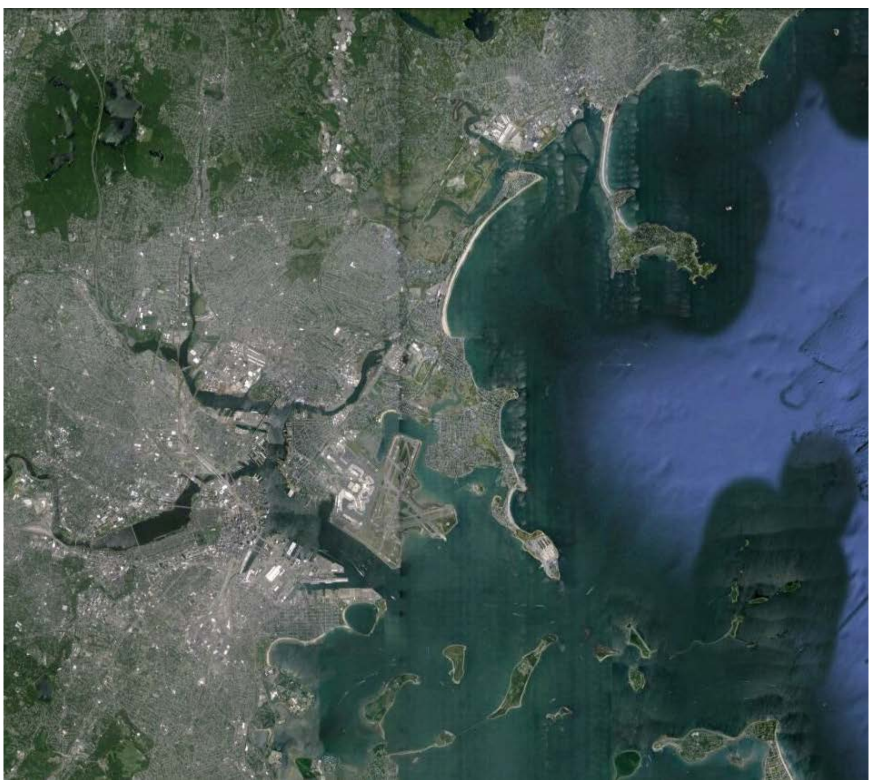
Evaluation of July 16, 2014 Federal Emergency Management Agency Flood Insurance Study for Town of Nahant, Essex, Co, MA



Prepared For:
Town of Nahant
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Table of Contents

List of Figures

List of Tables

1.0 INTRODUCTION

Woods Hole Group has completed an evaluation of the July 16, 2014 Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) for the Town of Nahant, MA. The evaluation included a coastal engineering analysis using methodologies described in the "Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update" (FEMA, 2007) to Appendix D and "Guidance for Coastal Flooding Analyses and Mapping" (FEMA, 2003). Specific components of the FEMA study evaluated by Woods Hole Group include the following:

- Stillwater elevations
- Wave climatology
- Wave setup
- Erosion and structure failure
- Overland wave transformation
- Wave runup
- Flood zone and Base Flood Elevation (BFE) mapping

FEMA's analyses for these components of the Flood Insurance Study (FIS) are described in this report, including data sources, assumptions, methods of analysis, and findings. Errors and inconsistencies in FEMA's approach were identified, and corrections were applied as part of an independent Woods Hole Group analysis. The evaluation was conducted for all areas of the Town of Nahant which are represented by FEMA's Transect Nos. 3, 4, 5, 6, 7, 8, 9, and 10 (Figure 1). Two additional transects were added to represent the north side of Little Nahant (Transect 10A) and the golf course area behind Willow Road (Transect 6A). Results of the Woods Hole Group analysis indicates that the preparation and filing of a Letter of Map Revision (LOMR) application to correct errors in the Special Flood Hazard Area (SFHA) mapped for the Town of Nahant is warranted. The revised Woods Hole Group mapping reduces the extent of the 100-yr SFHA in many areas of town, and also lowers the Base Flood Elevations (BFEs) in many areas.

1.0 Stillwater Elevations

A fundamental component of FEMA's detailed FIS process is the determination of the 1-percent-annual-chance stillwater level (SWL). The SWL is the elevation of the water due to the effects of astronomic tides and storm surge on the water surface. The SWL is integral in establishing the base inundation levels, determining the average slope for wave setup calculations, and determining water depths along transects for overland wave transformation.

For the current review, FEMA's SWLs for the Town of Nahant were determined to be too high, and more accurate and lower elevations were determined. The following narrative provides a discussion of the methodology utilized by FEMA in the July 2014 FIS to determine stillwater elevations for Essex County, MA. A detailed description of the revised analysis in support of the new stillwater elevations is also provided.

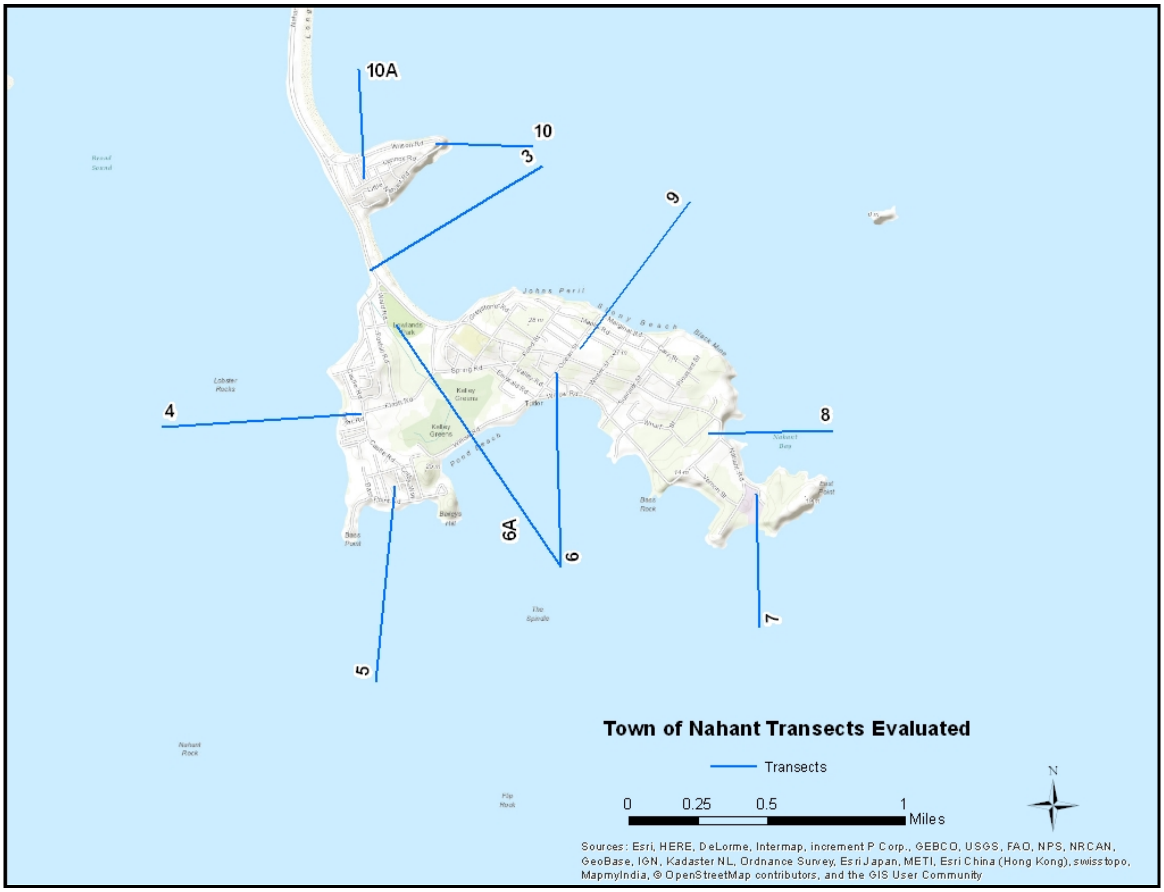

Figure 1. Location of transects evaluated as part of the Woods Hole Group study.

1.1 FEMA 2014 FIS STILLWATER ELEVATIONS

FEMA's 2014 FIS indicates that the 10-, 2-, 1-, and 0.2-percent-annual-chance flood elevations for Essex County were obtained from the *Regional Frequency Analyses using L-Moments* memorandum developed by STARR (2010). A summary of the statistical analysis methodology is also provided in a STARR report entitled *Updated Tidal Profiles for the New England Coastline* (2012). The approach utilized a frequency analysis of long-term tide gage data recorded at stations from New York to Maine, as well as supplemental highwater mark data from significant storm events (1938, 1954, and 1978). Annual maximum water elevations at the tide gage stations were adjusted to current sea levels and used with highwater mark elevations in a frequency analysis following the L-Moments approach, to determine the annual-chance flood elevations (SWLs) at each tide station.

As part of the STARR analysis the long-term tide gage locations were grouped into sub-regions based on site characteristics that best capture the relevant indicators upon which hydrological or climatological homogeneity can be predicted. Essex County was included in Region 4, which was defined by long-term water level measures at the three (3) NOAA/NOS stations shown in Table 1.

Table 1. Long-Term Tide Stations in Region 4 of STARR's Frequency Analysis.

Station	State	Station ID	Record Length
Boston Harbor	Massachusetts	8443970	1921-2007
Seavey Island	Maine	8419870	1926-2001[1]
Portland	Maine	8418150	1912-2007

[1] Missing 1935-1939, 1942, 1970-1972, 1987-1997, 1999

Maximum water elevations for each year were identified from the larger datasets at each station. For 1978, highwater marks of 14.3, 9.6, and 9.9 ft (NAVD) were used in place of the recorded tide gage data at Boston Harbor, Seavey Island, and Portland, respectively. The annual maximum water elevations and highwater marks were adjusted to current mean sea level (MSL) using sea level trends computed by NOAA/NOS. The L-Moments frequency analysis was then used with a Wakeby distribution to calculate the 1-percent-annual-chance flood elevations at the primary Region 4 stations. The sea level trends, mean annual maxima, and SWLs resulting from the STARR analysis are summarized in Table 2.

Table 2. Results of STARR Frequency Analysis for Region 4 Stations.

Station	Sea Level Trend (ft/yr)	Mean of Annual Maxima (ft, NAVD)[1]	1-Percent-Annual-Chance Flood Elevation Wakeby Dist. (ft, NAVD)
Boston Harbor	0.0087	7.72	10.04
Seavey Island	0.0057	7.30	9.48
Portland	0.0063	7.32	9.51

[1] Includes 1978 highwater marks adjusted to current MSL.

For portions of the Essex County shoreline between the primary stations at Boston Harbor and Seavey Island, tidal flood profiles for the mean annual and 1-percent-annual-chance flood elevations were developed. The profiles for New England were prepared using the elevations from Table 2 and the profile baseline shown in Figure 2. For areas between the primary stations, linear interpolation of the elevation information was used to extend the profiles. For example, the SWLs at Boston Harbor (10.04 ft) and Seavey Island (9.48 ft), which are 60 miles apart on the tidal flood profile, were used to linearly interpolate a SWL of 10.0 ft for the Town of Nahant, which is approximately 2.9 miles north of Boston Harbor. This revised SWL used in the 2014 FIS represents a 1.1 ft increase over the SWL used for Nahant in the previously effective FIS dated July 3, 2012.

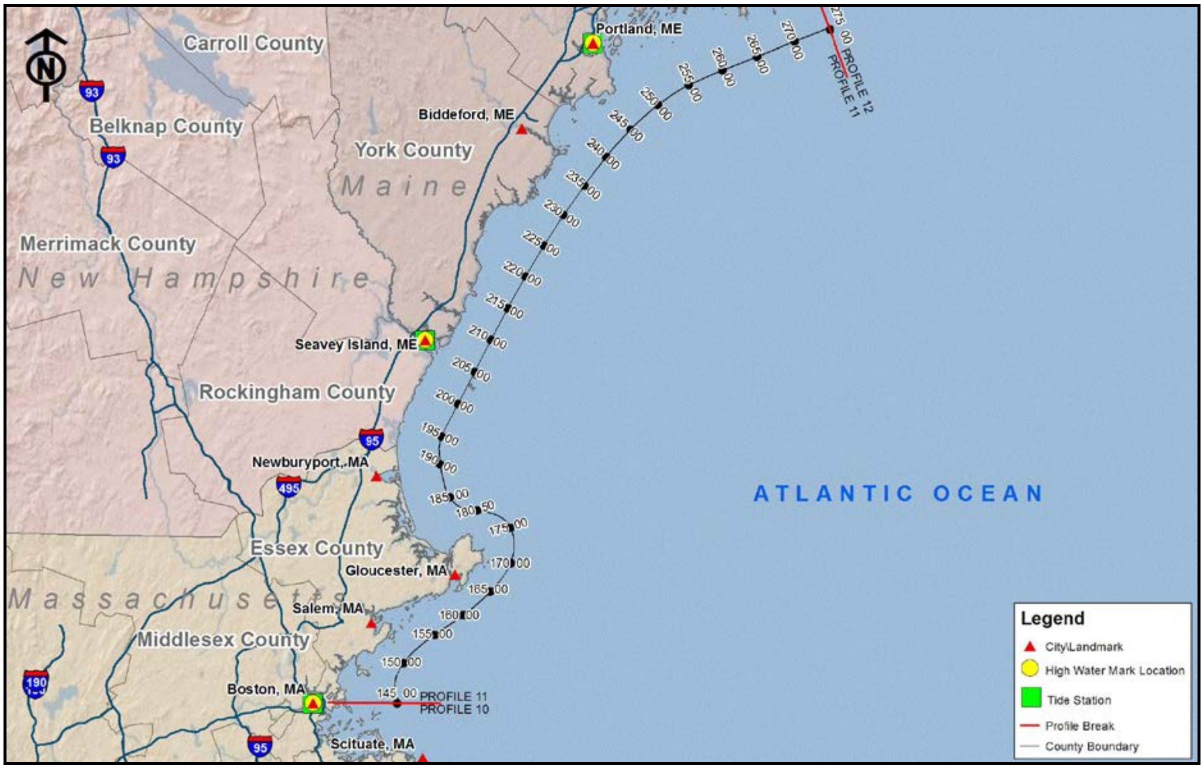

Figure 2. Base map for STARR (2012) profile 11 from Boston, MA to mile 275.

1.1 REVISIONS TO FEMA 2014 FIS STILLWATER LEVELS

Woods Hole Group conducted an independent frequency analyses of long-term water level data from the NOAA/NOS tide gage stations at Boston Harbor, Seavey Island, and Portland. The purpose of the analysis was to evaluate the 100-year SWLs utilized by FEMA as the basis for the Essex County 2014 FIS and FIRMs. Water level data were obtained from the NOAA/NOS web site as hourly measurements for the time periods shown in Table 1. The water elevations for Boston and Portland were obtained in feet referenced to the vertical datum NAVD88. Data for Seavey Island were requested directly from NOAA/NOS and the data were provided in meters referenced to the local station datum. The Seavey Island data were then converted to feet and referenced to NAVD88 by subtracting 6.98, as indicated on the NOAA/NOS tidal datums sheet for this station.

Peak annual water levels at each station were then identified, and adjusted to current MSL using the most recent sea level trends provided by NOAA/NOS, thereby using the same approach as used by STARR (2012). A L-Moments frequency analysis was then used to compute the 1-percent-annual-chance flood elevations at the Region 4 stations following a Wakeby distribution. Table 3 provides a comparison between the revised Woods Hole Group frequency analysis and STARR's (2012) results. The data show the 100-year SWLs computed by STARR (2012), and used as the basis for the 2014 FIS in Essex County, are higher than those developed as part of this revised analysis. For the Boston Harbor station, the STARR (2012) 100-year SWL is 0.93 ft higher than the revised analysis.

Table 3. Revised Frequency Analysis for Region 4 Stations

Station	Mean of Annual Maxima (ft, NAVD)[1]	1-Percent-Annual-Chance Flood Elevation Wakeby Dist. (ft, NAVD)	STARR (2012) 1-Percent-Annual Change Flood Elevation Wakeby Dist. (ft, NAVD)
Boston Harbor	7.59	9.11	10.04
Seavey Island	6.97	8.36	9.48
Portland	7.20	8.64	9.51

[1] Water levels adjusted to current MSL; 1978 highwater marks not included.

Differences between the two analyses can be attributed to STARR's (2012) substitution of the observed highwater marks from the 1978 storm in lieu of actual measurements at the tide gages. For example, at Boston Harbor STARR (2012) substituted a singular highwater mark of 14.3 ft NAVD observed at a location outside of the harbor in place of the actual observed water surface elevation of 9.52 ft NAVD recorded at the Boston Harbor tide gage. STARR provides no justification why the actual measured water surface elevation data should be replaced with highwater mark observations, which are inherently of lower accuracy and certainty (e.g., wet/dry line found on a seawall). If no storm-generated tide gage data were measured, then substitution of observed high water marks may be a reasonable approach; however, highwater marks should not be substituted in this type of analysis when actual data are recorded by the tide gage. NOAA/NOS water level data from the Boston Harbor, Seavey Island, and Portland tide gages indicate that the gages were recording continuously during the 1978 storm. Maximum water levels recorded at each of the NOAA/NOS stations are summarized in Table 4, and compared with the 1978 highwater marks utilized by STARR (2012) in their frequency analysis. The highwater mark data used in the STARR (2012) analysis are consistently higher than the actual gage measurements recorded at the peak of the storm. By substituting the highwater marks for the recorded measurements, the STARR (2012) frequency analysis skewed the 100-yr SWLs higher than should be. Use of the spurious highwater marks in lieu of the actual water levels recorded at the primary gage stations during the 1978 storm cannot be justified.

Table 4. Comparison of Peak Water Levels Measured at the NOAA/NOS Stations During the 1978 Storm With STARR (2012) Highwater Marks.

Station	Peak Measured Water Level (ft, NAVD)	Date and Time of Peak Water Level	STARR (2012) 1978 Highwater Marks (ft, NAVD)
Boston Harbor	9.52	Feb. 7, 1978 at 10:00 AM	14.3
Seavey Island	8.47	Feb. 7, 1978 at 4:00 PM	9.6
Portland	8.49	Feb. 7, 1978 at 3:00 PM	9.9

To correct this error, Woods Hole Group conducted an independent L-Moments analysis using the Pearson Type III, GEV, and Wakeby distributions. Long-term data from the three primary New England tide gage stations, adjusted to current MSL using sea level trends provided by NOAA/NOS, were used for the analysis. Results from the analysis are summarized in Table 5. For comparison, the 100-yr SWL's computed by STARR (2012) and used in the 2014 FEMA FIS for determining the Town of Nahant 100-yr SWL are provided. The revised storm surge elevations computed without the spurious highwater marks are consistently lower than the 2014 FIS values, regardless of the statistical fit being used.

Table 5. Comparison of 100-Yr SWLs Computed With and Without Highwater Marks from the 1978 Storm.

Station	STARR (2012) 100-Yr SWL (ft, NAVD) [1]	Revised 100-Yr SWL (ft, NAVD) [2]		
		Pearson Type III	GEV	Wakeby
L-Moments Analysis				
Boston	10.04	9.20	9.25	9.11
Seavey Island	9.51	8.43	8.48	8.36
Portland	9.48	8.71	8.77	8.64
Linear Interpolation				
Nahant	10.0	9.16	9.21	9.07

[1] Includes 1978 highwater marks.
[2] 1978 highwater marks not included.

Data presented in Table 5 were used to develop a revised, more accurate, 100-yr SWL for Nahant of 9.2 ft NAVD. This value was computed as the average of the three (3) revised 100-yr SWLs (9.16, 9.21, and 9.07), and is 0.8 ft lower than the SWL used by FEMA.

2.0 WAVE CLIMATOLOGY

Evaluation of 100-year wave conditions is another fundamental component of FEMA's detailed FIS process. FEMA utilizes offshore significant wave conditions (height and period) as the basis for coastal engineering analyses performed in support of mapping flood zones and associated water levels. Deepwater wave conditions are transformed closer to the shoreline and inner harbor areas, and then used for calculations of wave setup, wave runup and overtopping, and for overland wave transformation modeling.

Woods Hole Group conducted an independent analysis of significant wave conditions offshore of the Nahant coastline. The analysis was performed using 32 years of wave hindcast data (1980 to 2012) from the four (4) closest US Army Corps of Engineers (USACE) Wave Information Stations (WIS) located in Massachusetts Bay (Figure 3). At each WIS station the largest significant wave height and associated period for each of the 32 years in the dataset was processed using EXTRM2 extremal analysis software. The resulting 1% annual exceedance (100-year exceedance interval) significant wave heights were consistent with the deepwater values (height=30 ft; period=14 sec) utilized by FEMA for Nahant, and consequently no changes were made to FEMA's wave climatology.

For Transect No. 4, which is located on the west facing shoreline of Nahant and is sheltered by surrounding landmasses, FEMA used the Automated Coastal Engineering

System (ACES) software available through the Coastal Engineering and Design Analysis System (CEDAS, Version 4.0) to generate the 100-yr wave conditions. At this location, it is expected that wave conditions will be solely wind generated waves from storm winds. The geometry of the shoreline and landforms that surround Transect No. 4 were defined by establishing a series of radial fetches at evenly spaced intervals. The fetch bands were used in the Wave Prediction –Wind Adjustment and Wave Growth (restricted fetch) module of ACES to define the distance and depth over water that storm winds can generate local waves. A wind speed of 57 miles per hour was used to simulate the 100-year storm condition. The ACES simulation indicated that wave growth at Transect No. 4 is limited by the fetch distance and water depth along each radial band. FEMA's resulting 1% annual exceedance (100-year exceedance interval) significant wave height and period were consistent with values obtained by Woods Hole Group using the same methodology (height= 3.75 ft; period= 3.6 sec), and consequently no changes were made to FEMA's wave climatology for Transect No. 4.

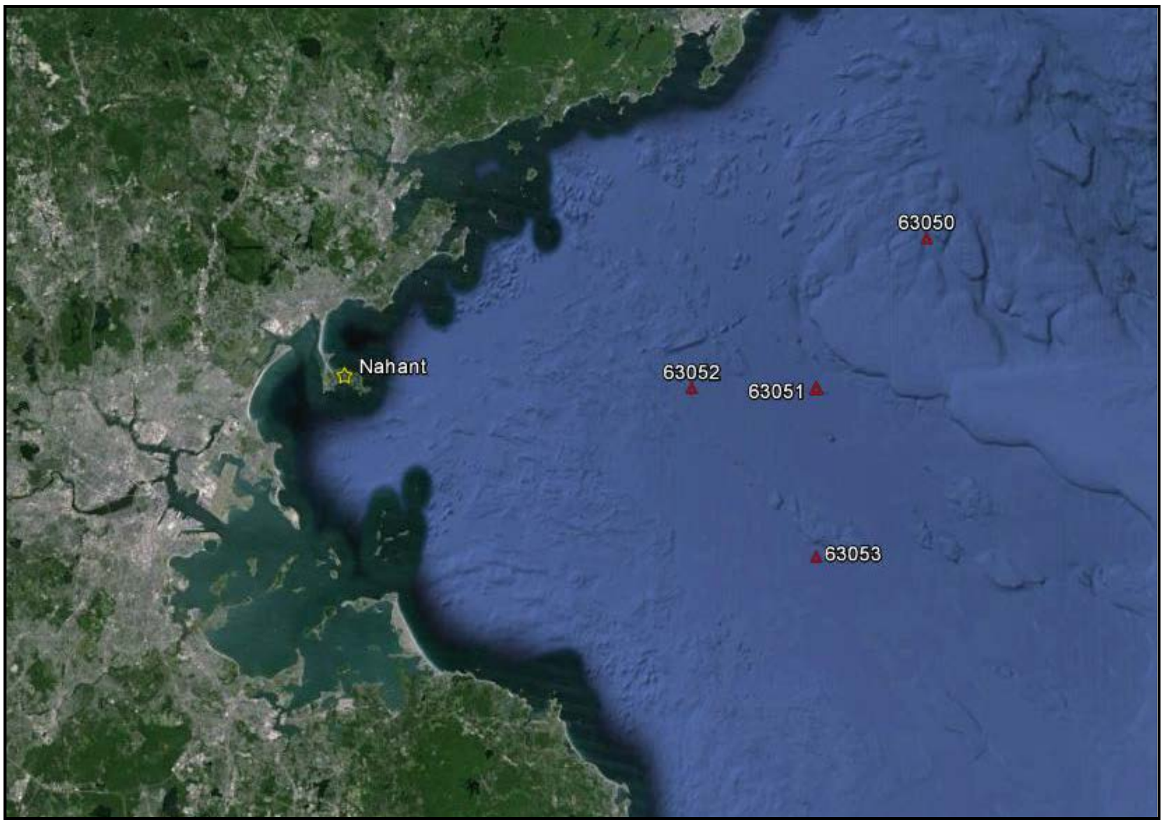

Figure 3. Wave Information Study locations in Massachusetts Bay.

3.0 WAVE SETUP

The processes associated with wave setup have been recently incorporated into FEMA's detailed FIS evaluations. Wave setup refers to the increase in water level at the shoreline due to the breaking of waves and transfer of momentum to the water column. Wave setup is affected by the height of the waves, the speed at which waves approach the shore, and the slope of the ground near the shoreline. For the 2014 Essex County FIS, wave setup was computed by FEMA using the Direct Integration Method (DIM).

Recent studies on wave setup have demonstrated that the DIM over predicts the magnitude of wave setup when compared with physics based modeling approaches. As such, Woods Hole Group conducted an independent analysis of wave setup using the numerical model Simulating Waves Nearshore (SWAN). SWAN is a third-generation wave model, approved by FEMA, for obtaining realistic estimates of wave parameters in coastal areas from given wind, bottom, and current conditions. SWAN includes wave generation, dissipation, non-linear interactions, and transformations. It also includes bottom friction, currents, shoaling, refraction, diffraction, depth induced breaking, and wave setup. SWAN represents a model based approach that accounts for the physics of the waves, including the process of wave setup. The model was therefore selected as an improved alternate to the empirically based Direct Integration Method (DIM) utilized by FEMA for computing wave setup.

SWAN can be operated in both 1-D and 2-D modes. The 1-D model approach was considered to be more conservative for wave setup, since the 2-D model accounts for effects of the surrounding bathymetry and shoreline configuration on the wave form as it travels towards the coastline. The 1-D model is also consistent with FEMA's transect based analyses and readily allows representation of rapidly changing shoreline conditions at a high resolution.

SWAN 1-D was run at each of the FEMA Transect Nos. (3, 4, 5, 6, 7, 8, 9, and10) using bathymetric and topographic conditions from the 2014 FIS FEMA CHAMP database. Topography for the new Transects at 6A and 10A was extracted from the 2011 LiDAR data available from MassGIS. Offshore bathymetry for Transect 6A was assumed to be the same as FEMA's Transect No. 6. Offshore bathymetry for Transect 10A was not readily available and therefore SWAN 1-D modeling was not performed at this site; instead the revised wave setup values computed at Transect No. 10 were assumed to be representative of Transect No. 10A. The transect data were interpolated to an evenly-spaced 1 meter resolution for input to SWAN 1-D. Water levels were set to reflect the revised 100-year SWL of 9.2 ft NAVD, as discussed in Section 1.2. An incident wave height of 30 ft and period of 14 seconds was utilized at the seaward ends of Transect Nos. 3, 5, 6, 7, 8, 9, and10; for Transect No. 4 an incident wave height of 3.75 ft and period of 4.6 sec was utilized. Waves were assumed to conservatively approach normal to the shoreline (along the axis of the transects) and spectral spreading was turned off in the model (to ensure that the peak energy was not muted). This represents a conservative assumption where the model computed wave setup using peak wave conditions, rather than a spectral spread of the waves.

Results from the SWAN 1-D simulation were reviewed and the maximum wave setup along each transect was identified. The revised wave setup and SWL values were then added to determine the total water level (TWL) for each of the Nahant transects. Table 6 shows a comparison between the wave setup, SWL and TWL applied by FEMA in the 2014 FIS for Essex County and the revised values computed by Woods Hole Group. The wave set-up dynamically computed by SWAN 1-D produced results that are lower than those used in the 2014 FIS.

Table 6. Comparison of FEMA's 2014 Wave Setup and Water Levels with Revised Values Computed for This Study.

Transect	FEMA (2014 FIS)			WHG Revised (current study)		
	Wave Setup (ft)	100-Yr SWEL (ft, NAVD)	100-Yr TWL (ft, NAVD)	Wave Setup (ft)	100-Yr SWEL (ft, NAVD)	100-Yr TWL (ft, NAVD)
3	3.5	10	13.5	2.2	9.2	11.4
4	0.5	10	10.5	0.0	9.2	9.2
5	4.5	10	14.5	2.3	9.2	11.5
6	3.9	10	13.9	1.9	9.2	11.1
6A	NA	NA	NA	3.2	9.2	12.4
7	5.1	10	15.1	3.3	9.2	12.5
8	4.8	10	14.8	2.9	9.2	12.1
9	3.9	10	13.9	2.8	9.2	12.0
10	3.9	10	13.9	2.6	9.2	11.8
10A	NA	NA	NA	2.6	9.2	11.8

4.0 EROSION AND STRUCTURE FAILURE

Topography for Transect Nos. 3, 4, 5, 6, 7, 8, 9, and 10 were taken directly from the 2014 FEMA CHAMP database. Topography for the new Transect Nos. 6A and 10A were taken from 2011 LiDAR data available from MassGIS. Transect No. 3 contains a primary frontal dune (PFD) feature at the landward edge of the coastal beach. The cross-sectional profiles of the dune was evaluated and found to have a reservoir of sand less than 540 square feet. Consequently, the FEMA guidelines that require removal of the dune, as would occur during the 100-year storm event, were followed. FEMA used the same assumptions for dune erosion when modeling Transect Nos. 3 for the 2014 FIS, and therefore, no changes were made to the eroded profile. Figure 4 shows a comparison of the intact and eroded profile conditions for Transect No. 3.

Transect No. 6 contains a concrete seawall, which according to FEMA's guidelines must be failed unless supporting documentation can be provided showing the structure is certified to withstand the 100-yr event. No such documentation was discovered for this structure and therefore failure was assumed. Transect No. 6A includes the stone revetment along Willow St., which was also failed in accordance with guidance in Section D.2.10 of the Atlantic Ocean and Gulf of Mexico Coastal Guidelines Updates (FEMA, 2007). Figure 5 shows a comparison of the intact and failed structure profiles at Transect No. 6A.

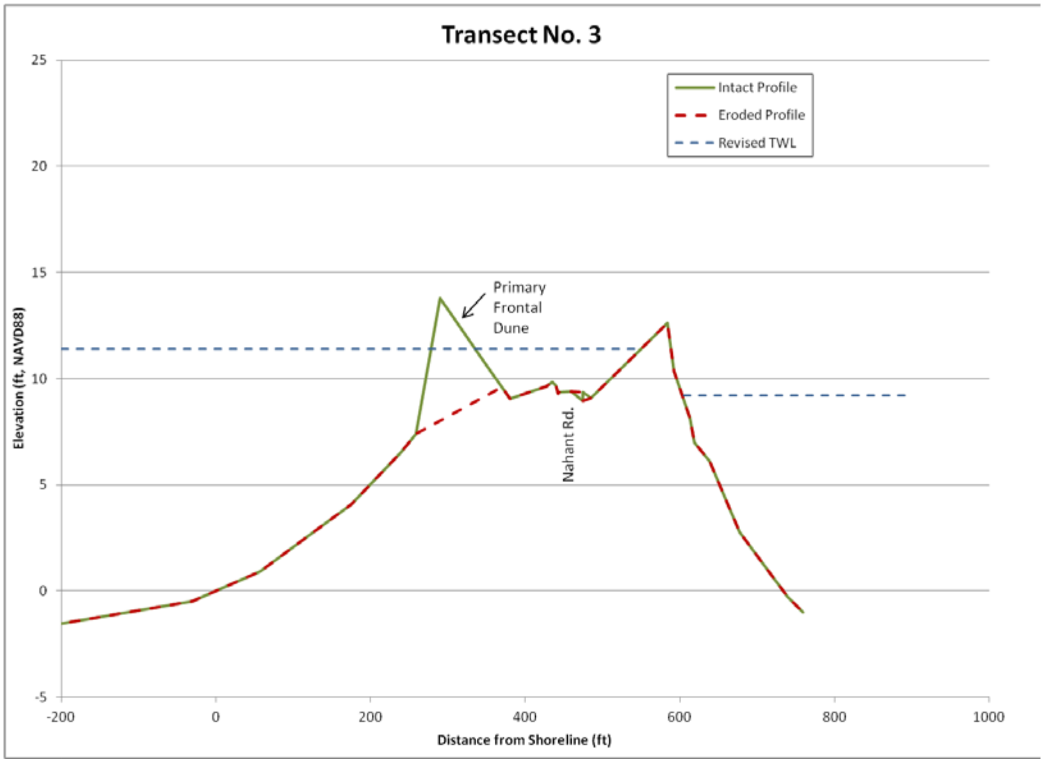

Figure 4. Intact vs. eroded profile used to model Transect No. 3.

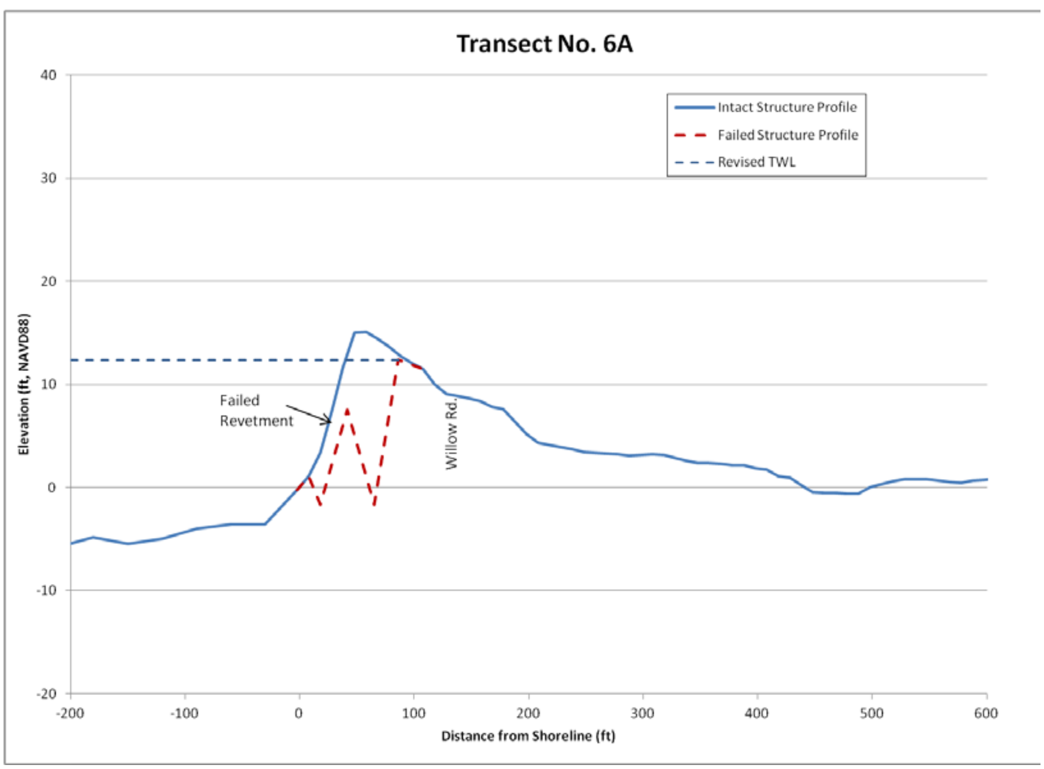

Figure 5. Intact vs. failed structure profile used to model Transect No. 6A.

5.0 WAVE RUNUP AND OVERTOPPING

Wave runup and overtopping was calculated using the methodologies described in the FEMA Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update (FEMA, 2007). At transects where the slopes were milder than 1:8 (V:H) FEMA's Runup 2.0, within the CHAMP program, was used to calculate the mean wave runup. Values of mean runup were then multiplied by 2.2 to obtain the 2% runup height. At other transects where the slopes were steeper and shore protection structures were present, FEMA's Operating Guidance 10-13 was used to determine the preferred methodology for computing wave runup based on the slope of the structure.

A summary of 2% wave runup heights, runup calculation method, and overtopping at the Town of Nahant transects is provided in Table 7. In most cases the revised wave runup values are lower than those used by FEMA in the 2014 FIS.

Table 7. Summary of Wave Runup and Overtopping Calculations.

Transect	FEMA 2014 FIS	WHG Revised (current study)			
	Wave Runup (ft)	Wave Runup (ft)	Method	Overtopping	Wave Runup Elevation (ft, NAVD)
3	1.6	1.2	Runup 2.0	No	10.4
4	4.6	12.2	TAW	Yes	14.0*
5	9.5	9.1	Runup 2.0	No	18.3
6	3.2	9.5	ACES	Yes	15.7*
6A	NA	11.4	TAW	Yes	15.4*
7	4.5	17.9	TAW	Yes	16.7*
8	33.4	19.3	TAW	No	31.9
9	23.4	14.8	TAW	No	26.8
10	26.5	17.9	TAW	No	29.7
10A	NA	13.9	TAW	No	15.9*

* Wave runup elevation reduced to 3 feet above the barrier crest in wave overtopping splash zones.

6.0 OVERLAND WAVE TRANSFORMATION

Overland wave heights were calculated using the Wave Height Analysis for Flood Insurance Studies (WHAFIS) software within the Coastal Hazard Analysis for Mapping Program (CHAMP), following the methodology described in the FEMA Guidelines and Specifications. Corrected water levels and wave setup values from Table 6 were specified in CHAMP to develop a TWL. Definitions for the major topographic, vegetative, and cultural features along each transect were taken directly from the 2014 FIS CHAMP database.

7.0 FLOOD ZONE AND BASE FLOOD ELEVATION (BFE) MAPPING

The flood zone, BFE, and Limit of Moderate Wave Action (LiMWA) mapping was performed according to the procedures outlined in FEMA's Guidelines and Specifications. Revised flood zone locations and BFEs based on modeling and engineering analyses for Nahant is shown in Figure 6. For comparison purposes, the June 2014 Effective FEMA flood zones and BFEs are shown in the left panel. Table 8 provides a summary of the flood zone and BFE changes resulting from the revised mapping.

Table 8. Summary of Wave Runup and Overtopping Calculations.

FEMA Transect No.	FEMA June 2014 FIRM Flood Zones and BFEs	Revised Flood Zones and BFEs
3	VE (El 21) VE (El 16) AE (El 15) VE (El 15)	VE (El 18) VE (El 16) VE (El 14) AE (El 12) VE (El 13)
4	VE (El 15)	VE (El 14)
5	VE (El 24) AO (2 ft)	VE (El 18) AO (2 ft)
6	VE (El 22) AE (El 15)	VE (El 17) AE (El 13)
6A	VE (El 22) AE (El 15) AE (El 14)	VE (El 18) VE (El 15) AE (El 13) AE (El 14)
7	VE (El 22) AE (El 15)	VE (El 18) VE (El 17) AE (El 13)
8	VE (El 48)	VE (El 31)
9	VE (El 38)	VE (El 27)
10	VE (El 40)	VE (El 30)
10A	VE (El 21)	VE (El 18) VE (El 16)

If the Town is interested in pursuing these flood map changes, it will be necessary to file a LOMR with FEMA. Woods Hole Group has successfully completed a number of LOMR applications for this area of Massachusetts. The process can take up to 6 months for review and acceptance by FEMA.

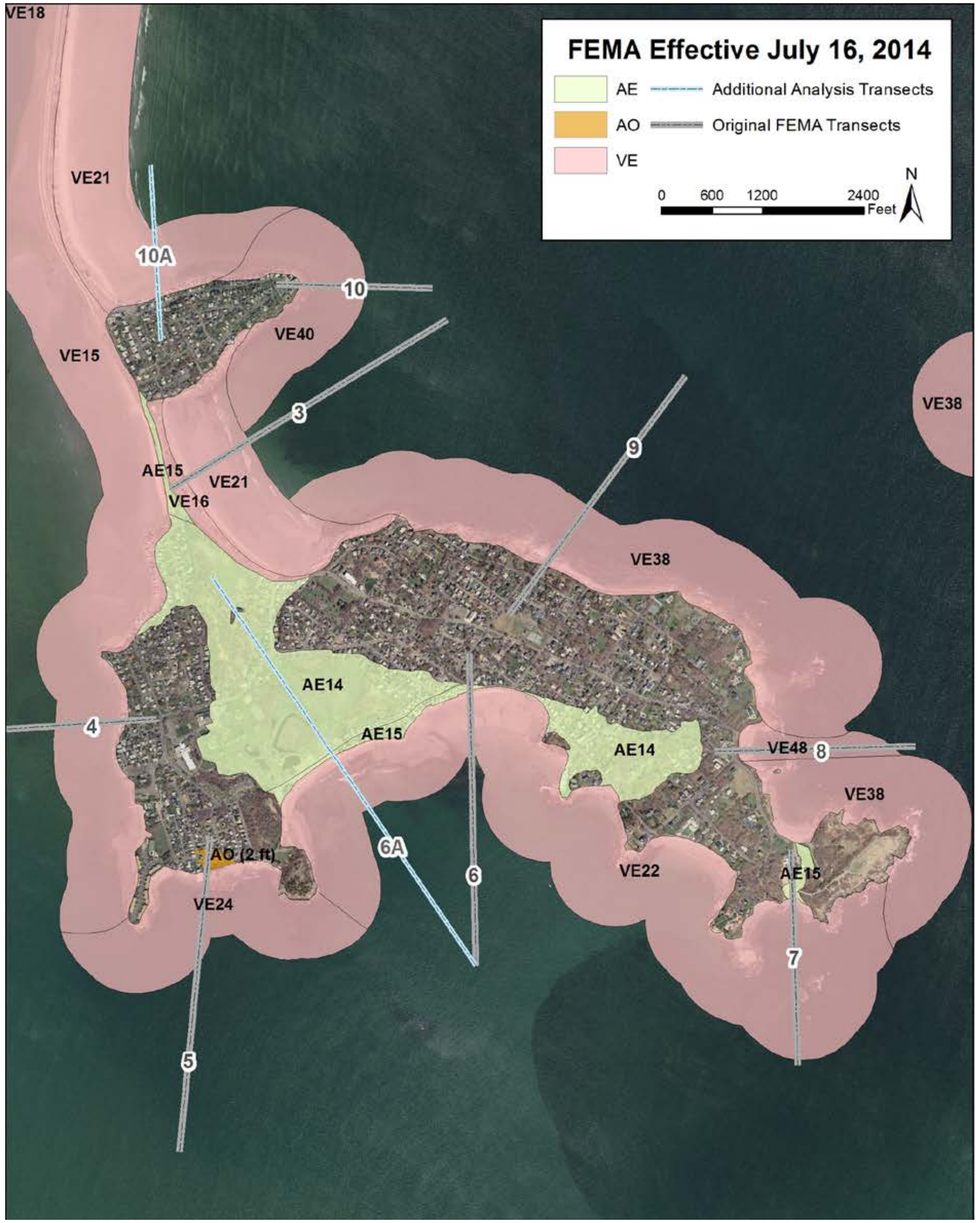

Figure 6. Comparison of flood zones and BFE between Effective July 2014 FIRM and revisions developed as part of this evaluation.

8.0 REFERENCES CITED

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