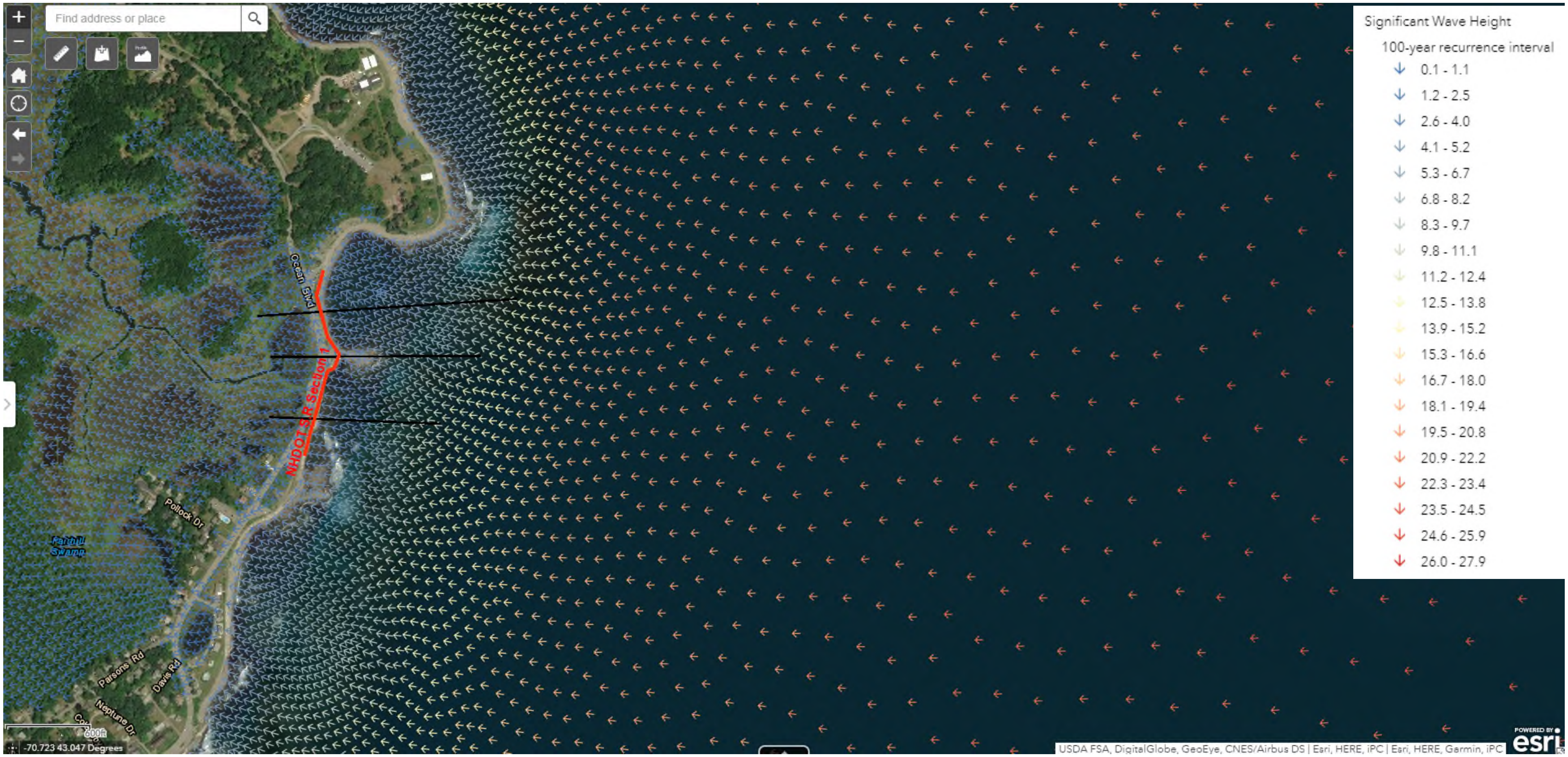


Figure 12. 100-year Recurrence Interval Wave Height (feet) for Transect 1, 2, 3 at NHDOT S.R. Section 1.

Figure 13. Transect Locations at NHDOT Shale Section 2.

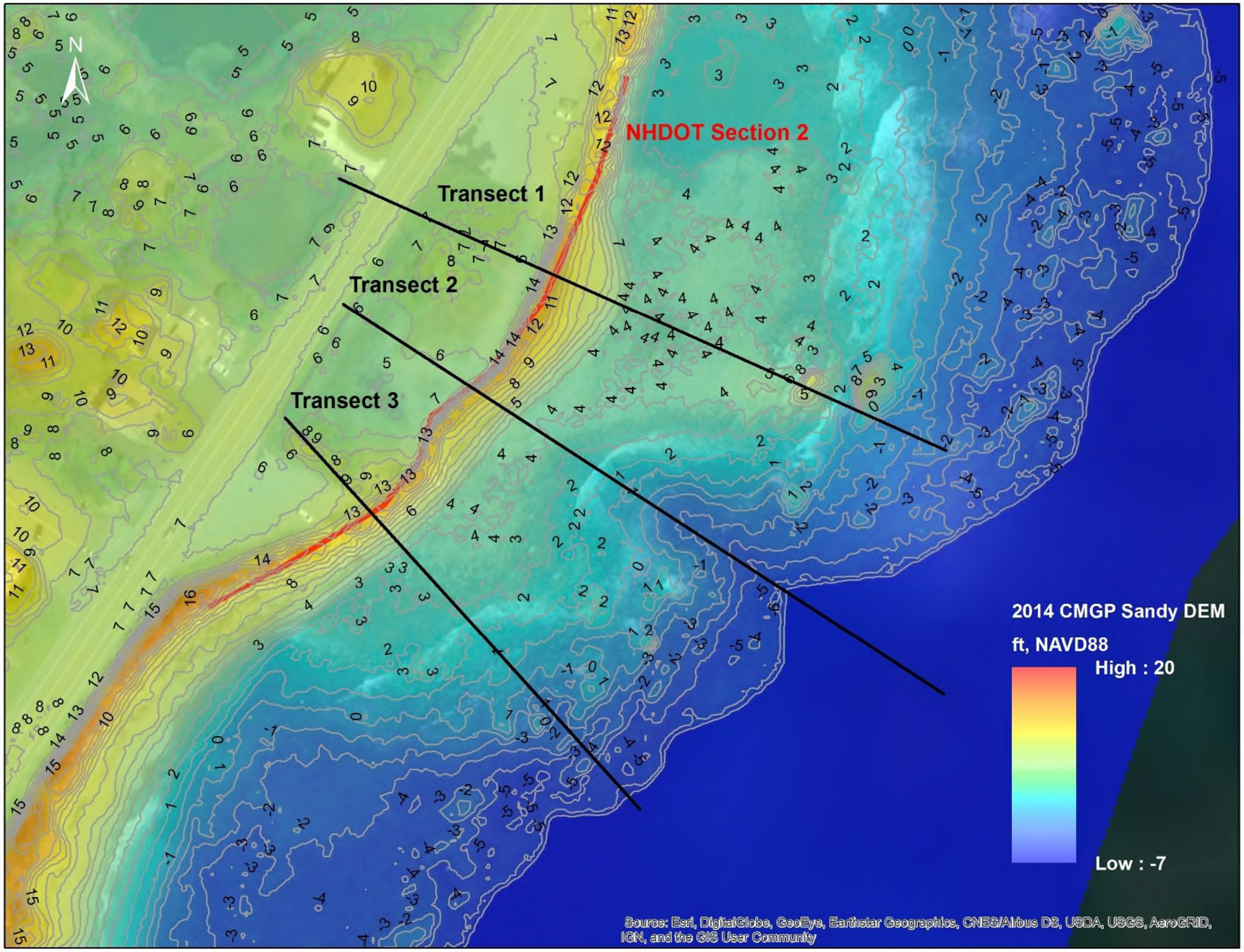


Figure 14. Transects and elevations at NHDOT Shale Section 2.

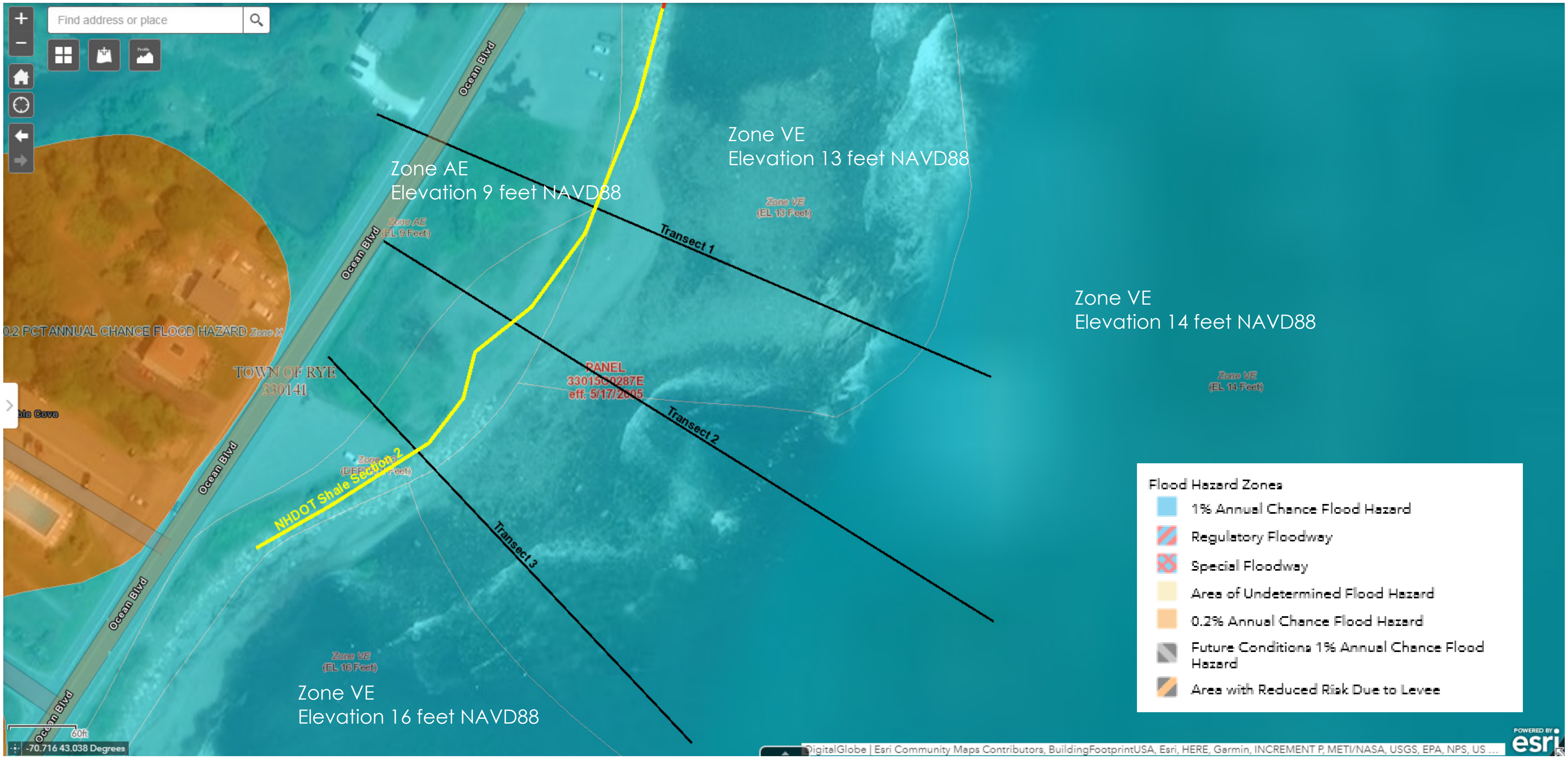


Figure 15. FEMA Flood Hazard Zones in vicinity of the NHDOT sections – Section 2.

Figure 16. Flood inundation at Stillwater Elevation 8.5 feet NAVD88 – Vicinity of Section 2.

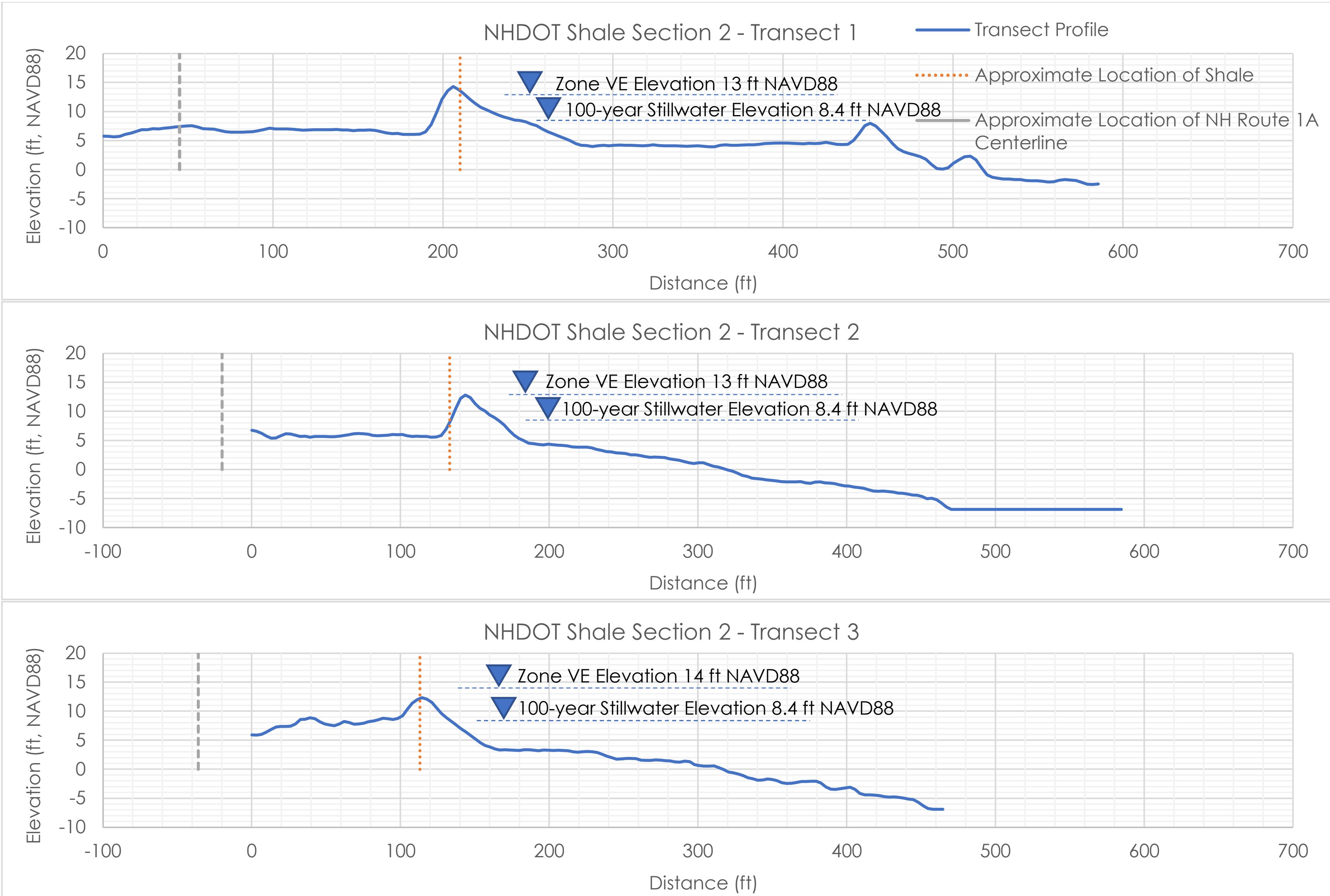


Figure 17. Elevation profile for Transect 1, 2, 3 at NHDOT Shale Section 2.

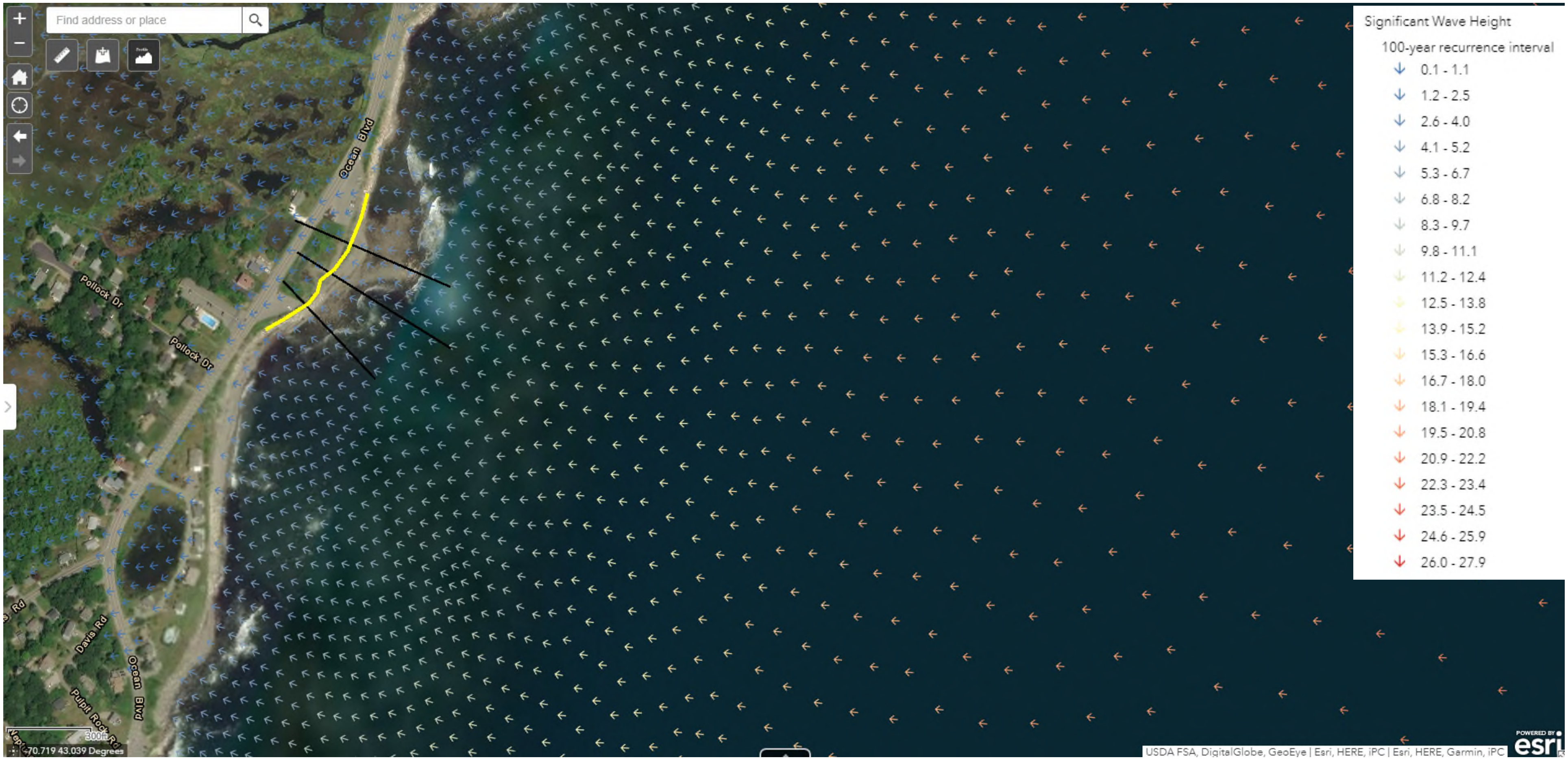


Figure 18. 100-year Recurrence Interval Wave Height (feet) for Transect 1, 2, 3 at NHDOT S.R. Section 2.

Figure 19. Transect Locations at NHDOT S.R. Section 3.

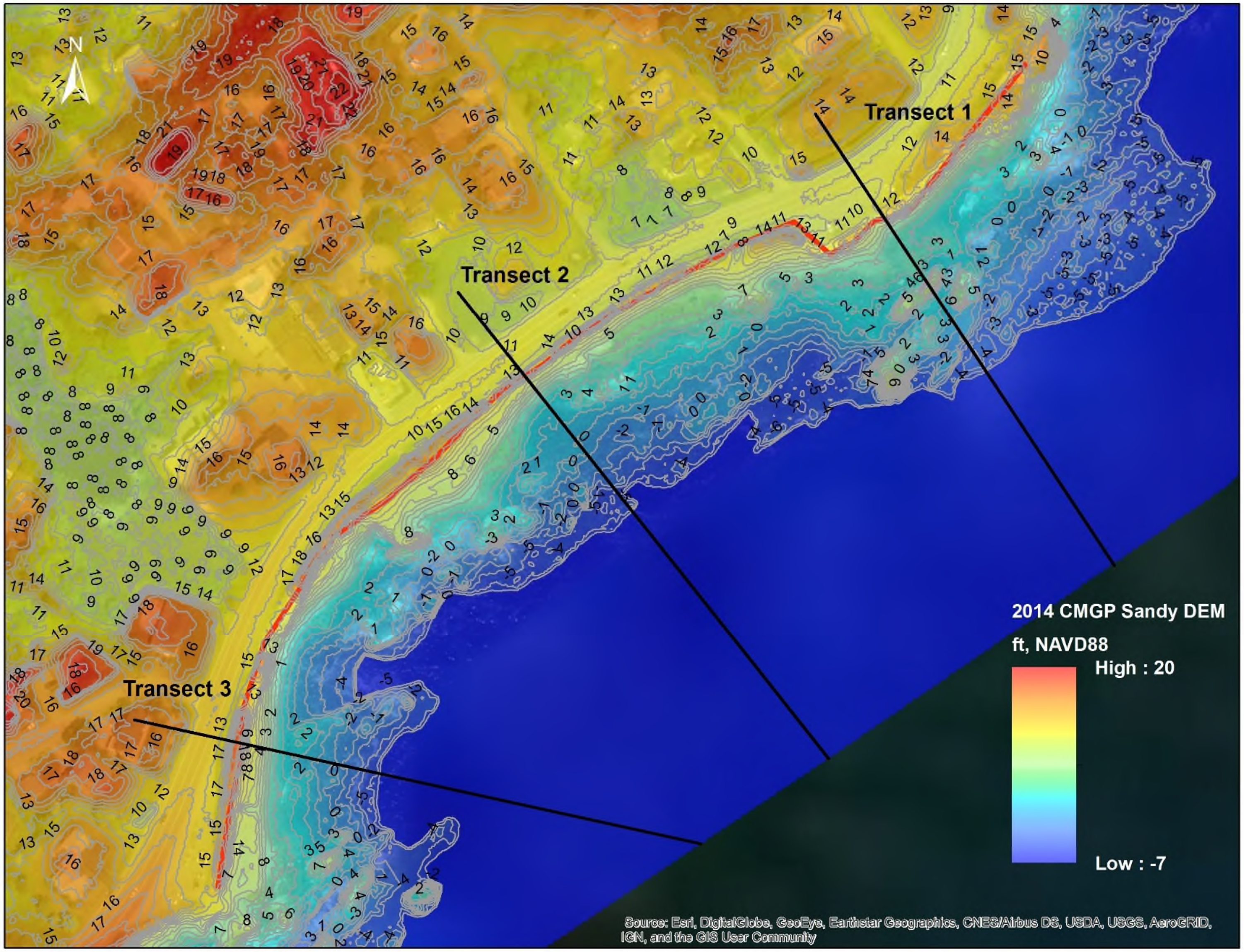


Figure 20. Transects and elevations at NHDOT S.R. Section 3.

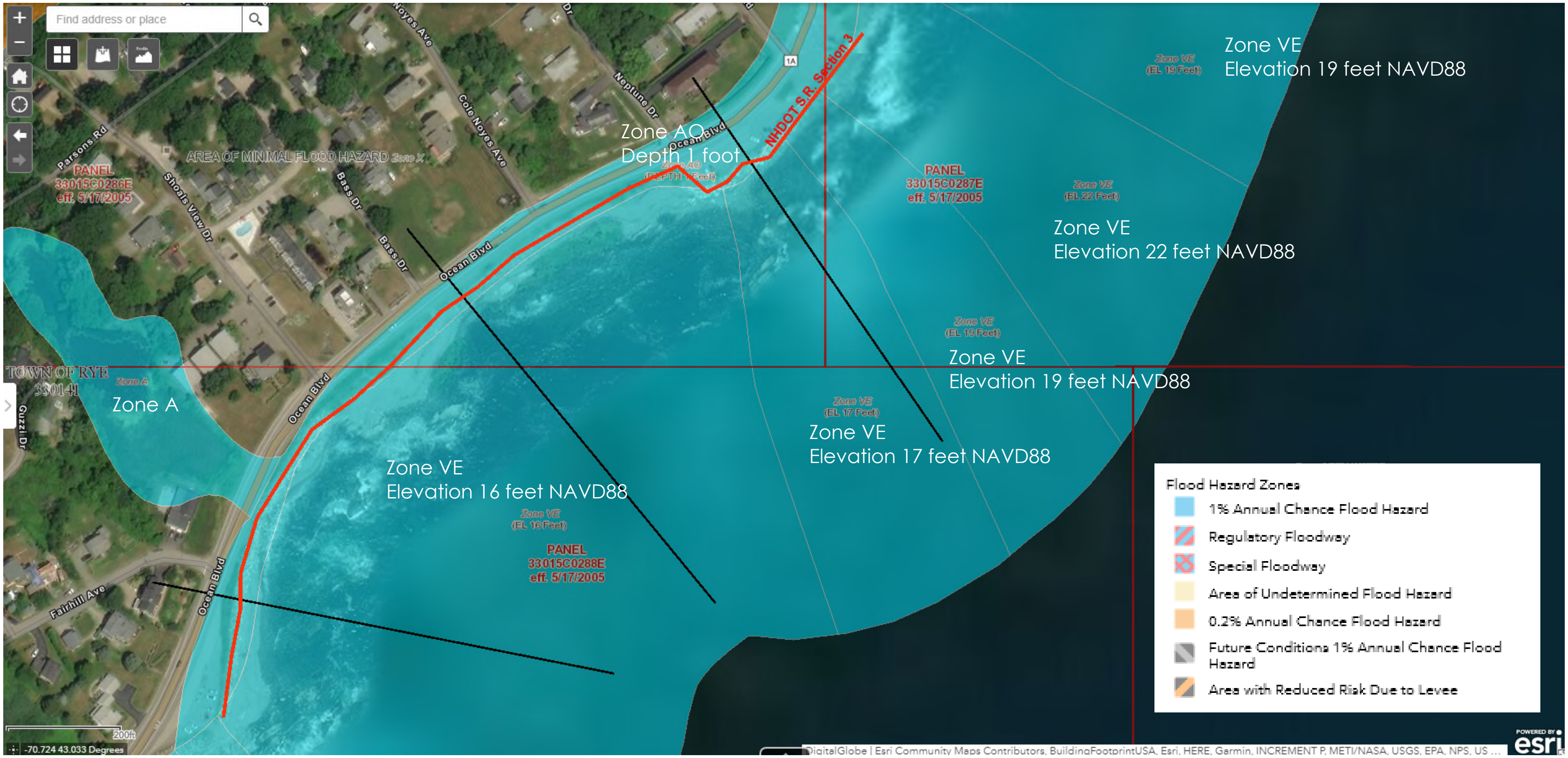


Figure 21. FEMA Flood Hazard Zones in vicinity of the NHDOT sections – Section 3.

Figure 22. Flood inundation at Stillwater Elevation 8.5 feet NAVD88 – Vicinity of Section 3.

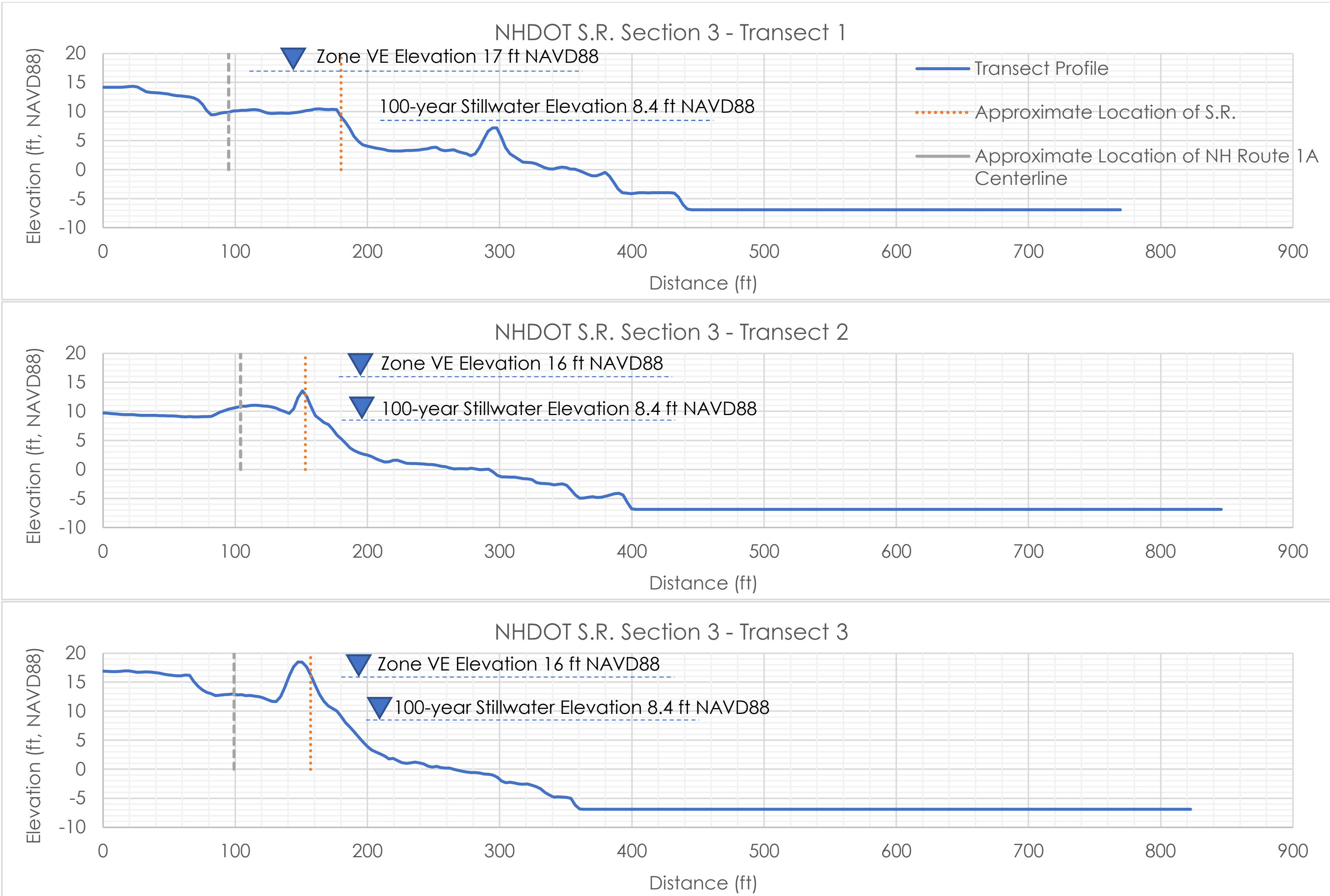


Figure 23. Elevation profile for Transect 1, 2, 3 at NHDOT S.R. Section 3.

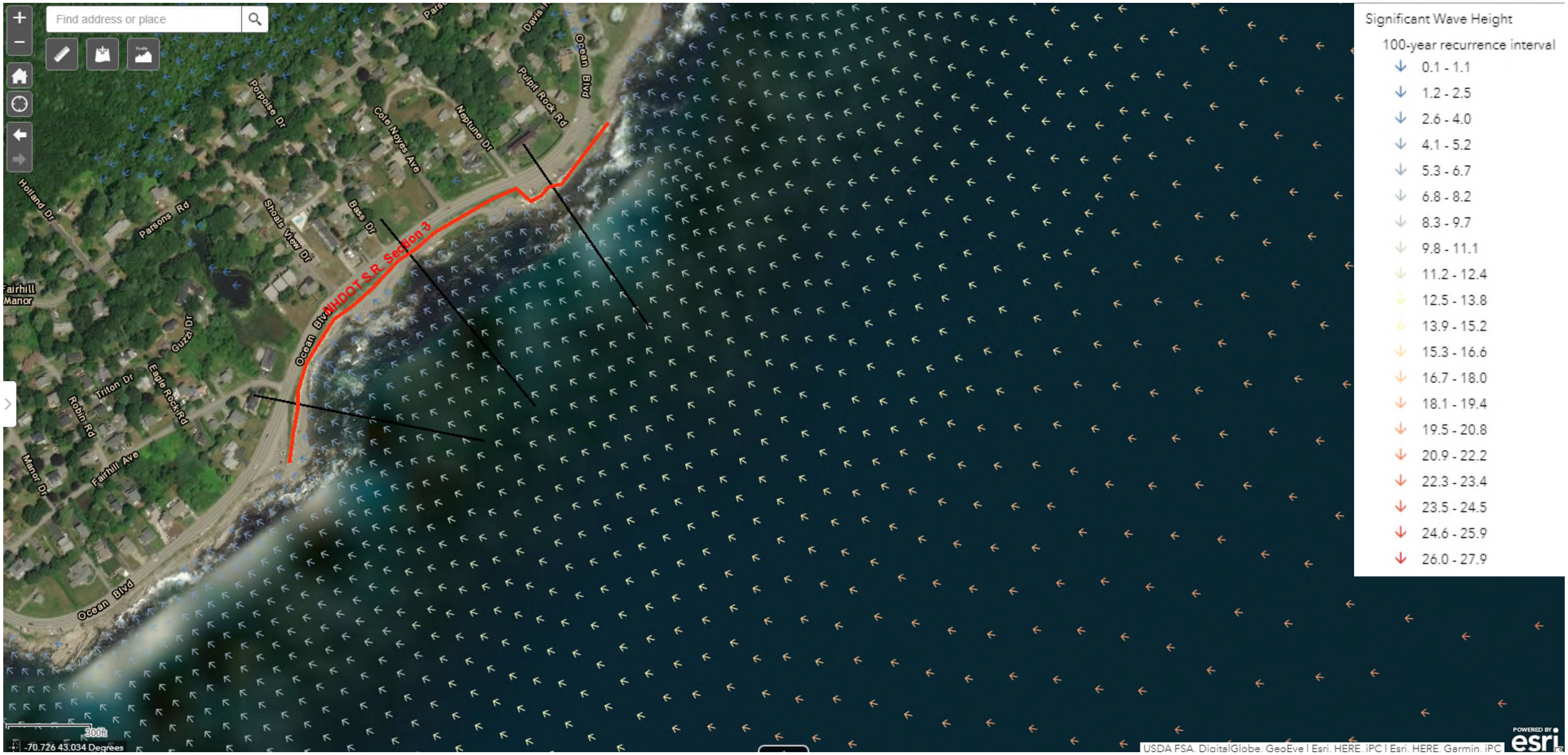


Figure 24. 100-year Recurrence Interval Wave Height (feet) for Transect 1, 2, 3 at NHDOT S.R. Section 3.

Figure 25. Transect Locations at NHDOT S.R. Section 4.

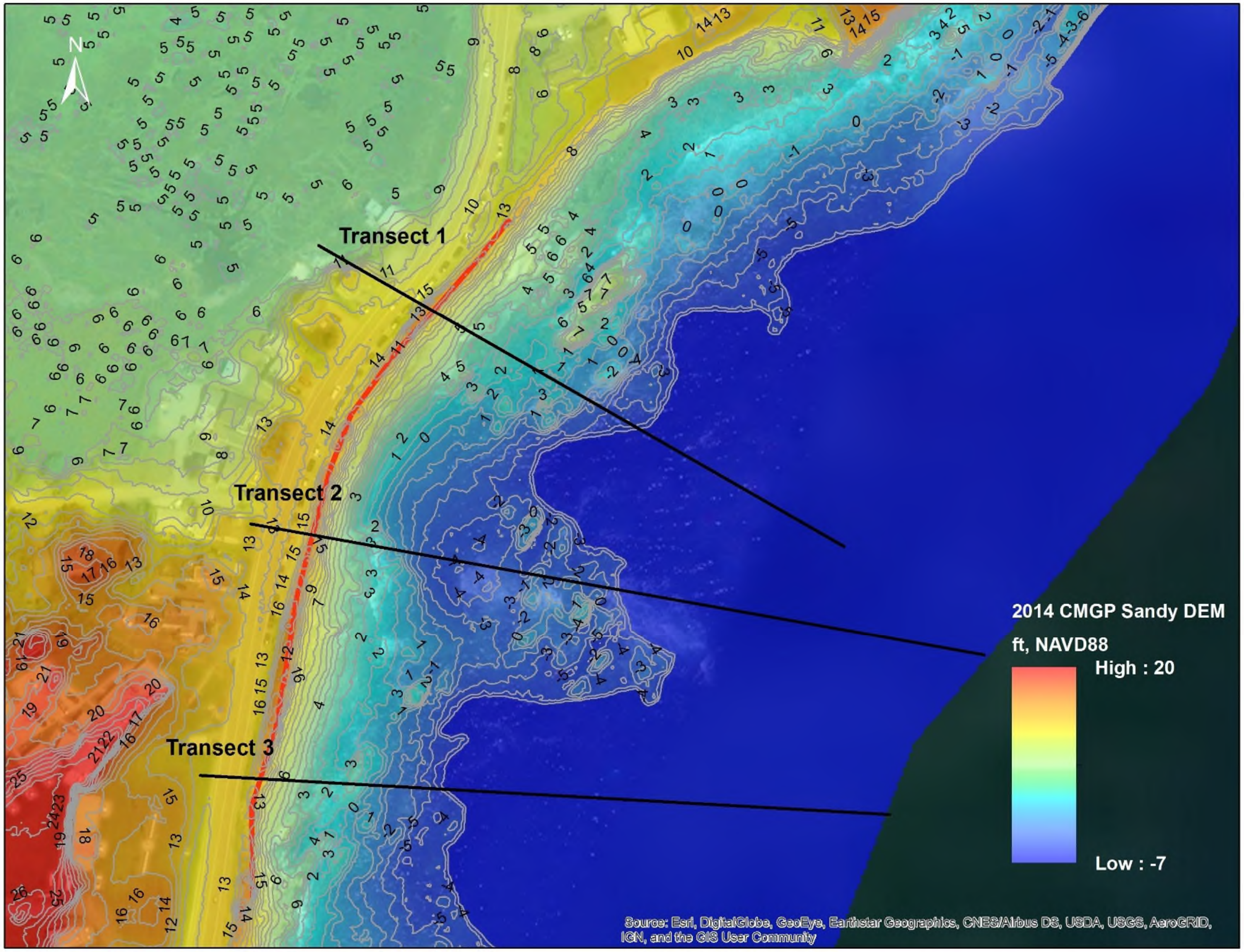


Figure 26. Transects and elevations at NHDOT S.R. Section 4.

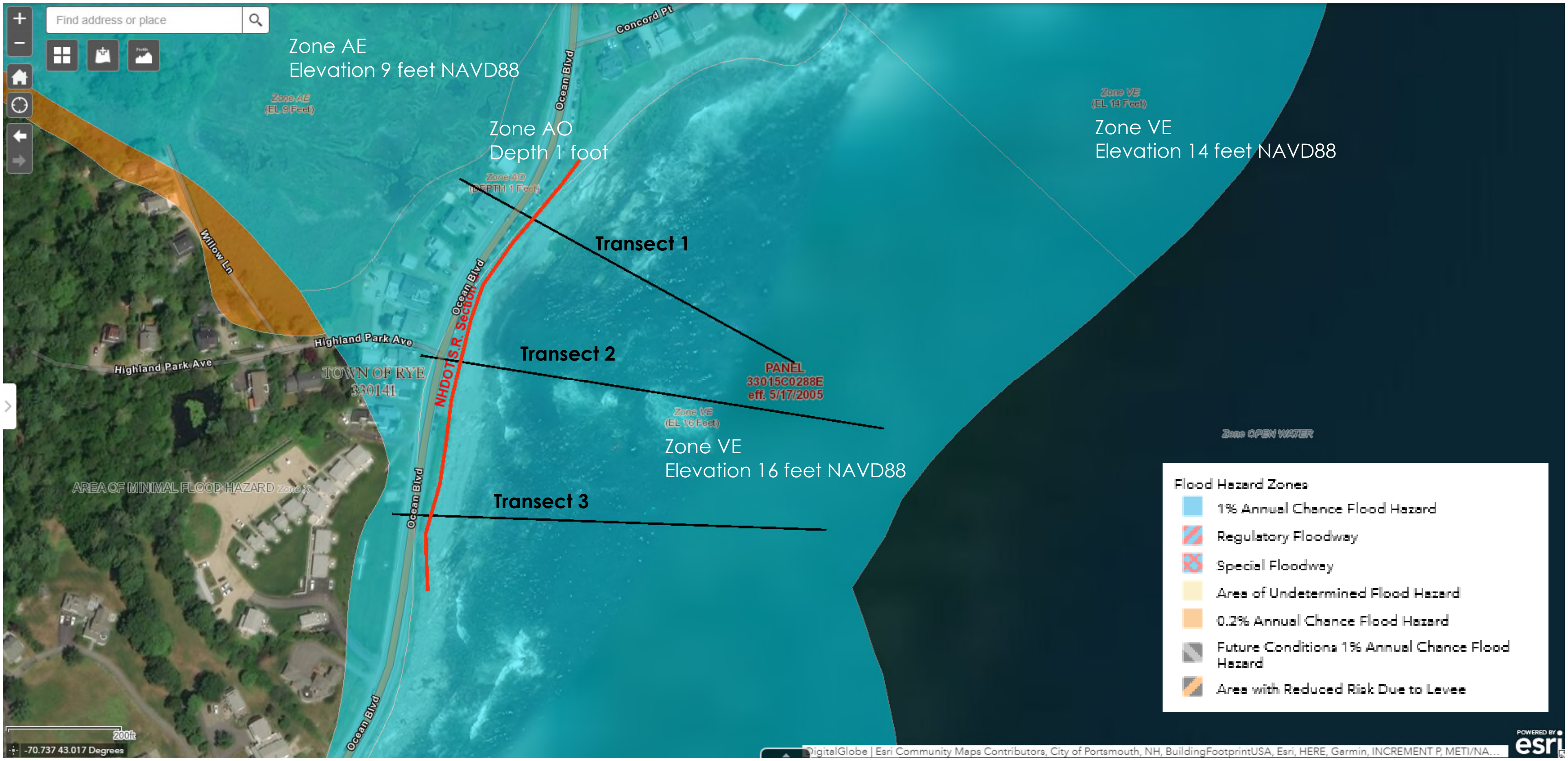


Figure 27. FEMA Flood Hazard Zones in vicinity of the NHDOT sections – Section 4.

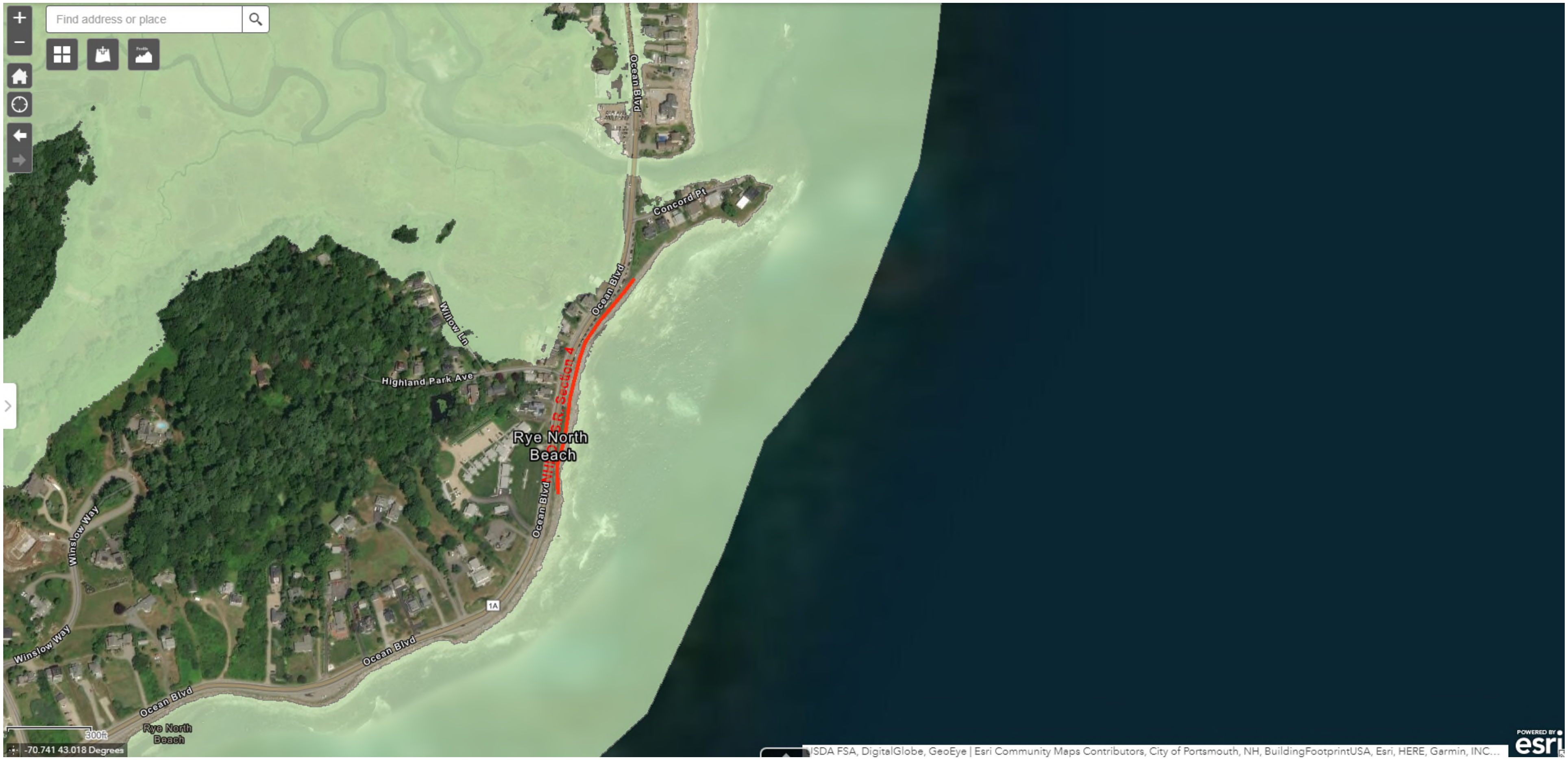


Figure 28. Flood inundation at Stillwater Elevation 8.5 feet NAVD88 – Vicinity of Section 4.

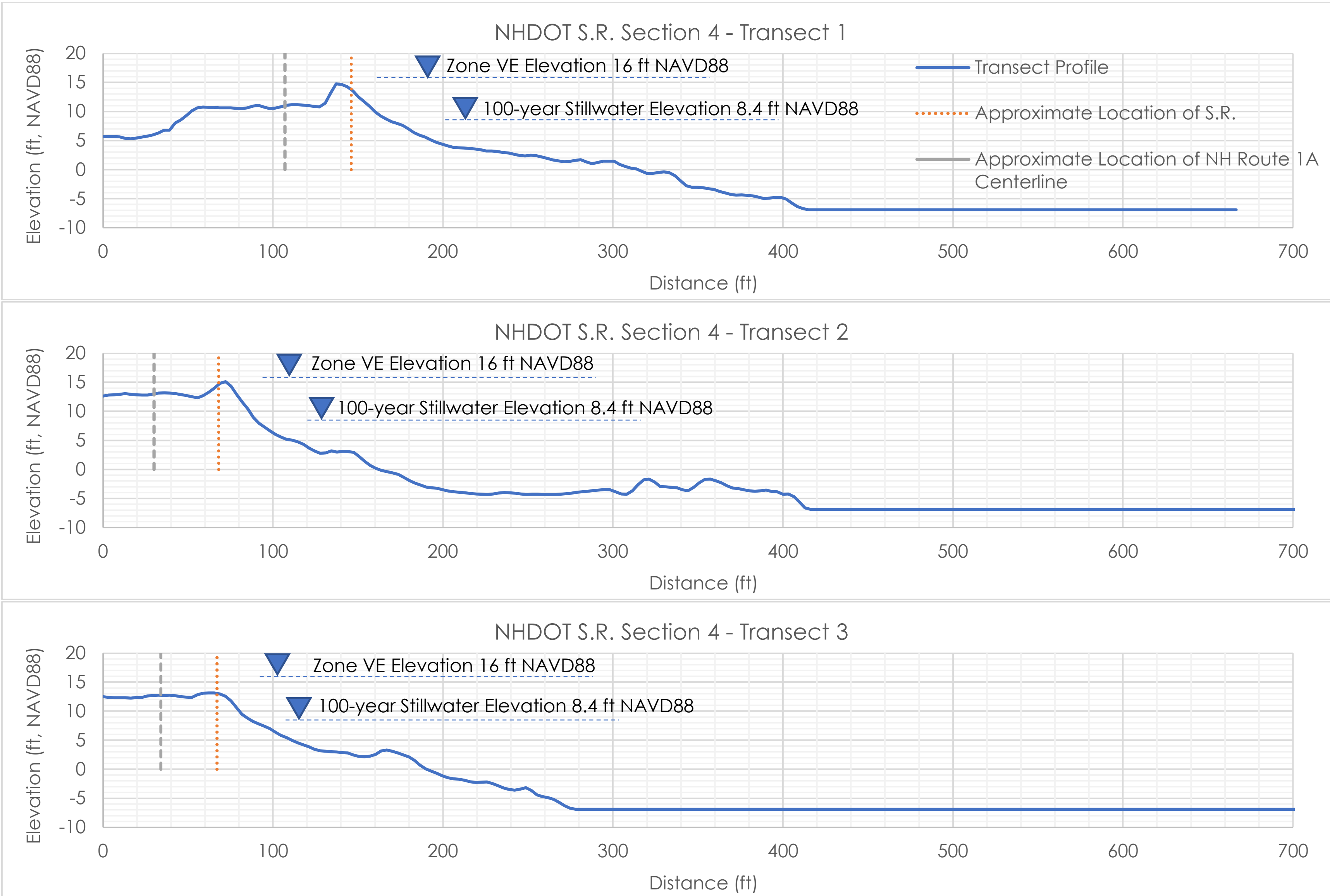


Figure 29. Elevation profile for Transect 1, 2, 3 at NHDOT S.R. Section 4.

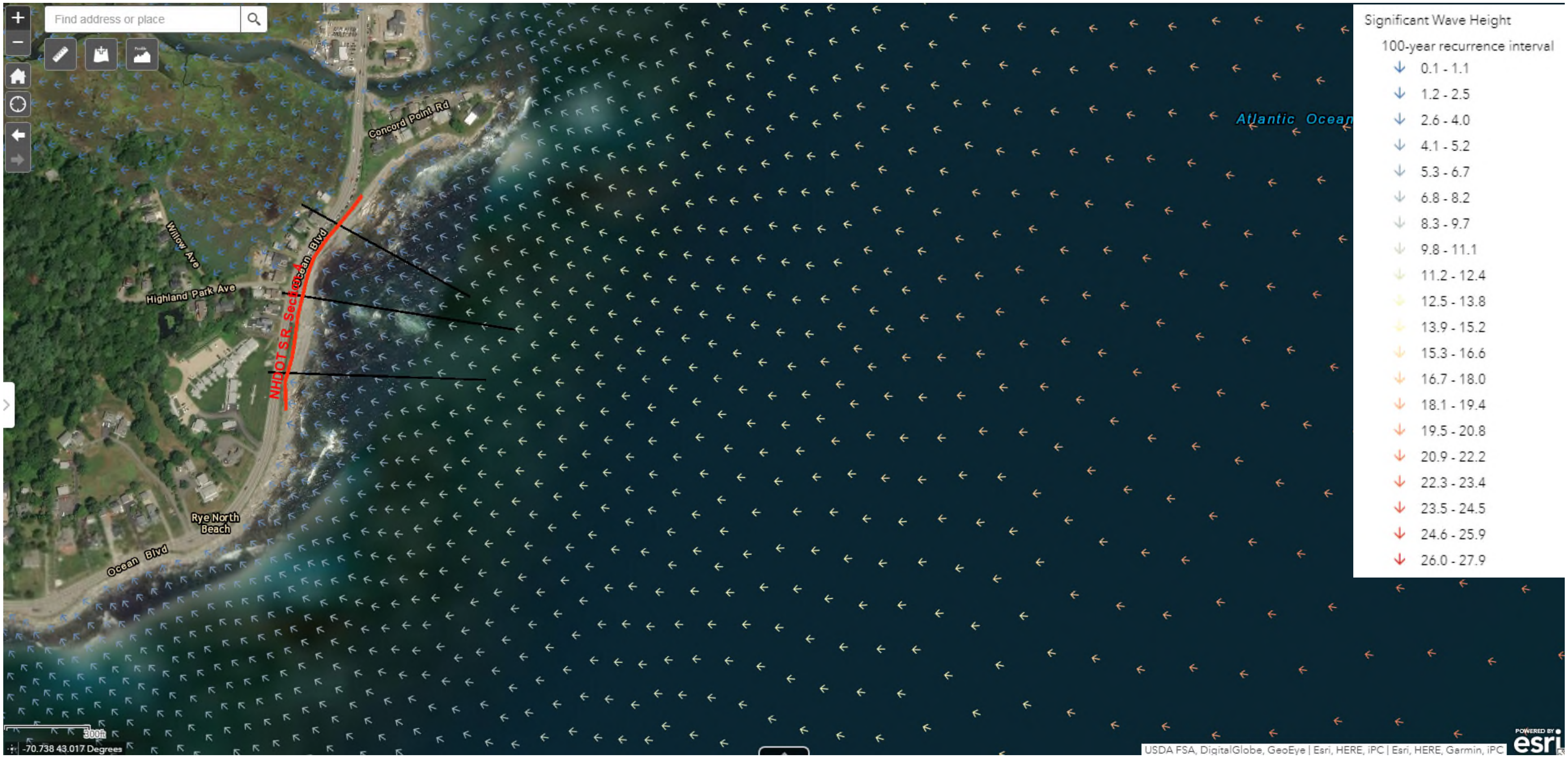


Figure 30. 100-year Recurrence Interval Wave Height (feet) for Transect 1, 2, 3 at NHDOT S.R. Section 4.

Figure 31. Transect Locations at NHDOT S.R. Section 5.

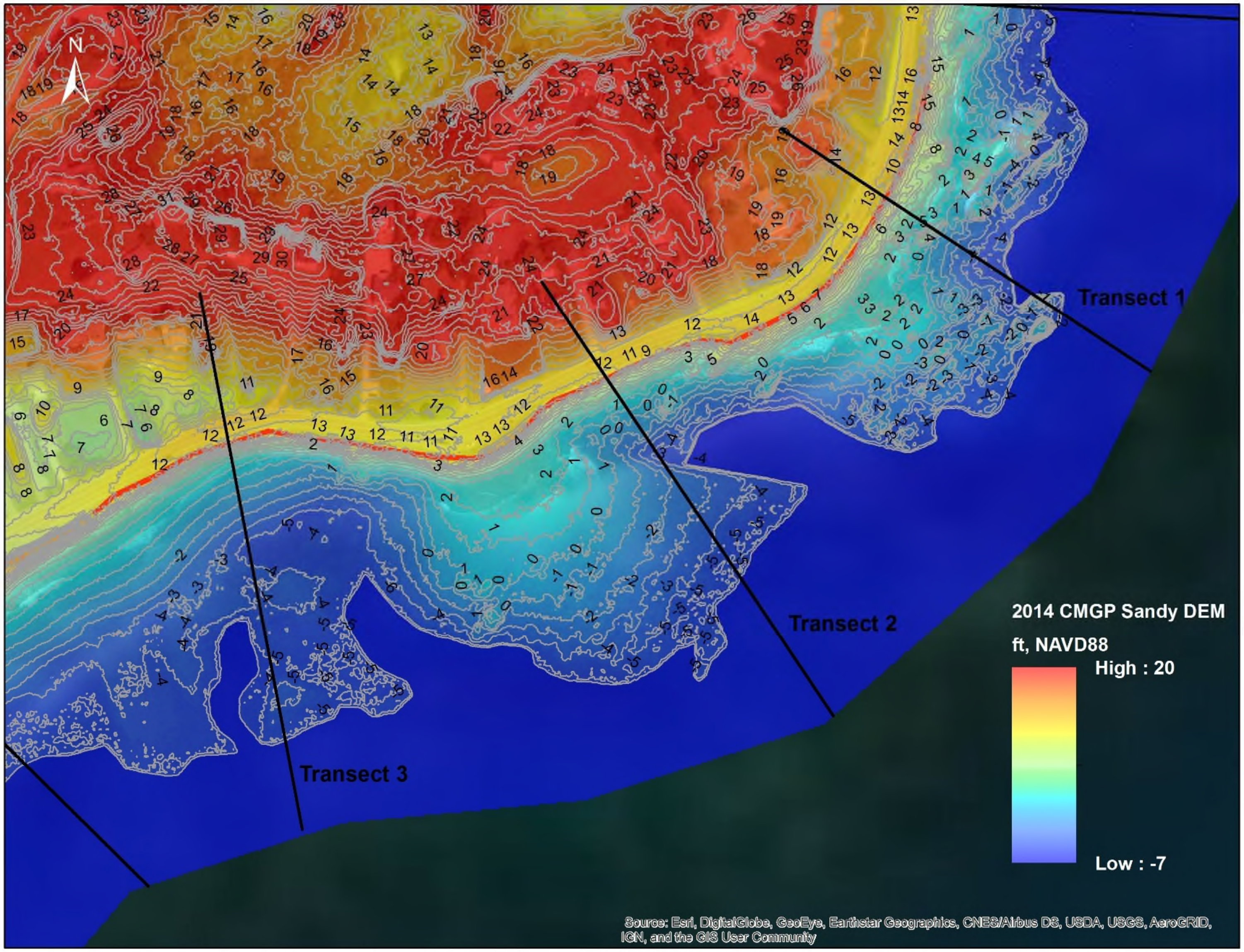


Figure 32. Transects and elevations at NHDOT S.R. Section 5.

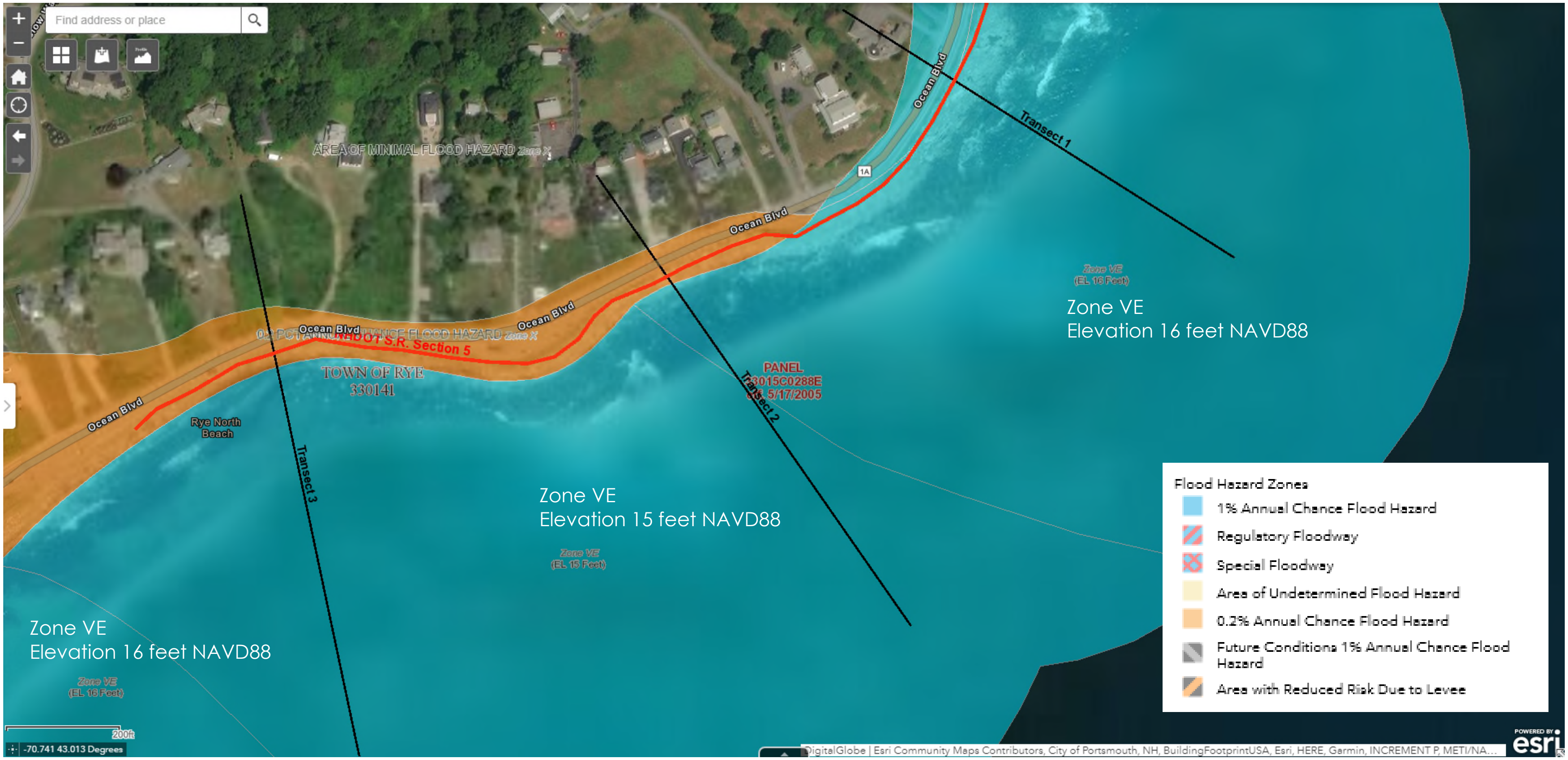


Figure 33. FEMA Flood Hazard Zones in vicinity of the NHDOT sections – Section 5.

Figure 34. Flood inundation at Stillwater Elevation 8.5 feet NAVD88 – Vicinity of Section 5.

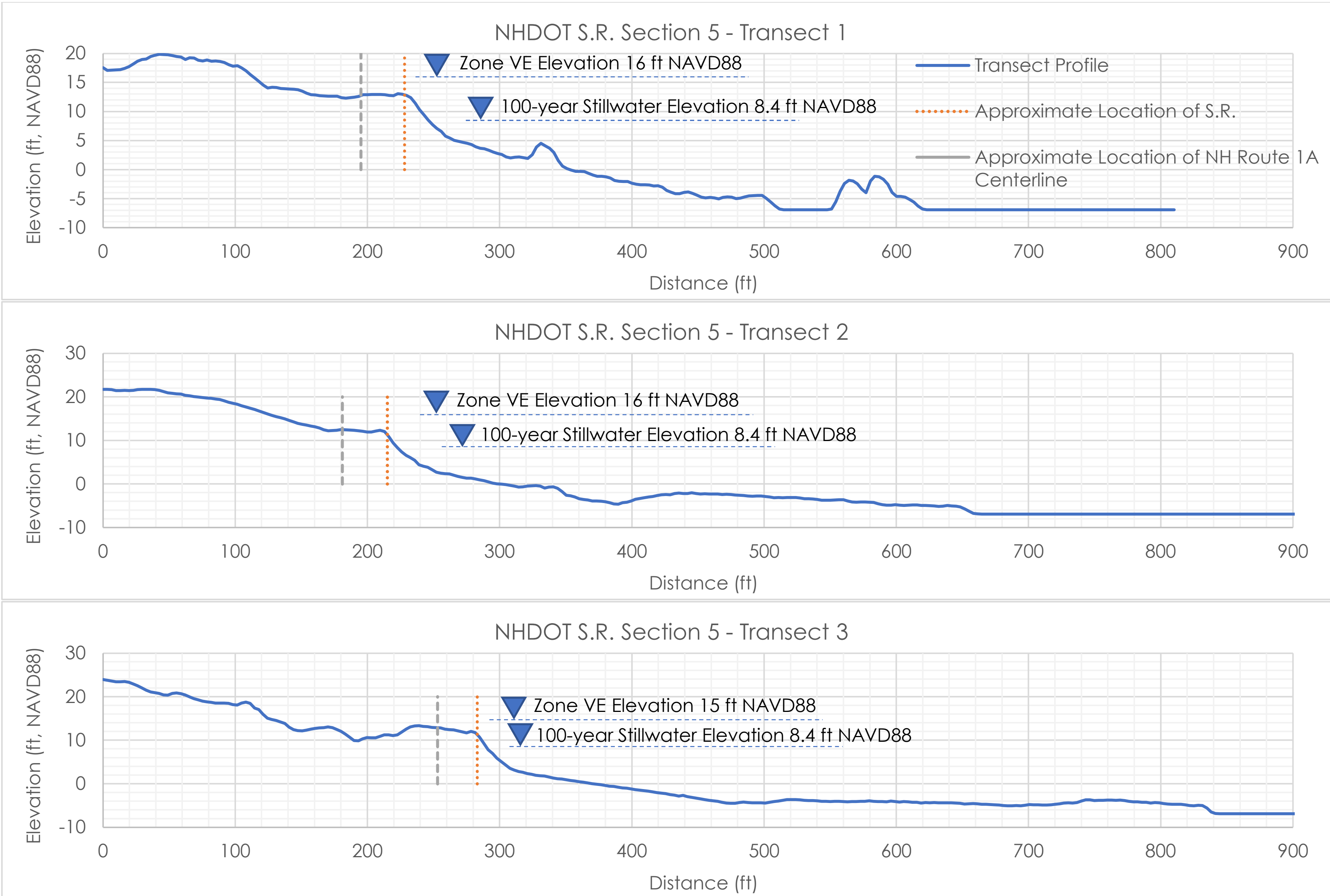


Figure 35. Elevation profile for Transect 1, 2, 3 at NHDOT S.R. Section 5.

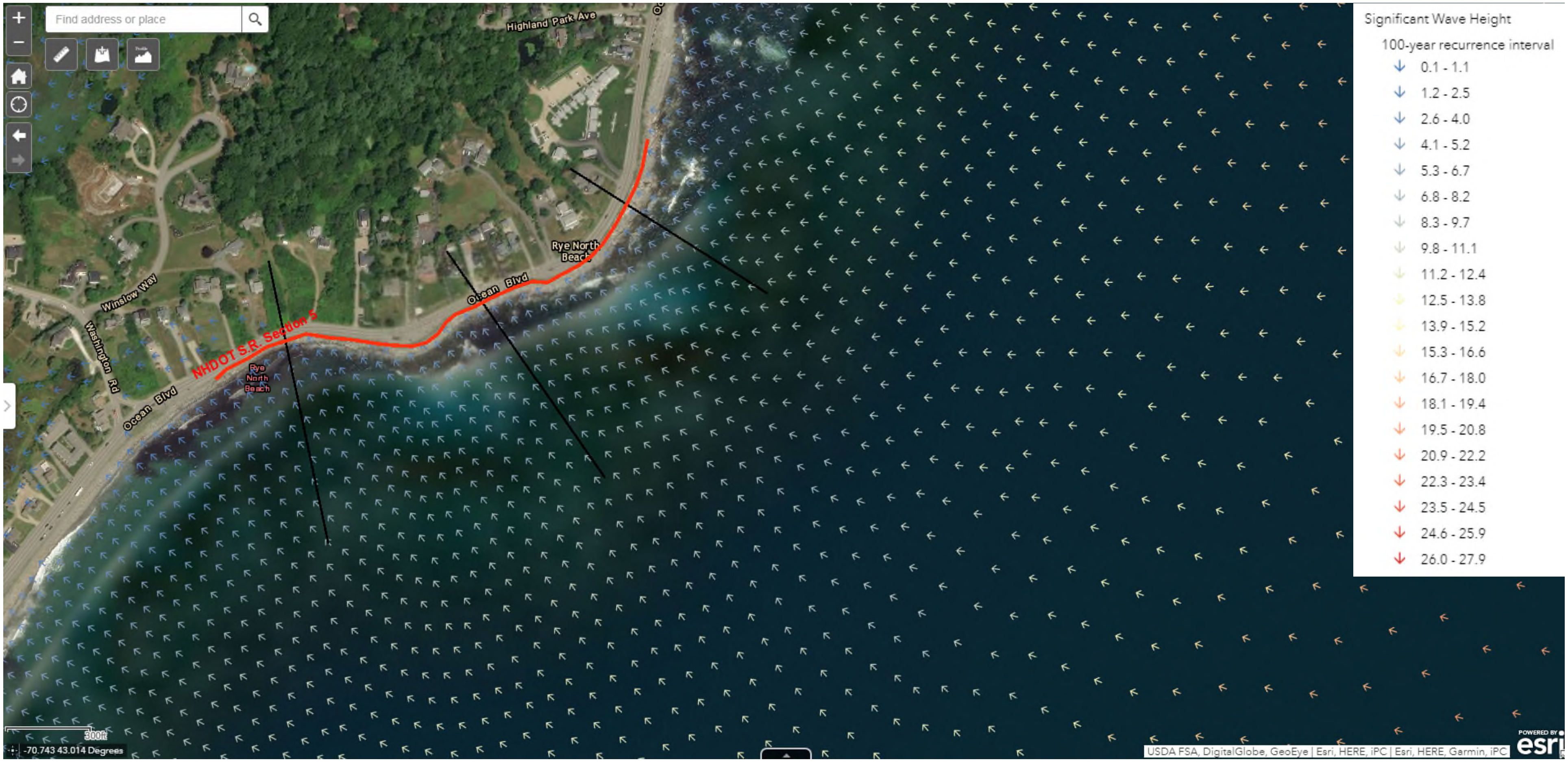


Figure 36. 100-year Recurrence Interval Wave Height (feet) for Transect 1, 2, 3 at NHDOT S.R. Section 5.

Figure 37. Transect Locations at NHDOT S.R. Section 6.

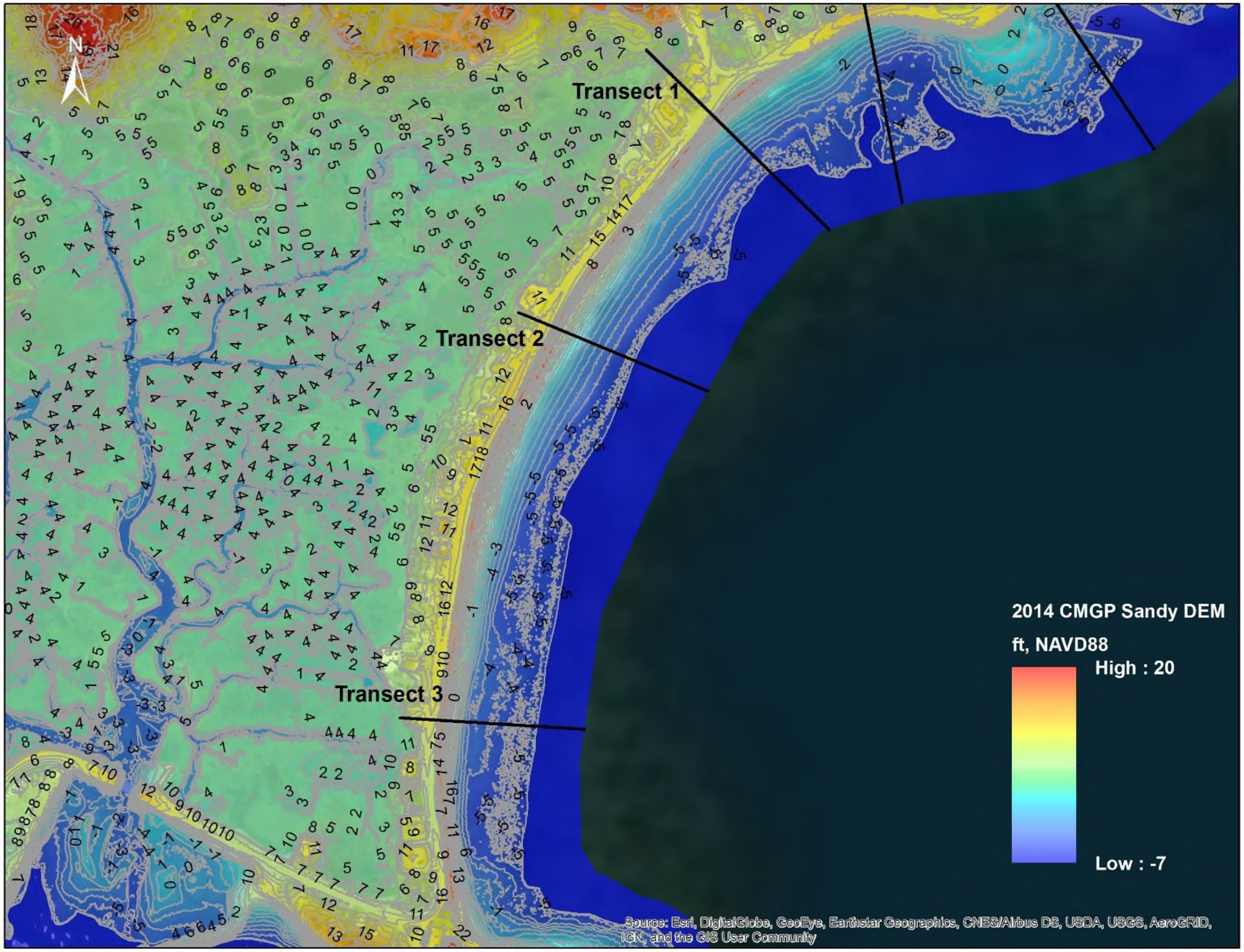


Figure 38. Transects and elevations at NHDOT S.R. Section 6.

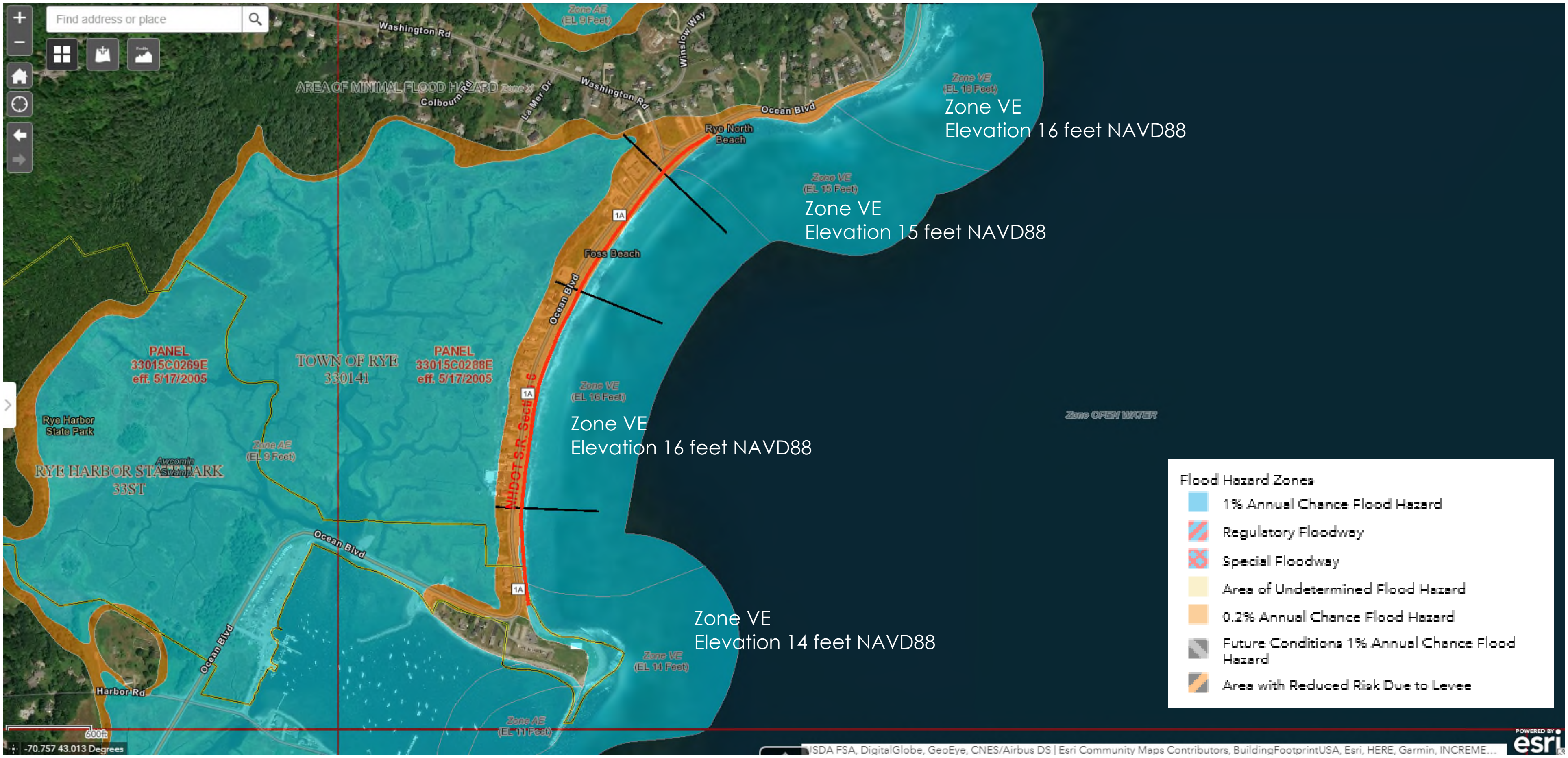


Figure 39. FEMA Flood Hazard Zones in vicinity of the NHDOT sections – Section 6.

Figure 40. Flood inundation at Stillwater Elevation 8.5 feet NAVD88 – Vicinity of Section 6.

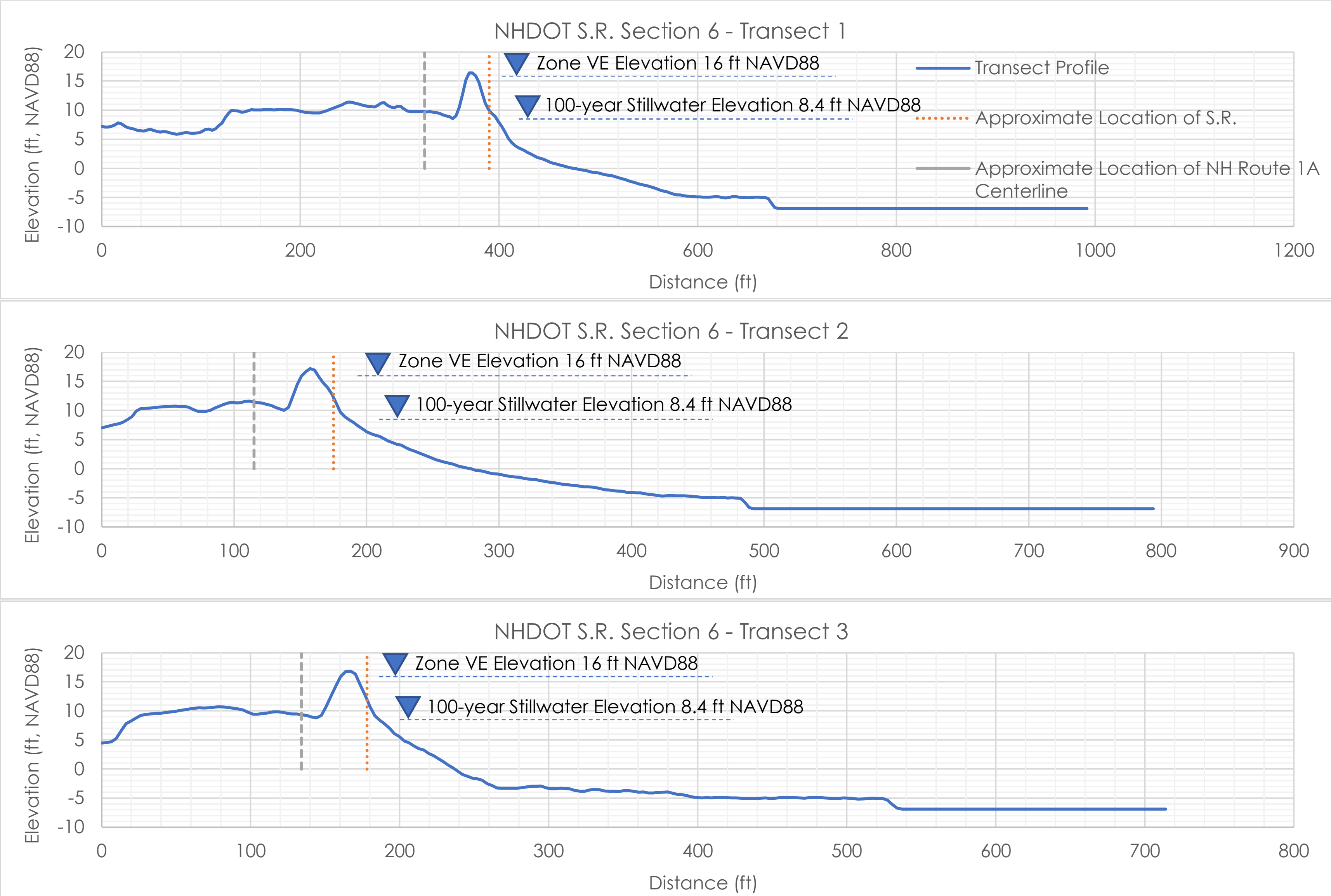


Figure 41. Elevation profile for Transect 1, 2, 3 at NHDOT S.R. Section 6.

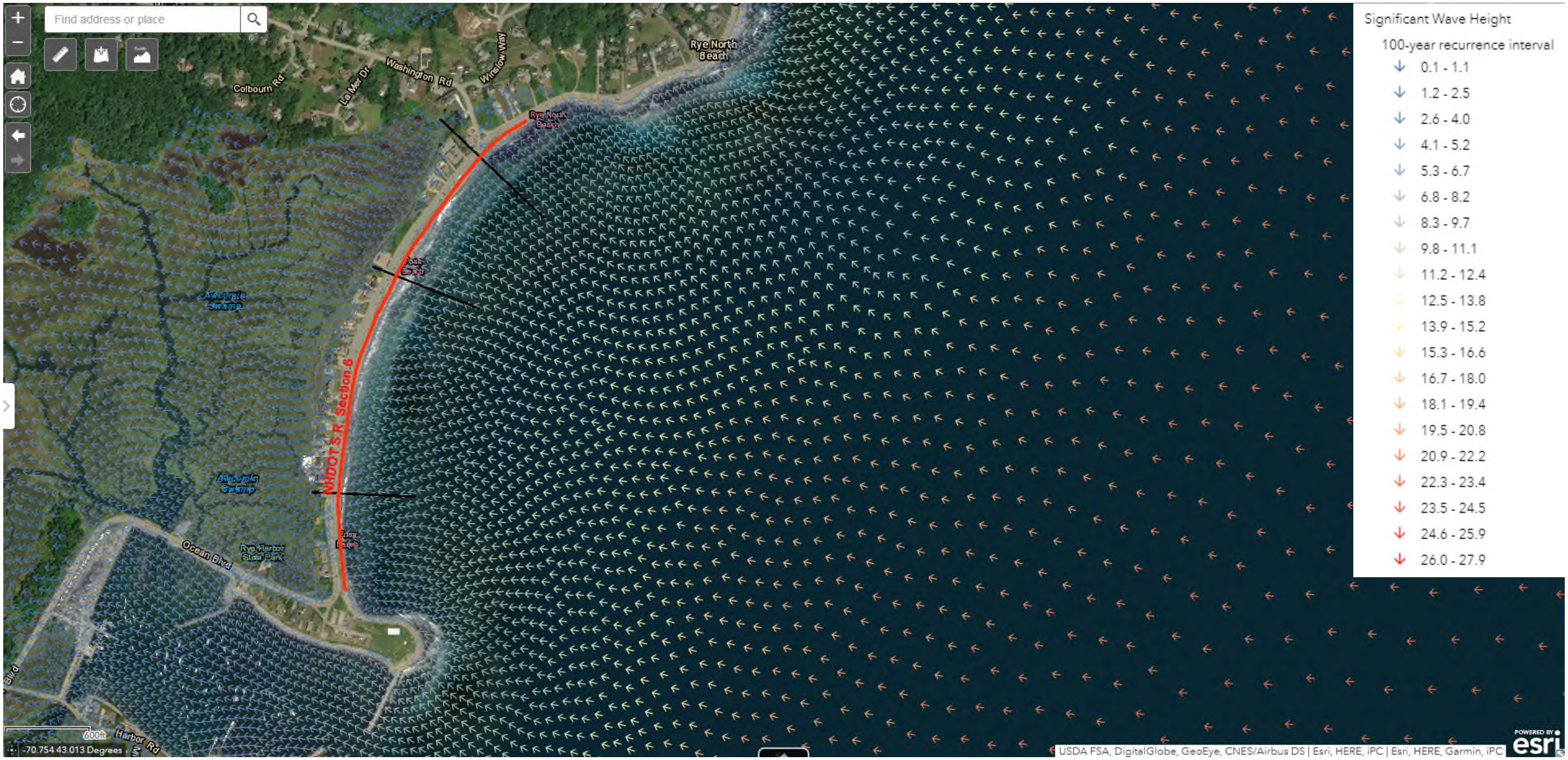


Figure 42. 100-year Recurrence Interval Wave Height (feet) for Transect 1, 2, 3 at NHDOT S.R. Section 6.

Figure 43. Transect Locations at NHDOT S.R. Section 7.

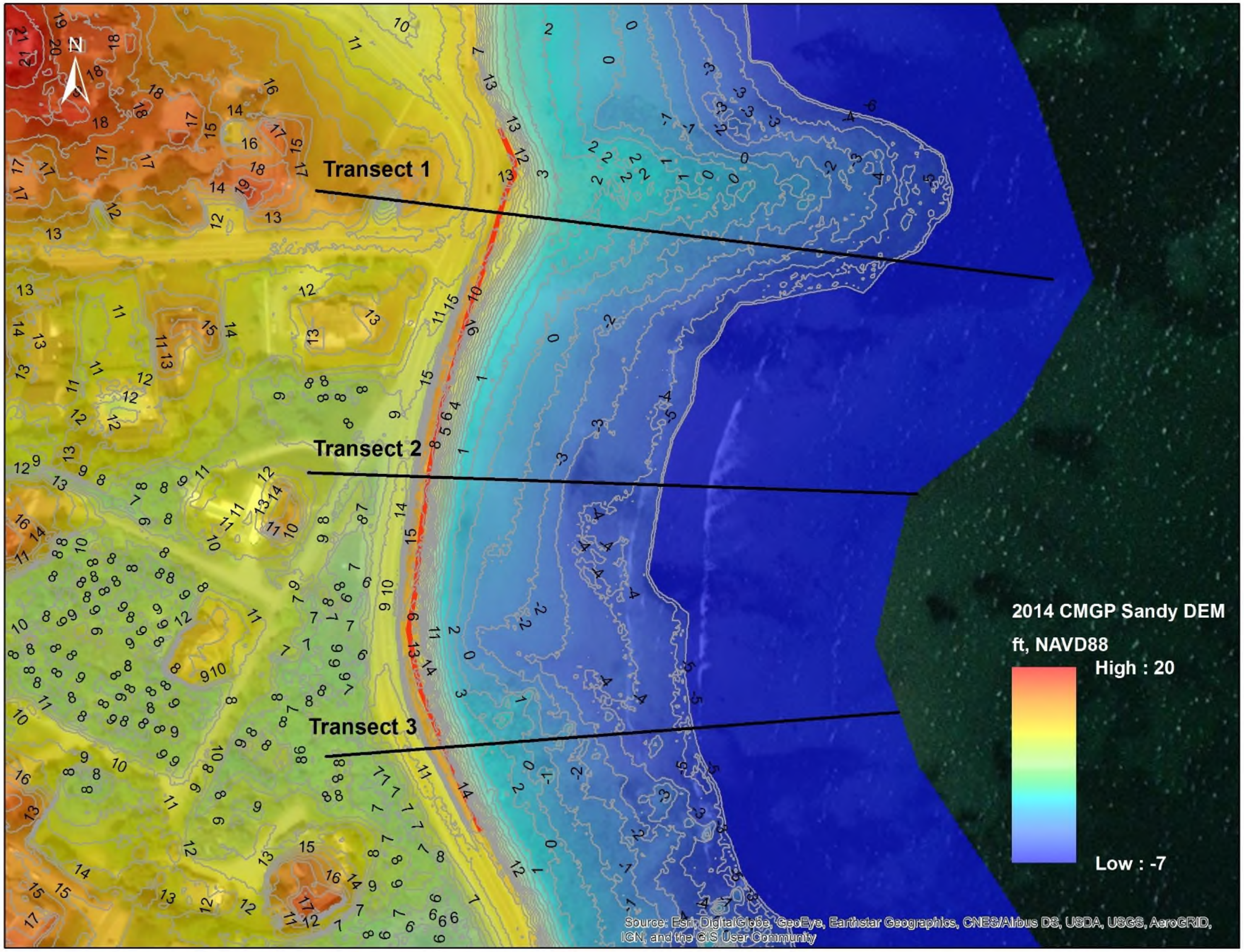


Figure 44. Transects and elevations at NHDOT S.R. Section 7.

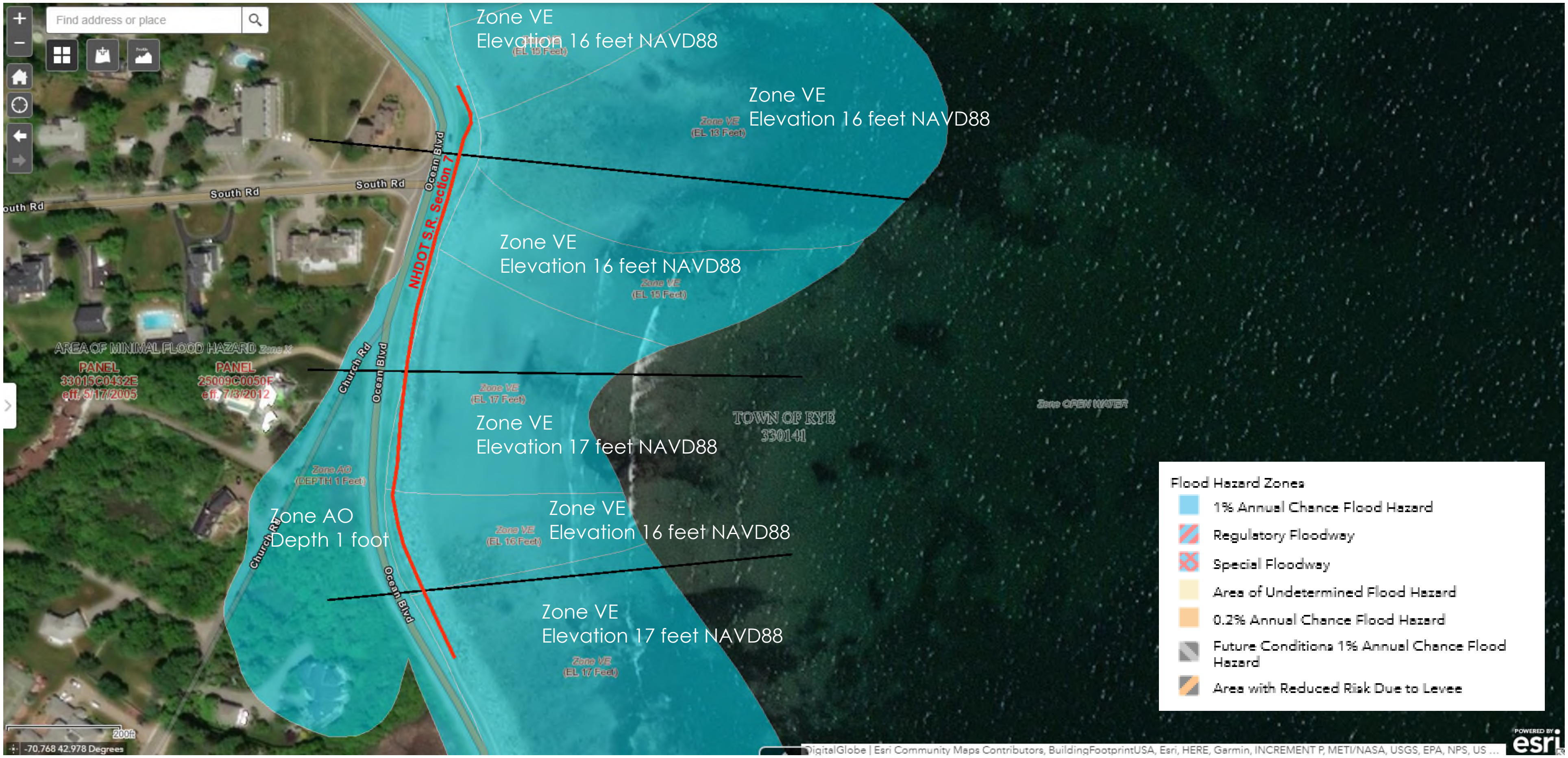


Figure 45. FEMA Flood Hazard Zones in vicinity of the NHDOT sections – Section 7.

Figure 46. Flood inundation at Stillwater Elevation 8.5 feet NAVD88 – Vicinity of Section 7.

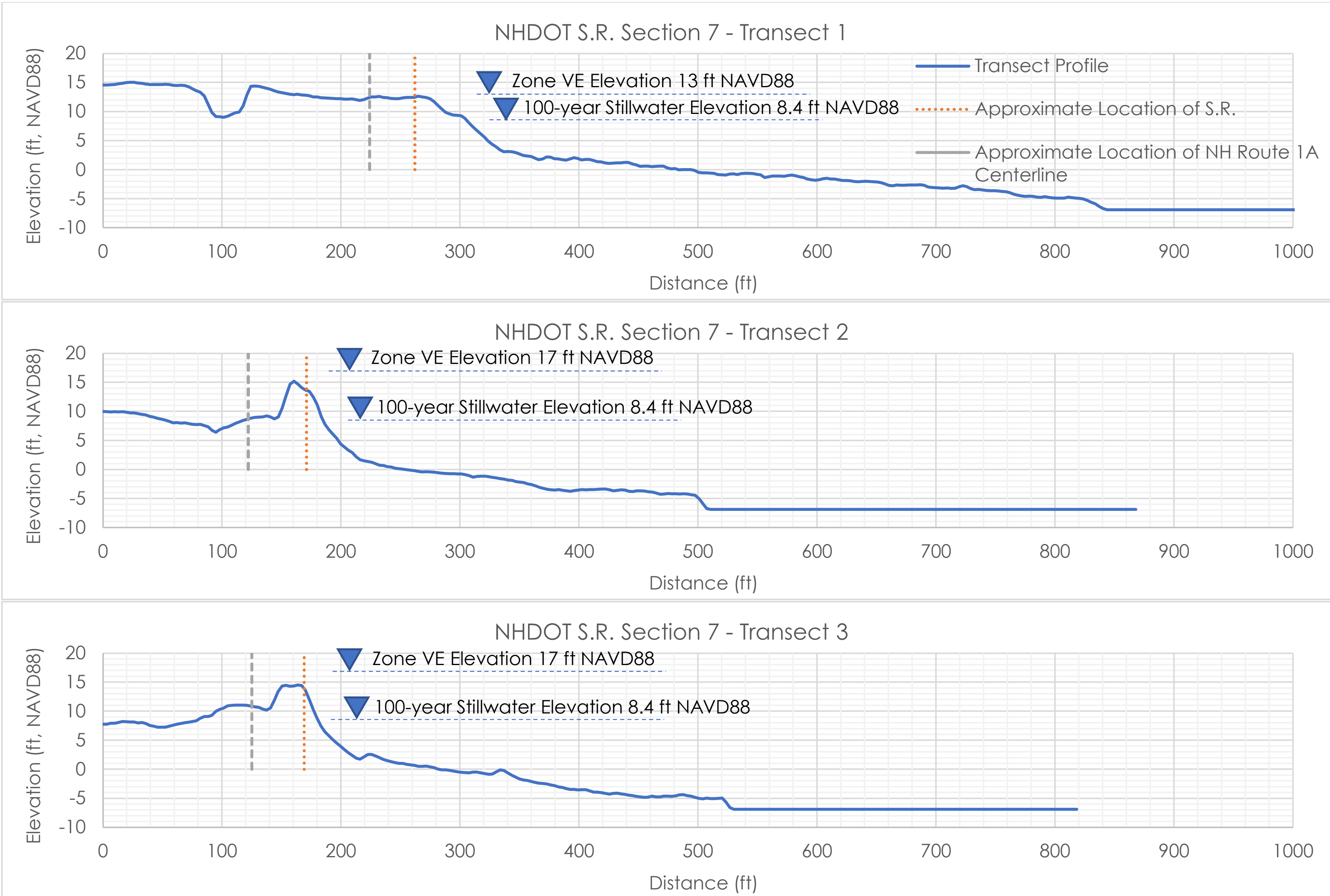


Figure 47. Elevation profile for Transect 1, 2, 3 at NHDOT S.R. Section 7.

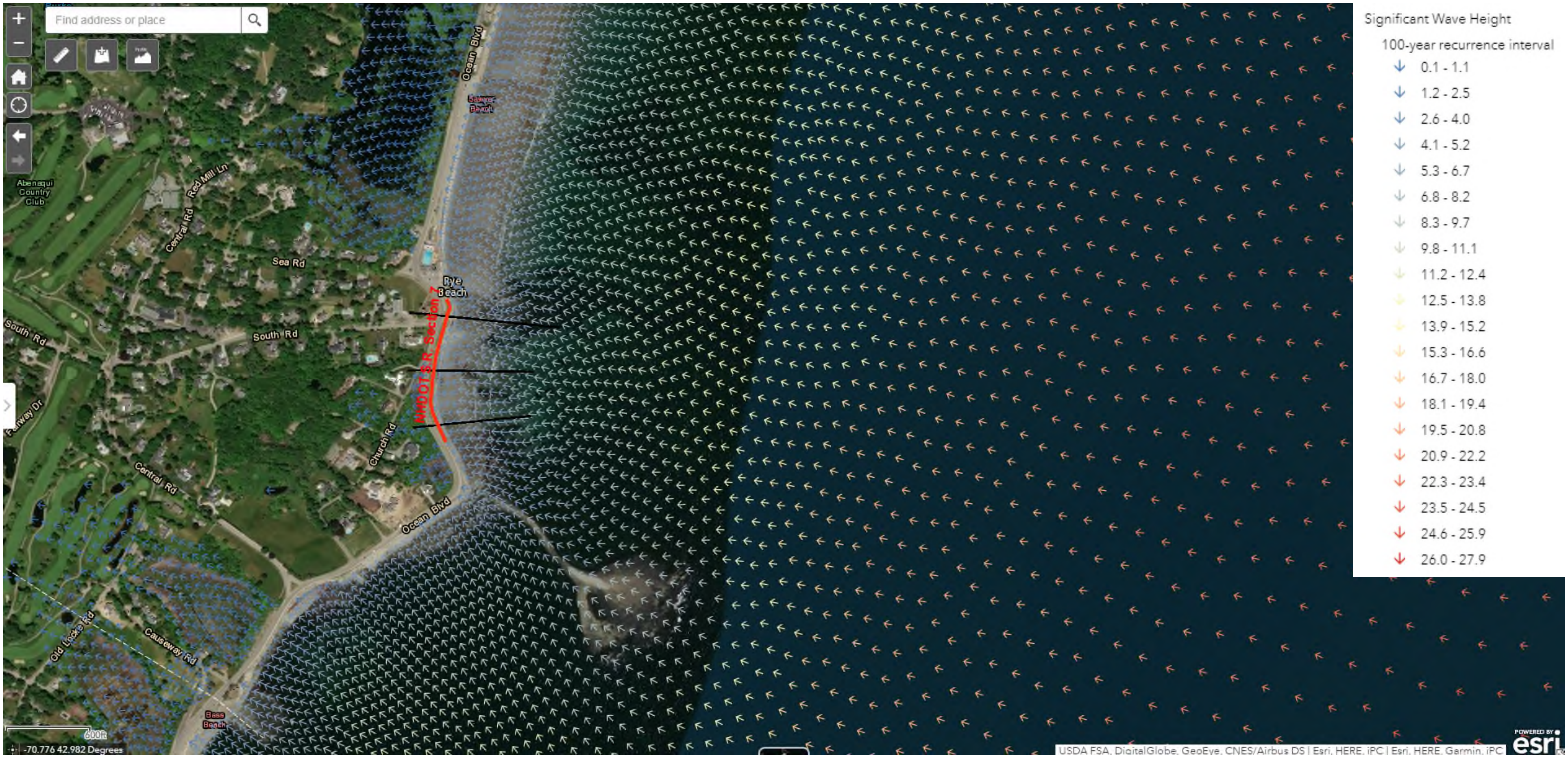


Figure 48. 100-year Recurrence Interval Wave Height (feet) for Transect 1, 2, 3 at NHDOT S.R. Section 7.

Figure 49. Transect Locations at NHDOT S.R. Section 10.

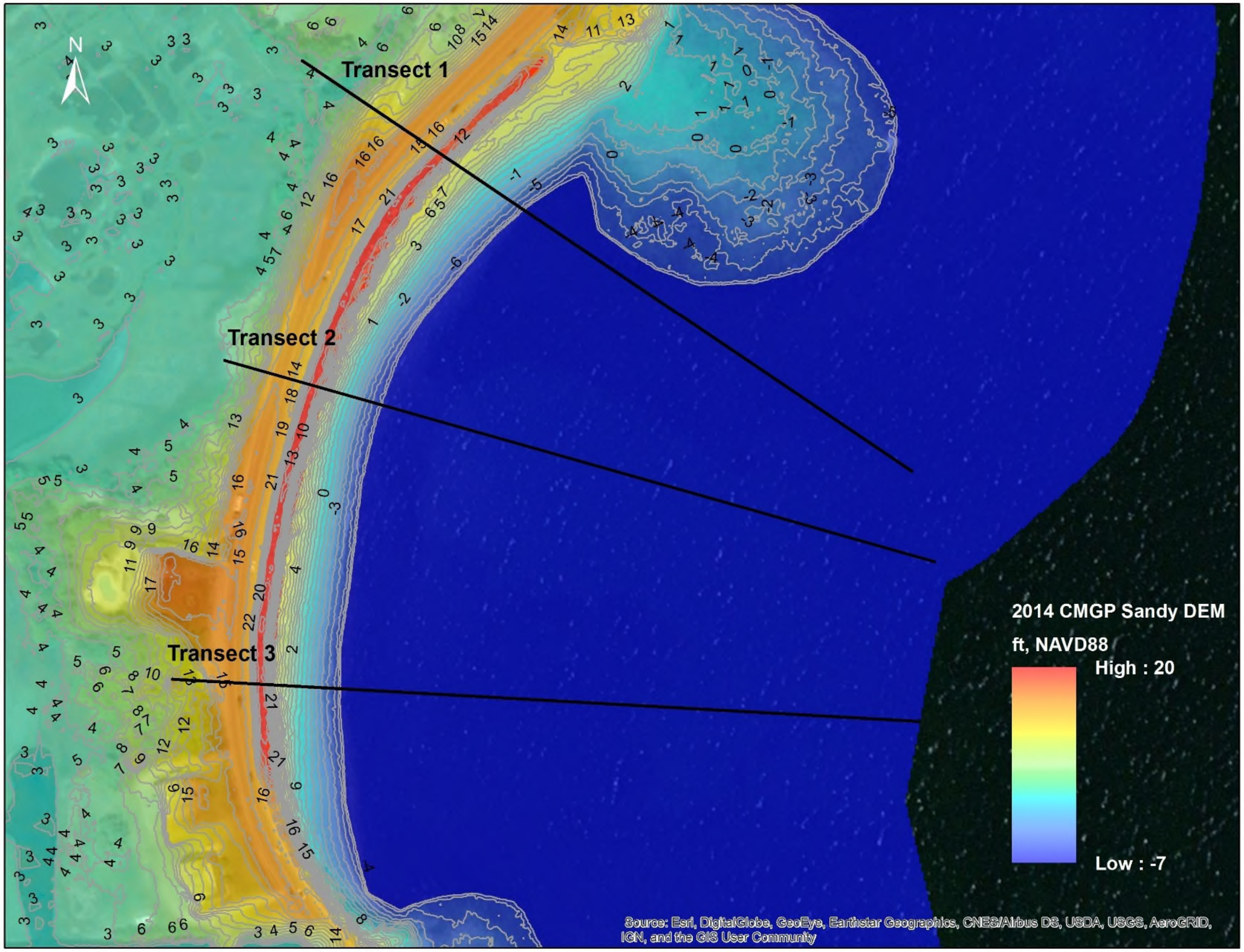


Figure 50. Transects and elevations at NHDOT S.R. Section 10.

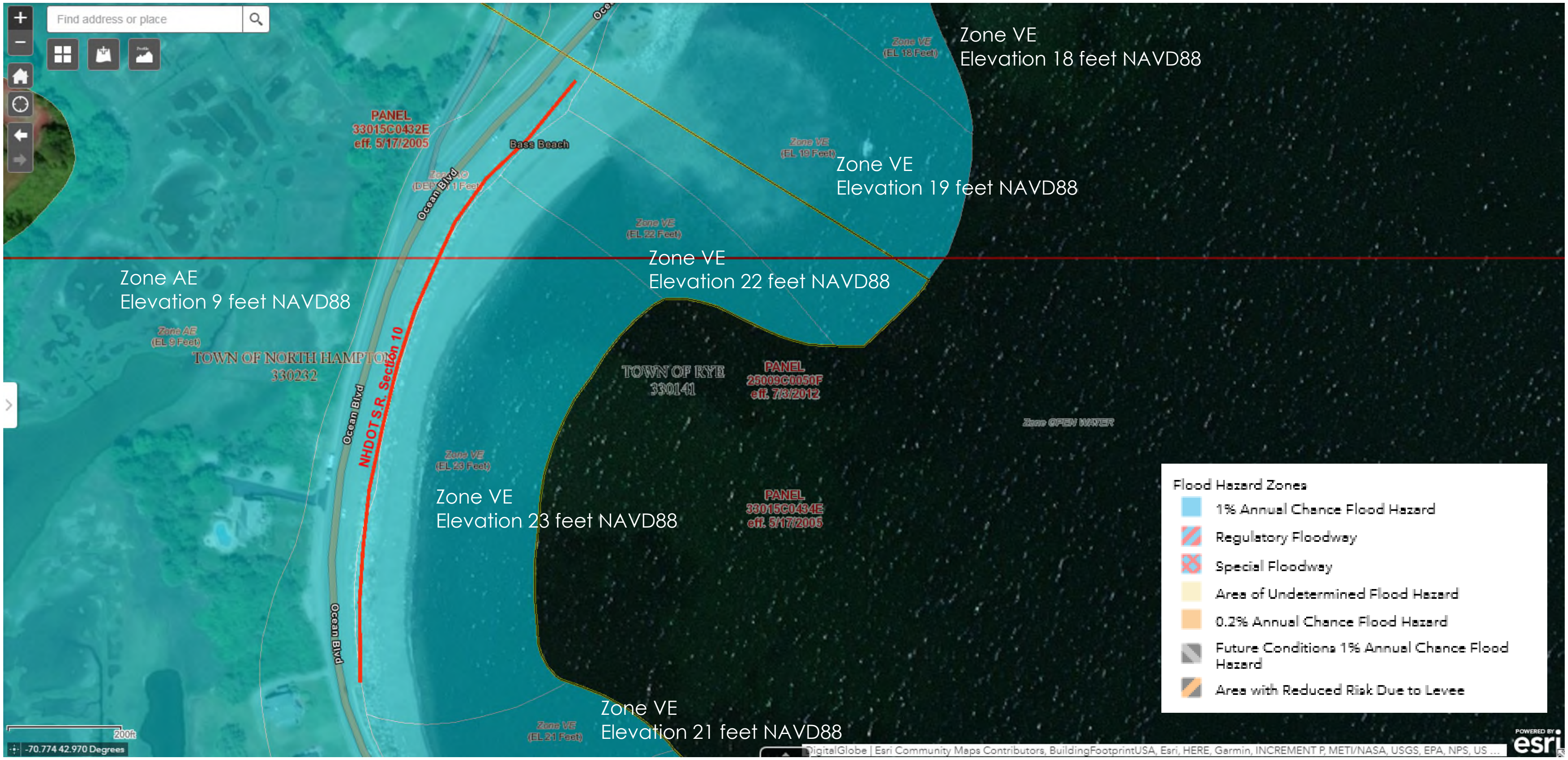


Figure 51. FEMA Flood Hazard Zones in vicinity of the NHDOT sections – Section 10.

Figure 52. Flood inundation at Stillwater Elevation 8.5 feet NAVD88 – Vicinity of Section 10.

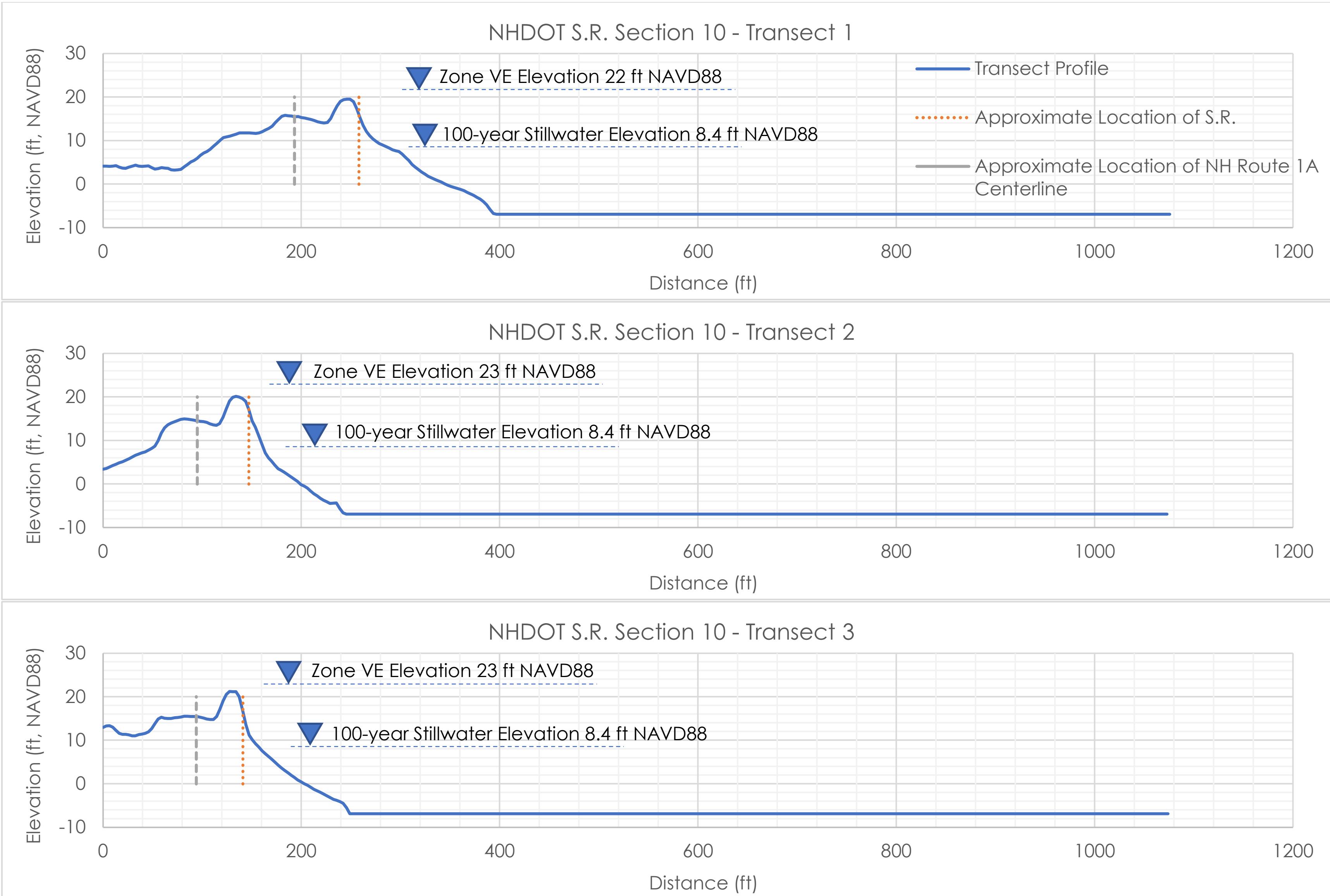


Figure 53. Elevation profile for Transect 1, 2, 3 at NHDOT S.R. Section 10.

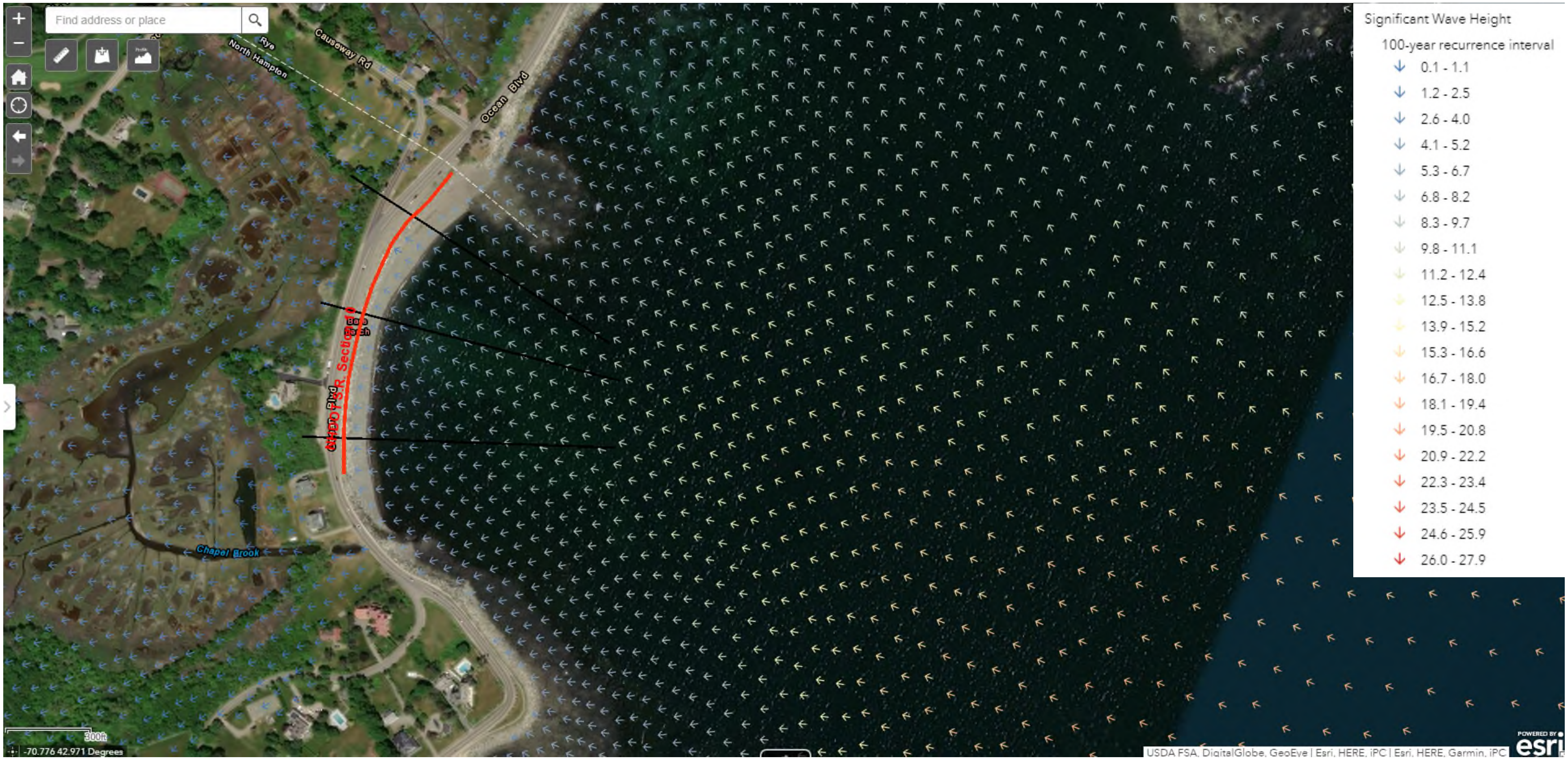


Figure 54. 100-year Recurrence Interval Wave Height (feet) for Transect 1, 2, 3 at NHDOT S.R. Section 10.

Figure 55. Transect Locations at NHDOT S.R. Section 13.

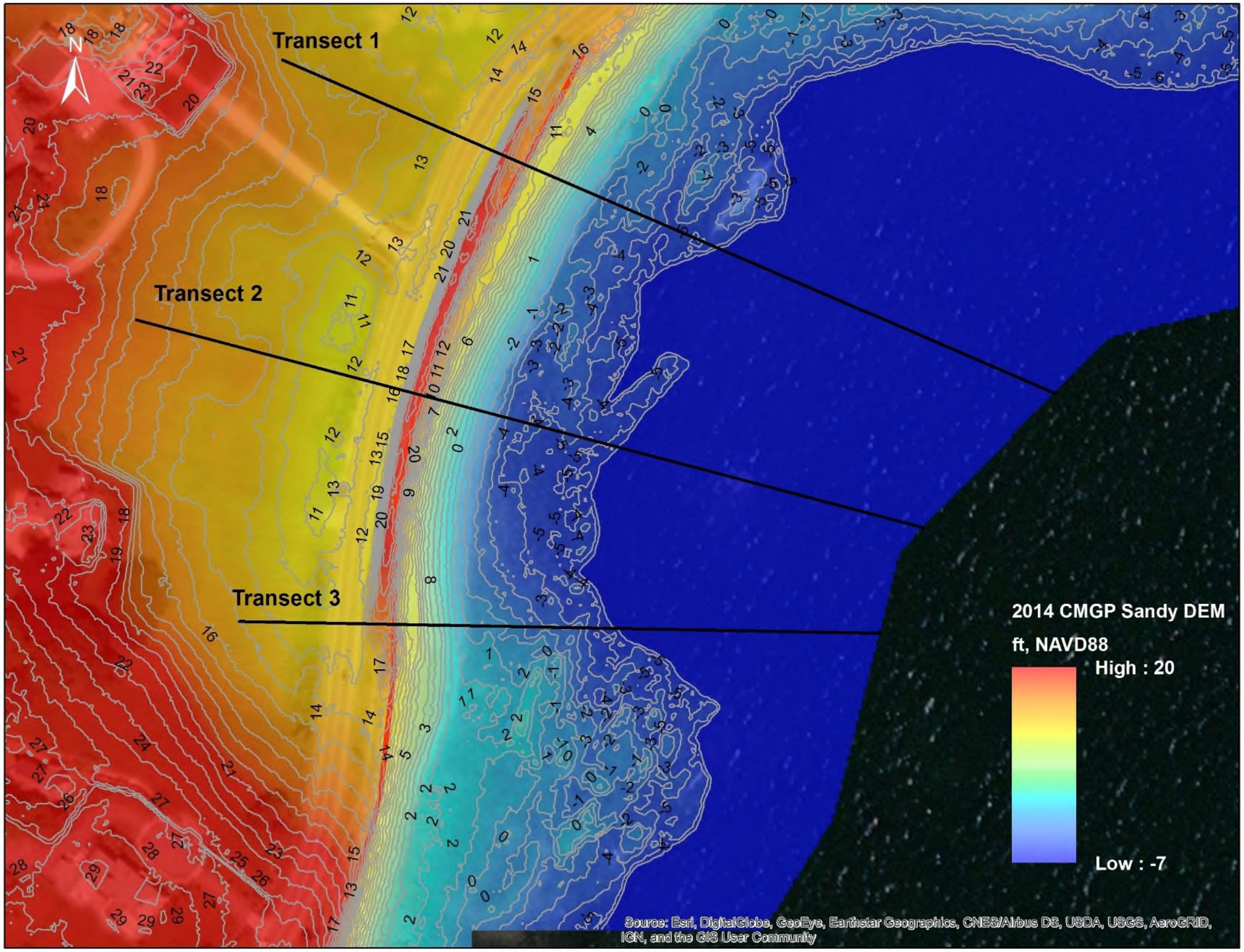


Figure 56. Transects and elevations at NHDOT S.R. Section 13.

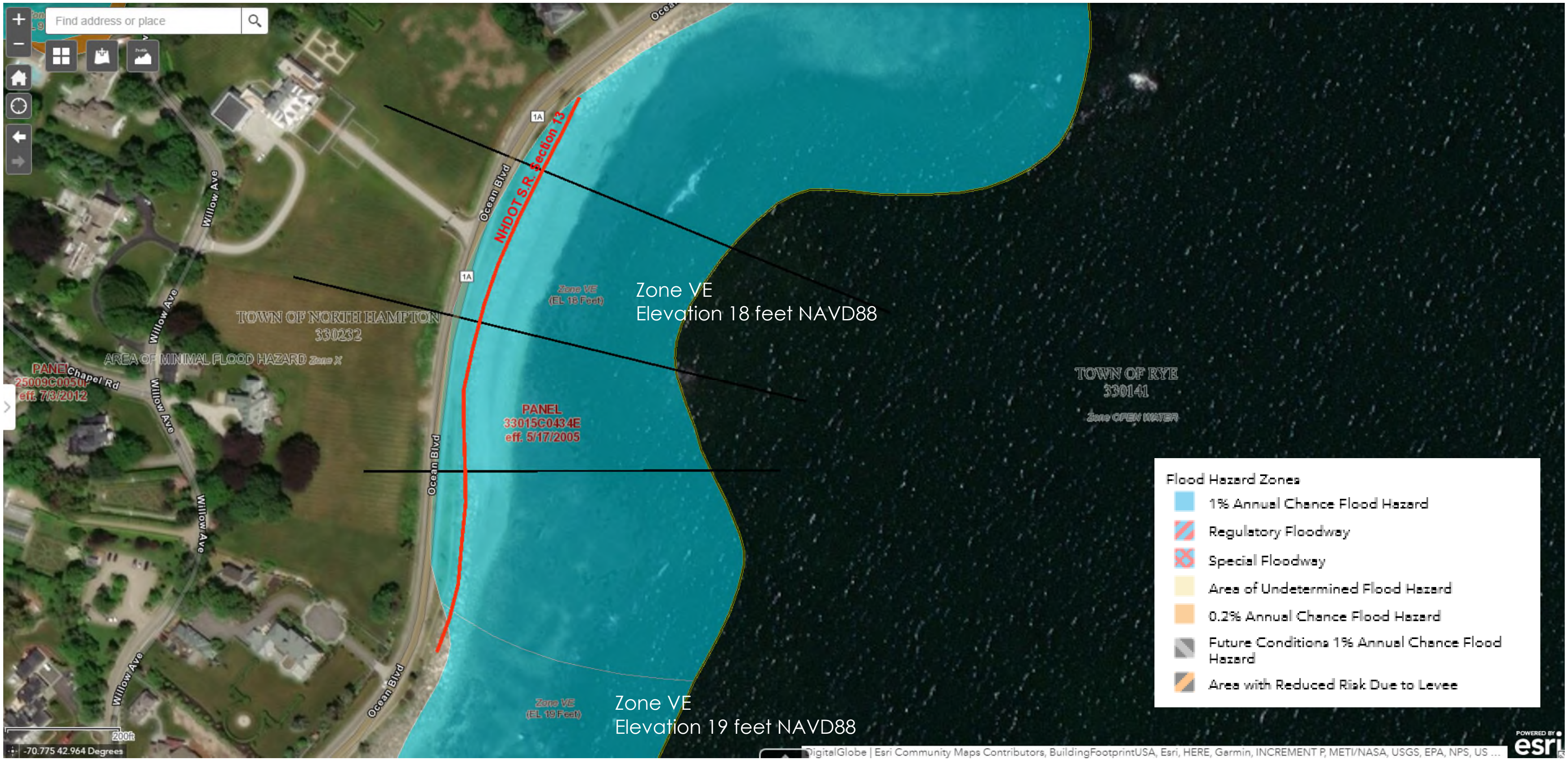


Figure 57. FEMA Flood Hazard Zones in vicinity of the NHDOT sections – Section 13.

Figure 58. Flood inundation at Stillwater Elevation 8.5 feet NAVD88 – Vicinity of Section 13.

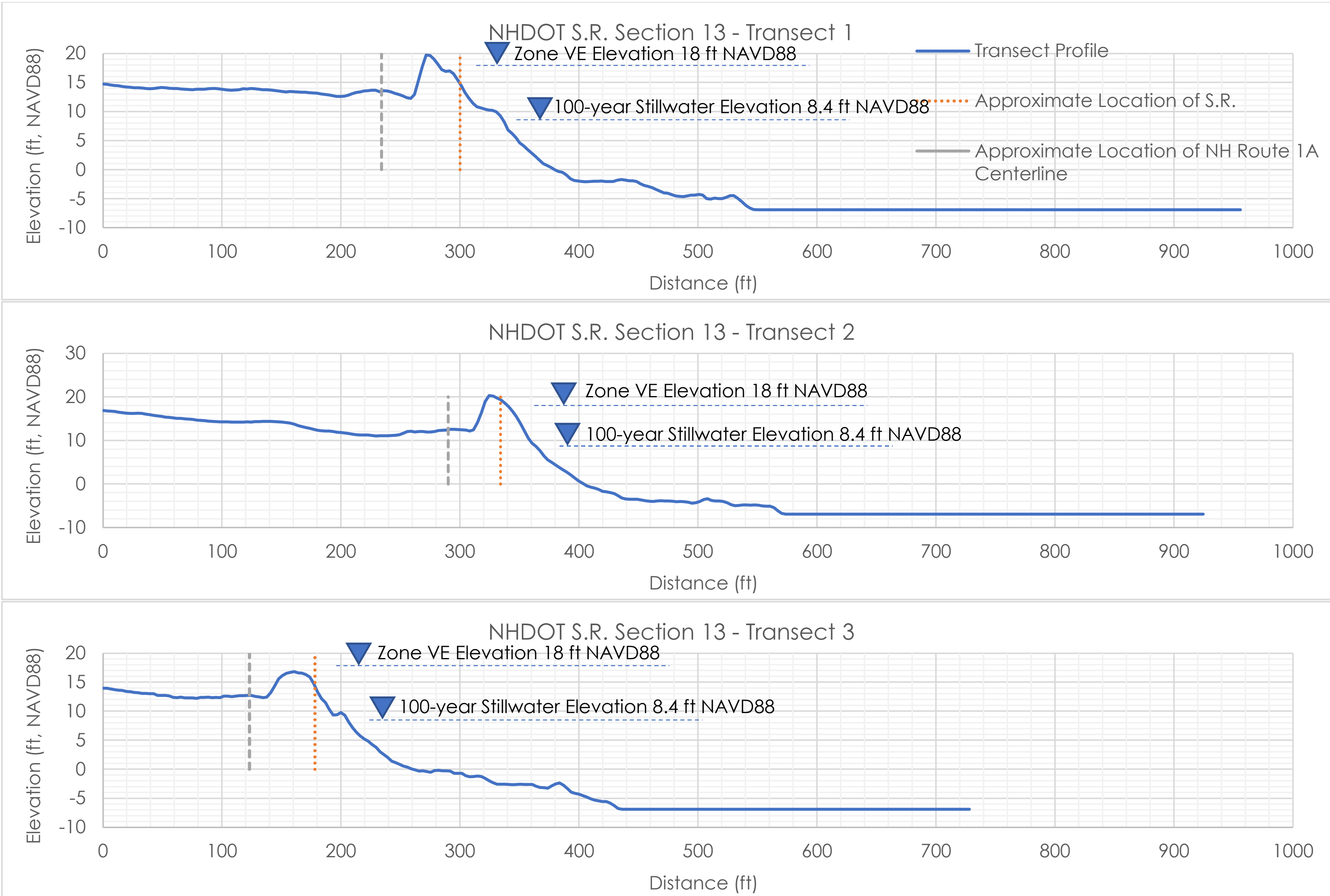


Figure 59. Elevation profile for Transect 1, 2, 3 at NHDOT S.R. Section 13.

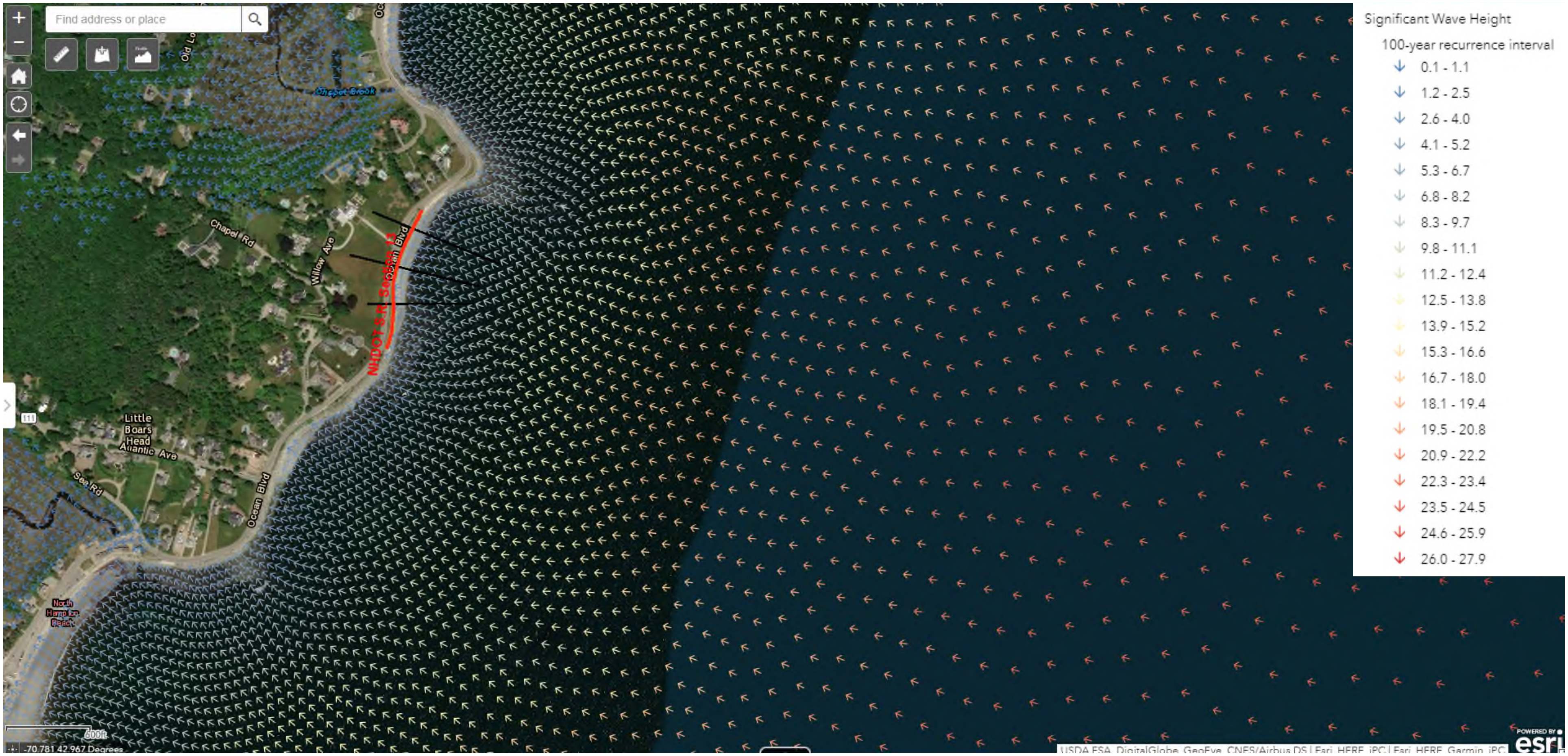


Figure 60. 100-year Recurrence Interval Wave Height (feet) for Transect 1, 2, 3 at NHDOT S.R. Section 13.

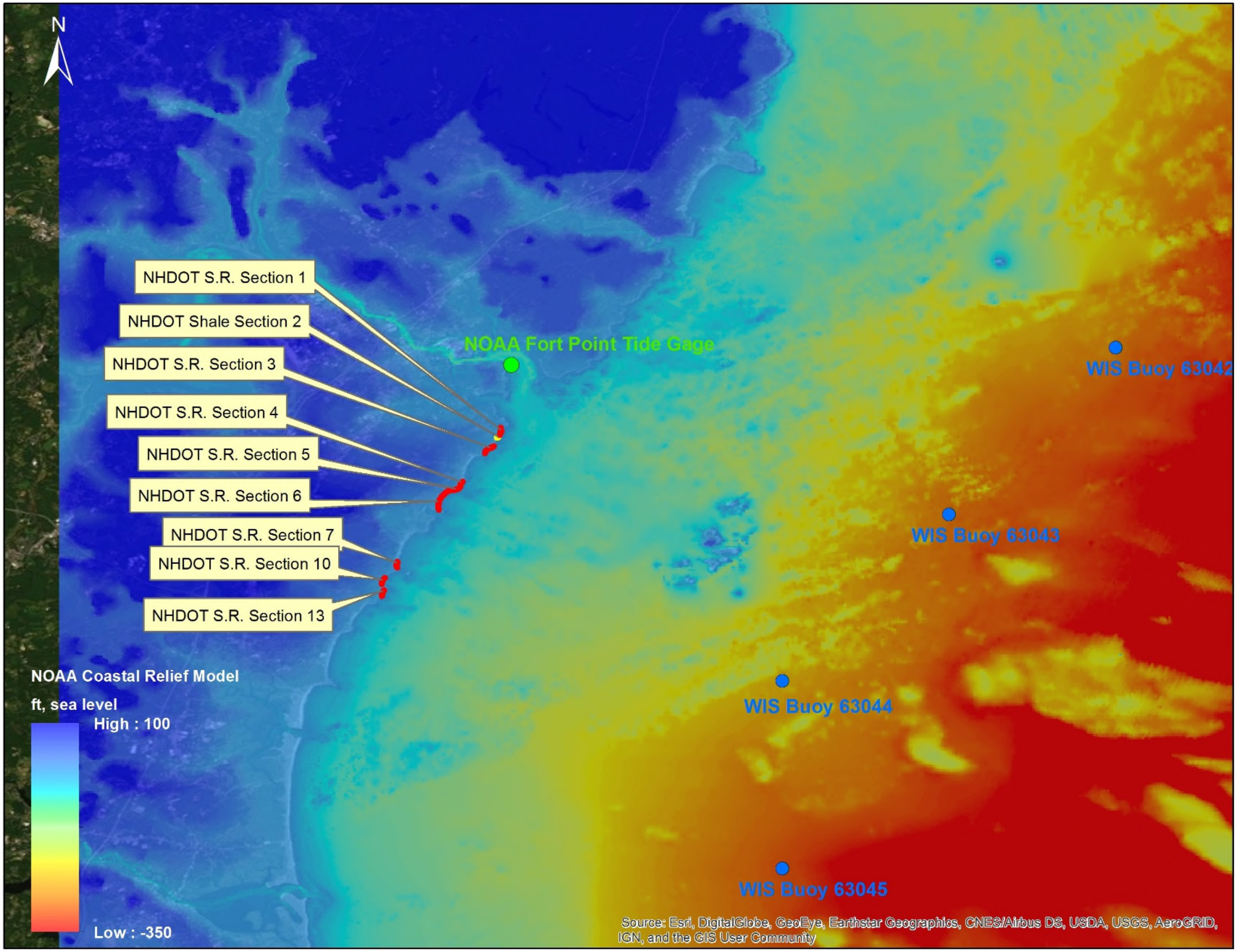


Figure 61. NOAA Coastal Relief Model (1998).

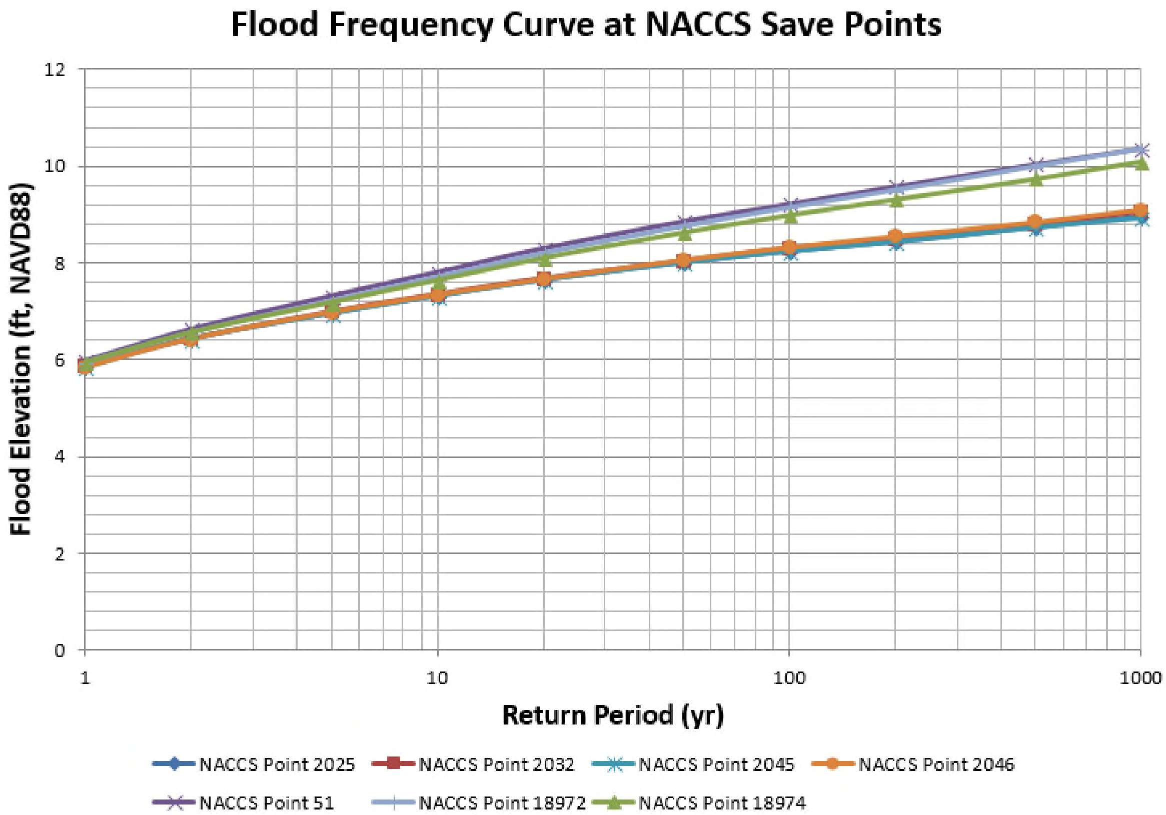


Figure 62. Flood frequency curve at NACCS save points (locations shown in **Figure 2**).

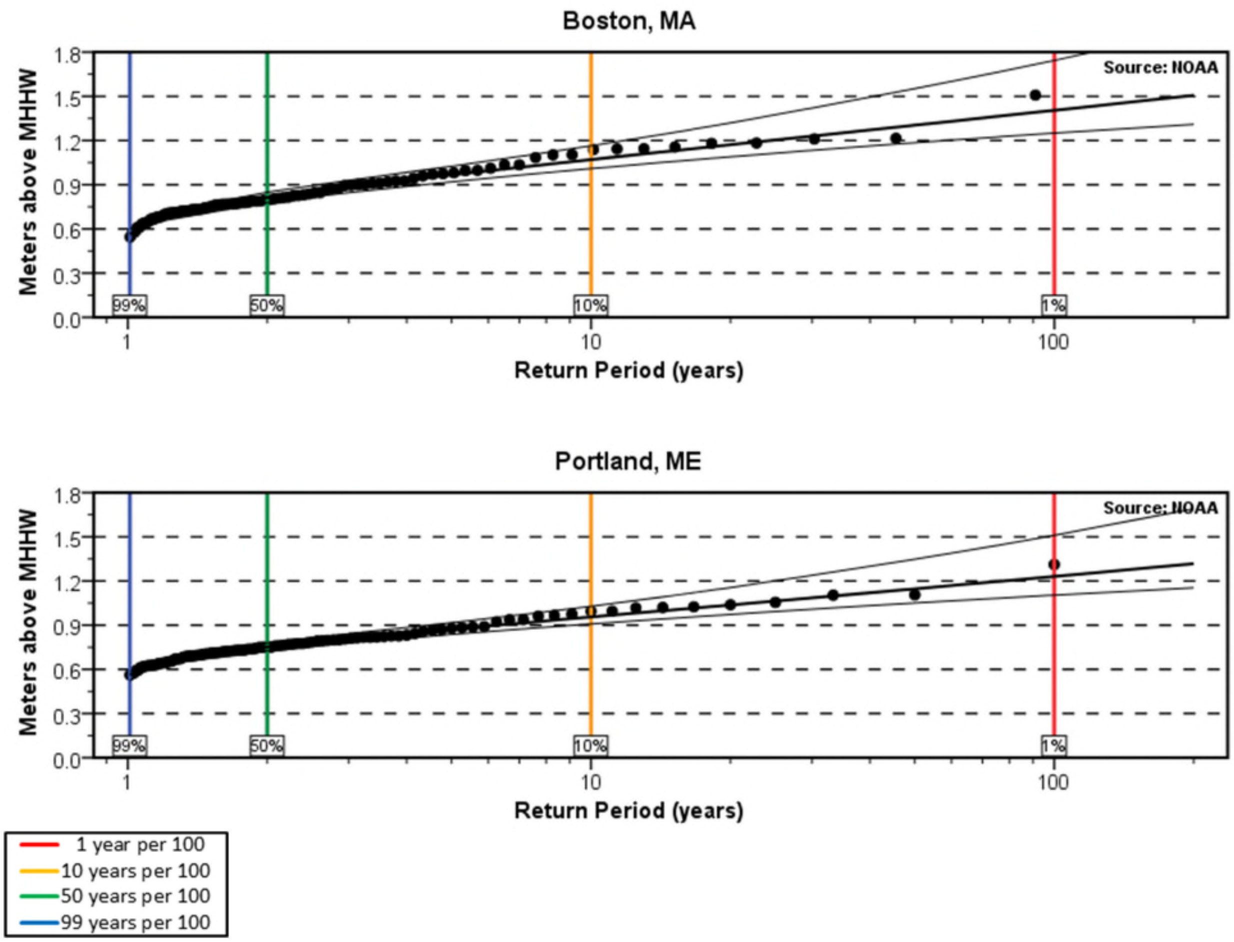


Figure 63. Flood frequency curve at NOAA Boston and Portland tide gage.

Figure 64. Water level data at NOAA Fort Point Gage during March 2018 Nor'Easter.

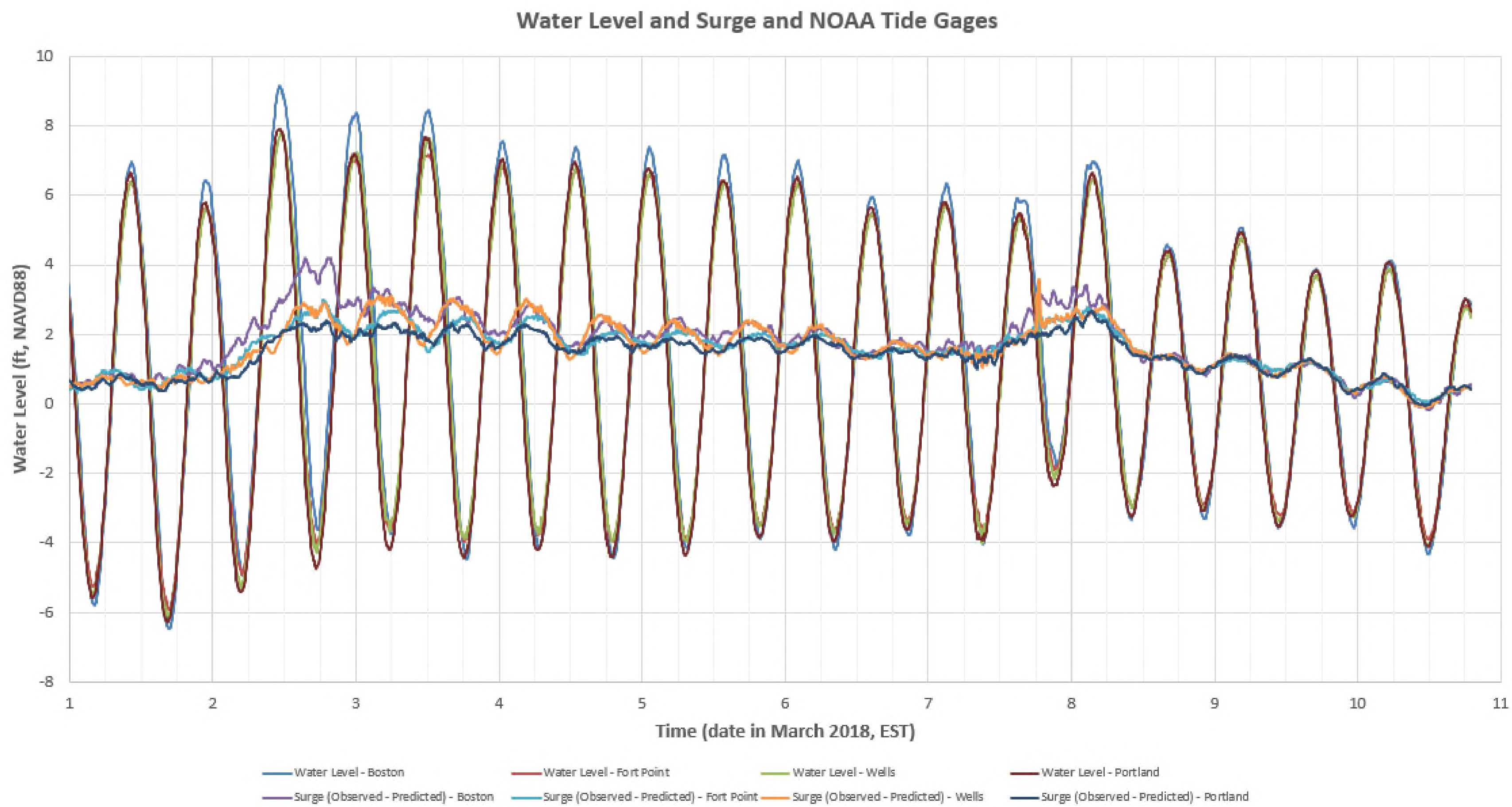
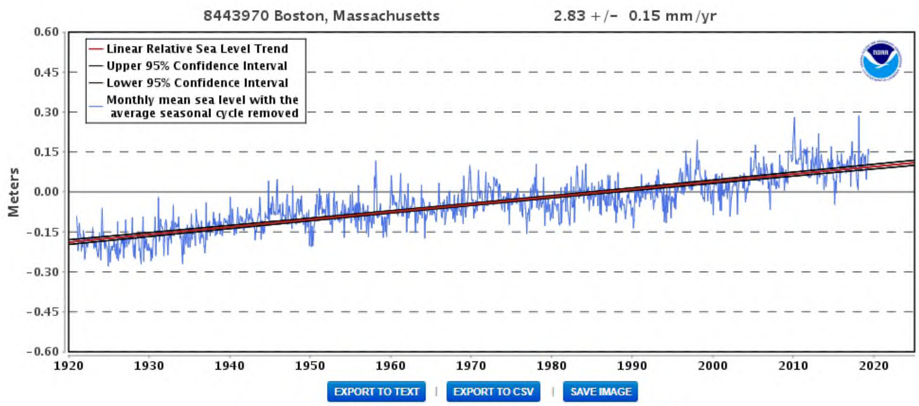


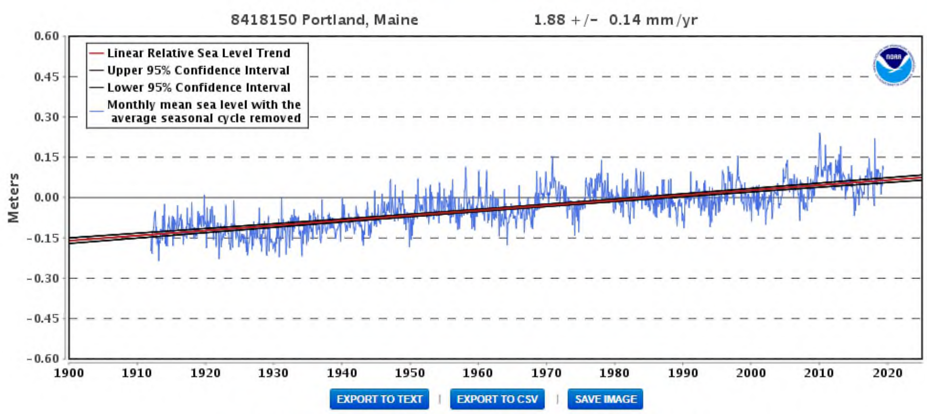
Figure 65. Water level data at NOAA Boston, Fort Point, Wells and Portland Gages during March 2018 Nor'Easter.

Relative Sea Level Trend
8443970 Boston, Massachusetts



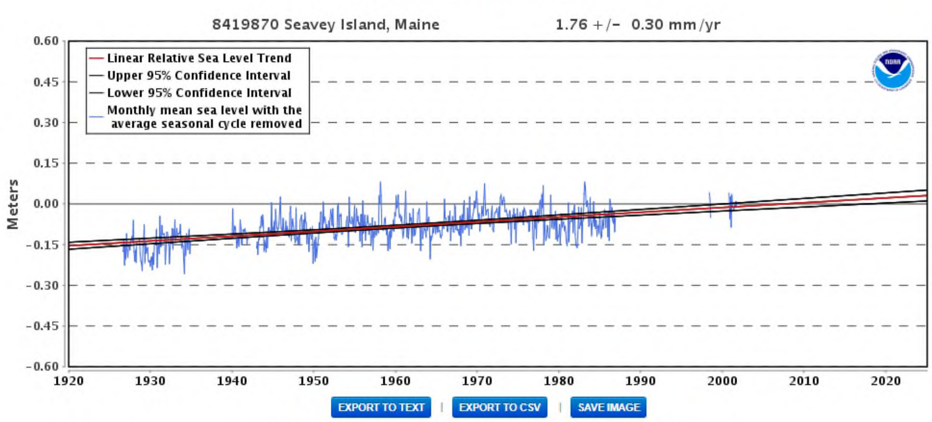
The relative sea level trend is 2.83 millimeters/year with a 95% confidence interval of +/- 0.15 mm/yr based on monthly mean sea level data from 1921 to 2018 which is equivalent to a change of 0.93 feet in 100 years.

Relative Sea Level Trend
8418150 Portland, Maine



The relative sea level trend is 1.88 millimeters/year with a 95% confidence interval of +/- 0.14 mm/yr based on monthly mean sea level data from 1912 to 2018 which is equivalent to a change of 0.62 feet in 100 years.

Relative Sea Level Trend
8419870 Seavey Island, Maine



The relative sea level trend is 1.76 millimeters/year with a 95% confidence interval of +/- 0.3 mm/yr based on monthly mean sea level data from 1926 to 2001 which is equivalent to a change of 0.58 feet in 100 years.

Figure 66. Relative sea level trend at NOAA Boston, Portland and Seavey Island Gage.

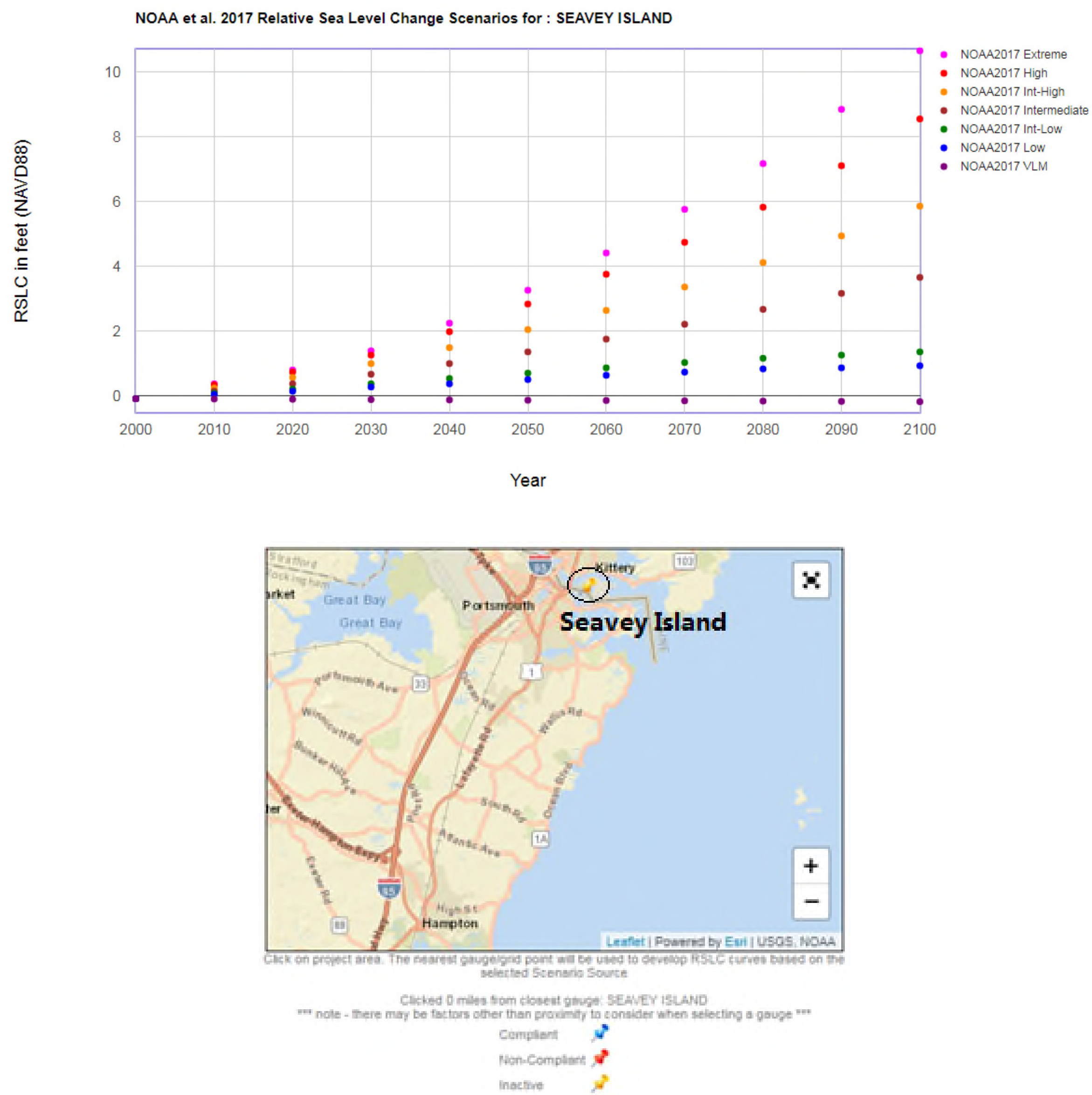


Figure 67. Sea Level Rise Projections at Seavey Island (using the USACE Relative Sea Level Change Calculator for NOAA et al. 2017 projections.

Figure 68. Location of wind observation sites.

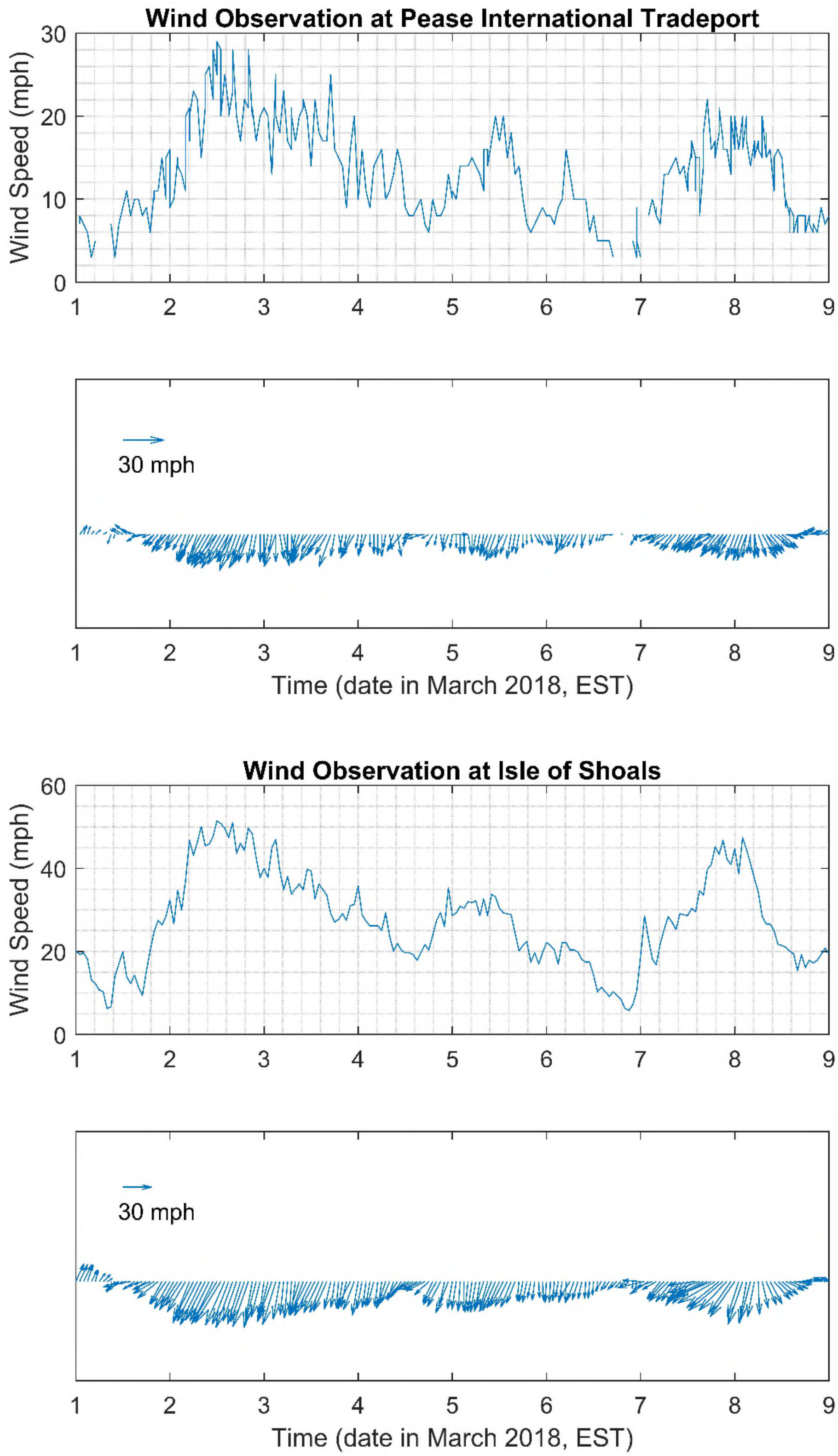


Figure 69. Wind observation during March 2018 Nor'Easter.

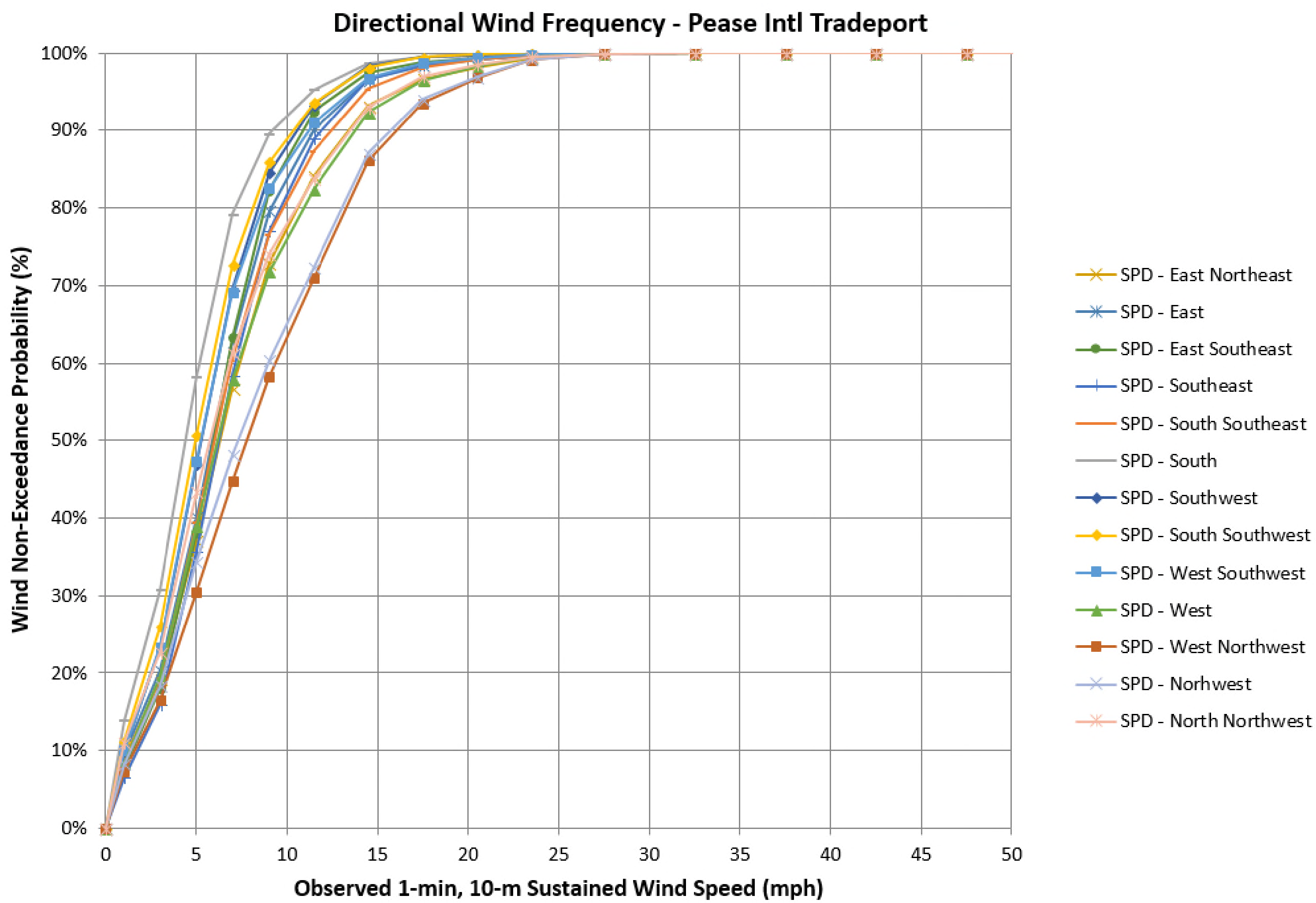


Figure 70. Directional Wind Frequency at Pease International Tradeport.

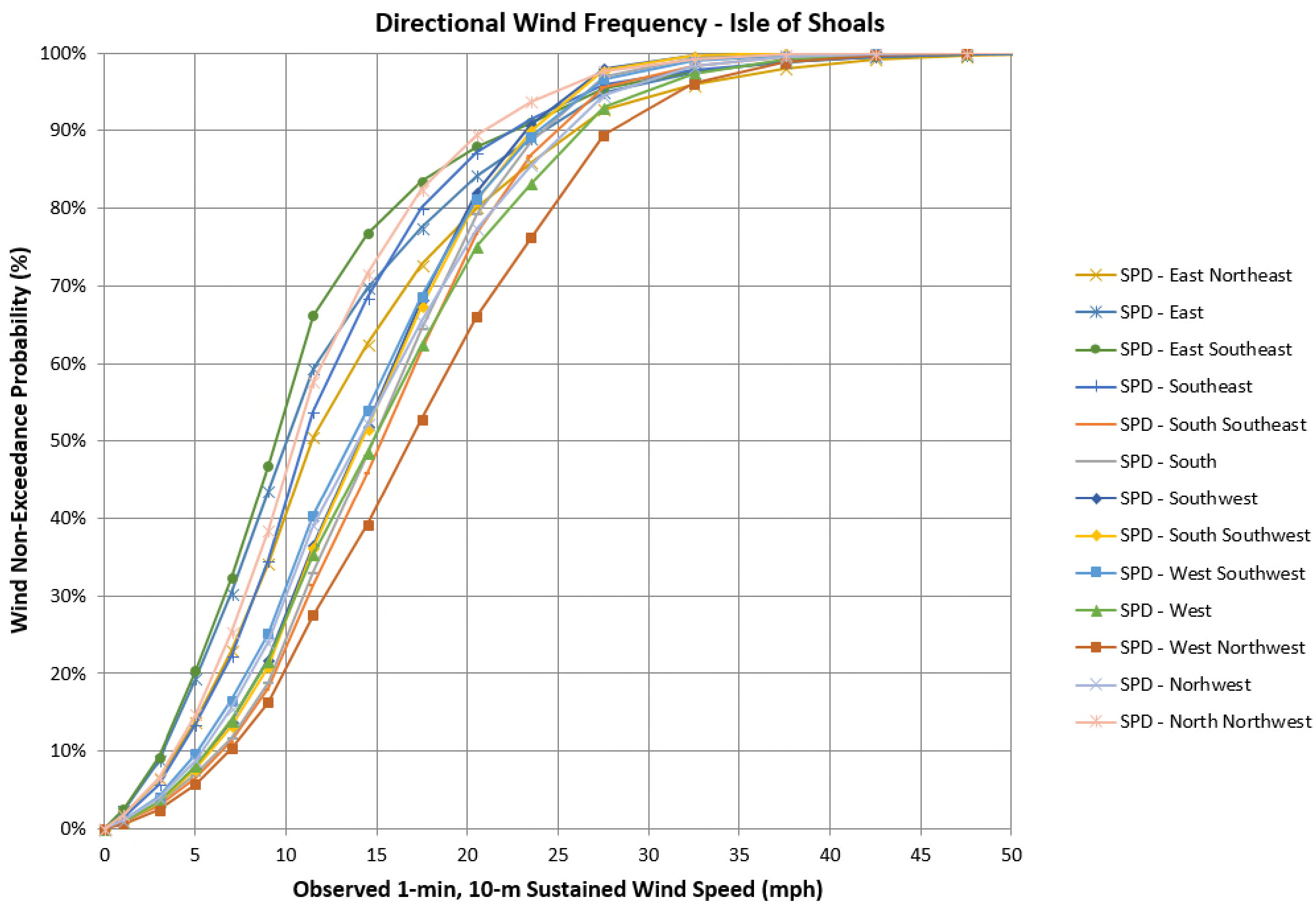


Figure 71. Directional Wind Frequency at Isle of Shoals.

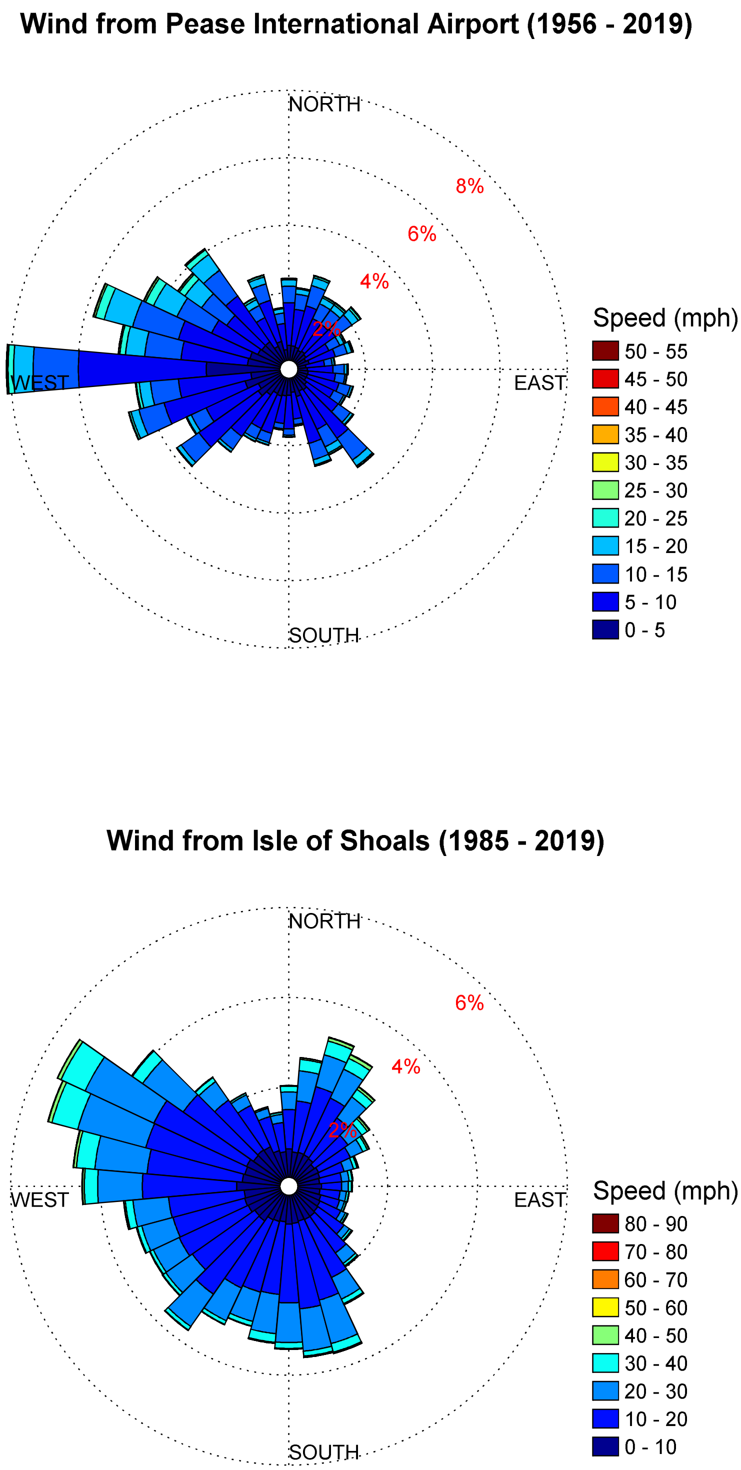


Figure 72. Wind rose based on all data records at Pease Intl Tradeport and Isle of Shoals.

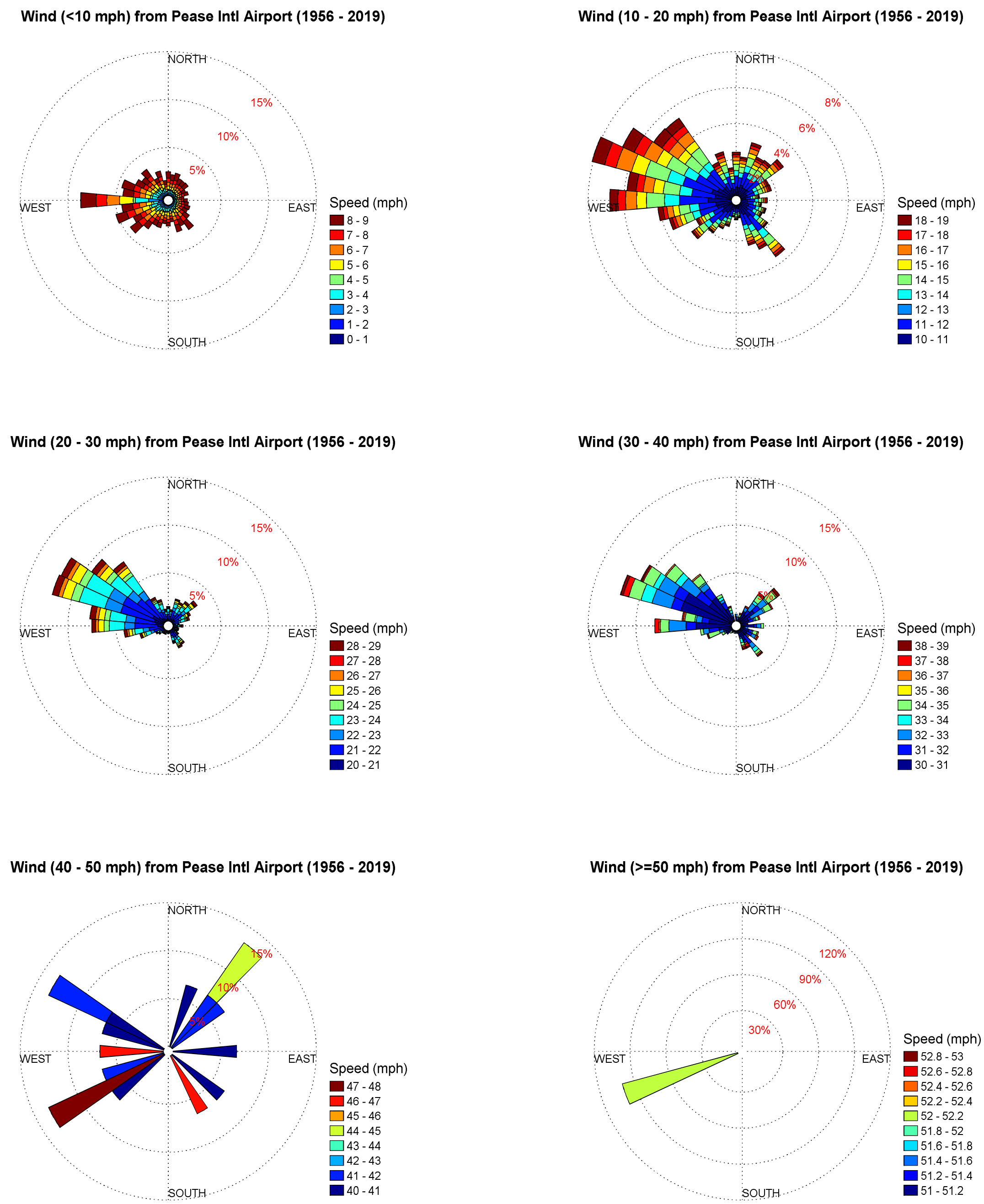


Figure 73. Wind rose for various speed ranges based on wind data at Pease Intl Tradeport.

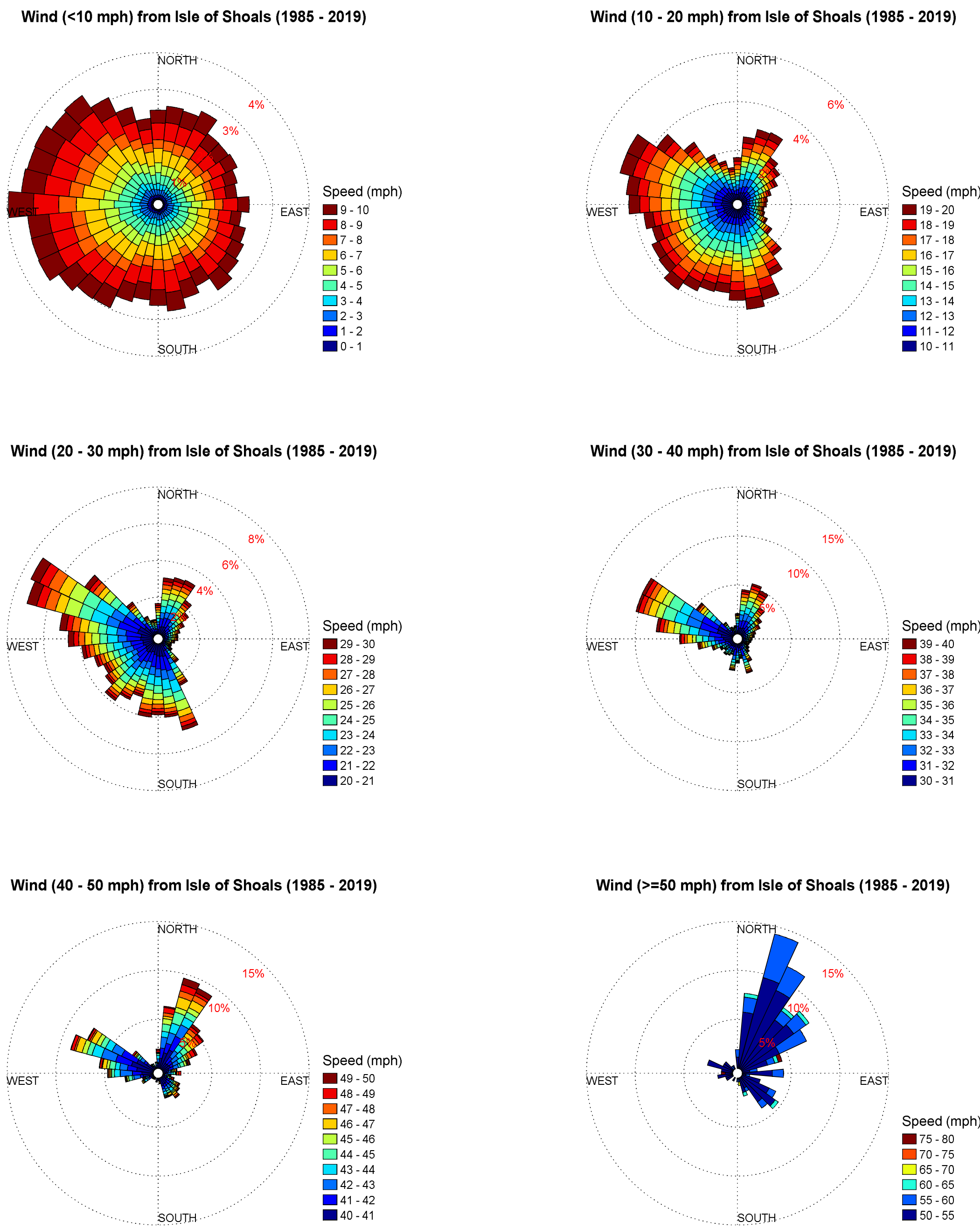
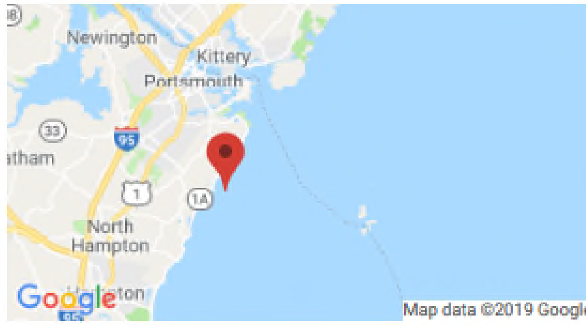


Figure 74. Wind rose for various speed ranges based on wind data at Isle of Shoals.

ATC Hazards by Location

Search Information

Coordinates:	42.999670316129595, -70.73487910185548
Elevation:	ft
Timestamp:	2019-08-02T19:59:36.777Z
Hazard Type:	Wind



ASCE 7-16

MRI 10-Year	74 mph
MRI 25-Year	83 mph
MRI 50-Year	88 mph
MRI 100-Year	96 mph
Risk Category I	107 mph
Risk Category II	116 mph
Risk Category III	124 mph
Risk Category IV	129 mph

ASCE 7-10

MRI 10-Year	78 mph
MRI 25-Year	87 mph
MRI 50-Year	94 mph
MRI 100-Year	100 mph
Risk Category I	113 mph
Risk Category II	123 mph
Risk Category III-IV	⚠ 134 mph

If the structure under consideration is a healthcare facility and you are also within 1 mile of the coastal mean high water line, you are in a wind-borne debris region. If other occupancy, use the Risk Category II basic wind speed contours to determine if you are in a wind-borne debris region.

ASCE 7-05

ASCE 7-05 Wind Speed	102 mph

The results indicated here DO NOT reflect any state or local amendments to the values or any delineation lines made during the building code adoption process. Users should confirm any output obtained from this tool with the local Authority Having Jurisdiction before proceeding with design.

Figure 75. ASCE wind speeds (3-sec gust) at NHDOT sections.

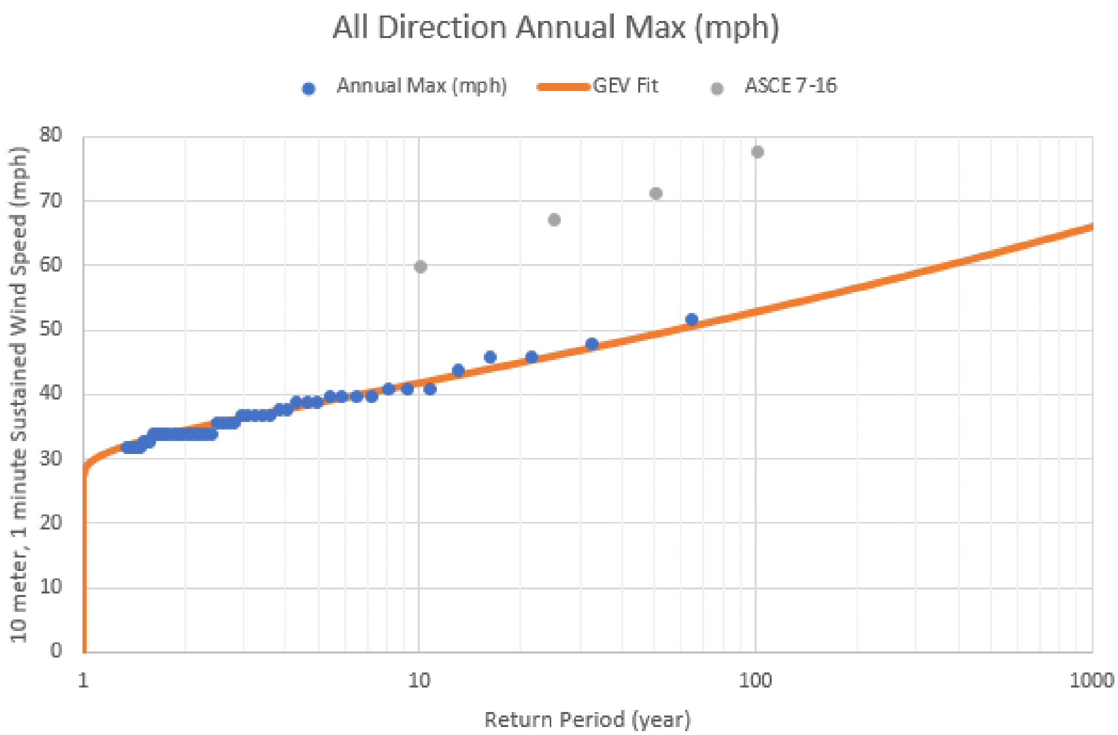


Figure 76. Wind Speed Frequency Curve at Pease International Tradeport based on GZA Wind Statistical Analysis – all direction wind.

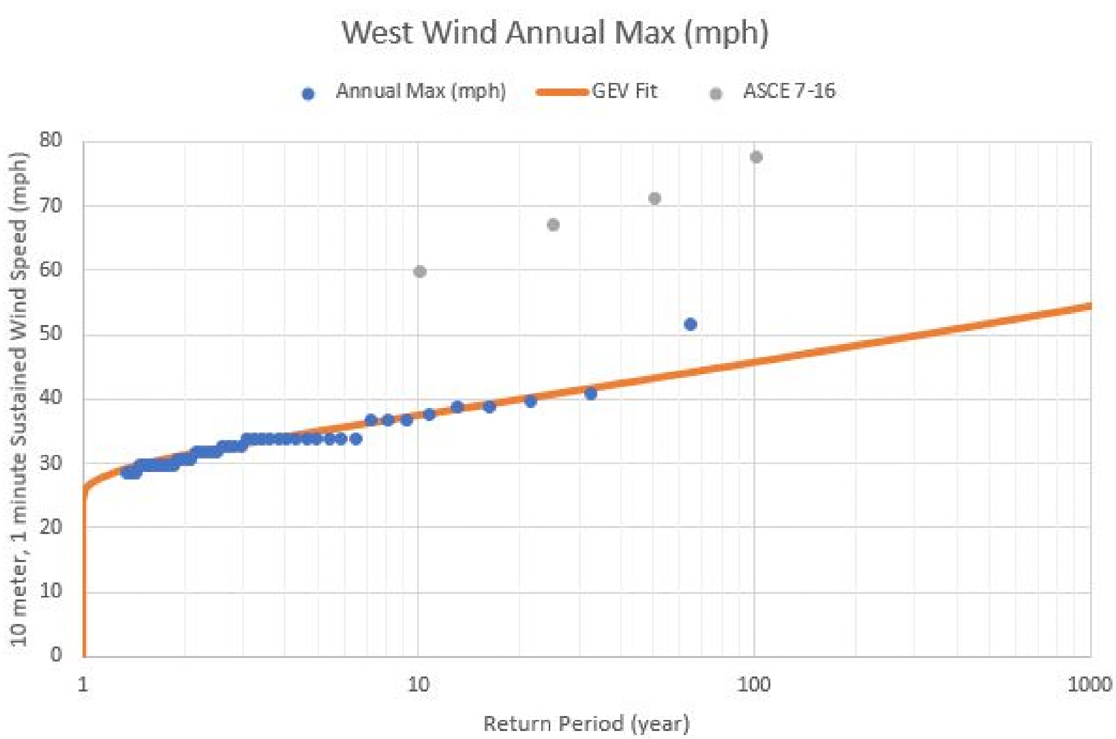


Figure 77. Wind Speed Frequency Curve at Pease International Tradeport based on GZA Wind Statistical Analysis – west wind.

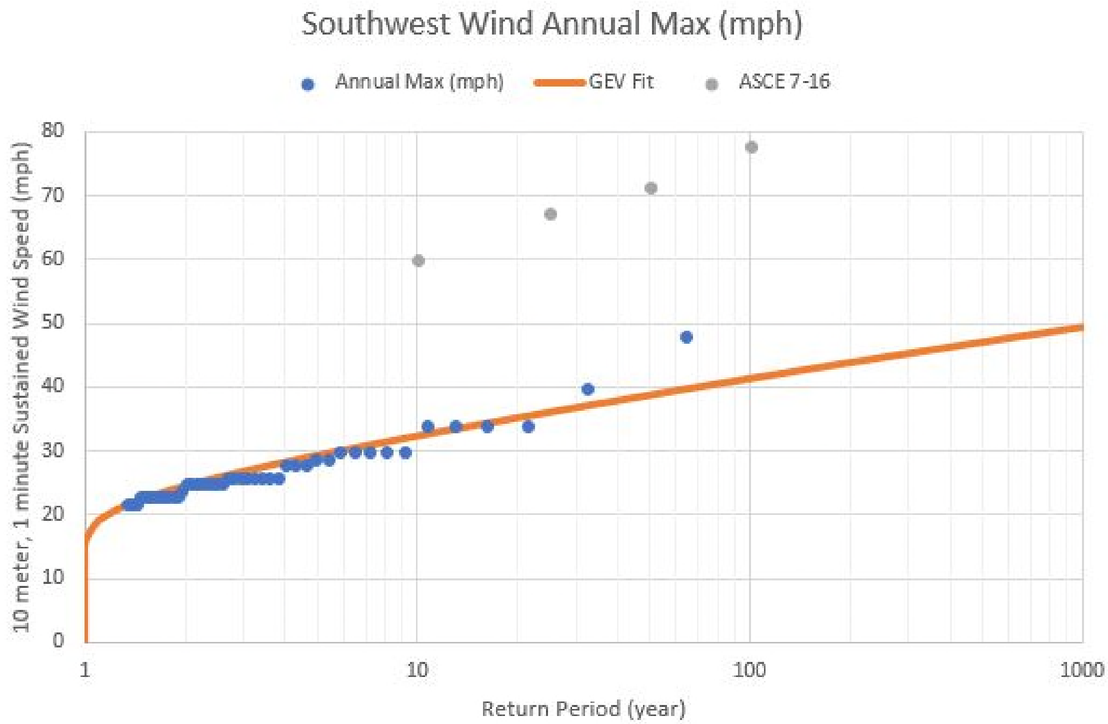


Figure 78. Wind Speed Frequency Curve at Pease International Tradeport based on GZA Wind Statistical Analysis – southwest wind.

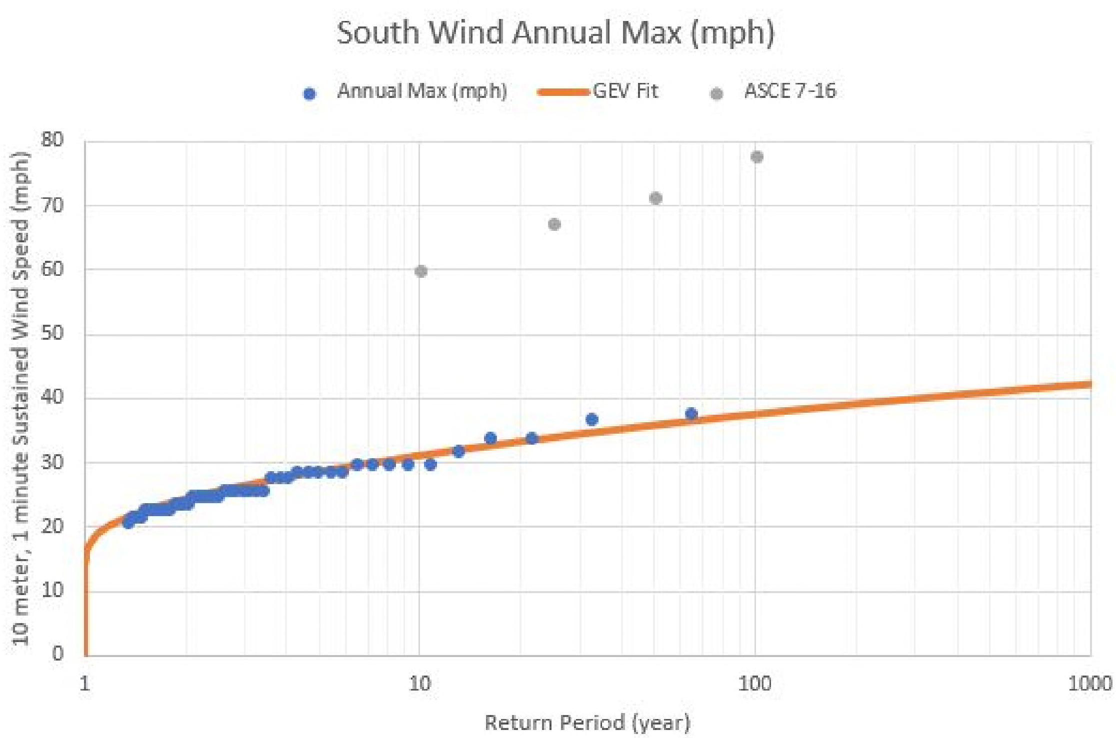


Figure 79. Wind Speed Frequency Curve at Pease International Tradeport based on GZA Wind Statistical Analysis – south wind.

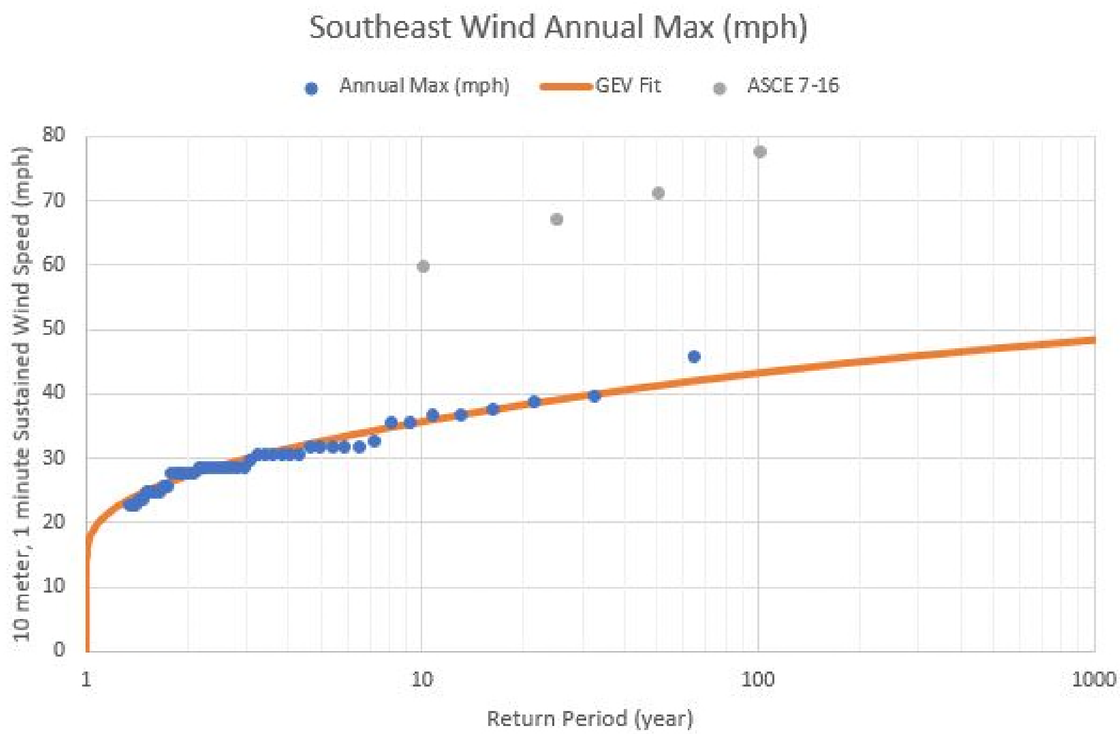


Figure 80. Wind Speed Frequency Curve at Pease International Tradeport based on GZA Wind Statistical Analysis – southeast wind.

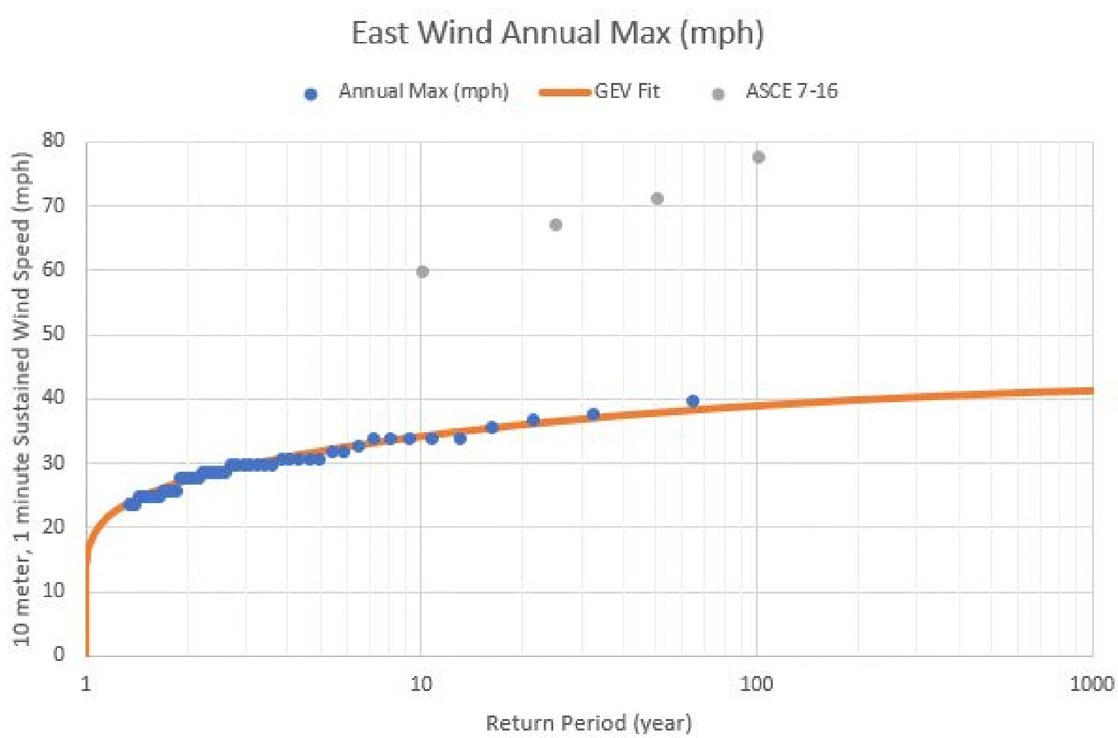


Figure 81. Wind Speed Frequency Curve at Pease International Tradeport based on GZA Wind Statistical Analysis – east wind.

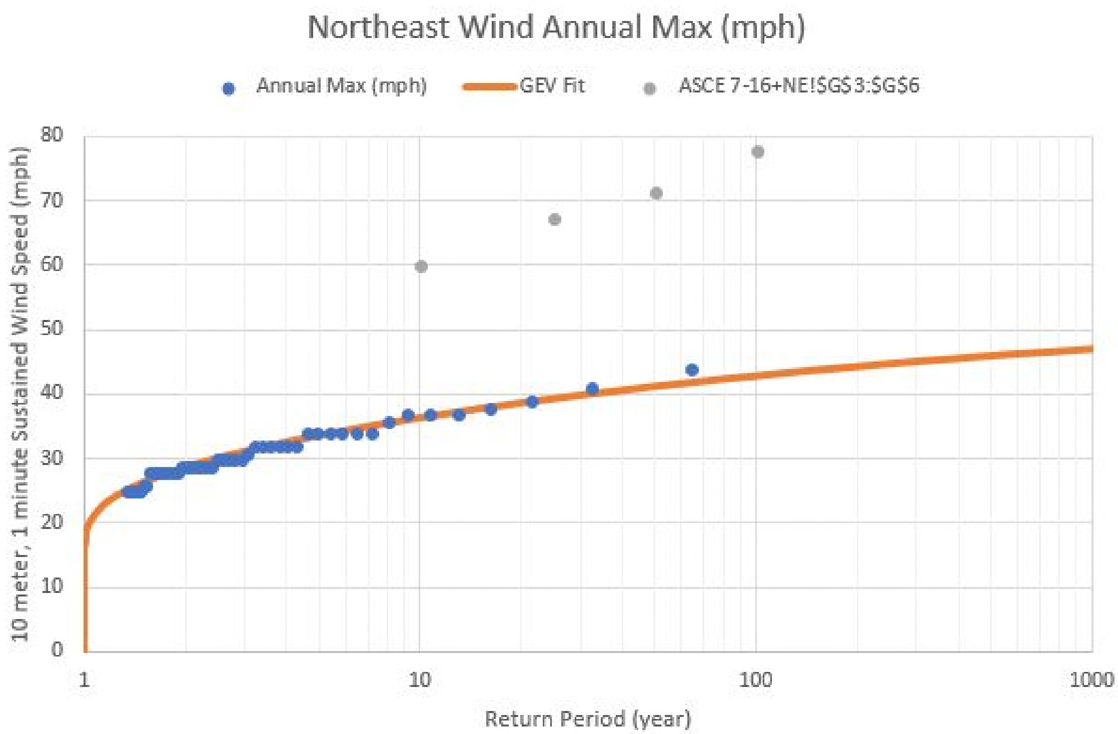


Figure 82. Wind Speed Frequency Curve at Pease International Tradeport based on GZA Wind Statistical Analysis – northeast wind.

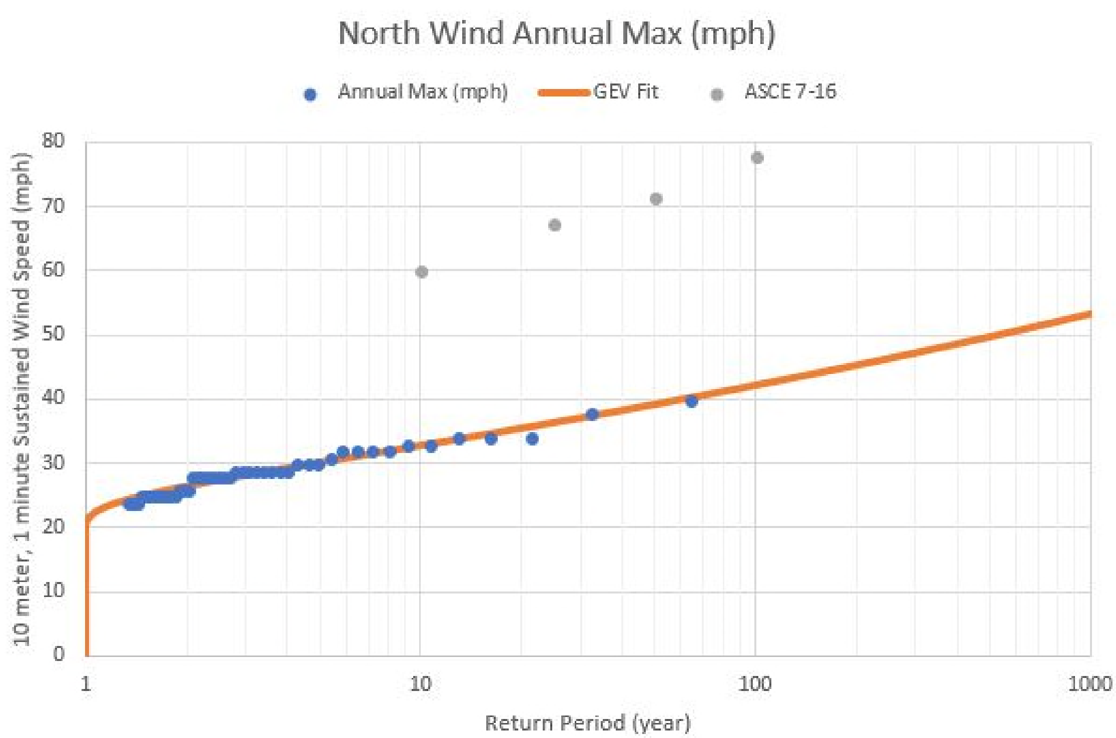


Figure 83. Wind Speed Frequency Curve at Pease International Tradeport based on GZA Wind Statistical Analysis – north wind.

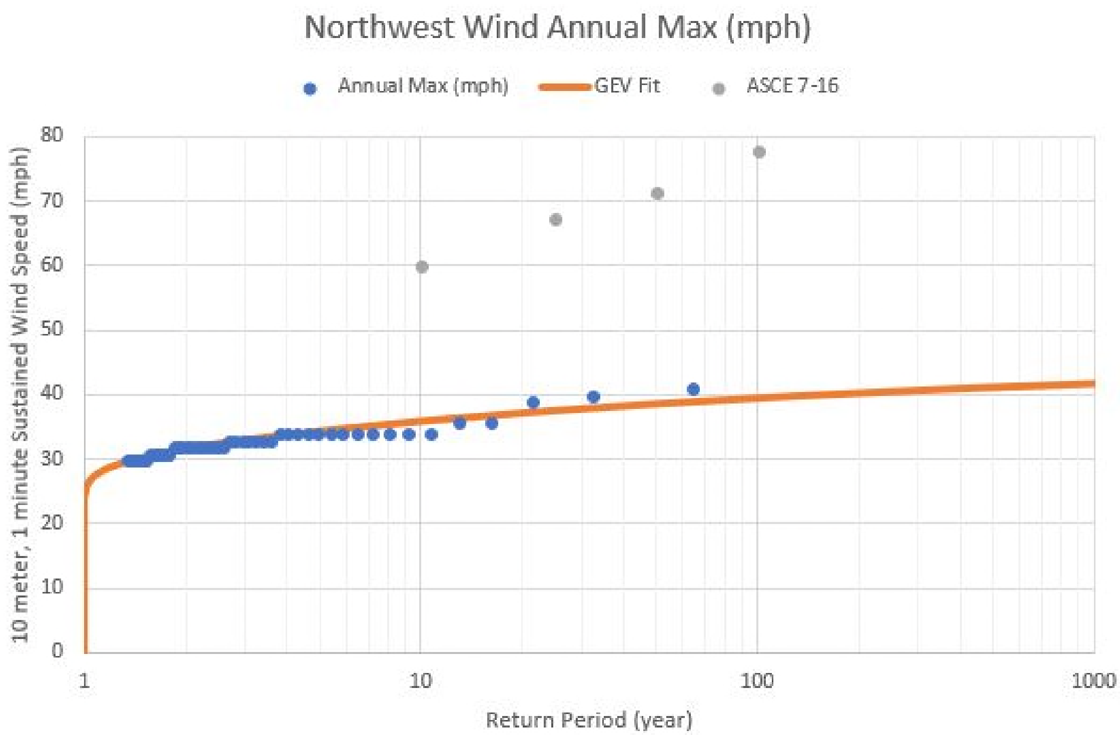


Figure 84. Wind Speed Frequency Curve at Pease International Tradeport based on GZA Wind Statistical Analysis – northwest wind

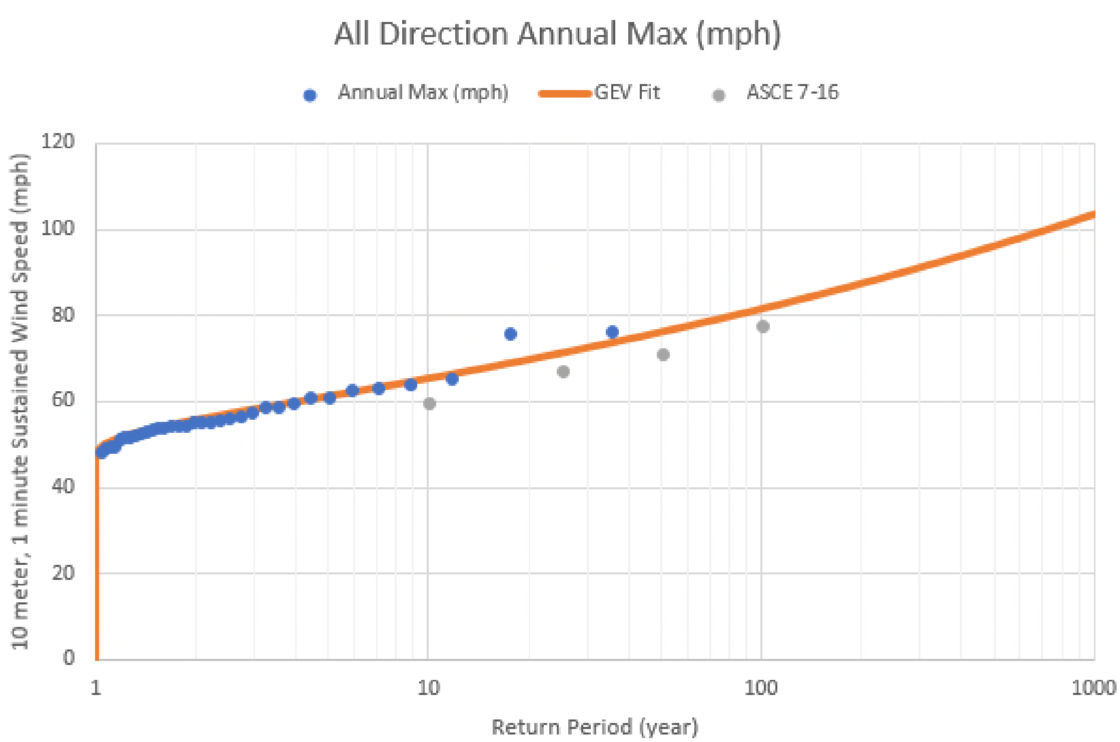


Figure 85. Wind Speed Frequency Curve at Isle of Shoals based on GZA Wind Statistical Analysis – all direction wind.

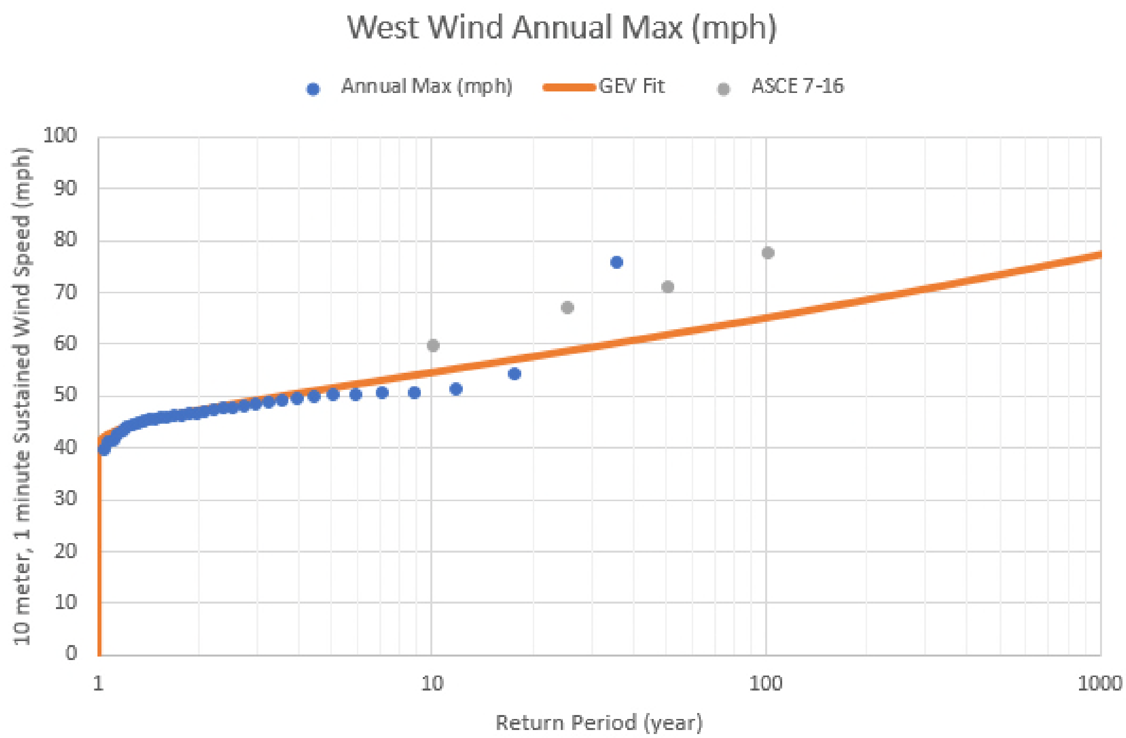


Figure 86. Wind Speed Frequency Curve at Isle of Shoals based on GZA Wind Statistical Analysis – west wind.

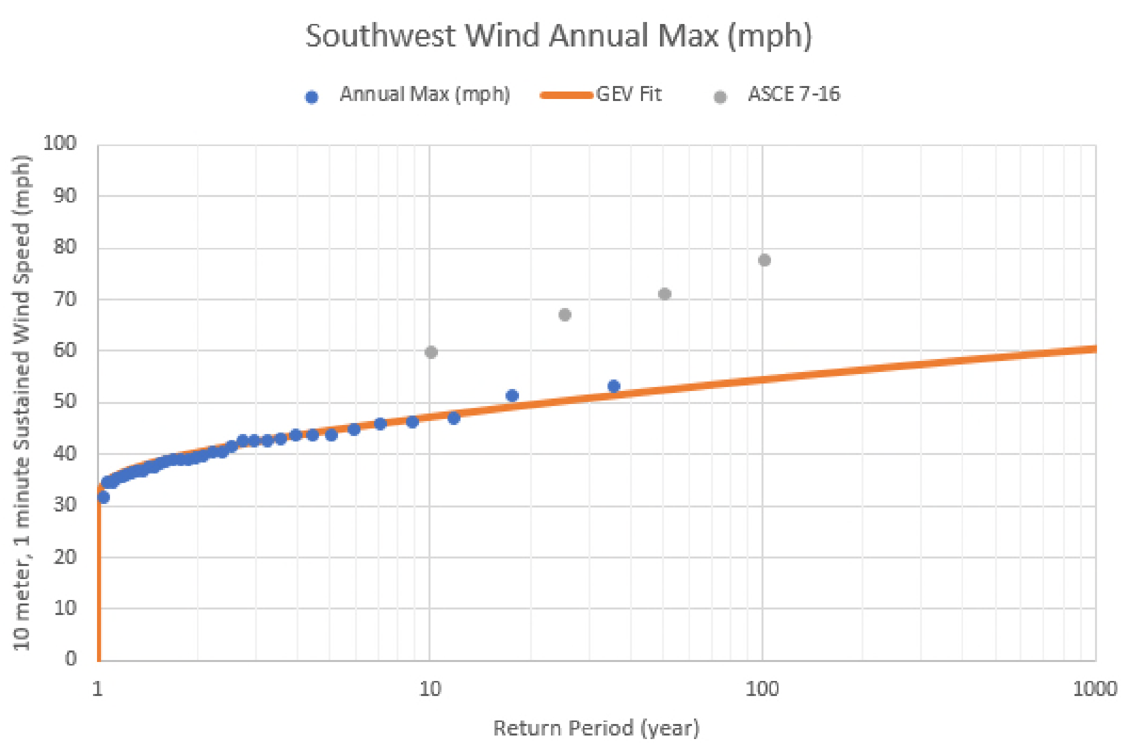


Figure 87. Wind Speed Frequency Curve at Isle of Shoals based on GZA Wind Statistical Analysis – southwest wind.

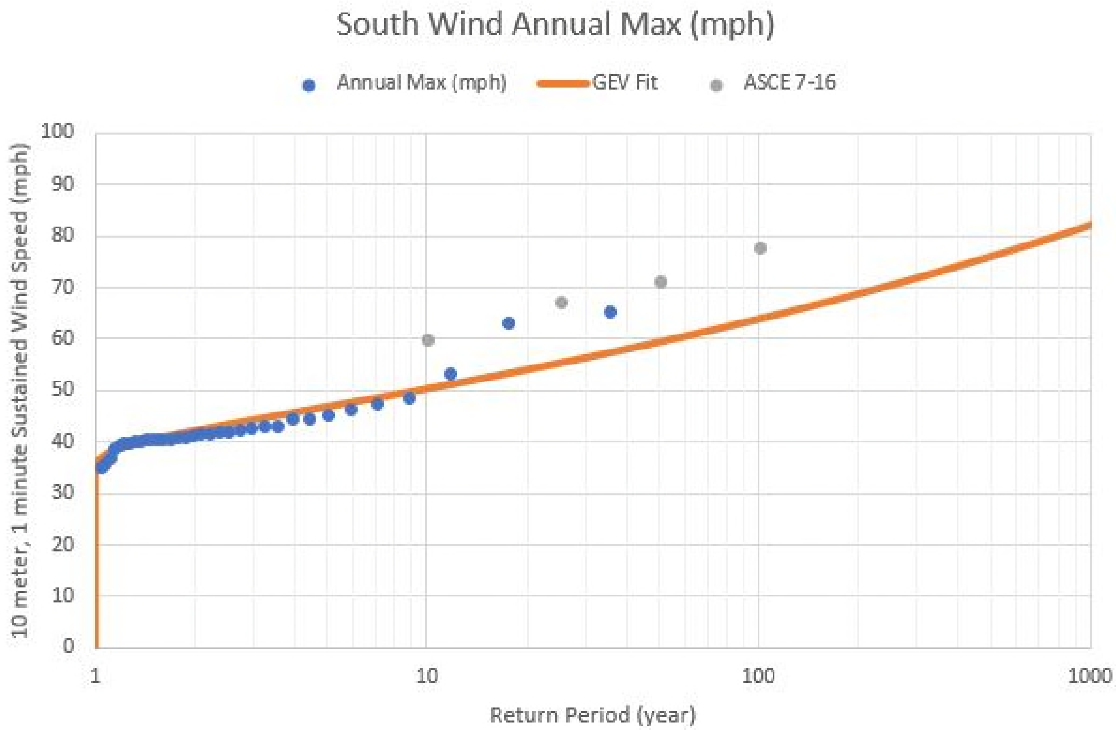


Figure 88. Wind Speed Frequency Curve at Isle of Shoals based on GZA Wind Statistical Analysis – south wind.

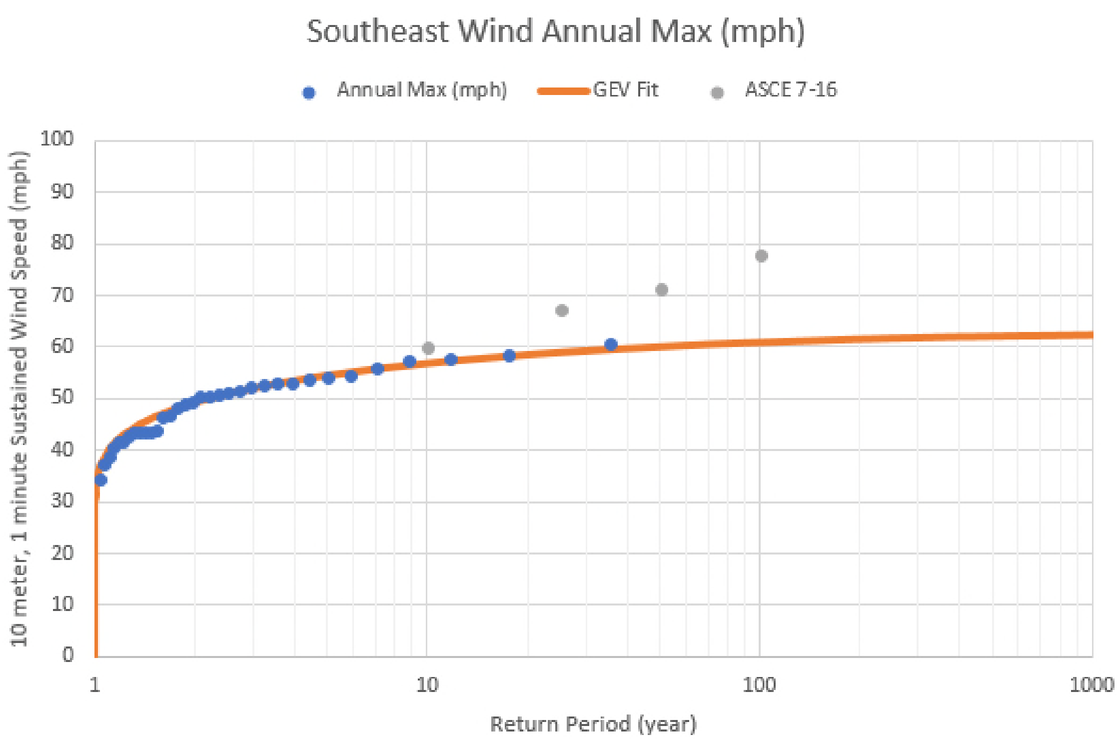


Figure 89. Wind Speed Frequency Curve at Isle of Shoals based on GZA Wind Statistical Analysis – southeast wind.

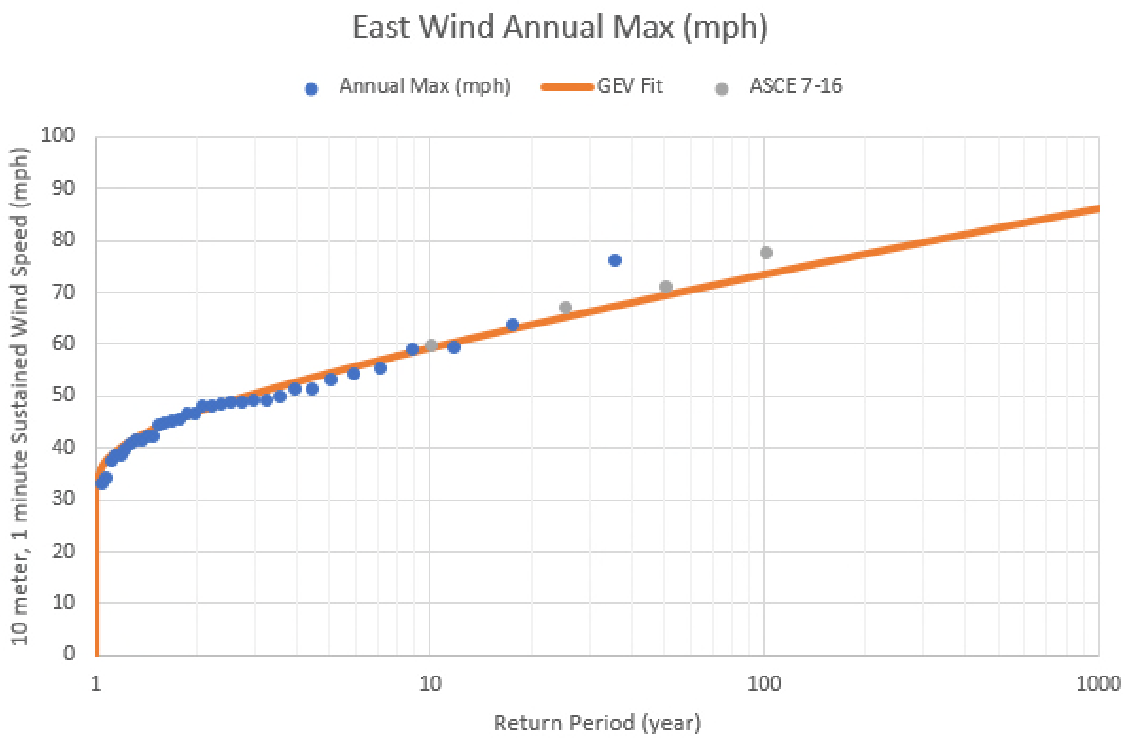


Figure 90. Wind Speed Frequency Curve at Isle of Shoals based on GZA Wind Statistical Analysis – east wind.

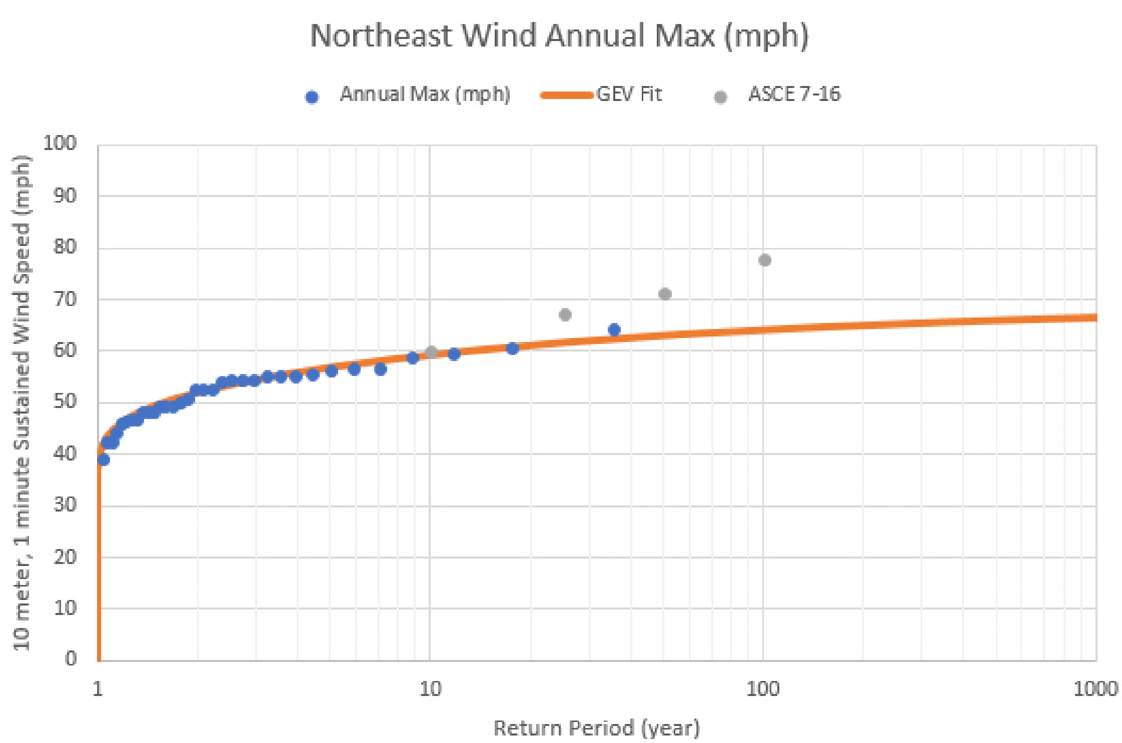


Figure 91. Wind Speed Frequency Curve at Isle of Shoals based on GZA Wind Statistical Analysis – northeast wind.

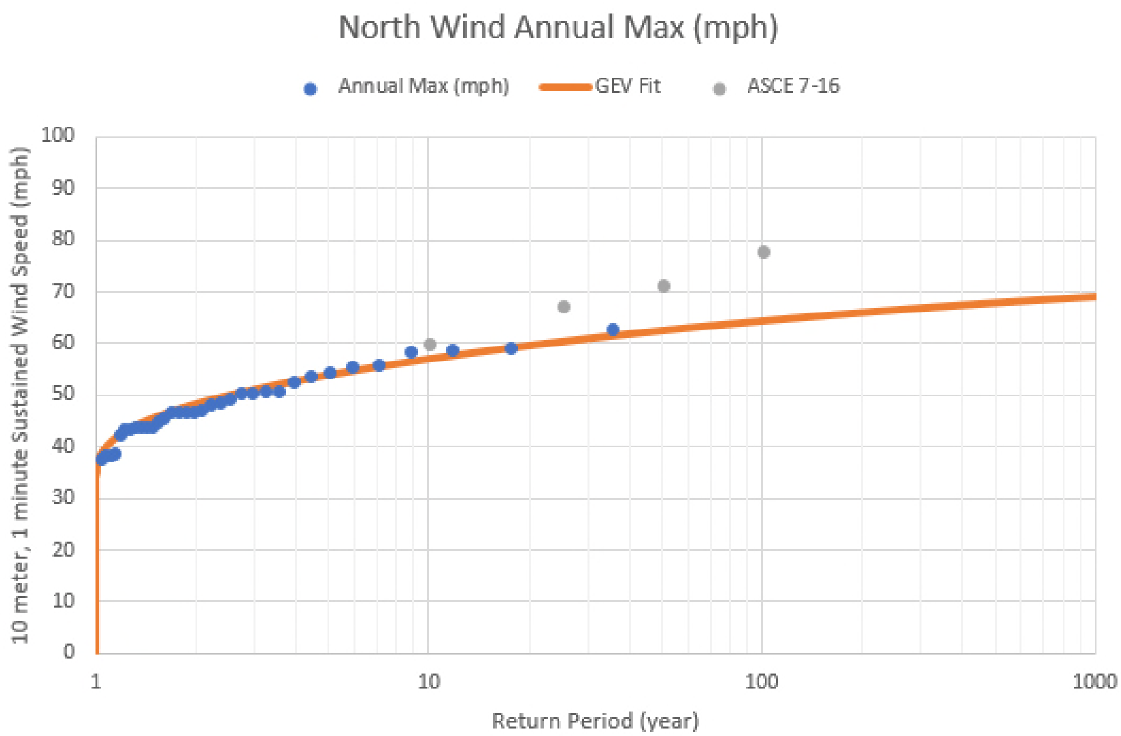


Figure 92. Wind Speed Frequency Curve at Isle of Shoals based on GZA Wind Statistical Analysis – north wind.

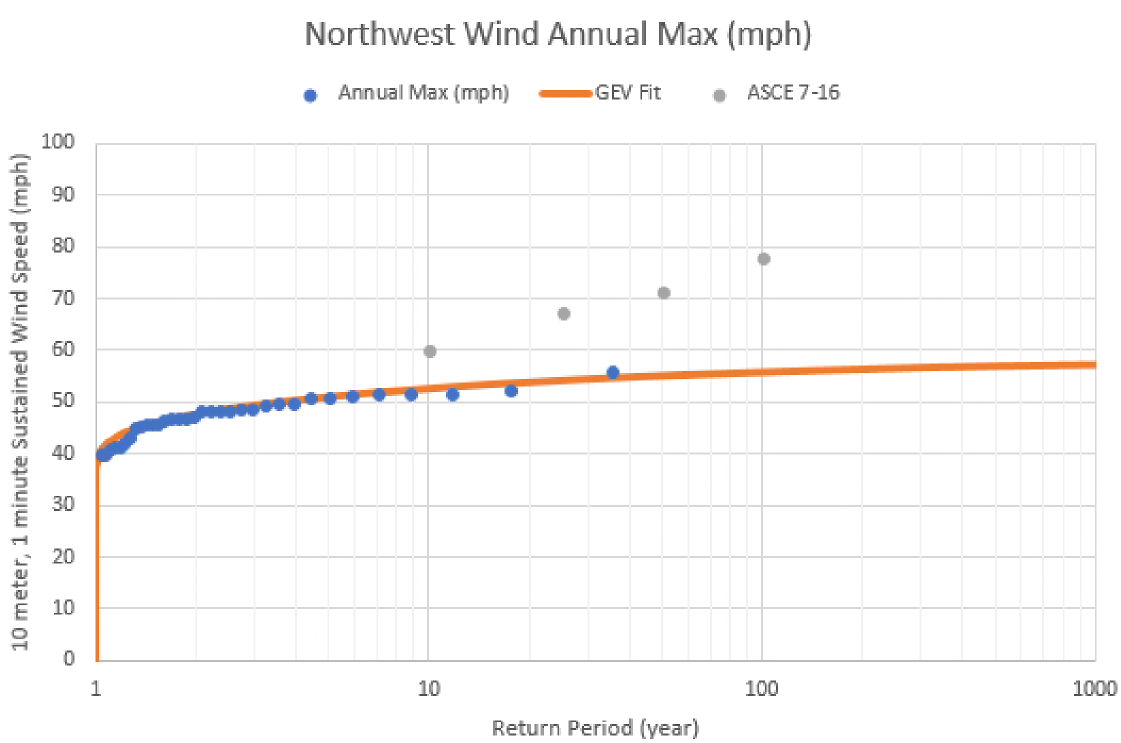


Figure 93. Wind Speed Frequency Curve at Isle of Shoals based on GZA Wind Statistical Analysis – northwest wind.

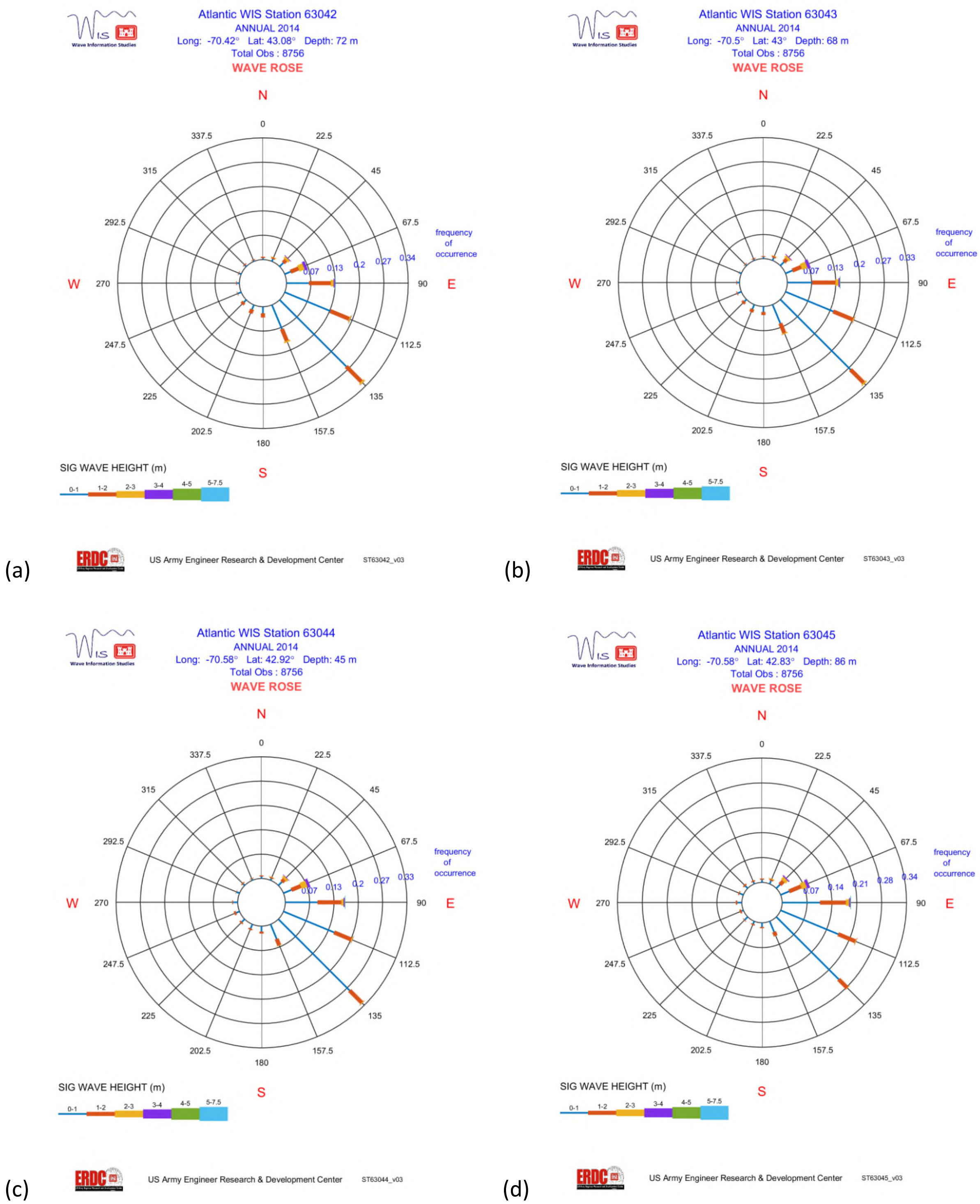


Figure 94. Wave rose at WIS wave buoys (a) 63042; (b) 63042; (c) 63042; (d) 63045.

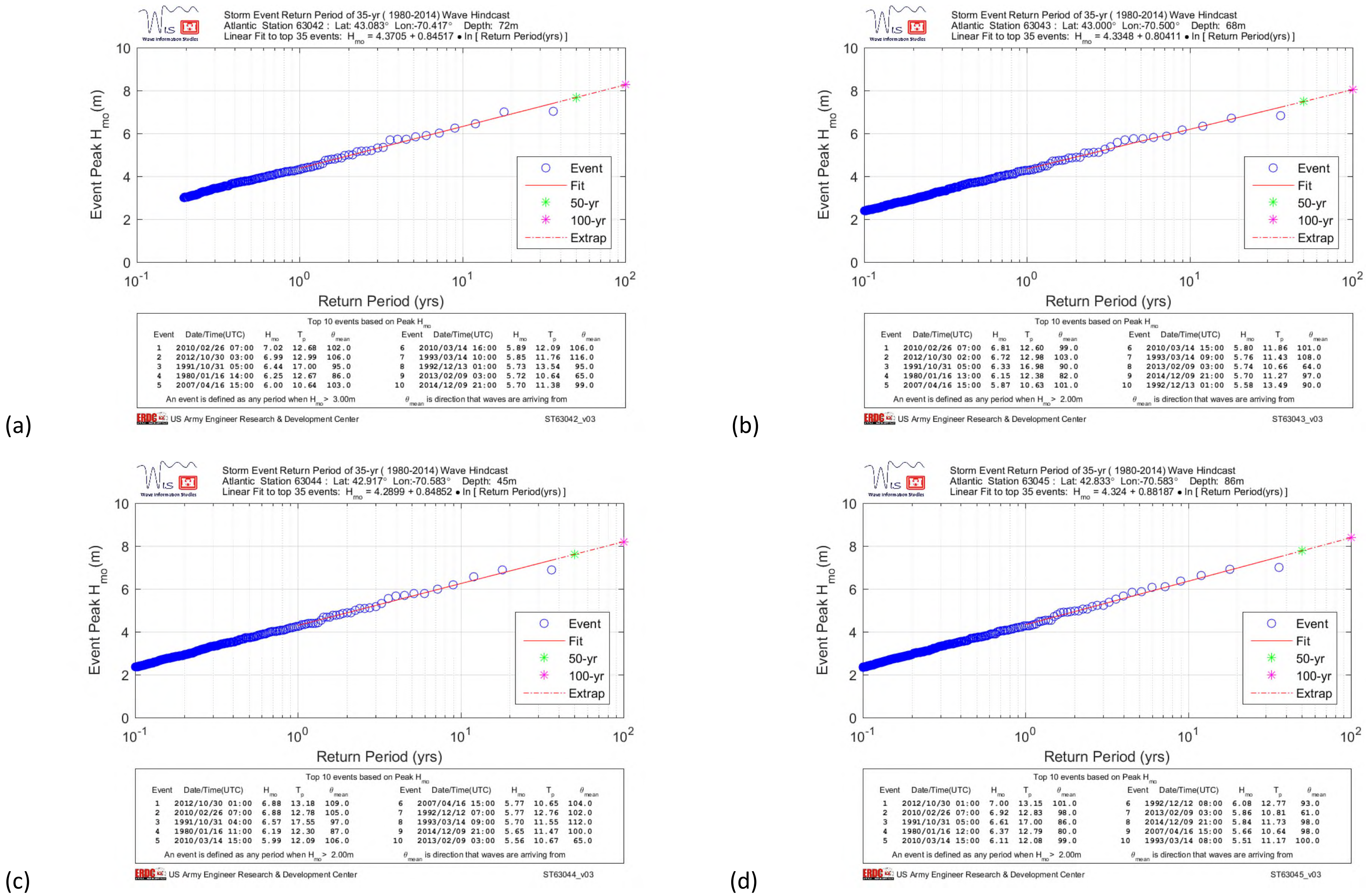
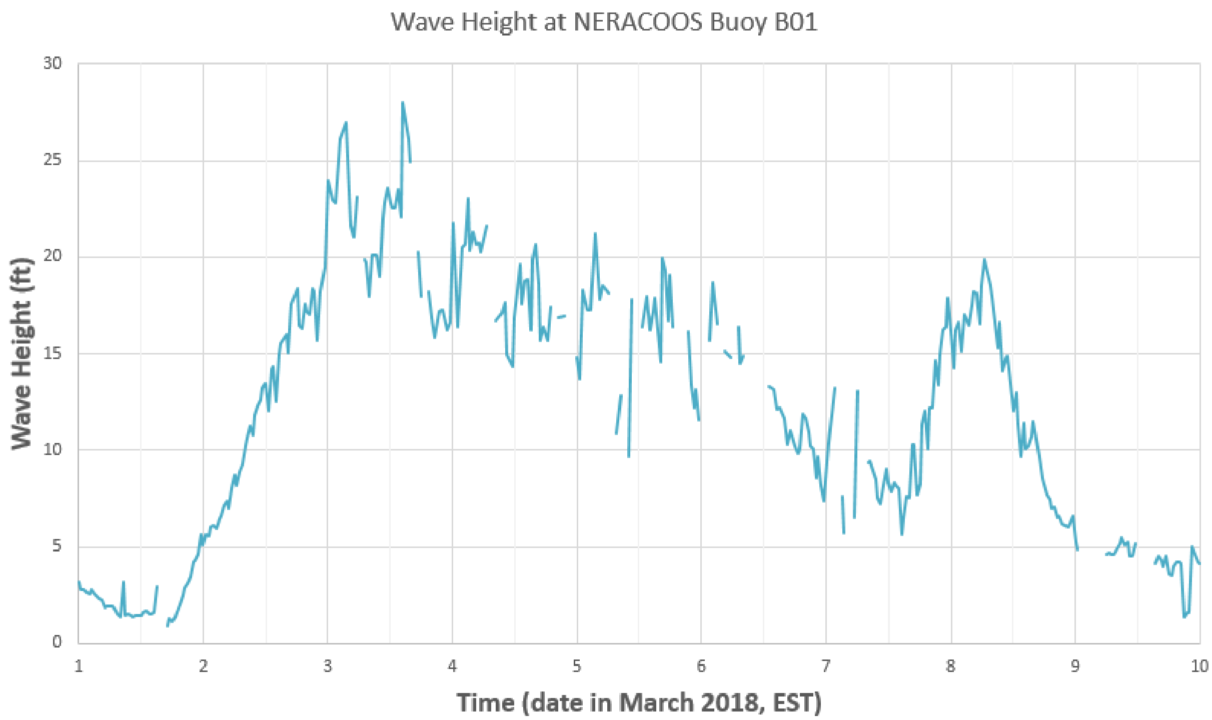


Figure 95. Extreme wave analysis at WIS wave buoys (a) 63042; (b) 63042; (c) 63042; (d) 63045.



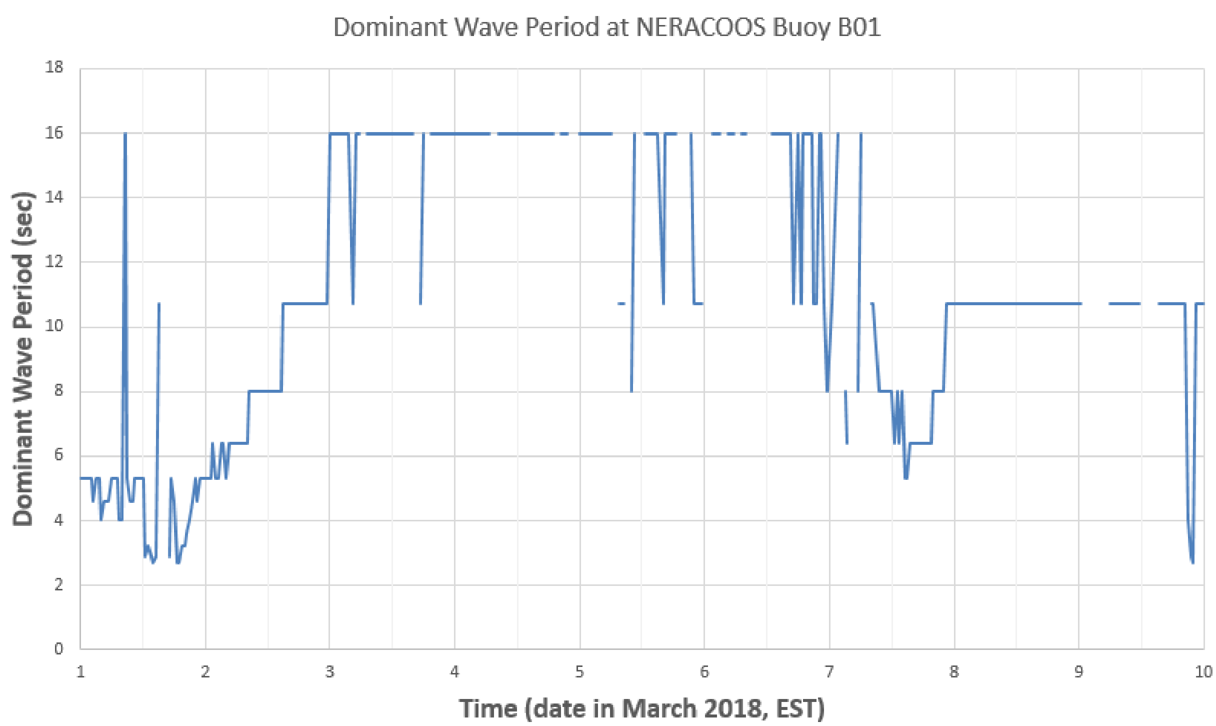


Figure 96. Observed wave height and wave period at NERACOOS buoy B01 during March 2018 Nor'Easter.

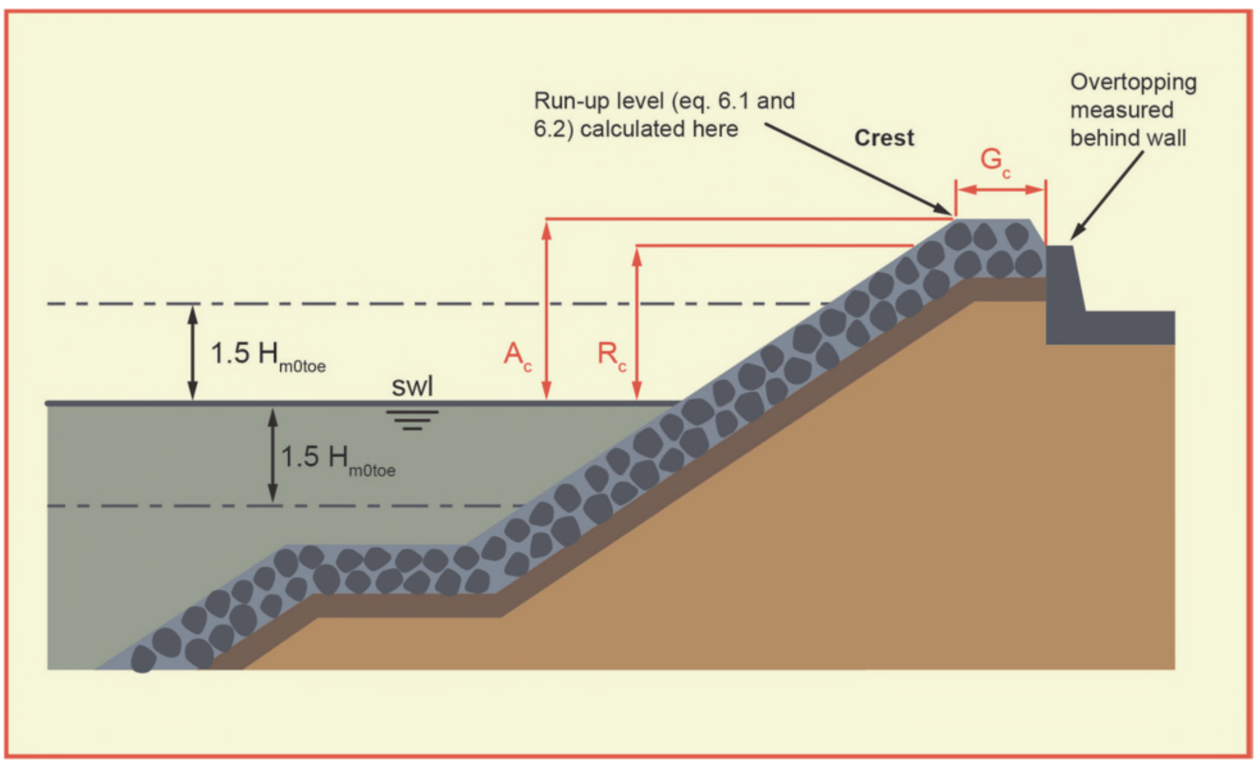
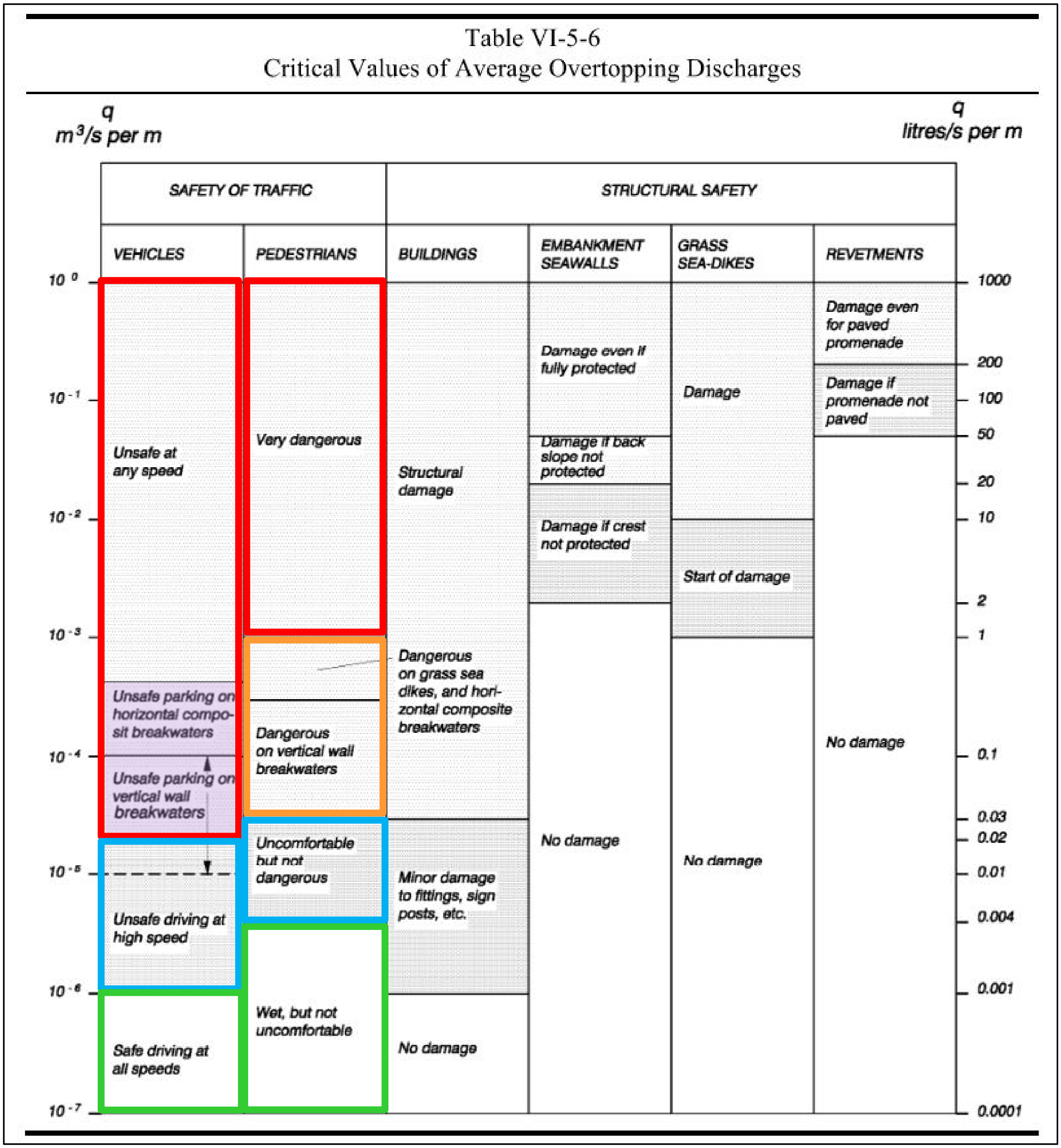


Figure 97. Applicable wave runup and overtopping condition for coastal revetments at Routh 1A (figures are from Figure 6.1 and Figure 6.4 from EurOtop Manual).

Attachment C
Summary Tables: Existing Revetments
Wave Runup & Roadway Use Impacts

<u>Basis of Evaluation for Vehicular and Pedestrian Roadway Use Impacts</u>

Roadway flood risk criteria in accordance with *Engineering Manual 1110-2-1100 – Coastal Engineering Manual, U.S. Army Corps of Engineer*s, September 2011



Excerpt from: EM 1110-2-1100 (Part VI) Change 3 (28 Sep 11)

Section 1 – Current Water Levels

	Crest EL ft, NAVD88	Toe EL ft, NAVD88	SWL EL ft, NAVD88	Wave Runup EL ft, NAVD88	LF of Section with Wave Runup above	Roadway Use - Wave Overtopping Impact					
						Traffic Condition	LF	% LF_{total}	Pedestrians Condition	LF	% LF_{total}
			100-yr 8.4	Max 15.8	500	No overtopping	742	60%	Wet but not uncomfortable	0	0%
	1978	1978		Min 13.2	40%	Safe driving at all speeds	742	60%	Uncomfortable but not dangerous	0	0%
Section 1	11.6	Break: 6.9		Ave 14.5		Unsafe driving at high speed	500	40%	Dangerous	0	0%
1,242		Toe: 4.2				Unsafe driving at any speed	500	40%	Very dangerous	500	40%
LF			50-yr 8.0	Max 14.9	500	No overtopping	742	60%	Wet but not uncomfortable	0	0%
	Current	Current		Min 12.1	40%	Safe driving at all speeds	742	60%	Uncomfortable but not dangerous	0	0%
	Max 15.7	Max 9.6		Ave 13.6		Unsafe driving at high speed	500	40%	Dangerous	0	0%
	Min 12.2	Min 2.8				Unsafe driving at any speed	500	40%	Very dangerous	500	40%
	Ave 14.5	Ave 6.2	10-yr 7.5	Max 13.7	0	No overtopping	1,242	100%	Wet but not uncomfortable	0	0%
				Min 10.9	0%	Safe driving at all speeds	1242	100%	Uncomfortable but not dangerous	0	0%
				Ave 12.2		Unsafe driving at high speed	0	0%	Dangerous	0	0%
						Unsafe driving at any speed	0	0%	Very dangerous	0	0%

Section 1 – + 2 Feet Sea Level Rise

	Crest EL ft, NAVD88	Toe EL ft, NAVD88	SWL EL ft, NAVD88	Wave Runup EL ft, NAVD88	LF of Section with Wave Runup above	Wave Overtopping Impact					
						Traffic Condition	LF	% LF_{total}	Pedestrians Condition	LF	% LF_{total}
			100-yr 10.4	Max 20.8	1242	No overtopping	0	0%	Wet but not uncomfortable	0	0%
SLR = 2'	1978	1978		Min 17.4	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
Section 1	11.6	Break: 6.9		Ave 19.0		Unsafe driving at high speed	0	0%	Dangerous	0	0%
1,242		Toe: 4.2				Unsafe driving at any speed	1242	100%	Very dangerous	1242	100%
LF			50-yr 10.0	Max 19.9	1242	No overtopping	0	0%	Wet but not uncomfortable	0	0%
	Current	Current		Min 16.2	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
	Max 15.7	Max 9.6		Ave 18.0		Unsafe driving at high speed	0	0%	Dangerous	0	0%
	Min 12.2	Min 2.8				Unsafe driving at any speed	1242	100%	Very dangerous	1,242	100%
	Ave 14.5	Ave 6.2	10-yr 9.5	Max 18.0	1,132	No overtopping	110	9%	Wet but not uncomfortable	0	0%
				Min 14.8	91%	Safe driving at all speeds	110	9%	Uncomfortable but not dangerous	0	0%
				Ave 16.5		Unsafe driving at high speed	0	0%	Dangerous	0	0%
						Unsafe driving at any speed	0	0%	Very dangerous	0	0%

LF = linear feet along NH Route 1A stationing per NHDOT survey December 2019

EL = elevation

Toe EL = elevation of ocean side toe of revetment slope

SWL = Stillwater level

SLR = Sea level rise

Section 2 – Current Water Levels

	Crest EL ft, NAVD88	Toe EL ft, NAVD88	SWL EL ft, NAVD88	Wave Runup EL ft, NAVD88	LF of Section with Wave Runup above	Roadway Use - Wave Overtopping Impact: Traffic Condition	LF	% LF_{total}	Pedestrians Condition	LF	% LF_{total}
			100-yr 8.4	Max 16.8	483	No overtopping	126	21%	Wet but not uncomfortable	0	0%
	1978	1978		Min 14.6	79%	Safe driving at all speeds	126	21%	Uncomfortable but not dangerous	0	0%
Section 2	11.6	Break: 6.9		Ave 15.6		Unsafe driving at high speed	0	0%	Dangerous	0	0%
609		Toe: 4.2				Unsafe driving at any speed	483	79%	Very dangerous	483	79%
LF			50-yr 8.0	Max 15.9	333	No overtopping	276	45%	Wet but not uncomfortable	0	0%
	Current	Current		Min 13.8	55%	Safe driving at all speeds	276	45%	Uncomfortable but not dangerous	0	0%
	Max 15.0	Max 10.0		Ave 14.6		Unsafe driving at high speed	0	0%	Dangerous	333	55%
	Min 14.8	Min 4.0				Unsafe driving at any speed	333	55%	Very dangerous	0	0%
	Ave 14.9	Ave 7.2	10-yr 7.5	Max 13.4	0	No overtopping	609	100%	Wet but not uncomfortable	0	0%
				Min 12.6	0%	Safe driving at all speeds	609	100%	Uncomfortable but not dangerous	0	0%
				Ave 13.0		Unsafe driving at high speed	0	0%	Dangerous	0	0%
						Unsafe driving at any speed	0	0%	Very dangerous	0	0%

Section 2 – + 2 Feet Sea Level Rise

	Crest EL ft, NAVD88	Toe EL ft, NAVD88	SWL EL ft, NAVD88	Wave Runup EL ft, NAVD88	LF of Section with Wave Runup above	Wave Overtopping Impact: Traffic Condition	LF	% LF_{total}	Pedestrians Condition	LF	% LF_{total}
			100-yr 10.4	Max 21.8	609	No overtopping	0	0%	Wet but not uncomfortable	0	0%
SLR = 2'	1978	1978		Min 19.1	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
Section 2	11.6	Break: 6.9		Ave 20.6		Unsafe driving at high speed	0	0%	Dangerous	0	0%
609		Toe: 4.2				Unsafe driving at any speed	609	100%	Very dangerous	609	100%
LF			50-yr 10.0	Max 20.8	609	No overtopping	0	0%	Wet but not uncomfortable	0	0%
	Current	Current		Min 18.3	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
	Max 15.0	Max 10.0		Ave 19.4		Unsafe driving at high speed	0	0%	Dangerous	0	0%
	Min 14.8	Min 4.0				Unsafe driving at any speed	609	100%	Very dangerous	609	100%
	Ave 14.9	Ave 7.2	10-yr 9.5	Max 19.3	609	No overtopping	0	0%	Wet but not uncomfortable	0	0%
				Min 17.0	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
				Ave 18.0		Unsafe driving at high speed	0	0%	Dangerous	0	0%
						Unsafe driving at any speed	609	100%	Very dangerous	609	100%

LF = linear feet along NH Route 1A stationing per NHDOT survey December 2019

EL = elevation

Toe EL = elevation of ocean side toe of revetment slope

SWL = Stillwater level

SLR = Sea level rise

Section 3 – Current Water Levels

	Crest EL	Toe EL	SWL EL	Wave Runup EL	LF of Section with Wave Runup above	Roadway Use - Wave Overtopping Impact					
	ft, NAVD88	ft, NAVD88	ft, NAVD88	ft, NAVD88		Traffic Condition	LF	% LF_{total}	Pedestrians Condition	LF	% LF_{total}
			100-yr 8.4	Max 23.3	1156	No overtopping	594	34%	Wet but not uncomfortable	0	0%
	1978	1978		Min 10.4	66%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
Section 3	16	Break: -		Ave 18.2		Unsafe driving at high speed	0	0%	Dangerous	0	0%
1,750		Toe: 3.9				Unsafe driving at any speed	1156	66%	Very dangerous	1156	66%
LF			50-yr 8.0	Max 22.4	1156	No overtopping	594	34%	Wet but not uncomfortable	0	0%
	Current	Current		Min 8.7	66%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
	Max 18.5	Max 9.4		Ave 17.1		Unsafe driving at high speed	0	0%	Dangerous	0	0%
	Min 13.3	Min 4.7				Unsafe driving at any speed	1156	66%	Very dangerous	1,156	66%
	Ave 15.4	Ave 7.6	10-yr 7.5	Max 19.8	1156	No overtopping	594	34%	Wet but not uncomfortable	0	0%
				Min 7.5	66%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
				Ave 15.6		Unsafe driving at high speed	0	0%	Dangerous	0	0%
						Unsafe driving at any speed	1156	66%	Very dangerous	1156	66%

Section 3 – + 2 Feet Sea Level Rise

	Crest EL	Toe EL	SWL EL	Wave Runup EL	LF of Section with Wave Runup above	Wave Overtopping Impact					
	ft, NAVD88	ft, NAVD88	ft, NAVD88	ft, NAVD88		Traffic Condition	LF	% LF_{total}	Pedestrians Condition	LF	% LF_{total}
			100-yr 10.4	Max 28.6	1750	No overtopping	0	0%	Wet but not uncomfortable	0	0%
SLR = 2'	1978	1978		Min 21.2	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
Section 3	16	Break: -		Ave 25.6		Unsafe driving at high speed	0	0%	Dangerous	0	0%
1,750		Toe: 3.9				Unsafe driving at any speed	1750	100%	Very dangerous	1750	100%
LF			50-yr 10.0	Max 27.6	1750	No overtopping	0	0%	Wet but not uncomfortable	0	0%
	Current	Current		Min 20.2	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
	Max 18.5	Max 9.4		Ave 24.6		Unsafe driving at high speed	0	0%	Dangerous	0	0%
	Min 13.3	Min 4.7				Unsafe driving at any speed	1750	100%	Very dangerous	1,750	100%
	Ave 15.4	Ave 7.6	10-yr 9.5	Max 25.4	1,606	No overtopping	144	8%	Wet but not uncomfortable	0	0%
				Min 14.9	92%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
				Ave 21.0		Unsafe driving at high speed	0	0%	Dangerous	0	0%
						Unsafe driving at any speed	1606	92%	Very dangerous	1,606	92%

LF = linear feet along NH Route 1A stationing per NHDOT survey December 2019
EL = elevation
Toe EL = elevation of ocean side toe of revetment slope
SWL = Stillwater level
SLR = Sea level rise

Section 4 – Current Water Levels

	Crest EL ft, NAVD88	Toe EL ft, NAVD88	SWL EL ft, NAVD88	Wave Runup EL ft, NAVD88	LF of Section with Wave Runup above	Roadway Use - Wave Overtopping Impact					
						Traffic Condition	LF	$\% LF_{total}$	Pedestrians Condition	LF	$\% LF_{total}$
			100-yr 8.4	Max 21.7	117	No overtopping	594	70%	Wet but not uncomfortable	0	0%
	1978	1978		Min 13.8	14%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
Section 4	11.8	Break: 6.3		Ave 16.9		Unsafe driving at high speed	0	0%	Dangerous	0	0%
846		Toe: 3.9				Unsafe driving at any speed	117	14%	Very dangerous	117	14%
LF			50-yr 8.0	Max 19.2	117	No overtopping	594	70%	Wet but not uncomfortable	0	0%
	Current	Current		Min 13.0	14%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
	Max 16.0	Max 10.0		Ave 15.5		Unsafe driving at high speed	0	0%	Dangerous	117	14%
	Min 14.6	Min 7.5				Unsafe driving at any speed	117	14%	Very dangerous	0	0%
	Ave 15.2	Ave 9.2	10-yr 7.5	Max 17.4	117	No overtopping	729	86%	Wet but not uncomfortable	0	0%
				Min 11.8	14%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
				Ave 14.0		Unsafe driving at high speed	0	0%	Dangerous	117	14%
						Unsafe driving at any speed	117	14%	Very dangerous	0	0%

Section 4 – + 2 Feet Sea Level Rise

	Crest EL ft, NAVD88	Toe EL ft, NAVD88	SWL EL ft, NAVD88	Wave Runup EL ft, NAVD88	LF of Section with Wave Runup above	Wave Overtopping Impact					
						Traffic Condition	LF	$\% LF_{total}$	Pedestrians Condition	LF	$\% LF_{total}$
			100-yr 10.4	Max 30.2	846	No overtopping	0	0%	Wet but not uncomfortable	0	0%
SLR = 2'	1978	1978		Min 18.7	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
Section 4	11.8	Break: 6.3		Ave 23.0		Unsafe driving at high speed	0	0%	Dangerous	0	0%
846		Toe: 3.9				Unsafe driving at any speed	846	100%	Very dangerous	846	100%
LF			50-yr 10.0	Max 28.8	846	No overtopping	0	0%	Wet but not uncomfortable	0	0%
	Current	Current		Min 17.4	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
	Max 16.0	Max 10.0		Ave 21.8		Unsafe driving at high speed	0	0%	Dangerous	0	0%
	Min 14.6	Min 7.5				Unsafe driving at any speed	846	100%	Very dangerous	846	100%
	Ave 15.2	Ave 9.2	10-yr 9.5	Max 26.6	846	No overtopping	0	0%	Wet but not uncomfortable	0	0%
				Min 16.1	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
				Ave 20.2		Unsafe driving at high speed	0	0%	Dangerous	0	0%
						Unsafe driving at any speed	846	100%	Very dangerous	846	100%

LF = linear feet along NH Route 1A stationing per NHDOT survey December 2019
EL = elevation
Toe EL = elevation of ocean side toe of revetment slope
SWL = Stillwater level
SLR = Sea level rise

Section 5 – Current Water Levels

	Crest EL ft, NAVD88	Toe EL ft, NAVD88	SWL EL ft, NAVD88	Wave Runup EL ft, NAVD88	LF of Section with Wave Runup above	Roadway Use - Wave Overtopping Impact					
						Traffic Condition	LF	% LF_{total}	Pedestrians Condition	LF	% LF_{total}
			100-yr 8.4	Max 20.5	1,533	No overtopping	280	15%	Wet but not uncomfortable	0	0%
	1978	1978		Min 15.7	85%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
Section 5	11.8	Break: 6.3		Ave 18.8		Unsafe driving at high speed	0	0%	Dangerous	283	16%
1,813		Toe: 3.9				Unsafe driving at any speed	1533	85%	Very dangerous	1250	69%
LF			50-yr 8.0	Max 19.6	1,533	No overtopping	280	15%	Wet but not uncomfortable	0	0%
	Current	Current		Min 14.8	85%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
	Max 16.4	Max 10.0		Ave 17.7		Unsafe driving at high speed	0	0%	Dangerous	913	50%
	Min 15.0	Min 4.4				Unsafe driving at any speed	1533	85%	Very dangerous	620	34%
	Ave 15.9	Ave 7.1	10-yr 7.5	Max 17.7	1233	No overtopping	580	32%	Wet but not uncomfortable	0	0%
				Min 13.6	68%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	283	16%
				Ave 16.1		Unsafe driving at high speed	283	16%	Dangerous	950	52%
						Unsafe driving at any speed	950	52%	Very dangerous	0	0%

Section 5 – + 2 Feet Sea Level Rise

	Crest EL ft, NAVD88	Toe EL ft, NAVD88	SWL EL ft, NAVD88	Wave Runup EL ft, NAVD88	LF of Section with Wave Runup above	Wave Overtopping Impact					
						Traffic Condition	LF	% LF_{total}	Pedestrians Condition	LF	% LF_{total}
			100-yr 10.4	Max 27.2	1813	No overtopping	0	0%	Wet but not uncomfortable	0	0%
SLR = 2'	1978	1978		Min 21.9	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
Section 5	11.8	Break: 6.3		Ave 24.7		Unsafe driving at high speed	0	0%	Dangerous	0	0%
1,813		Toe: 3.9				Unsafe driving at any speed	1813	100%	Very dangerous	1813	100%
LF			50-yr 10.0	Max 26.1	1813	No overtopping	0	0%	Wet but not uncomfortable	0	0%
	Current	Current		Min 21.0	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
	Max 16.4	Max 10.0		Ave 23.7		Unsafe driving at high speed	0	0%	Dangerous	0	0%
	Min 15.0	Min 4.4				Unsafe driving at any speed	1813	100%	Very dangerous	1,813	100%
	Ave 15.9	Ave 7.1	10-yr 9.5	Max 23.6	1813	No overtopping	0	0%	Wet but not uncomfortable	0	0%
				Min 18.4	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
				Ave 21.7		Unsafe driving at high speed	0	0%	Dangerous	0	0%
						Unsafe driving at any speed	1813	100%	Very dangerous	1,813	100%

LF = linear feet along NH Route 1A stationing per NHDOT survey December 2019
EL = elevation
Toe EL = elevation of ocean side toe of revetment slope

SWL = Stillwater level
SLR = Sea level rise

Section 6 – Current Water Levels

	Crest EL ft, NAVD88	Toe EL ft, NAVD88	SWL EL ft, NAVD88	Wave Runup EL ft, NAVD88	LF of Section with Wave Runup above	Roadway Use - Wave Overtopping Impact					
						Traffic Condition	LF	% LF_{total}	Pedestrians Condition	LF	% LF_{total}
			100-yr 8.4	Max 22.6	2,271	No overtopping	1,535	40%	Wet but not uncomfortable	0	0%
	1978	1978		Min 14.4	60%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
Section 6	17.3	Break: -		Ave 17.4		Unsafe driving at high speed	0	0%	Dangerous	1835	48%
3,806		Toe: 4.8				Unsafe driving at any speed	2271	60%	Very dangerous	436	11%
LF			50-yr 8.0	Max 21.0	731	No overtopping	3075	81%	Wet but not uncomfortable	0	0%
	Current	Current		Min 12.2	19%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
	Max 17.6	Max 11.5		Ave 16.2		Unsafe driving at high speed	0	0%	Dangerous	731	19%
	Min 14.5	Min 4.0				Unsafe driving at any speed	731	19%	Very dangerous	0	0%
	Ave 16.2	Ave 6.9	10-yr 7.5	Max 19.5	436	No overtopping	3370	89%	Wet but not uncomfortable	0	0%
				Min 10.9	11%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
				Ave 14.9		Unsafe driving at high speed	0	0%	Dangerous	436	11%
						Unsafe driving at any speed	436	11%	Very dangerous	0	0%

Section 6 – + 2 Feet Sea Level Rise

	Crest EL ft, NAVD88	Toe EL ft, NAVD88	SWL EL ft, NAVD88	Wave Runup EL ft, NAVD88	LF of Section with Wave Runup above	Wave Overtopping Impact					
						Traffic Condition	LF	% LF_{total}	Pedestrians Condition	LF	% LF_{total}
			100-yr 10.4	Max 28.8	3806	No overtopping	0	0%	Wet but not uncomfortable	0	0%
SLR = 2'	1978	1978		Min 19.5	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
Section 6	17.3	Break: -		Ave 23.0		Unsafe driving at high speed	0	0%	Dangerous	0	0%
3,806		Toe: 4.8				Unsafe driving at any speed	3806	100%	Very dangerous	3806	100%
LF			50-yr 10.0	Max 27.6	3806	No overtopping	0	0%	Wet but not uncomfortable	0	0%
	Current	Current		Min 18.5	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
	Max 17.6	Max 11.5		Ave 22.0		Unsafe driving at high speed	0	0%	Dangerous	0	0%
	Min 14.5	Min 4.0				Unsafe driving at any speed	3806	100%	Very dangerous	3,806	100%
	Ave 16.2	Ave 6.9	10-yr 9.5	Max 25.8	3806	No overtopping	0	0%	Wet but not uncomfortable	0	0%
				Min 17.1	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
				Ave 20.2		Unsafe driving at high speed	0	0%	Dangerous	1285	34%
						Unsafe driving at any speed	3806	100%	Very dangerous	2,521	66%

LF = linear feet along NH Route 1A stationing per NHDOT survey December 2019
EL = elevation
Toe EL = elevation of ocean side toe of revetment slope

SWL = Stillwater level
SLR = Sea level rise

Section 7 – Current Water Levels

	Crest EL ft, NAVD88	Toe EL ft, NAVD88	SWL EL ft, NAVD88	Wave Runup EL ft, NAVD88	LF of Section with Wave Runup above	Roadway Use - Wave Overtopping Impact					
						Traffic Condition	LF	% LF_{total}	Pedestrians Condition	LF	% LF_{total}
			100-yr 8.4	Max 17.4	781	No overtopping	178	19%	Wet but not uncomfortable	0	0%
	1978	1978		Min 16.8	81%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
Section 7	15	Break: -		Ave 17.1		Unsafe driving at high speed	0	0%	Dangerous	781	81%
959		Toe: 1.5				Unsafe driving at any speed	781	81%	Very dangerous	0	0%
LF			50-yr 8.0	Max 16.3	0	No overtopping	959	100%	Wet but not uncomfortable	0	0%
	Current	Current		Min 16.0	0%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
	Max 17.7	Max 6.0		Ave 16.2		Unsafe driving at high speed	0	0%	Dangerous	0	0%
	Min 17.0	Min 17.0				Unsafe driving at any speed	0	0%	Very dangerous	0	0%
	Ave 17.2	Ave 5.4	10-yr 7.5	Max 15.2	0	No overtopping	959	100%	Wet but not uncomfortable	0	0%
				Min 14.7	0%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
				Ave 15.0		Unsafe driving at high speed	0	0%	Dangerous	0	0%
						Unsafe driving at any speed	0	0%	Very dangerous	0	0%

Section 7 – + 2 Feet Sea Level Rise

	Crest EL ft, NAVD88	Toe EL ft, NAVD88	SWL EL ft, NAVD88	Wave Runup EL ft, NAVD88	LF of Section with Wave Runup above	Wave Overtopping Impact					
						Traffic Condition	LF	% LF_{total}	Pedestrians Condition	LF	% LF_{total}
			100-yr 10.4	Max 22.0	959	No overtopping	0	0%	Wet but not uncomfortable	0	0%
SLR = 2'	1978	1978		Min 21.6	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
Section 7	15	Break: -		Ave 21.9		Unsafe driving at high speed	0	0%	Dangerous	0	0%
959		Toe: 1.5				Unsafe driving at any speed	959	100%	Very dangerous	959	100%
LF			50-yr 10.0	Max 21.1	959	No overtopping	0	0%	Wet but not uncomfortable	0	0%
	Current	Current		Min 20.8	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
	Max 17.7	Max 6.0		Ave 21.0		Unsafe driving at high speed	0	0%	Dangerous	0	0%
	Min 17.0	Min 17.0				Unsafe driving at any speed	959	100%	Very dangerous	959	100%
	Ave 17.2	Ave 5.4	10-yr 9.5	Max 19.8	959	No overtopping	0	0%	Wet but not uncomfortable	0	0%
				Min 19.3	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
				Ave 19.5		Unsafe driving at high speed	0	0%	Dangerous	0	0%
						Unsafe driving at any speed	959	100%	Very dangerous	959	100%

LF = linear feet along NH Route 1A stationing per NHDOT survey December 2019

EL = elevation

Toe EL = elevation of ocean side toe of revetment slope

SWL = Stillwater level

SLR = Sea level rise

Section 10 – Current Water Levels

	Crest EL ft, NAVD88	Toe EL ft, NAVD88	SWL EL ft, NAVD88	Wave Runup EL ft, NAVD88	LF of Section with Wave Runup above	Roadway Use - Wave Overtopping Impact					
						Traffic Condition	LF	% LF_{total}	Pedestrians Condition	LF	% LF_{total}
			100-yr 8.4	Max 22.5	249	No overtopping	981	80%	Wet but not uncomfortable	0	0%
	1978	1978		Min 17.8	20%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
Section 10	19 (roadside)	Break: -		Ave 19.8		Unsafe driving at high speed	0	0%	Dangerous	249	20%
1,230	21.5 (oceanside)	Toe: 11.1				Unsafe driving at any speed	249	20%	Very dangerous	0	0%
LF			50-yr 8.0	Max 21.5	249	No overtopping	981	80%	Wet but not uncomfortable	0	0%
	Current	Current		Min 16.9	20%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
	Max 20.6	Max 12.5		Ave 18.8		Unsafe driving at high speed	0	0%	Dangerous	249	20%
	Min 19.0	Min 6.0				Unsafe driving at any speed	249	20%	Very dangerous	0	0%
	Ave 20.0	Ave 7.6	10-yr 7.5	Max 19.4	249	No overtopping	981	80%	Wet but not uncomfortable	0	0%
				Min 15.7	20%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	249	20%
				Ave 17.2		Unsafe driving at high speed	249	20%	Dangerous	0	0%
						Unsafe driving at any speed	0	0%	Very dangerous	0	0%

Section 10 – + 2 Feet Sea Level Rise

	Crest EL ft, NAVD88	Toe EL ft, NAVD88	SWL EL ft, NAVD88	Wave Runup EL ft, NAVD88	LF of Section with Wave Runup above	Wave Overtopping Impact					
						Traffic Condition	LF	% LF_{total}	Pedestrians Condition	LF	% LF_{total}
			100-yr 10.4	Max 29.1	1230	No overtopping	0	0%	Wet but not uncomfortable	0	0%
SLR = 2'	1978	1978		Min 22.7	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
Section 10	19 (roadside)	Break: -		Ave 25.3		Unsafe driving at high speed	0	0%	Dangerous	0	0%
1,230	21.5 (oceanside)	Toe: 11.1				Unsafe driving at any speed	1230	100%	Very dangerous	1230	100%
LF			50-yr 10.0	Max 28.0	1230	No overtopping	0	0%	Wet but not uncomfortable	0	0%
	Current	Current		Min 21.7	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
	Max 20.6	Max 12.5		Ave 24.3		Unsafe driving at high speed	0	0%	Dangerous	650	53%
	Min 19.0	Min 6.0				Unsafe driving at any speed	1230	100%	Very dangerous	580	47%
	Ave 20.0	Ave 7.6	10-yr 9.5	Max 25.4	980	No overtopping	250	20%	Wet but not uncomfortable	0	0%
				Min 20.3	80%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
				Ave 22.5		Unsafe driving at high speed	0	0%	Dangerous	731	59%
						Unsafe driving at any speed	980	80%	Very dangerous	249	20%

LF = linear feet along NH Route 1A stationing per NHDOT survey December 2019
EL = elevation
Toe EL = elevation of ocean side toe of revetment slope

SWL = Stillwater level
SLR = Sea level rise

Section 13 – Current Water Levels

	Crest EL ft, NAVD88	Toe EL ft, NAVD88	SWL EL ft, NAVD88	Wave Runup EL ft, NAVD88	LF of Section with Wave Runup above	Roadway Use - Wave Overtopping Impact					
						Traffic Condition	LF	% LF_{total}	Pedestrians Condition	LF	% LF_{total}
			100-yr 8.4	Max 18.8	110	No overtopping	910	89%	Wet but not uncomfortable	0	0%
	1978	1978		Min 16.9	11%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
Section 13	16.9	Break: -		Ave 17.8		Unsafe driving at high speed	0	0%	Dangerous	0	0%
1,020		Toe: 8.3				Unsafe driving at any speed	110	11%	Very dangerous	110	11%
LF			50-yr 8.0	Max 17.3	110	No overtopping	910	89%	Wet but not uncomfortable	0	0%
	Current	Current		Min 16.1	11%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
	Max 21.7	Max 12.5		Ave 16.8		Unsafe driving at high speed	0	0%	Dangerous	0	0%
	Min 13.7	Min 6.4				Unsafe driving at any speed	110	11%	Very dangerous	110	11%
	Ave 18.3	Ave 9.8	10-yr 7.5	Max 16.0	110	No overtopping	910	89%	Wet but not uncomfortable	0	0%
				Min 14.9	11%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
				Ave 15.5		Unsafe driving at high speed		0%	Dangerous	0	0%
						Unsafe driving at any speed	110	11%	Very dangerous	110	11%

Section 13 – + 2 Feet Sea Level Rise

	Crest EL ft, NAVD88	Toe EL ft, NAVD88	SWL EL ft, NAVD88	Wave Runup EL ft, NAVD88	LF of Section with Wave Runup above	Wave Overtopping Impact					
						Traffic Condition	LF	% LF_{total}	Pedestrians Condition	LF	% LF_{total}
			100-yr 10.4	Max 23.7	1020	No overtopping	0	0%	Wet but not uncomfortable	0	0%
SLR = 2'	1978	1978		Min 21.7	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
Section 13	16.9	Break: -		Ave 22.6		Unsafe driving at high speed	0	0%	Dangerous	0	0%
1,020		Toe: 8.3				Unsafe driving at any speed	1020	100%	Very dangerous	1020	100%
LF			50-yr 10.0	Max 22.7	1020	No overtopping	0	0%	Wet but not uncomfortable	0	0%
	Current	Current		Min 20.7	100%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
	Max 21.7	Max 12.5		Ave 21.6		Unsafe driving at high speed	0	0%	Dangerous	200	20%
	Min 13.7	Min 6.4				Unsafe driving at any speed	1020	100%	Very dangerous	820	80%
	Ave 18.3	Ave 9.8	10-yr 9.5	Max 21.2	655	No overtopping	365	36%	Wet but not uncomfortable	0	0%
				Min 19.4	64%	Safe driving at all speeds	0	0%	Uncomfortable but not dangerous	0	0%
				Ave 20.2		Unsafe driving at high speed	0	0%	Dangerous	0	0%
						Unsafe driving at any speed	655	64%	Very dangerous	655	64%

LF = linear feet along NH Route 1A stationing per NHDOT survey December 2019
EL = elevation
Toe EL = elevation of ocean side toe of revetment slope
SWL = Stillwater level
SLR = Sea level rise

Attachment D
Summary Tables: Existing and 1978 Revetments
Compiled Impacts for Current Water Levels and Projected Relative Sea Level Rise

Table Legend

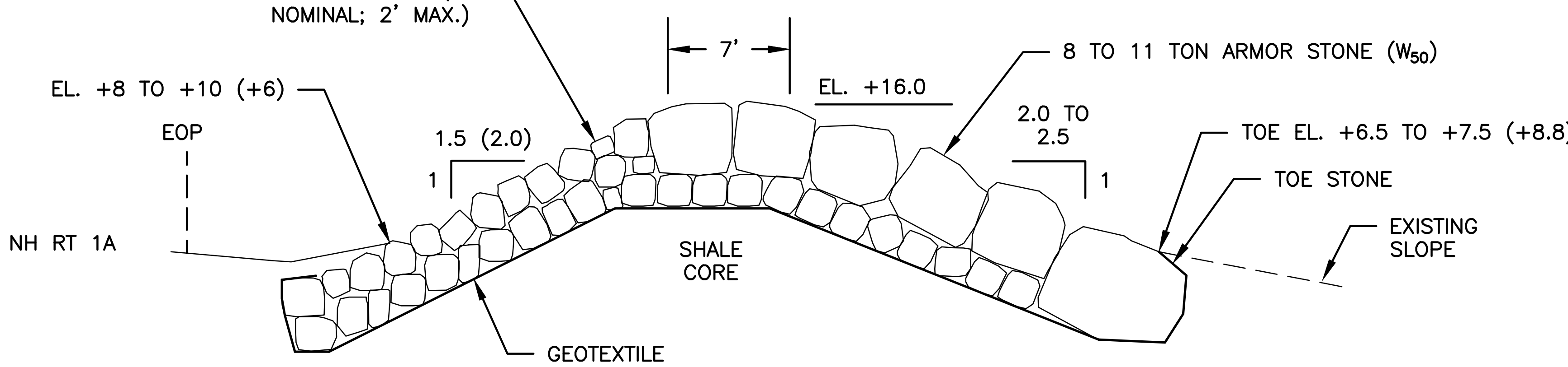
Backwater Flood	Roadway flooding from estuary
NHDOT Rt 1A Flood	Roadway flooding from revetment overtopping, breaks in revetment, etc.
Overtopping	Waves overtopping the revetment crest
% Length Unsafe Driving – High Speeds	Percentage of the linear feet of revetment with unsafe driving at high speeds due to wave overtopping flow rate (see criteria per Attachment C)
% Length Unsafe Driving – Any Speed	Percentage of the linear feet of revetment with unsafe driving at any speed due to wave overtopping flow rate (see criteria per Attachment C)
% Length w/Oceanside D50 Armor Stone Damage	Percentage of the linear feet of revetment with wave damage to the armor stone on the oceanside of the revetment slope
% Length w/Shale Overtopping Damage	Percentage of linear feet of revetment with damage to the exposed shale stone on the crest and/or roadway side of the revetment slope due to wave overtopping flow rate. Flow rate criteria based on recommended limits for wave overtopping flowrates for structural safety in the design of breakwaters, seawalls and grass sea-dikes per the EurOtop Manual (2018) and on the flowrates for structural safety of embankment seawalls and grass sea-dikes per Engineer Manual 1110-2-1100

10-Year Flood Recurrence Interval Evaluation Summary Table	**Revetment Section along NH RT 1A**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**10**	**13**
Linear Feet of Revetment along NH Route 1A	1242	609	1750	846	1813	3806	959	1230	1020
10-yr Flood Recurrence - Existing Geometry									
Back Water Flood	✓	✓	-	✓	-	✓	-	-	-
NH Rt 1A Flood	✓	✓	-	-	-	-	-	-	-
Overtopping	-	-	✓	✓	✓	✓		✓	✓
% Length Unsafe Driving - High Speed	-	-	-	-	16%	-	-	20%	-
% Length Unsafe Driving - Any Speed	-	-	66%	14%	68%	11%	-	-	11%
% Length w/Oceanside D50 Armor Stone Damage	8%	-	75%	-	82%	40%	24%	20%	100%
% Length w/Shale Overtopping Damage	-	-	66%	-	-	-	-	-	11%
10-yr + 2ft SLR Flood Recurrence - Existing Geometry									
Back Water Flood	✓	✓	✓	✓	✓	✓	-	-	-
NH Rt 1A Flood	✓	✓	-	✓	-	✓	-	-	-
Overtopping	✓	✓	✓	✓	✓	✓	✓	✓	✓
% Length Unsafe Driving - High Speed	-	-	-	-	-	-	-	-	-
% Length Unsafe Driving - Any Speed	91%	100%	92%	100%	100%	100%	100%	80%	64%
% Length w/Oceanside D50 Armor Stone Damage	37%	100%	91%	41%	100%	71%	43%	80%	100%
% Length w/Shale Overtopping Damage	91%	100%	91%	100%	100%	66%	100%	20%	64%
10-yr Flood Recurrence - 1978 Geometry									
Back Water Flood	✓	✓	-	✓	-	✓	-	-	-
NH Rt 1A Flood	✓	✓	-	-	-	-	-	-	-
Overtopping	✓	✓	✓	✓	✓	-	✓	-	-
% Length Unsafe Driving - High Speed	-	-	-	-	-	-	-	-	-
% Length Unsafe Driving - Any Speed	100%	100%	75%	100%	100%	-	100%	-	-
% Length w/Oceanside D50 Armor Stone Damage	62%	100%	75%	73%	100%	52%	100%	-	100%
% Length w/Shale Overtopping Damage	42%	100%	26%	73%	100%	-	-	-	-
10-yr + 2ft SLR Flood Recurrence - 1978 Geometry									
Back Water Flood	✓	✓	✓	✓	✓	✓	-	-	-
NH Rt 1A Flood	✓	✓	-	✓	-	✓	-	-	-
Overtopping	✓	✓	✓	✓	✓	✓	✓	-	✓
% Length Unsafe Driving - High Speed	-	-	-	-	-	-	-	-	-
% Length Unsafe Driving - Any Speed	100%	100%	92%	100%	100%	100%	100%	-	100%
% Length w/Oceanside D50 Armor Stone Damage	100%	100%	92%	100%	100%	100%	100%	100%	100%
% Length w/Shale Overtopping Damage	100%	100%	92%	100%	100%	52%	100%	-	100%

50-Year Flood Recurrence Interval Evaluation Summary Table	Revetment Section along NH RT 1A								
	1	2	3	4	5	6	7	10	13
Linear Feet of Revetment along NH Route 1A	1242	609	1750	846	1813	3806	959	1230	1020
50-yr Flood Recurrence - Existing Geometry									
Back Water Flood	✓	✓	-	✓	-	✓	-	-	-
NH Rt 1A Flood	✓	✓	-	-	-	✓	-	-	-
Overtopping	✓	✓	✓	✓	✓	✓	-	✓	✓
% Length Unsafe Driving - High Speed	-	-	-	-	-	-	-	-	-
% Length Unsafe Driving - Any Speed	40%	55%	66%	14%	85%	19%	-	20%	11%
% Length w/Oceanside D50 Armor Stone Damage	8%	100%	75%	-	82%	40%	43%	80%	100%
% Length w/Shale Overtopping Damage	40%	-	66%	-	34%	-	-	-	11%
50-yr + 2ft SLR Flood Recurrence - Existing Geometry									
Back Water Flood	✓	✓	✓	✓	✓	✓	-	-	-
NH Rt 1A Flood	✓	✓	✓	✓	-	✓	-	-	-
Overtopping	✓	✓	✓	✓	✓	✓	✓	✓	✓
% Length Unsafe Driving - High Speed	-	-	-	-	-	-	-	-	-
% Length Unsafe Driving - Any Speed	100%	100%	100%	100%	100%	100%	100%	100%	100%
% Length w/Oceanside D50 Armor Stone Damage	58%	100%	100%	41%	100%	83%	43%	100%	100%
% Length w/Shale Overtopping Damage	100%	100%	100%	100%	100%	100%	100%	47%	80%
50-yr Flood Recurrence - 1978 Geometry									
Back Water Flood	✓	✓	-	✓	-	✓	-	-	-
NH Rt 1A Flood	✓	✓	-	-	-	✓	-	-	-
Overtopping	✓	✓	✓	✓	✓	-	✓	-	✓
% Length Unsafe Driving - High Speed	-	-	-	-	-	-	-	-	-
% Length Unsafe Driving - Any Speed	100%	100%	92%	100%	100%	-	100%	-	100%
% Length w/Oceanside D50 Armor Stone Damage	73%	100%	92%	100%	100%	52%	100%	-	100%
% Length w/Shale Overtopping Damage	100%	100%	66%	100%	100%	-	100%	-	11%
50-yr + 2ft SLR Flood Recurrence - 1978 Geometry									
Back Water Flood	✓	✓	✓	✓	✓	✓	-	-	-
NH Rt 1A Flood	✓	✓	✓	✓	-	✓	-	-	-
Overtopping	✓	✓	✓	✓	✓	✓	✓	✓	✓
% Length Unsafe Driving - High Speed	-	-	-	-	-	-	-	-	-
% Length Unsafe Driving - Any Speed	100%	100%	100%	100%	100%	100%	100%	80%	100%
% Length w/Oceanside D50 Armor Stone Damage	100%	100%	100%	100%	100%	100%	100%	100%	100%
% Length w/Shale Overtopping Damage	100%	100%	100%	100%	100%	100%	100%	-	100%

100-Year Flood Recurrence Interval Evaluation Summary Table	Revetment Section along NH RT 1A								
	1	2	3	4	5	6	7	10	13
Linear Feet of Revetment along NH Route 1A	1242	609	1750	846	1813	3806	959	1230	1020
100-yr Flood Recurrence - Existing Geometry									
Back Water Flood	✓	✓	-	✓	-	✓	-	-	-
NH Rt 1A Flood	✓	✓	-	✓	-	✓	-	-	-
Overtopping	✓	✓	✓	✓	✓	✓	✓	✓	✓
% Length Unsafe Driving - High Speed	-	-	-	-	-	-	-	-	-
% Length Unsafe Driving - Any Speed	40%	79%	66%	14%	85%	60%	81%	20%	11%
% Length w/Oceanside D50 Armor Stone Damage	26%	100%	75%	-	82%	71%	43%	80%	100%
% Length w/Shale Overtopping Damage	40%	79%	66%	14%	69%	11%	-	-	11%
100-yr + 2ft SLR Flood Recurrence - Existing Geometry									
Back Water Flood	✓	✓	✓	✓	✓	✓	-	-	-
NH Rt 1A Flood	✓	✓	✓	✓	✓	✓	-	-	-
Overtopping	✓	✓	✓	✓	✓	✓	✓	✓	✓
% Length Unsafe Driving - High Speed	-	-	-	-	-	-	-	-	-
% Length Unsafe Driving - Any Speed	100%	100%	100%	100%	100%	100%	100%	100%	100%
% Length w/Oceanside D50 Armor Stone Damage	71%	100%	100%	41%	100%	83%	100%	100%	100%
% Length w/Shale Overtopping Damage	100%	100%	100%	100%	100%	100%	100%	100%	100%
100-yr Flood Recurrence - 1978 Geometry									
Back Water Flood	✓	✓	-	✓	-	✓	-	-	-
NH Rt 1A Flood	✓	✓	-	✓	-	✓	-	-	-
Overtopping	✓	✓	✓	✓	✓	✓	✓	-	✓
% Length Unsafe Driving - High Speed	-	-	-	-	-	-	-	-	-
% Length Unsafe Driving - Any Speed	100%	100%	92%	100%	100%	52%	100%	-	100%
% Length w/Oceanside D50 Armor Stone Damage	100%	100%	92%	100%	100%	52%	100%	80%	100%
% Length w/Shale Overtopping Damage	100%	100%	75%	100%	100%	-	100%	-	27%
100-yr + 2ft SLR Flood Recurrence - 1978 Geometry									
Back Water Flood	✓	✓	✓	✓	✓	✓	-	-	-
NH Rt 1A Flood	✓	✓	✓	✓	✓	✓	-	-	-
Overtopping	✓	✓	✓	✓	✓	✓	✓	✓	✓
% Length Unsafe Driving - High Speed	-	-	-	-	-	-	-	-	-
% Length Unsafe Driving - Any Speed	100%	100%	100%	100%	100%	100%	100%	100%	100%
% Length w/Oceanside D50 Armor Stone Damage	100%	100%	100%	100%	100%	100%	100%	100%	100%
% Length w/Shale Overtopping Damage	100%	100%	100%	100%	100%	100%	100%	47%	100%

Attachment E
Conceptual Revetment Reconstruction Cross Sections with Crest and Backslope Armor Stone



REVETMENT SECTIONS 1 AND 2 ALONG ROADWAY

SCALE: 1"=10'

SECTION 1 SHOWN. REVETMENT SECTION 2 SHOWN ( ).

* SECTION ALONG PARKING PULL–OUT SIMILAR. EXTEND BACK SLOPE TO EXISTING FINISH GRADE OF PARKING AREA.

NO.	ISSUE/DESCRIPTION	BY	DATE

NHDOT NORTH HAMPTON-RYE 42312
CONCEPT REVETMENT SECTIONS

PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com

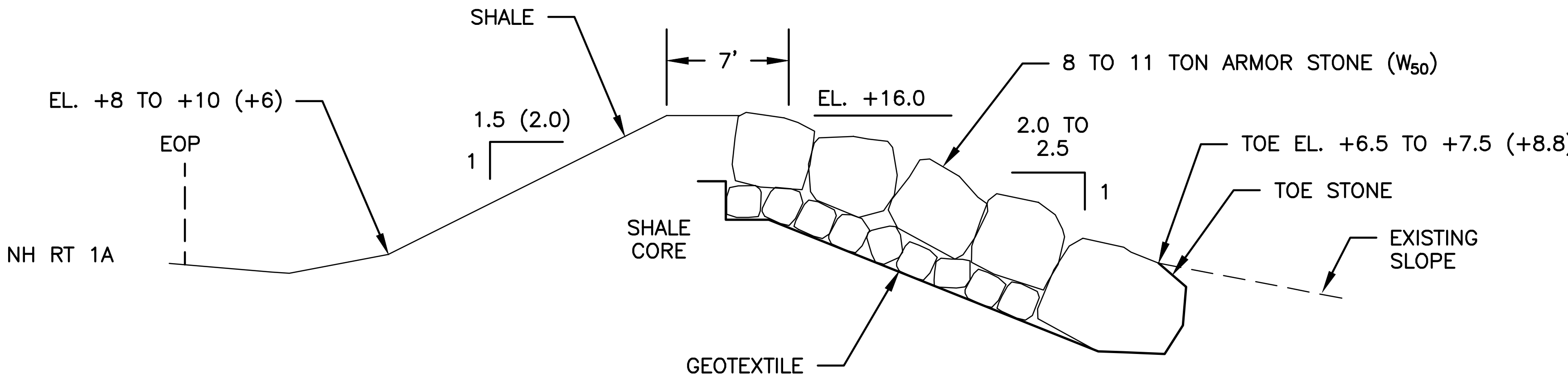
PREPARED FOR:
NHDOT

CONCEPT REVETMENT SECTIONS
SK-1

PROJ MGR: CWC	REVIEWED BY:	CHECKED BY: CWC
DESIGNED BY: CWC/RKT	DRAWN BY: RKT	SCALE: AS NOTED
DATE: APRIL, 2021	PROJECT NO. 04.0190838.04	REVISION NO.

SK 1
SHEET NO. 1 OF 6

Example Revetment Cross Section for Full Reconstruction with Exposed Shale on the Crest and Backslope Similar to 1978



ALTERNATE – REVETMENT SECTIONS 1 AND 2 ALONG ROADWAY

SCALE: 1"=10'

SECTION 1 SHOWN. REVETMENT SECTION 2 SHOWN ( ).

* SECTION ALONG PARKING PULL–OUT SIMILAR. EXTEND BACK SLOPE TO EXISTING FINISH GRADE OF PARKING AREA.

NO.	ISSUE/DESCRIPTION	BY	DATE

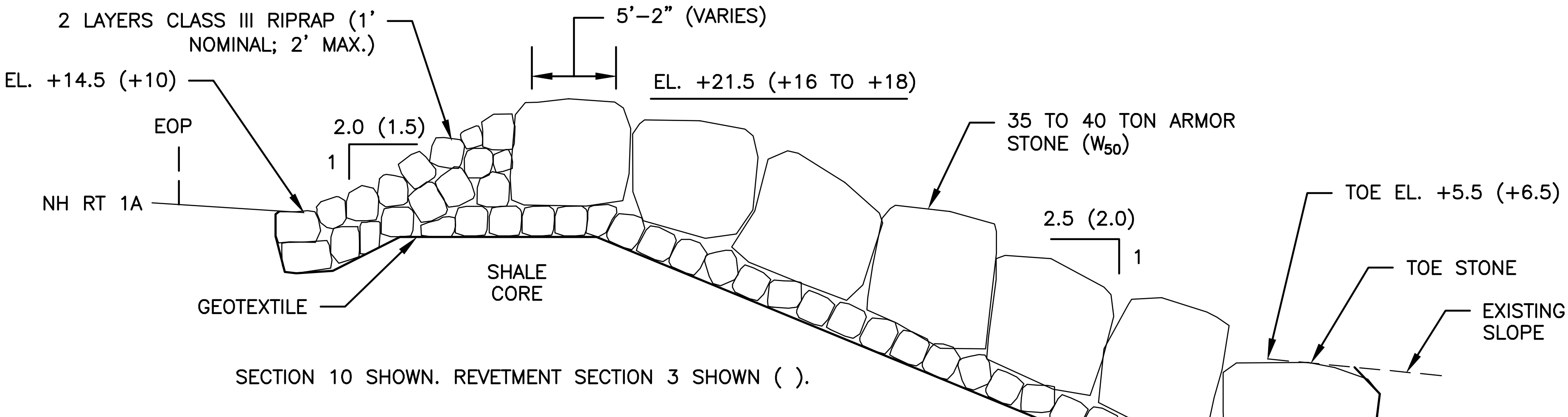
NHDOT NORTH HAMPTON-RYE 42312
CONCEPT REVETMENT SECTIONS

PREPARED BY: GZA GeoEnvironmental, Inc. Engineers and Scientists www.gza.com

PREPARED FOR: NHDOT

CONCEPT REVETMENT SECTIONS
SK-2

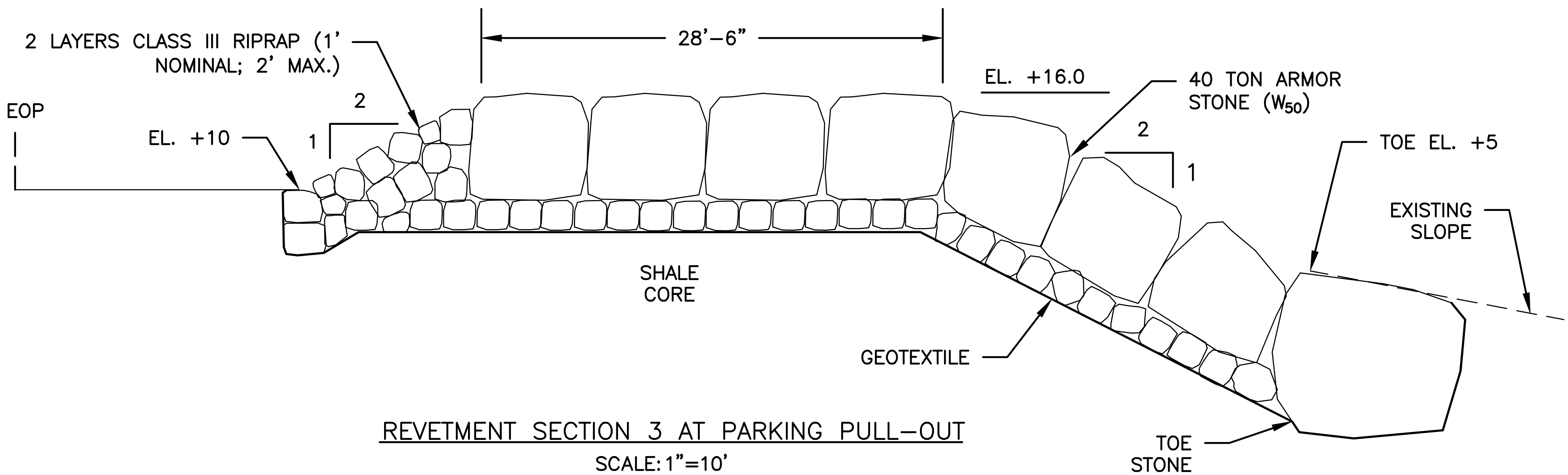
PROJ MGR: CWC	REVIEWED BY:	CHECKED BY: CWC	SK 2
DESIGNED BY: CWC/RKT	DRAWN BY: RKT	SCALE: AS NOTED	
DATE: APRIL, 2021	PROJECT NO. 04.0190838.04	REVISION NO.	SHEET NO. 2 OF 6



SECTION 10 SHOWN. REVETMENT SECTION 3 SHOWN ( ).

REVETMENT SECTIONS 3 AND 10 ALONG ROADWAY

SCALE: 1"=10'



REVETMENT SECTION 3 AT PARKING PULL–OUT

SCALE: 1"=10'

NO.	ISSUE/DESCRIPTION	BY	DATE

NHDOT NORTH HAMPTON-RYE 42312
CONCEPT REVETMENT SECTIONS

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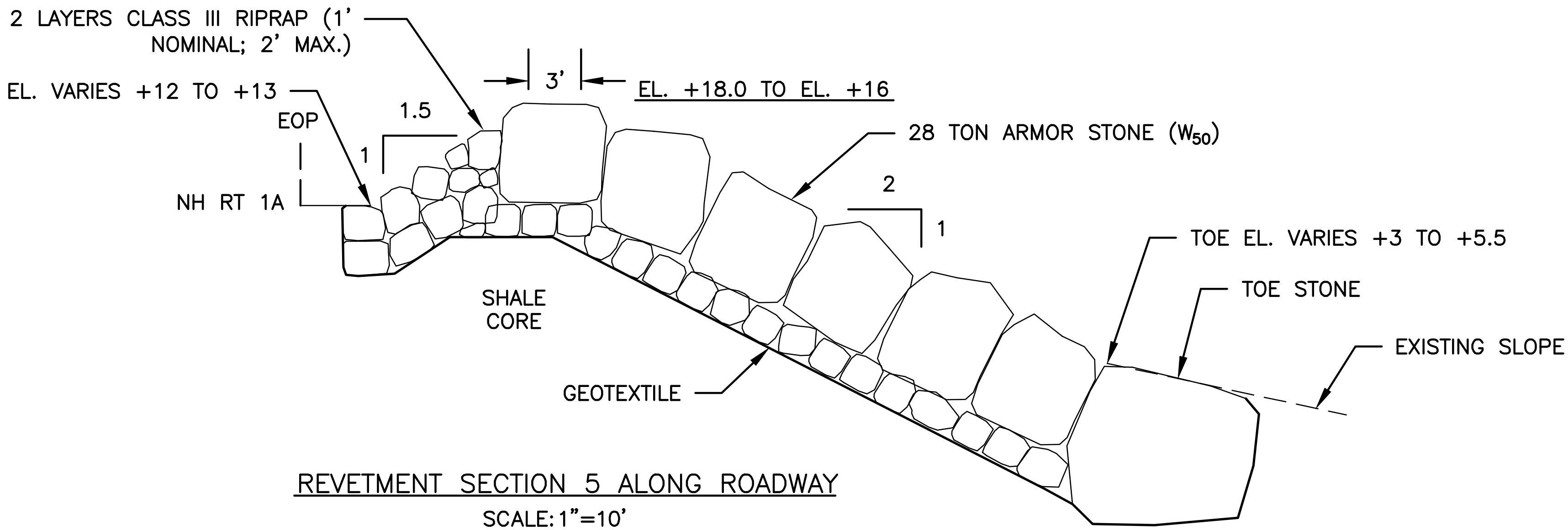
PREPARED FOR:
NHDOT

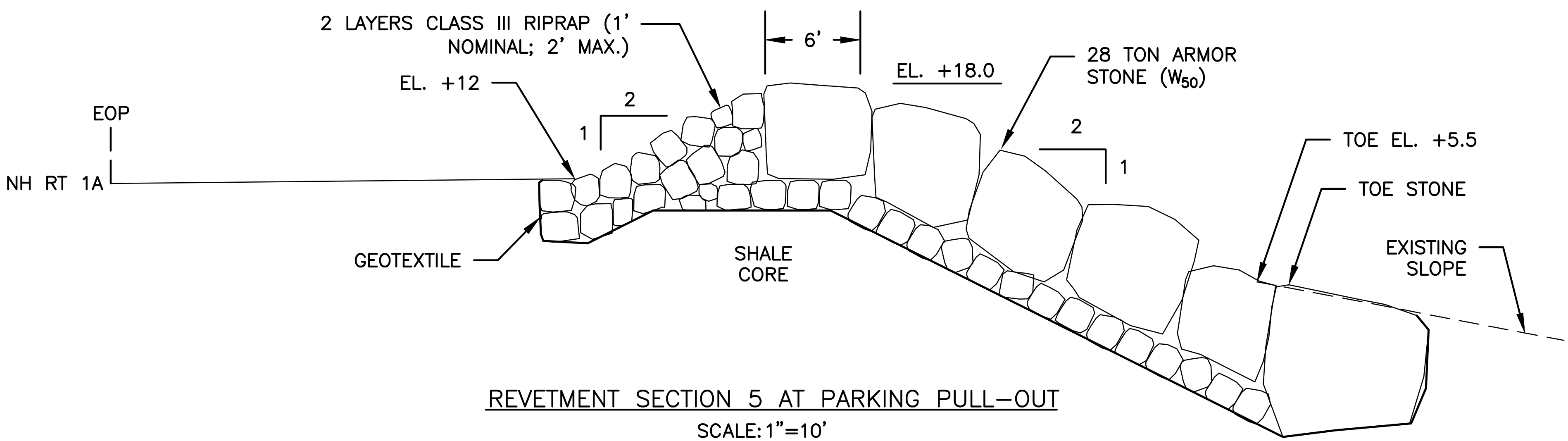
CONCEPT REVETMENT SECTIONS
SK-3

PROJ MGR: CWC	REVIEWED BY:	CHECKED BY: CWC	DWG 3
DESIGNED BY: CWC/RKT	DRAWN BY: RKT	SCALE: AS NOTED	
DATE: APRIL, 2021	PROJECT NO. 04.0190838.04	REVISION NO.	SHEET NO. 3 OF 6



REVETMENT SECTION 5 ALONG ROADWAY

SCALE: 1"=10'



REVETMENT SECTION 5 AT PARKING PULL–OUT

SCALE: 1"=10'

NO.	ISSUE/DESCRIPTION	BY	DATE

NHDOT NORTH HAMPTON-RYE 42312
CONCEPT REVETMENT SECTIONS

CONCEPT REVETMENT SECTIONS
SK-4

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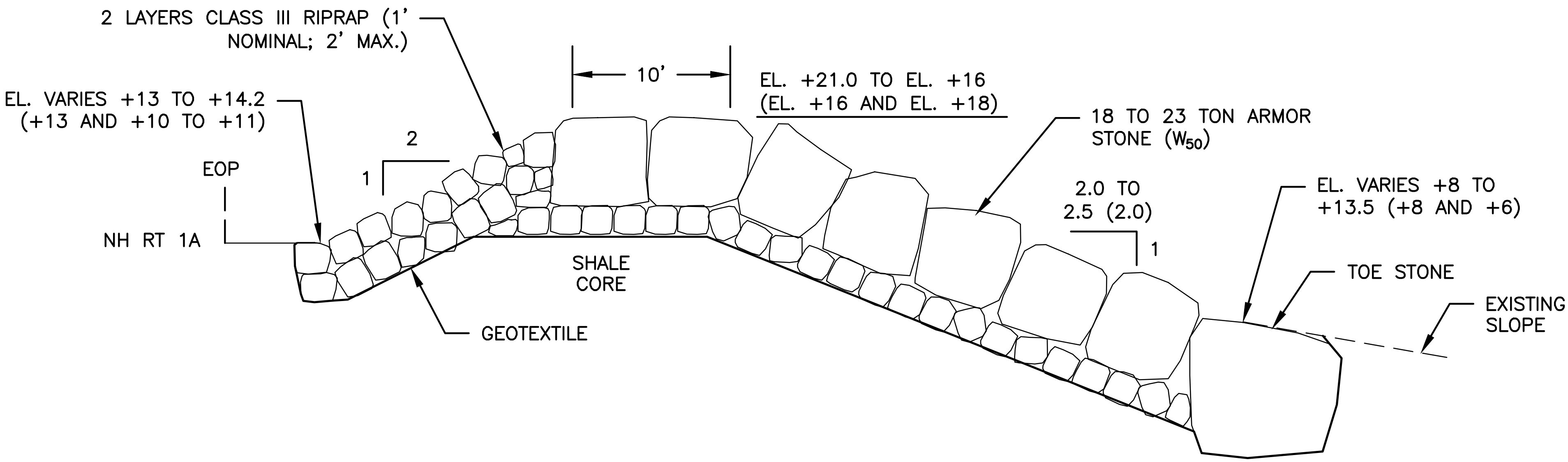
PREPARED FOR:
NHDOT

PROJ MGR: CWC	REVIEWED BY:	CHECKED BY: CWC	DWG 4
DESIGNED BY: CWC/RKT	DRAWN BY: RKT	SCALE: AS NOTED	
DATE: APRIL, 2021	PROJECT NO. 04.0190838.04	REVISION NO.	SHEET NO. 4 OF 6



REVETMENT SECTIONS 4, 6 AND 13 ALONG ROADWAY

SCALE: 1"=10'

SECTION 13 SHOWN. REVETMENT SECTION 4 AND 6 SHOWN ( ).

NO.	ISSUE/DESCRIPTION	BY	DATE

NHDOT NORTH HAMPTON-RYE 42312
CONCEPT REVETMENT SECTIONS

CONCEPT REVETMENT SECTIONS
SK-5

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Engineers and Scientists
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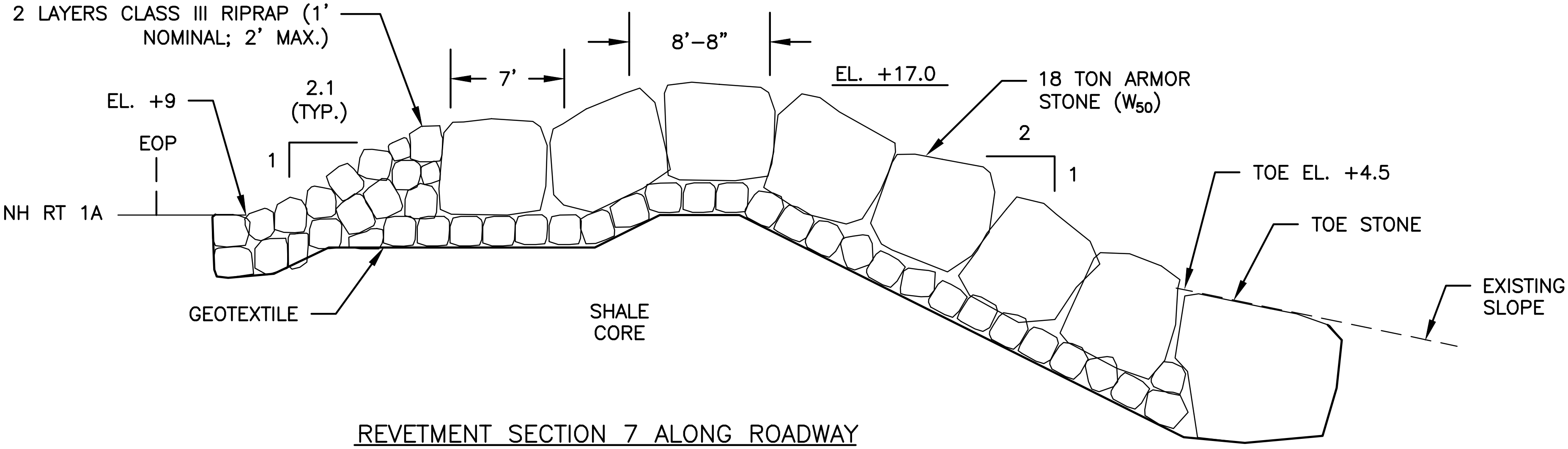
PREPARED FOR:
NHDOT

PROJ MGR: CWC	REVIEWED BY:	CHECKED BY: CWC	DWG 5
DESIGNED BY: CWC/RKT	DRAWN BY: RKT	SCALE: AS NOTED	
DATE: APRIL, 2021	PROJECT NO. 04.0190838.04	REVISION NO.	SHEET NO. 5 OF 6



REVETMENT SECTION 7 ALONG ROADWAY

SCALE: 1"=10'

NO.	ISSUE/DESCRIPTION	BY	DATE

NHDOT NORTH HAMPTON-RYE 42312
CONCEPT REVETMENT SECTIONS

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PREPARED FOR:
NHDOT

CONCEPT REVETMENT SECTIONS
SK-6

PROJ MGR: CWC	REVIEWED BY:	CHECKED BY: CWC	DWG
DESIGNED BY: CWC/RKT	DRAWN BY: RKT	SCALE: AS NOTED	6
DATE: APRIL, 2021	PROJECT NO. 04.0190838.04	REVISION NO.	SHEET NO. 6 OF 6

Attachment F
Conceptual Construction Cost Estimates

SECTION 1 - CONCEPTUAL CONSTRUCTION COST ESTIMATE

FULL RECONSTRUCTION WITH CREST AND BACK SLOPE ARMOR STONE

FURNISH			CONSTRUCTION	
Armor Stone	**Riprap Stone**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1400/LF)**	**Access ($600/LF)**
$2,000,000	$100,000	$50,000	$1,900,000	$800,000
$2,150,000			$2,700,000	
Total			$4,850,000	
25% Conceptual Design Contingency			$1,200,000	
Conceptual Design Estimate			$6,050,000	$4,400 per LF
Say			**$5.5M to $6.5M**	$4,000 - $4,700 per LF

FULL RECONSTRUCTION WITH SHALE CREST AND BACK SLOPE SIMILAR TO 1978

FURNISH			CONSTRUCTION	
Armor Stone	**Add'l Shale**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1200/LF)**	**Access ($600/LF)**
$560,000	$100,000	$30,000	$1,900,000	$830,000
$690,000			$2,730,000	
Total			$3,420,000	
25% Conceptual Design Contingency			$900,000	
Conceptual Design Estimate			$4,320,000	$3,100 per LF
Say			**$3.5M to $4.5M**	$2,500 - $3,300 per LF

* This conceptual cost estimate is for general planning purposes for reconstruction of revetment sections along NH Route 1A. Actual cost may vary depending on the project phasing, when the work is completed, labor and material costs and the waterfront marine construction bid environment. Individual line items are order of magnitude estimates with respect to the total project cost estimate. Actual costs may vary and could be significantly more, or less, than shown.

SECTION 2 - CONCEPTUAL CONSTRUCTION COST ESTIMATE

FULL RECONSTRUCTION WITH CREST AND BACK SLOPE ARMOR STONE

FURNISH			CONSTRUCTION	
Armor Stone	**Riprap Stone**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1400/LF)**	**Access ($600/LF)**
$1,100,000	$70,000	$50,000	$900,000	$400,000
$1,220,000			$1,300,000	
Total			$2,520,000	
25% Conceptual Design Contingency			$600,000	
Conceptual Design Estimate			$3,120,000	$4,800 per LF
Say			**$2.5M to $3.5M**	$3,900 - $5,400 per LF

FULL RECONSTRUCTION WITH SHALE CREST AND BACK SLOPE SIMILAR TO 1978

FURNISH			CONSTRUCTION	
Armor Stone	**Add'l Shale**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1200/LF)**	**Access ($600/LF)**
$280,000	$0	$20,000	$900,000	$390,000
$300,000			$1,290,000	
Total			$1,590,000	
25% Conceptual Design Contingency			$400,000	
Conceptual Design Estimate			$1,990,000	$3,100 per LF
Say			**$1.5M to $2.5M**	$2,300 - $3,900 per LF

* This conceptual cost estimate is for general planning purposes for reconstruction of revetment sections along NH Route 1A. Actual cost may vary depending on the project phasing, when the work is completed, labor and material costs and the waterfront marine construction bid environment. Individual line items are order of magnitude estimates with respect to the total project cost estimate. Actual costs may vary and could be significantly more, or less, than shown.

SECTION 3 - CONCEPTUAL CONSTRUCTION COST ESTIMATE

FULL RECONSTRUCTION WITH CREST AND BACK SLOPE ARMOR STONE

FURNISH			CONSTRUCTION	
Armor Stone	**Riprap Stone**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1400/LF)**	**Access ($600/LF)**
$4,900,000	$170,000	$60,000	$2,500,000	$1,100,000
$5,130,000			$3,600,000	
Total			$8,730,000	
25% Conceptual Design Contingency			$2,200,000	
Conceptual Design Estimate			$10,930,000	$6,000 per LF
Say			**$10.5M to $11.5M**	$5,800 - $6,300 per LF

FULL RECONSTRUCTION WITH SHALE CREST AND BACK SLOPE SIMILAR TO 1978

FURNISH			CONSTRUCTION	
Armor Stone	**Add'l Shale**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1200/LF)**	**Access ($600/LF)**
$2,680,000	$240,000	$30,000	$2,500,000	$1,090,000
$2,950,000			$3,590,000	
Total			$6,540,000	
25% Conceptual Design Contingency			$1,600,000	
Conceptual Design Estimate			$8,140,000	$4,500 per LF
Say			**$7.5M to $8.5M**	$4,100 - $4,700 per LF

* This conceptual cost estimate is for general planning purposes for reconstruction of revetment sections along NH Route 1A. Actual cost may vary depending on the project phasing, when the work is completed, labor and material costs and the waterfront marine construction bid environment. Individual line items are order of magnitude estimates with respect to the total project cost estimate. Actual costs may vary and could be significantly more, or less, than shown.

SECTION 4 - CONCEPTUAL CONSTRUCTION COST ESTIMATE

FULL RECONSTRUCTION WITH CREST AND BACK SLOPE ARMOR STONE

FURNISH			CONSTRUCTION	
Armor Stone	**Riprap Stone**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1400/LF)**	**Access ($600/LF)**
$1,200,000	$60,000	$10,000	$1,200,000	$500,000
$1,270,000			$1,700,000	
Total			$2,970,000	
25% Conceptual Design Contingency			$700,000	
Conceptual Design Estimate			$3,670,000	$4,200 per LF
Say			**$3.5M to $4.5M**	$4,000 - $5,100 per LF

FULL RECONSTRUCTION WITH SHALE CREST AND BACK SLOPE SIMILAR TO 1978

FURNISH			CONSTRUCTION	
Armor Stone	**Add'l Shale**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1200/LF)**	**Access ($600/LF)**
$70,000	$260,000	$10,000	$1,200,000	$530,000
$340,000			$1,730,000	
Total			$2,070,000	
25% Conceptual Design Contingency			$500,000	
Conceptual Design Estimate			$2,570,000	$2,900 per LF
Say			**$2M to $3M**	$2,300 - $3,400 per LF

* This conceptual cost estimate is for general planning purposes for reconstruction of revetment sections along NH Route 1A. Actual cost may vary depending on the project phasing, when the work is completed, labor and material costs and the waterfront marine construction bid environment. Individual line items are order of magnitude estimates with respect to the total project cost estimate. Actual costs may vary and could be significantly more, or less, than shown.

SECTION 5 - CONCEPTUAL CONSTRUCTION COST ESTIMATE

FULL RECONSTRUCTION WITH CREST AND BACK SLOPE ARMOR STONE

FURNISH			CONSTRUCTION	
Armor Stone	**Riprap Stone**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1400/LF)**	**Access ($600/LF)**
$3,400,000	$140,000	$20,000	$2,600,000	$1,100,000
$3,560,000			$3,700,000	
Total			$7,260,000	
25% Conceptual Design Contingency			$1,800,000	
Conceptual Design Estimate			$9,060,000	$4,800 per LF
Say			**$8.5M to $9.5M**	$4,5000 - $5,000 per LF

FULL RECONSTRUCTION WITH SHALE CREST AND BACK SLOPE SIMILAR TO 1978

FURNISH			CONSTRUCTION	
Armor Stone	**Add'l Shale**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1200/LF)**	**Access ($600/LF)**
$1,610,000	$260,000	$20,000	$2,600,000	$1,130,000
$1,890,000			$3,730,000	
Total			$5,620,000	
25% Conceptual Design Contingency			$1,400,000	
Conceptual Design Estimate			$7,020,000	$3,700 per LF
Say			**$6.5M to $7.5M**	$3,500 - $4,000 per LF

* This conceptual cost estimate is for general planning purposes for reconstruction of revetment sections along NH Route 1A. Actual cost may vary depending on the project phasing, when the work is completed, labor and material costs and the waterfront marine construction bid environment. Individual line items are order of magnitude estimates with respect to the total project cost estimate. Actual costs may vary and could be significantly more, or less, than shown.

SECTION 6 - CONCEPTUAL CONSTRUCTION COST ESTIMATE

FULL RECONSTRUCTION WITH CREST AND BACK SLOPE ARMOR STONE

FURNISH			CONSTRUCTION	
Armor Stone	**Riprap Stone**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1400/LF)**	**Access ($600/LF)**
$6,300,000	$560,000	$230,000	$5,300,000	$2,300,000
$7,090,000			$7,600,000	
Total			$14,690,000	
25% Conceptual Design Contingency			$3,700,000	
Conceptual Design Estimate			$18,390,000	$4,900 per LF
Say			**$17.5M to $18.5M**	$4,7000 - $4,900 per LF

FULL RECONSTRUCTION WITH SHALE CREST AND BACK SLOPE SIMILAR TO 1978

FURNISH			CONSTRUCTION	
Armor Stone	**Add'l Shale**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1200/LF)**	**Access ($600/LF)**
$3,770,000	$0	$110,000	$5,300,000	$2,260,000
$3,880,000			$7,560,000	
Total			$11,440,000	
25% Conceptual Design Contingency			$2,900,000	
Conceptual Design Estimate			$14,340,000	$3,800 per LF
Say			**$13.5M to $14.5M**	$3,600 - $3,900 per LF

* This conceptual cost estimate is for general planning purposes for reconstruction of revetment sections along NH Route 1A. Actual cost may vary depending on the project phasing, when the work is completed, labor and material costs and the waterfront marine construction bid environment. Individual line items are order of magnitude estimates with respect to the total project cost estimate. Actual costs may vary and could be significantly more, or less, than shown.

SECTION 7 - CONCEPTUAL CONSTRUCTION COST ESTIMATE

FULL RECONSTRUCTION WITH CREST AND BACK SLOPE ARMOR STONE

FURNISH			CONSTRUCTION	
Armor Stone	**Riprap Stone**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1400/LF)**	**Access ($600/LF)**
$1,100,000	$110,000	$30,000	$1,300,000	$600,000
$1,240,000			$1,900,000	
Total			$3,140,000	
25% Conceptual Design Contingency			$800,000	
Conceptual Design Estimate			$3,940,000	$4,200 per LF
Say			**$3.5M to $4.5M**	$3,7000 - $4,800 per LF

FULL RECONSTRUCTION WITH SHALE CREST AND BACK SLOPE SIMILAR TO 1978

FURNISH			CONSTRUCTION	
Armor Stone	**Add'l Shale**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1200/LF)**	**Access ($600/LF)**
$190,000	$200,000	$30,000	$1,300,000	$560,000
$420,000			$1,860,000	
Total			$2,280,000	
25% Conceptual Design Contingency			$600,000	
Conceptual Design Estimate			$2,880,000	$3,100 per LF
Say			**$2.5M to $3.5M**	$2,700 - $3,700 per LF

* This conceptual cost estimate is for general planning purposes for reconstruction of revetment sections along NH Route 1A. Actual cost may vary depending on the project phasing, when the work is completed, labor and material costs and the waterfront marine construction bid environment. Individual line items are order of magnitude estimates with respect to the total project cost estimate. Actual costs may vary and could be significantly more, or less, than shown.

SECTION 10 - CONCEPTUAL CONSTRUCTION COST ESTIMATE

FULL RECONSTRUCTION WITH CREST AND BACK SLOPE ARMOR STONE

FURNISH			CONSTRUCTION	
Armor Stone	**Riprap Stone**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1400/LF)**	**Access ($600/LF)**
$3,400,000	$220,000	$100,000	$1,700,000	$700,000
$3,720,000			$2,400,000	
Total			$6,120,000	
25% Conceptual Design Contingency			$1,500,000	
Conceptual Design Estimate			$7,620,000	$6,400 per LF
Say			**$7M to $8M**	$5,9000 - $6,700 per LF

FULL RECONSTRUCTION WITH SHALE CREST AND BACK SLOPE SIMILAR TO 1978

FURNISH			CONSTRUCTION	
Armor Stone	**Add'l Shale**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1200/LF)**	**Access ($600/LF)**
$2,420,000	$0	$50,000	$1,700,000	$710,000
$2,470,000			$2,410,000	
Total			$4,880,000	
25% Conceptual Design Contingency			$1,200,000	
Conceptual Design Estimate			$6,080,000	$5,100 per LF
Say			**$5.5M to $6.5M**	$4,600 - $5,500 per LF

* This conceptual cost estimate is for general planning purposes for reconstruction of revetment sections along NH Route 1A. Actual cost may vary depending on the project phasing, when the work is completed, labor and material costs and the waterfront marine construction bid environment. Individual line items are order of magnitude estimates with respect to the total project cost estimate. Actual costs may vary and could be significantly more, or less, than shown.

SECTION 13 - CONCEPTUAL CONSTRUCTION COST ESTIMATE

FULL RECONSTRUCTION WITH CREST AND BACK SLOPE ARMOR STONE

FURNISH			CONSTRUCTION	
Armor Stone	**Riprap Stone**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1400/LF)**	**Access ($600/LF)**
$2,000,000	$30,000	$50,000	$1,400,000	$600,000
$2,080,000			$2,000,000	
Total			$4,080,000	
25% Conceptual Design Contingency			$1,000,000	
Conceptual Design Estimate			$5,080,000	$5,100 per LF
Say			**$4.5M to $5.5M**	$4,5000 - $5,500 per LF

FULL RECONSTRUCTION WITH SHALE CREST AND BACK SLOPE SIMILAR TO 1978

FURNISH			CONSTRUCTION	
Armor Stone	**Add'l Shale**	**Remove Excess & Unsuitable Material**	**Remove & Construct ($1200/LF)**	**Access ($600/LF)**
$1,340,000	$0	$30,000	$1,400,000	$600,000
$1,370,000			$2,000,000	
Total			$3,370,000	
25% Conceptual Design Contingency			$800,000	
Conceptual Design Estimate			$4,170,000	$4,200 per LF
Say			**$3.5M to $4.5M**	$3,500 - $4,500 per LF

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