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SENT VIA ELECTRONIC MAIL OCTOBER 21, 2020
October 21, 2020
File No. 18.0171674.04

Mr. David H. Knowlton, P.E.
City Engineer/DPS Director
City of Salem, MA
98 Washington Street, 2nd Floor
Salem, Massachusetts 01970

Re: Preliminary Design Summary Letter
Columbus Avenue Seawall Reconstruction Project (EEA #258-2020-3)
Salem, Massachusetts

Dear Mr. Knowlton:

GZA GeoEnvironmental, Inc. (GZA) is pleased to submit this summary letter of preliminary design progress for the Columbus Avenue Seawall Reconstruction Project to the City of Salem (Client). The summary letter is provided in accordance with our agreement for design and permitting services for the above-referenced project, dated January 22, 2020. This summary letter is subject to the Limitations indicated in **Attachment A**. Elevations provided are referenced to the North American Vertical Datum 1988 (NAVD88).

BACKGROUND

GZA was retained by the City of Salem to conduct a site visit in May 2018 to inspect and evaluate the existing seawall conditions at the site in response to the coastal flooding and damage that occurred to the seawalls during the March 2018 Nor'easter storm events. GZA has provided the City with a preliminary seawall evaluation letter report dated October 21, 2019 describing the existing conditions and providing the City with alternate repairs/reconstruction recommendations.

Based on the March 2018 Nor'Easter Storm Damage Seawall Assessment letter, the City has chosen the option to replace the existing seawall with consideration to raise the height of the seawall for greater protection and resilience to wave surge/flooding conditions. In addition, the City is looking to improve coastal resiliency of the area by implementing an improved living shoreline adjacent to the wall in areas of existing and deteriorated salt marsh habitat.

The City, with the assistance of GZA, applied for and received a grant for the design and permitting services of the proposed seawall reconstruction and living shoreline. The following summarizes the preliminary project design progress to date, including a summary of coastal wave and flood analysis proposed as part of the scope of services.

EXISTING CONDITIONS

The Columbus Avenue seawall is an older fieldstone and granite block masonry structure approximately 474 linear feet long, located along the north western portion of Juniper Cove in Salem, Massachusetts between the properties of 44 Columbus Avenue and 30 Bay View Avenue. The seawall provides foreshore protection to; the public roadway (Columbus Avenue), public sidewalk, utilities, and residential dwellings. The seawall is fronted by the publicly accessible 'Steps Beach' and an area of salt marsh vegetation along the southwest portion of the beach area.

At the entrance to Juniper Cove there is an existing deteriorated breakwater approximately 750 feet seaward of the seawall. The breakwater extends approximately 120 feet perpendicular from existing bedrock outcrops at the northern shoreline of Juniper Cove, at the approximate property of 72 Bay View Avenue.

In general, the seawall is composed of angular and rounded stones that range approximately 4-inch by 4-inch to 2-feet by 3-feet in size with varied coursing. In general, the stone sizing decreases towards the top of the wall on the seaward face. The exposed landward face of the wall generally appears to consist of more dimensioned stone blocks. The top of the wall is an uneven surface, consisting of vertically protruding stones (anecdotally to limit visitors to Juniper Cove from comfortably sitting on the wall). The seawall varies in elevation from approximately 10.1 feet NAVD88 at the southwestern corner to 8.5 feet NAVD88 at the northeastern corner. Neighboring private walls on each end are at the same approximate elevation as the adjacent Columbus Ave wall.

The seawall has never had the benefit of any ongoing, periodic preventative maintenance program but has received spot repairs from time to time especially after the damage that occurred during the 2018 Nor'easters. The seawall is vulnerable to the ever-increasing severity of coastal storms and higher water levels than previously experienced. If left as-is the structure is likely to experience additional degradation and potentially failure compromising the roadway, public access, utilities and residential dwellings.

SITE INVESTIGATIONS AND ASSESSMENT

GZA has performed investigations to document the existing conditions of the site and to assist in the development of proposed reconstruction and restoration designs including an updated topographic survey of the site, inspections of the seawall structure, limited inspections of the breakwater, and limited ecological survey of the salt marsh habitat area. Inspections included taking field notes, sketches, photographic and video documentation of the site.

The seawall inspections included documentation of the above-ground accessible portions of the seawall structure to assess existing conditions and identify storm damaged areas. The seawall was observed to have minor to advanced defects and deterioration. Various areas with loose or missing chinking stones and areas with loose, cracked, missing and deteriorated mortar between the stones were observed along the entire top and seaward face. Voids and cracks in the core of the existing seawall were observed at several locations along the top and seaward side of the wall, and stones and mortar were missing at the face and around the pipe penetrations. Several sinkholes were observed landward of the wall along the sidewalk. The seawall is particularly susceptible to failure, due to age, existing deteriorated condition, lack of consistent maintenance, and lack of proper stone sizing and design.

The limited inspections of the existing breakwater included documentation of the above-ground and above-water accessible portions of the breakwater structure, as well as elevation measurements to establish approximate top of crest elevations. The existing breakwater has a crest at approximate elevation 0 feet NAVD88 and the width varies from approximate 10 feet to 14 feet. Side slopes vary at approximately one vertical to three horizontal (1V:3H). Armor stone generally appeared to consist of 0.5-ton sized stone with limited 2 ton to 4-ton stone and minimal stone greater than 4 tons. Stones appeared to be raveled in some areas where the bedrock core of the breakwater was exposed.

The ecological survey performed at the site included documentation of existing conditions of the salt marsh habitat to identify local biota and habitat characteristics as well as document current ecological trajectory and potential vulnerability. The salt marsh area was observed to be partly desiccated and degraded. The salt marsh area was observed to have various 'pockmark' voids up to 2 feet deep throughout the marsh area, severe erosion along the seaward end with complete loss of salt marsh vegetation and substrate up to 2 feet deep presumably at locations of preferential flow paths of tidal water and/or groundwater, and erosion and undermining at the toe of the salt marsh substrate presumably due to erosive tidal and wave forces. Protection and enhancement of the salt marsh area will stabilize the shoreline and reduce erosion, attenuate waves, and provide habitat for plant and animal species.

COASTAL WAVE AND FLOOD ANALYSIS

GZA has performed a metocean and wave analysis for the project site to determine design parameters for the reconstructed seawall and living shoreline marsh restoration. Specifically, analyses were performed for coastal flood elevations, wave effects, and relative sea level rise at the site. The metocean characteristics (e.g., water level, wave height, wind) and wave model results are presented in **Attachment B**. A summary is provided as follows:

COASTAL FLOOD ELEVATIONS

Stillwater elevations represent flood level not including wave effects (wave amplitude and wave setup). **Table 1** represents the Stillwater elevations based on the FEMA Flood Insurance Study at Transect 30 in the vicinity of the project site.

Table 1: FEMA-predicted Peak Stillwater Elevations	
Return Period	**FEMA Stillwater Elevation (ft, NAVD88)**
10-year (10-percent)	8.4
50-year (2-percent)	9.4
100-year (1-percent)	10.0
500-year (0.2-percent)	11.4

Predicted water level data statistics are also available from the U.S. Army Corps of Engineers (USACE) North Atlantic Coast Comprehensive Study (NACCS). Multiple NACCS points are located out of Juniper Cove, approximately 2,500 feet from the Columbus Avenue Seawall. The 100-year recurrence interval mean peak water level predicted by the NACCS points is approximately 9.0 feet NAVD88. Additionally, the highest observed water levels at the NOAA Boston tide gage are elevation 9.6 feet and 9.7 feet NAVD88 during the 1978 Blizzard and the January 4, 2018 Nor'easter.

The top elevation of the existing seawall varies from about elevation 8.5 feet NAVD88 at the northeast end to 10.1 feet NAVD88 at the southwest end. The relative low wall height contributes to the flooding conditions previously observed during the recent storm events. Other contributors to flooding conditions at the site may include wave effects, 'back-door' flooding effects, and utility drainage effects.

WAVE HEIGHTS

Wave modeling and analysis was performed to determine approximate localized wave heights (within the Cove and along the seawall), effects of waves at the northeast end of the seawall, and the effects the breakwater has on incoming waves. Numerical wave analyses were performed using the SWAN (Simulating WAves Nearshore) model to evaluate waves generated by wind and deep-water waves propagating toward the site for various storm events. The FEMA 10-year (10-percent), 50-year (2-percent), and 100-year (1-percent) recurrence interval flood events were evaluated. Input variables for the SWAN wave model is summarized in **Table 2**.

Table 2: SWAN Wave Model Inputs

Storm Event Return Period	Stillwater Elevation (ft, NAVD88)[1]	Significant Wave Height at Cove (ft)[2]	Wave Period at Cove (sec)[3]	Wind Speed (mph)[4]	Wind/Wave Direction
10-year	8.4	21.2	11	61	From due east
50-year	9.4	26.2	11	75	From due east
100-year	10.0	28	11	80	From due east

[1]FEMA 100-year Stillwater elevation
[2]Based on wave data at WIS buoy 63050
[3]Estimated based on wave period measurement at NERACOOS Buoy A01
[4]ASCE 7-16 1-min sustained wind speed

The simulated wave heights indicated significant wave attenuation within Juniper Cove from about 10 feet at the Cove inlet to about 1.4 feet to 2.6 feet at the seawall for the predicted 100-year recurrence interval flood event. Waves along the seawall range from approximately 1.4 feet to 2.6 feet in height for the 100-year storm event. Comparatively, for the 10-year storm event, waves along the seawall range from no waves at the southwest corner to approximately 2.3 feet towards the center of the seawall. **Figure B-24** shows the SWAN model results for the significant wave heights at various output stations along the existing seawall and just seaward of the seawall for the 10-year, 50-year, and 100-year recurrence interval events.

Figure B-24: Output Stations 10 to 13 adjacent to the CAS for SWAN Model Results.

Generally, the largest predicted waves occur towards the center of the seawall and the smallest predicted waves occur at the northeast corner, likely due to the topographic difference and natural sheltering. Although significant wave attenuation occurs within the Cove, the wave heights would still likely overtop the existing seawall based on the existing conditions.

WAVE RUNUP/OVERTOPPING

An assessment of wave runup and overtopping was performed for an increased seawall height to elevations 11 feet NAVD88 and 12 feet NAVD88 for the FEMA 10-year, 50-year, and 100-year recurrence interval flood events. Additionally, an assessment of wave runup at the northeast wall corner was performed for the existing topography and for the theoretical removal of the sand build-up. **Table 3** summarizes the results of wave runup and overtopping at the seawall for the predicted 10-year, 50-year, and 100-year recurrence interval flood events.

Table 3: Wave Runup and Overtopping

Storm Event	Output Station	Wall Elevation (ft, NAVD88)	Wave Runup Height (ft)	Wave Runup Elevation (ft, NAVD88)[1]	Overtopping Flowrate per Foot (gallon/min.)[1]
10-year	10	11	2.1	10.5	0
		12	2.1	10.5	0
	11	11	3.5	11.9	5

		12	3.5	11.9	0
	12	11	4.4	12.8	21
		12	4.4	12.8	4
	13	11	0.0	8.4	0
		12	0.0	8.4	0
50-year	10	11	2.5	11.9	6
		12	2.5	11.9	0
	11	11	3.9	13.3	53
		12	3.9	13.3	9
	12	11	4.8	14.2	123
		12	4.8	14.2	33
	13	11	3.1	12.5	21
		12	3.1	12.5	2
100-year	10	11	2.7	12.7	41
		12	2.7	12.7	6
	11	11	4.2	14.2	157
		12	4.2	14.2	48
	12	11	5.0	15.0	243
		12	5.0	15.0	89
	13	11	3.9	13.9	121
		12	3.9	13.9	33

[1]Calculated by EurOtop Manual (2018)

Wave runup heights along the seawall for the predicted 100-year recurrence interval flood event range from approximately 2.7 feet to 5.0 feet, corresponding to approximate elevations of 12.7 feet NAVD88 to 15.0 feet NAVD88. These calculated wave runup heights would lead to significant wall overtopping. Wave runup heights along the seawall for the predicted 10-year recurrence interval flood event range from approximately 0 feet to 4.4 feet, corresponding to elevations of 8.4 feet NAVD88 to 12.8 feet NAVD88. Wall overtopping is expected even during a 10-year storm event.

An additional wave runup analysis was performed for the theoretical removal of sand build-up at the northeast corner, represented by output station 10. Removal of sand at the northeast corner reduces the wave runup height for the 100-year recurrence interval flood event at the seawall from 2.7 feet to 2.1 feet.

WAVE REFLECTION/REDIRECTION

The following includes a summary of the qualitative analysis for the wave reflection/redirection caused by an increased seawall height on adjacent structures. For stillwater induced flooding, raising the seawall is unlikely to affect the inundation in the adjacent properties, because storm surge can enter this area over the low adjacent structures. Raising the seawall would not affect the flood depth or flood zone on the adjacent properties and along Columbus Avenue (currently both categorized as AE zone), although the wave heights and overtopping behind the seawall would be reduced.

Raising the seawall could potentially affect the reflected wave height (e.g., overtopping condition), because with a raised wall, the ocean water (mass and momentum) that may previously have gone over the seawall and splash the street, may be redirected or fall back to the Cove or to the adjacent property at the seawall corner (see yellow arrows in **Figure 1**). The influence of such redirected water to the adjacent property is uncertain and cannot be fully estimated, however those areas may have already experienced overtopping directly during the storm event.

Overtopping to the adjacent properties is mostly due to waves directly impacting the adjacent wall (see purple line in **Figure 1**), with some possible increase from redirected water. It is difficult to quantify the redirected water impacts within the Cove due to erratic and turbulent conditions that could occur. The influence of such redirected water to the adjacent property is uncertain and cannot be fully estimated, however those areas may have already experienced overtopping directly during the storm event.

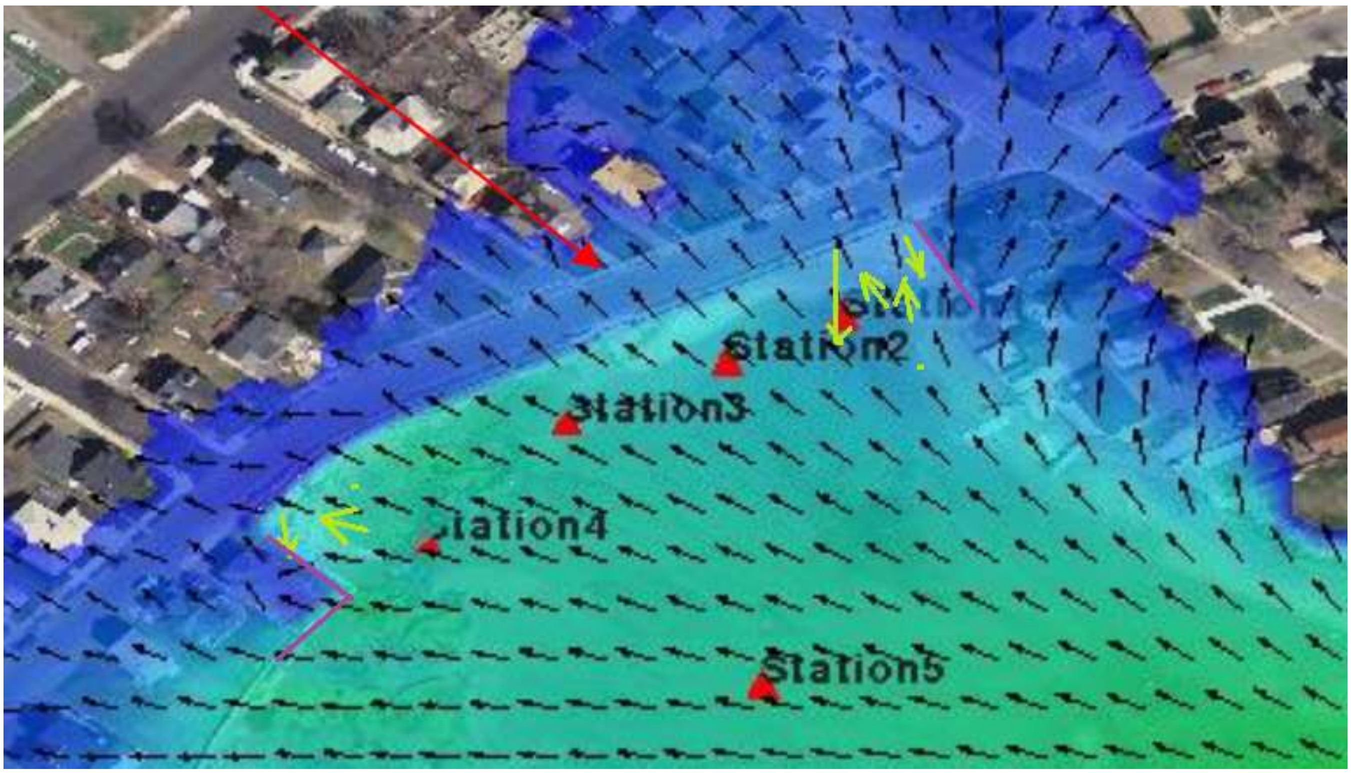


Figure 1: Schematic Analysis of Wave Reflection from the Columbus Avenue Seawall

At the southwest corner, the redirected water seems to partially affect the adjacent wall during the 100-year flood event. The elevation close to the toe of the seawall is approximately 8 to 10 feet NAVD88, indicating a breaking wave condition during the 100-year storm event. The breaking wave condition is highly turbulent and chaotic, so the influence of redirected water in this highly turbulent environment is difficult to estimate. The adjacent wall would likely experience the most impulsive condition from the breaking waves nearby, instead of the redirected water due to the raise in seawall height. During 50-year or weaker storms, the stillwater level is less than or equal to the elevation of the seawall toe, indicating stillwater may not reach the seawall, and most waves would break over the shoreline slope, leading to relatively minor wave overtopping the seawall and even lesser influences from redirected water whether the seawall is raised or not.

BREAKWATER EFFECTS ON WAVES

The existing rubble stone breakwater provides some, but minor, wave attenuation. The existing breakwater has a crest at approximate elevation 0 feet NAVD88 and the width varies from approximate 10 feet to 14 feet. Side slopes vary at approximately one vertical to three horizontal (1V:3H). Armor stone generally appeared to consist of 0.5-ton sized stone with limited 2 ton to 4-ton stone and minimal stone greater than 4 tons. Stones appeared to be raveled in some areas where the bedrock core of the breakwater was exposed.

The breakwater provides approximately 25 percent to 30 percent wave attenuation within the Cove based on the SWAN wave model. For example, the simulated wave heights at the breakwater crest ranged from approximately 5.8 feet to 6.0 feet (Output Station 7) for the 100-year storm event, and wave heights immediately landward of the breakwater ranged from elevation 4.2 feet to 4.4 feet (Output Station 6) for the 100-year storm event. The 25 percent to 30 percent reduction is also consistent for the 10-year and 50-year storm events.

The simulated wave height is approximately 6 feet at the breakwater crest and the water depth under the FEMA 100-year Stillwater elevation is approximately 10 feet. The ratio of wave height to water depth is less than the breaking wave threshold of 0.78, indicating the breakwater does not cause wave breaking to reduce wave height under the 100-year recurrence interval flood event.

Significant wave heights were estimated using the SWAN model for increased breakwater heights. If the breakwater crest was raised 5 feet to elevation 5 feet NAVD88, the wave height at the seawall would be reduced by approximately 0feet to 0.4 feet. The small reduction of wave height is likely because there would be a water depth of 5 feet above the breakwater under 100-year flood event of elevation 10 feet NAVD88, which does not cause significant wave breaking. If the breakwater height is increased to elevation 10 feet NAVD88 the wave heights at the seawall would be reduced by approximately 0.5 feet to 1.4 feet for the 100-year recurrence interval flood event. **Table 4** summarizes the wave height reductions along the seawall for the 10-year, 50-year, and 100-year recurrence interval flood events. Refer to **Tables B-8**, **B-9**, and **B-10** in **Attachment B** for results of various output stations.

Table 4: Summary of Wave Height Reductions along Seawall

Storm Event	Breakwater Height 5 feet (El. 5 ft-NAVD88)	Breakwater Height 8 feet (El. 8 ft-NAVD88)	Breakwater Height 10 feet (El. 10 ft-NAVD88)
10-year	0 to 0.5 feet	0 to 1.4 feet	0 to 1.2 feet
50-year	0.1 to 0.3 feet	0.4 to 0.7 feet	0.5 to 0.7 feet
100-year	0 to 0.4 feet	0.4 to 1.3 feet	0.5 to 1.4 feet

Shallow water depths within the Cove landward of the breakwater further attenuate wave heights. A significant reconstruction and raise in crest elevation would be required to increase wave attenuation due to the existing breakwater. Given that the Cove elevation increases toward the seawall (resulting in attenuated waves near the wall), the added wave attenuation benefit of reconstructing the breakwater is expected to be minor.

RELATIVE SEA LEVEL RISE

The relative sea level rise at the project site was estimated using the USACE sea level rise calculator and the NOAA sea level rise projection at NOAA Boston tide station. Summary of the results are shown in **Table 5**. All values are expressed in feet.

Table 5: Relative Sea Level Rise Projections						
Year	**Low**	**Intermediate to Low**	**Intermediate**	**Intermediate to High**	**High**	**Extreme**
2050	0.42	0.56	1.05	1.51	2.14	2.49
2070	0.78	0.99	1.96	2.92	4.17	5.12
2100	1.05	1.45	3.54	5.55	8.08	10.14

Sea level rise will increase the wave and flood risks at the site. If the existing seawall condition is left as-is, the landside area is at a high risk of inundation and flooding, especially during coastal storms. Other contributors to flooding conditions at the site may include wave effects, 'back-door' flooding effects, and utility drainage effects.

SEAWALL RECONSTRUCTION DESIGN

The objective of the project is to replace an existing deteriorated seawall and provide increased protection and coastal resiliency against wave effects, flooding, and sea level rise. Based on our understanding of the project site and conditions the following includes a design summary for the proposed seawall reconstruction and living shoreline marsh improvements.

It is our understanding that the City is looking to replace the existing Columbus Avenue seawall with a new, large cut granite stone wall option. The proposed reconstructed seawall will conform to the 'natural' (existing) shape of the shoreline and will be reconstructed within the same footprint as the existing structure and will not extend further seaward. Relocating the wall landward is not considered appropriate due to the proximity to public roadway, public walkway, utilities, and residential dwellings. The proposed seawall will tie-in with existing adjacent stone seawalls on the adjacent properties.

WALL TYPE/MATERIAL

The existing seawall is proposed to be reconstructed with a new, large cut granite stone option. GZA has previously provided the City with alternate repairs/reconstruction recommendations in response to the coastal flooding and damage that occurred to the seawalls during the March 2018 Nor'easter storm events. GZA summarized alternate repair/reconstruction recommendations which consisted of the following:

- Reconstruct with Existing and Supplemental Stone
- Reconstruct with Large Cut Granite Stone
- Reconstruct with Reinforced Concrete Wall
- Reconstruct with Hybrid-Concrete and Stone Veneer Wall

The City has chosen the large cut granite stone option based on the balance of cost, increased coastal resilience and flood protection, and aesthetics. The proposed granite stone seawall will act as a mass gravity wall designed considering wall stability against sliding and overturning conditions. Each course of granite stone will be pinned together to provide increased stability.

WALL HEIGHT

The proposed new granite stone seawall will have an increased height ranging from approximately 1.5 feet to 3 feet, up to elevation 11.5 feet NAVD88, roughly at the approximate top of the existing planter/pillars. Increased wall height will provide greater protection against wave surge and flooding. A proposed top of wall elevation of 11.5 feet NAVD88 may provide protection against the FEMA 100-year flood event plus an additional 1.5 feet of wave effect. The following equation can be used to calculate the wave crest elevation for depth-limited waves observed along the seawall structure.

$$Wave\ Crest\ El. = Stillwater\ El. + (Wave\ Height\ X\ 0.7)$$

Even at a proposed elevation of 11.5 feet NAVD88 which is 1.5 feet above the FEMA 100-yr Stillwater elevation, there will likely be some flood vulnerability due to wave run-up and overtopping. Temporary flood protection measures may be used such as sand filled bags placed along the top of the seawall in advance of coastal storms for additional protection against wave surge and flooding. Additional discussion of flood protection is discussed in the **Wall Opening and Flood Barrier** section.

An increased structure height will provide some protection against sea level rise. Increasing the top of wall elevation may be a necessary step in combating the effects of sea level rise and protection to necessary infrastructure.

WALL GEOMETRY

The proposed seawall geometry generally follows the MassDOT construction standard for the cemented stone masonry wall. The granite stone block wall will be founded on a reinforced cast-in-place concrete footing that will extend a minimum of four feet below existing grade on a crushed stone base over compacted subgrade soils unless bedrock is encountered at a shallower depth. If bedrock is encountered above the proposed footing elevation the concrete footing will be cast directly on existing sound bedrock with dowels drilled and grouted into the rock. A minimum depth of four feet will be maintained to help protect against scour and erosion.

The proposed minimum front (seaward) face batter is four percent, as recommended by the MassDOT construction standard. The proposed back (landward) face batter is 1V:4H. The proposed top of wall width shall be approximately 2 feet (matching the approximate existing top of wall width). Each course of stone block will be dowelled to adjacent courses for increased stability and resilience. See proposed schematic wall section, **Figure 2**.

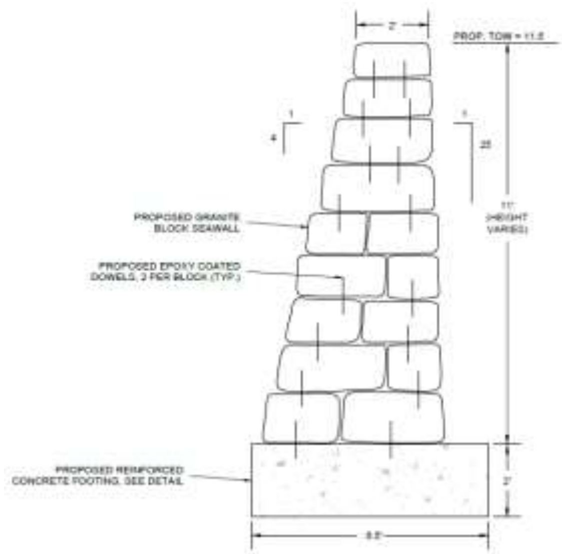


Figure 2: Proposed Wall Reconstruction Detail

WALL OPENING AND FLOOD BARRIER

The existing seawall has an approximate 20 linear foot opening for the beach access granite block landing. It is our understanding that during the off-season and during storm events the opening is blocked using sandbags and concrete blocks. The proposed project will incorporate the design of removable flood barriers for increased protection and resiliency against waves and flooding events. The design will likely consist of permanent fixed end steel channel brackets with removable stop-log type beams, with consideration for a mid-span support or lateral brace anchors. The flood barriers will be designed based on the anticipated metocean and wave conditions as previously discussed. See example flood barrier, **Figure 3.**

Figure 3: Example Stop-Log Type Removable Flood Barrier

In addition to the removable flood barriers we recommend limiting the width of the wall opening for increased protection against coastal flooding. It is our understanding that the opening is used for pedestrian access to the beach. As such, we recommend a maximum width of 10 feet at the reconstructed seawall opening.

As an additional flood protection measure, temporary sand filled bags may be used in addition to the proposed removable flood barriers. Sand filled bags (like what is currently used) may be placed on the landward side of the removable flood barriers for additional flood protection. Smaller sand filled bags may also be placed along the top of the seawall for increased protection against wave runup and flooding conditions.

BEACH ACCESS LANDING

The existing seawall has an approximate 20 linear foot opening with concrete steps from the concrete sidewalk down to a granite block landing. The landing is approximately 24-feet by 19-feet in plan area and is comprised of a granite block topping surface with mortar/concrete fill between the block joints. At the seaward end there are approximately 6-foot wide granite block steps for access to the beach. The beach access landing structure is proposed to be reconstructed in-kind with existing granite blocks and supplemental bedding stone fill material. The landing and access steps to the beach will be maintained and reconstructed for greater strength and resilience against coastal storms.

LIVING SHORELINE SALT MARSH ENHANCEMENT DESIGN

To further improve coastal resiliency of the shoreline area the City would like to implement an improved living shoreline element to restore the existing deteriorated salt marsh and dissipate wave energy. Salt marshes, as defined under the Massachusetts Wetlands Protection Act (WPA) 310 CMR 10.32, are significant to the protection of marine fisheries, wildlife habitat, land containing shellfish, prevention of pollution, and likely to be significant to storm damage prevention and ground water supply. The project seeks to not only protect the existing salt marsh but to allow for potential enhancement and restoration.

As shown from the metocean and wave analysis, wave heights were reduced by approximately 30 to 40 percent at the existing marsh for the 50-year and 100-year recurrence interval storm events. Comparatively, immediately adjacent to the east where there is no existing marsh, waves were reduced by less than 5 percent for the 10-year, 50-year, and 100-year recurrence interval storm events.

The proposed salt marsh enhancement design aims to stabilize the shoreline and reduce erosion, attenuate waves, and provide habitat for plant and animal species. The conceptual design was originally developed by Chester Engineers, Inc. in 2016 as part of a Salem Living Shoreline Project – Conceptual Designs report. Refer to the rendering by Chester Engineers, **Figure 4**.

Figure 4: Living Shoreline Salt Marsh Enhancement Rendering by Chester Engineers

The proposed salt marsh enhancement includes new toe protection sills at the seaward edge, sand nourishment to meet the level of the existing remnant salt marsh and to fill voids within the existing marsh, and new salt marsh plantings for enhanced vegetative cover.

TOE PROTECTION SILL

The proposed living shoreline salt marsh enhancement consists of the construction of new toe protection sills with sand nourishment fill, and salt marsh plantings. The site has existing stone riprap partially surrounded by salt marsh vegetation. The existing riprap generally consists of stone 2 to 2.5-feet in diameter (approximately 0.5 to 1 ton in weight). The top elevation of the existing stone ranges from approximately 2.1 feet NAVD88 to 2.7 feet NAVD88. The existing stone riprap will be manipulated and restacked so that each stone shall be interlocked and obtain firm contact with adjacent stones. Existing stone riprap will be restacked at an approximate consistent elevation 2.7 feet NAVD88.

A toe sill is proposed as a long-term toe protection measure for the marsh. The toe sill is proposed to be constructed with rock instead of coir logs, rocks are a longer-term solution and less prone to breaking down over time or movement due to coastal storms or sea level rise. Based on guidance from the Living Shorelines in New England State of the Practice Report, toe sills are recommended for moderate energy environments with potential wave heights of 2 to 5 feet.

A new toe sill will be constructed approximately 10 feet seaward of the existing stone riprap to allow for potential salt marsh vegetation establishment and growth. The top of the seaward sill will be at approximate elevation 2.0 feet NAVD88. Drainage ditches will also be incorporated in the sill to allow for tidal exchange to the salt marsh beyond.

SAND NOURISHMENT

Areas landward of the proposed new rock sill will be filled with sand nourishment fill with minimum 12-inches of wetland topsoil to match the existing elevation of adjacent salt marsh/ existing riprap stone. Edges of these infill areas will be stabilized with geotextile fabric and constructed in 12-inch lifts for stability. The top of the sandy infill area shall be anchored with coir matting and planted with elevation appropriate vegetation. The design focuses on mimicking the natural existing marsh system with target elevations for a low marsh (up to elevation 4.0 feet NAVD88) to be planted with *Spartina alterniflora*; and elevations for a high marsh (above elevation 4.0 feet NAVD88) to be planted with *Spartina patens*. Salt marsh plugs will be planted in staggered rows at maximum 18-inches on center.

Sand nourishment fill will be blended to match surrounding existing elevations. No more than 4-inches of sand nourishment fill should be placed over existing salt marsh vegetation. Chemical and grain size testing should be performed for suitable reuse of existing sand proposed for marsh nourishment fill.

Areas of 'pockmark' voids within the existing marsh will be treated by adding a boulder infill wrapped in erosion control blanket and surrounded by sand and with a minimum 6-inch clean sandy fill cover. This will, in addition to plantings, allow for accretion of sediments over these areas. The existing salt marsh area will receive additional plantings within bare or void areas. Salt marsh below elevation 4.0 feet NAVD88 will be augmented with plugs of *Spartina alterniflora*; and salt marsh above elevation 4.0 feet NAVD88 will be augmented with plugs of *Spartina patens.*

PLANTING, MONITORING AND MANAGEMENT

Planting of new vegetation should be performed in early to mid-spring to promote root growth and successful plant establishment. The salt marsh enhancement area should be protected with herbivory fencing and anti-goose netting. Fencing/netting should be in place from mid-April to mid-October and removed seasonally. It is recommended that a monitoring and adaptive management plan be established to outline specific criteria for successful salt marsh growth. Plantings should be monitored once per year during the peak biomass period (i.e. July or August) so that the vegetative cover may remain complete and durable.

BUDGETARY COST ESTIMATE

GZA has developed a preliminary budgetary cost estimate for the construction of the proposed work plan based on recent similar project experience and competitive bid prices and solicited quotes for similar work. GZA's preliminary budgetary cost estimate for the proposed scope of work is approximately $1,200,000. Refer to the cost estimate breakdown included in **Attachment C**.

PROJECT SCHEDULE

The following includes an updated project schedule based on work performed to date and in accordance with the project scope.

- **Task 1: Project Review** *(Completed)*

- **Task 2: Survey/Investigations and Existing Conditions Plan** *(Completed)*

- **Task 3: Design – Develop Proposed Plan and Sections** *(Completion by end of November 2020)*
    - Review meeting – anticipated by the end of October 2020.
    - Design/drawing and cost estimate revisions – estimated 2- to 4-weeks following the review meeting, to be completed by the end of November 2020.
- **Task 4: Permitting** *(Completion by September 2021)**
    - File an Environmental Notification Form (ENF) with the Massachusetts Environmental Policy Act (MEPA) – estimated 3-month duration to be completed by December 2020.
    - File a Notice of Intent (NOI) to obtain an Order of Conditions from the Salem Conservation Commission – estimated 3-month duration to be completed by February 2021.
    - File Waterways Chapter 91 License with the Massachusetts Department of Environmental Protection (MADEP) – estimated 6-month duration to be completed by September 2021.
    - File a Pre-Construction Notification (PCN) application with the U.S. Army Corps of Engineers (USACE) – estimated 2-month duration to be completed by June 2021.
- **Task 5: Final Design/Bid Document Preparation** *(August to September 2021)*
- **Task 6: Bid Solicitation** *(August to September 2021)*
- **Grant Funding for Construction** (Spring/Summer 2021)
- **Construction** *(November 2021 to April 2022 – 5-month duration, Plantings and Restoration late Spring 2022)*

*Since the granting of permits is at the discretion of the regulatory agencies, GZA cannot guarantee that permits will be issued nor can GZA control the time required to obtain permits after the initial submission of the applications.

SUMMARY AND CLOSING

The existing seawall has experienced significant recent storm damage during the 2018 Nor'easters including raveled stones and failed portions of wall. The surrounding area also experienced damage including flooding of residential dwellings and sinkholes within the public sidewalk adjacent to the seawall. If left as-is, the wall will likely continue to degrade and fail, further compromising the residential dwellings and safety of residents.

The proposed project seawall reconstruction and living shoreline salt marsh enhancement designs will provide a holistic improvement with increased shoreline stabilization and coastal storm/flood protection and resiliency. Specific site improvements of the proposed project include:

- Reconstructed seawall to provide increased protection to the roadway, public walkway, dwellings, utilities, and other landside features.

- A more resilient structure and shoreline area less prone to degradation from wave surge/flooding conditions and design elements that help dissipate wave energy.
- Increased protection and flood prevention with a reduced access opening and improved access to the beach.
- Promotion of nature-based and natural elements to provide a more resilient shoreline able to withstand the significant flooding and coastal storm events.
- Minimized maintenance to the seawall and associated costs.
- Reconstruction within same wall footprint

We have anticipated that a meeting will be arranged, upon the City's review of this letter. If you have any further questions or require any additional information, please do not hesitate to call David Smith at 781-278-4806 or email at David.smith@gza.com.

Very truly yours,
GZA GEOENVIRONMENTAL, INC.

Lucas Taylor
Project Engineer

David A. Smith
Senior Project Manager

Attachments:
Figures 1 through 6, Dated October 2020
Attachment A – Limitations
Attachment B – Metocean and Wave Analysis
Attachment C – Preliminary Budgetary Cost Estimate

Figures

SEAWALL RECONSTRUCTION

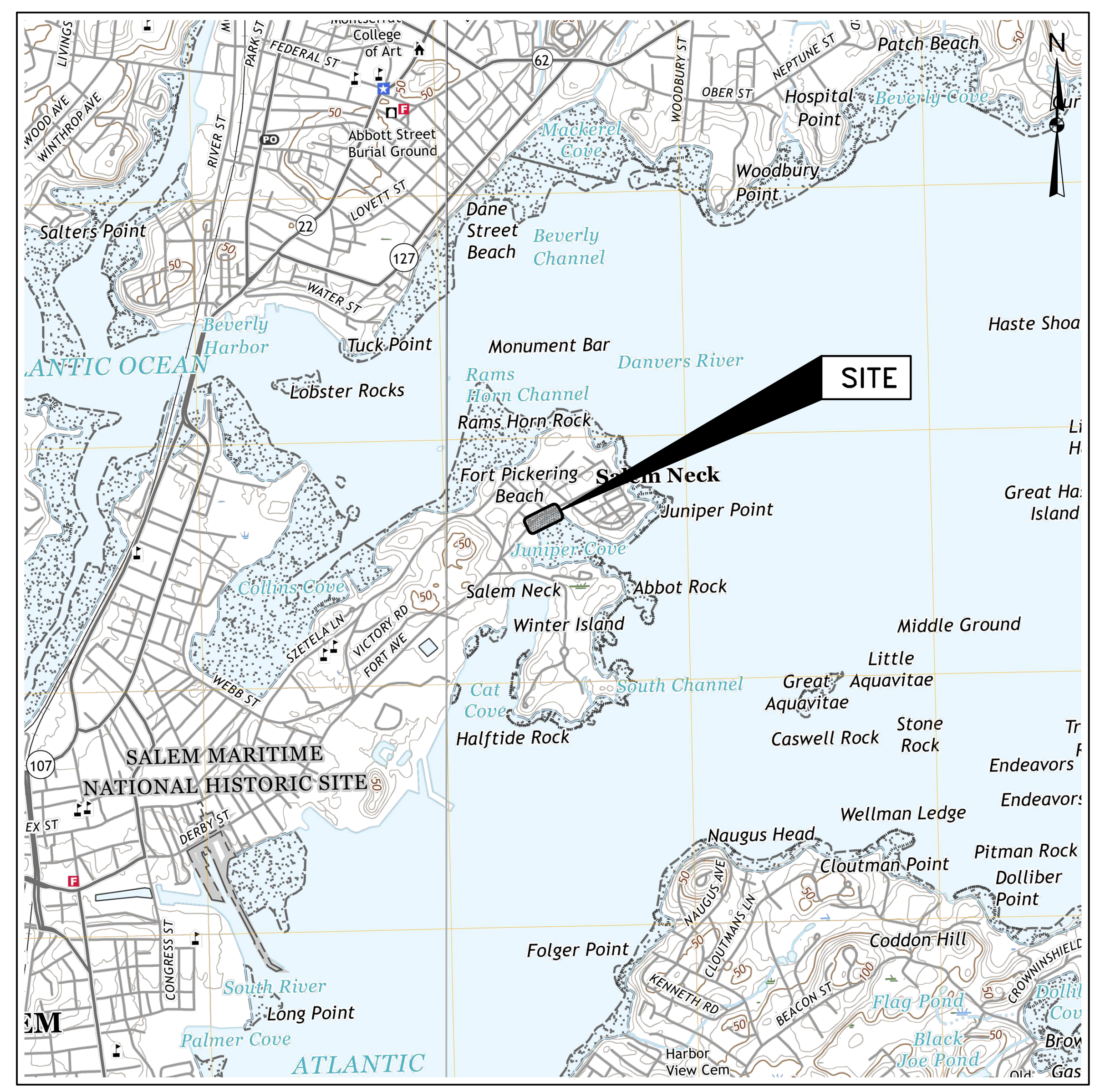
COLUMBUS AVENUE SEAWALL RECONSTRUCTION
SALEM, MASSACHUSETTS
EEA #258-2020-3

OWNER

CITY OF SALEM
120 WASHINGTON STREET
SALEM, MASSACHUSETTS

PROJECT ENGINEER

GZA GEOENVIRONMENTAL, INC.
144 ELM STREET
AMESBURY, MA 01913



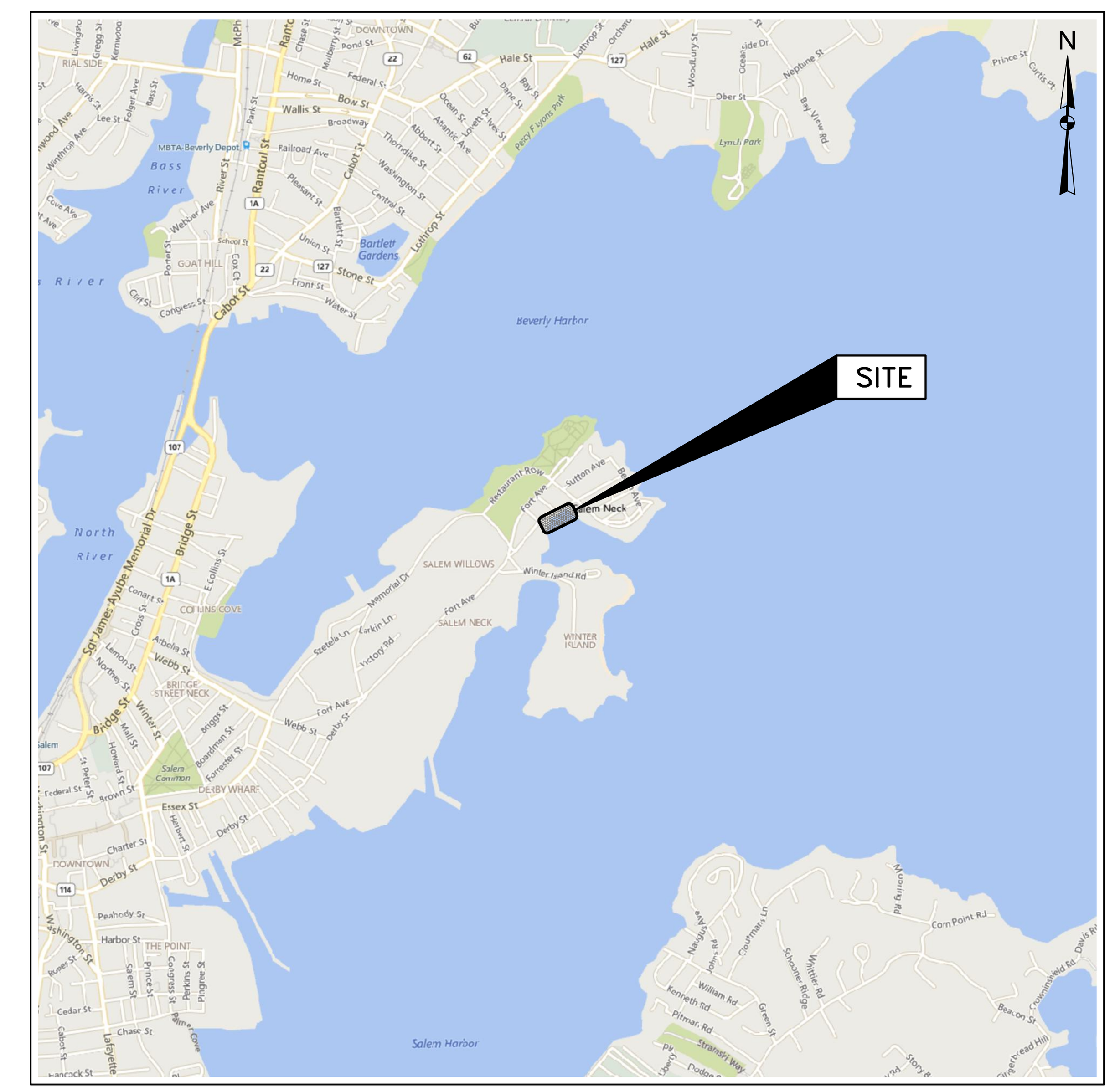
PROJECT LOCUS MAP

SOURCE: USGS TOPOGRAPHIC QUADRANGLES
SCANNED BY MASSGIS AND DISTRIBUTED IN 2018

CONTOUR ELEVATIONS REFERENCE NAVD 88,
CONTOURS AND ELEVATIONS ARE SHOWN IN FEET

0 1000' 2000' 4000' 6000'

SCALE: 1" = 2000 FEET



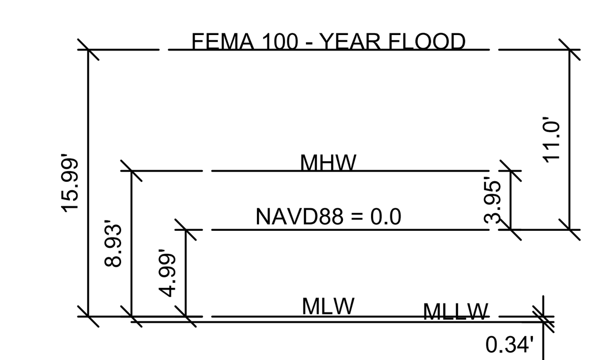
AREA ROAD MAP

SOURCE: BING ROAD MAP DOWNLOADED FROM
AUTOCAD GEOLOCATION MAP SERVICES

0 1000' 2000' 4000' 6000'

SCALE: 1" = 2000 FEET

INDEX OF DRAWINGS



DATUM RELATIONSHIP
NOT TO SCALE

GENERAL NOTES

1. ELEVATIONS ARE IN FEET AND REFERENCE THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88): MLW=-4.99, NAVD88=0.0, MHW=3.95, HTL=6.36, FEMA 100-YEAR FLOOD ZONE AE=11.0.
2. LIMITED TOPOGRAPHIC SURVEY PERFORMED BY GZA GEOENVIRONMENTAL, INC., ON MARCH 31, 2020 AND REPRESENTS CONDITIONS AT THE TIME OF THE SURVEY.
3. APPROXIMATE SALT MARSH LIMITS SHOWN BASED ON SURVEY OBSERVATIONS BY GZA GEOENVIRONMENTAL, INC., ON MARCH 31, 2020.
4. PROPERTY LINES ARE APPROXIMATE AND WERE SCALED FROM ONLINE AVAILABLE MASSGIS DATA LAYERS.

Executive Office of Energy and Environmental Affairs

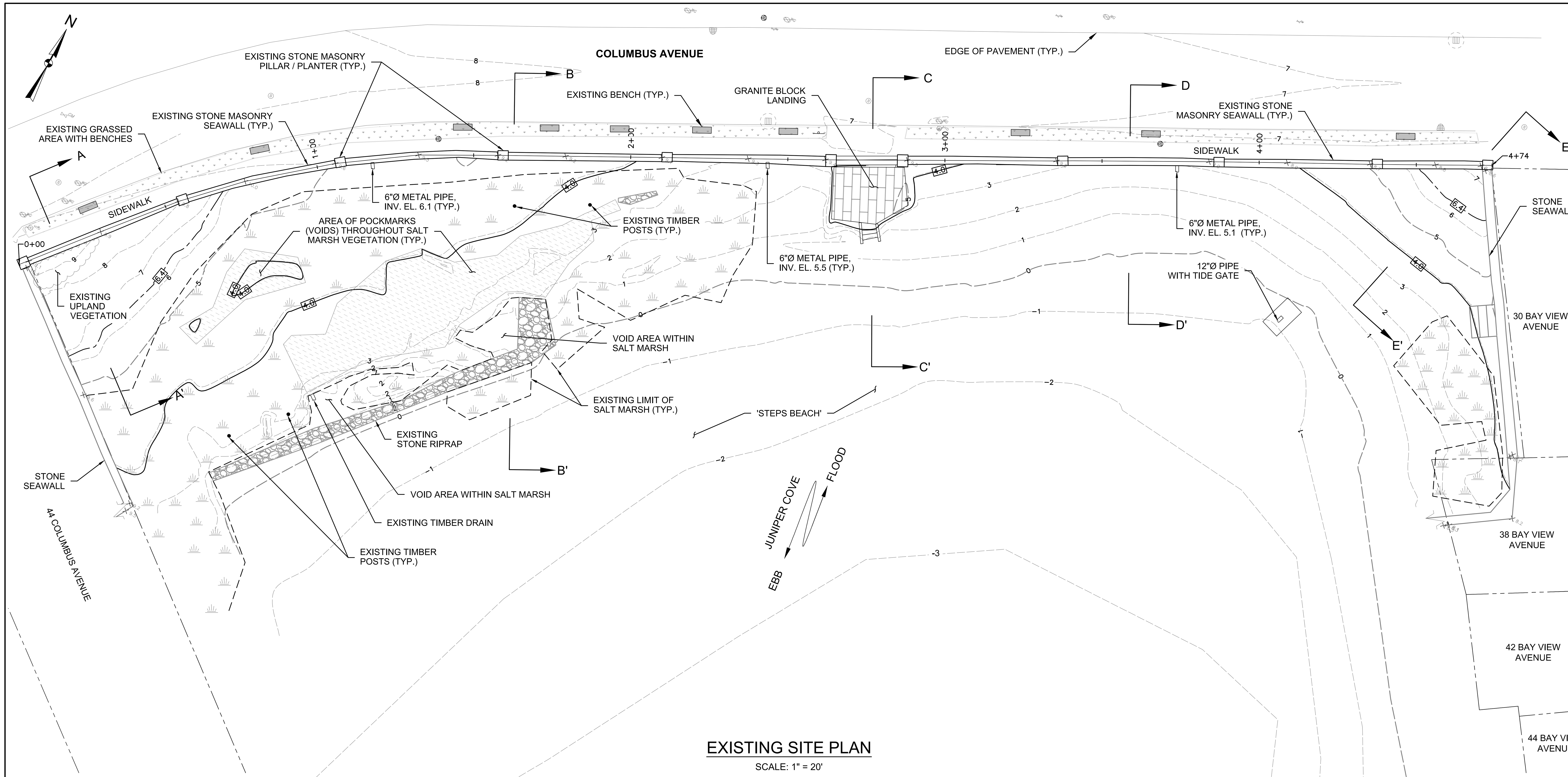
EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS
DAM, LEVEE AND COASTAL FORESHORE PROTECTION REPAIR AND REMOVAL

THIS PROJECT IS FUNDED BY THE EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS

COLUMBUS AVENUE SEAWALL RECONSTRUCTION
SALEM, MASSACHUSETTS
(EEA #258-2020-3)

COVER SHEET

PREPARED BY:		PREPARED FOR:	
GZA GeoEnvironmental, Inc. Engineers and Scientists www.gza.com		CITY OF SALEM 120 WASHINGTON STREET SALEM, MASSACHUSETTS	
PROJ MGR: DAS	REVIEWED BY: DAS	CHECKED BY: -	DRAWING
DESIGNED BY: DAS	DRAWN BY: AJP	SCALE: AS SHOWN	1
DATE: OCTOBER 2020	PROJECT NO. 18.0171674.04	REVISION NO. -	SHEET NO. 1 OF 6



EXISTING SITE PLAN

SCALE: 1" = 20'

GENERAL NOTES

1. ELEVATIONS ARE IN FEET AND REFERENCE THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88): MLW=-4.99, NAVD88=0.0, MHW=3.95, HTL=6.36, FEMA 100-YEAR FLOOD ZONE AE=11.0.
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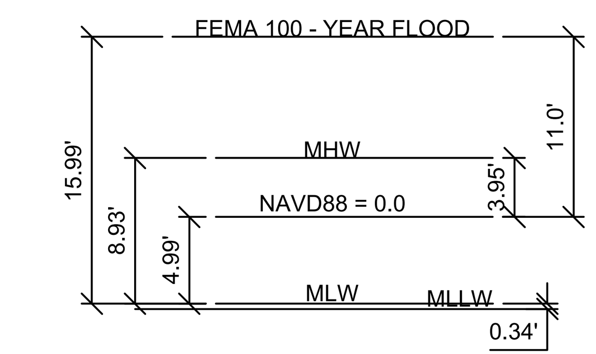
4. PROPERTY LINES ARE APPROXIMATE AND WERE SCALED FROM ONLINE AVAILABLE MASSGIS DATA LAYERS.

LEGEND

- EXISTING CONTOUR MAJOR
- EXISTING CONTOUR MINOR
- MEAN HIGH WATER [MHW]
- HIGH TIDE LINE [HTL]
- APPROXIMATE PROPERTY LINE
- SALT MARSH AREA
- POCKMARKS WITHIN SALT MARSH AREA
- GRASS



DATUM RELATIONSHIP

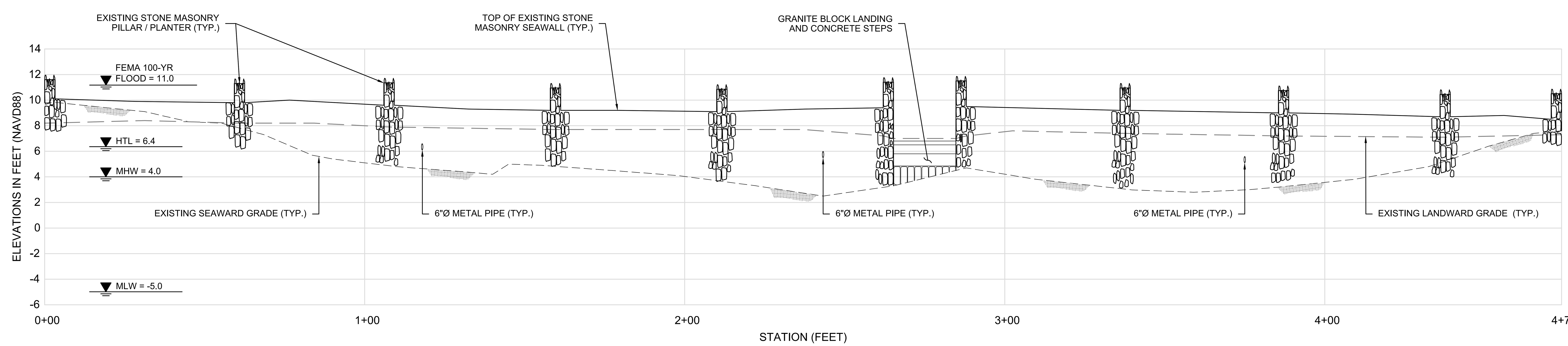
NOT TO SCALE

VERTICAL SCALE IN FEET: 0, 2.5, 5, 10, 15

HORIZONTAL SCALE IN FEET: 0, 10, 20, 40, 60

SCALE IN FEET: 0, 10, 20, 40, 60

DRAFT COPY
NOT FOR CONSTRUCTION



EXISTING SEAWALL PROFILE

VERTICAL SCALE: 1" = 5'
HORIZONTAL SCALE: 1" = 20'

EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS
DAM, LEVEE AND COASTAL FORESHORE PROTECTION REPAIR AND REMOVAL

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NO.	ISSUE/DESCRIPTION	BY	DATE

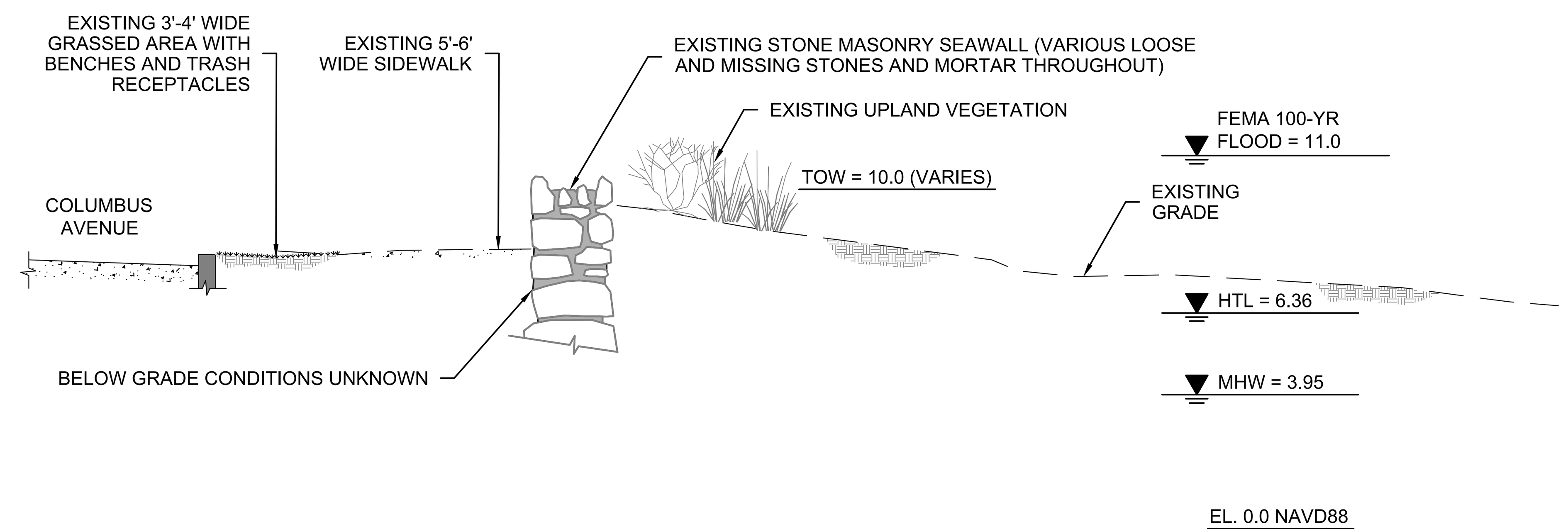
COLUMBUS AVENUE SEAWALL RECONSTRUCTION
SALEM, MASSACHUSETTS
(EEA #258-2020-3)

EXISTING CONDITIONS PLAN AND PROFILE

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

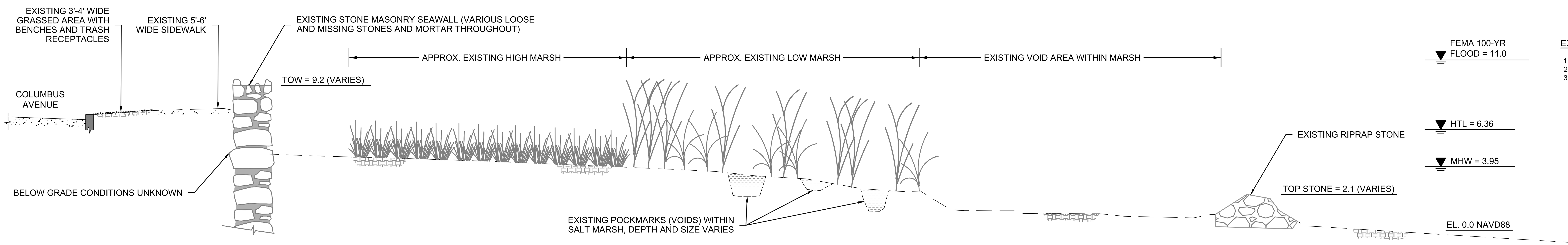
PREPARED FOR: CITY OF SALEM, 120 WASHINGTON STREET, SALEM, MASSACHUSETTS

PROJ MGR: DAS	REVIEWED BY: DAS	CHECKED BY: -	DRAWING
DESIGNED BY: DAS	DRAWN BY: LFT	SCALE: AS SHOWN	2
DATE: OCTOBER 2020	PROJECT NO. 18.0171674.04	REVISION NO. -	SHEET NO. 2 OF 6



EXISTING SECTION A - A': STA 0+14

SCALE: 1" = 4'

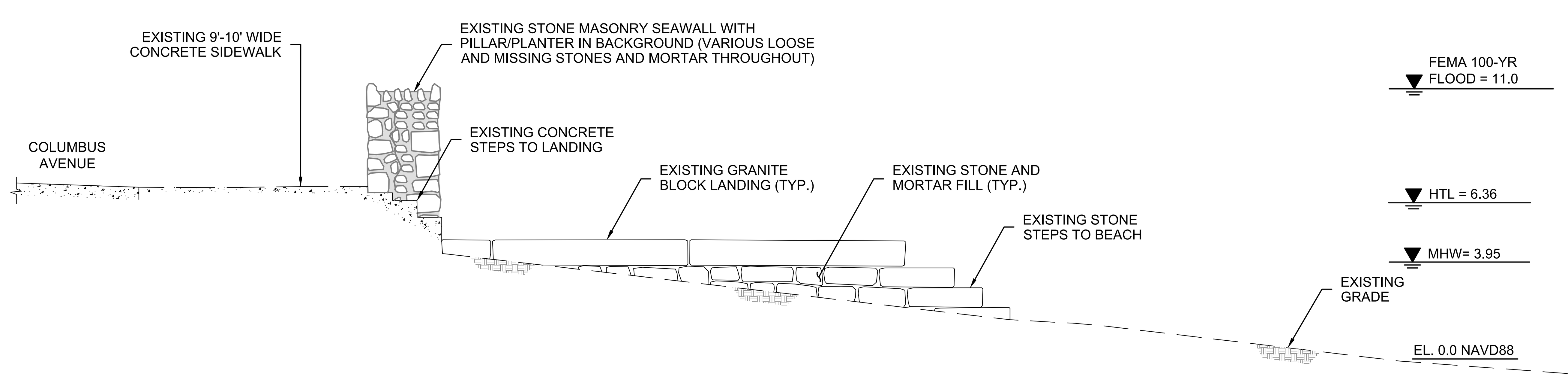


EXISTING STONE RIPRAP NOTES

1. EXISTING RIPRAP GENERALLY CONSISTS OF STONE SIZED ±2' TO 2.5'Ø (±0.5 TO 1 TON IN WEIGHT).
2. TOP OF STONE ELEVATION VARIES FROM APPROXIMATELY 2.1 TO 2.7 FEET NAVD88.
3. RIPRAP SILL IS GENERALLY 5' WIDE BUT VARIES ALONG ITS LENGTH.

EXISTING SECTION B - B': STA 1+63

SCALE: 1" = 4'



0 2 4 8 12

SCALE IN FEET

DRAFT COPY
NOT FOR CONSTRUCTION

EXISTING SECTION C - C': STA 2+77

SCALE: 1" = 4'

EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS
DAM, LEVEE AND COASTAL FORESHORE PROTECTION REPAIR AND REMOVAL

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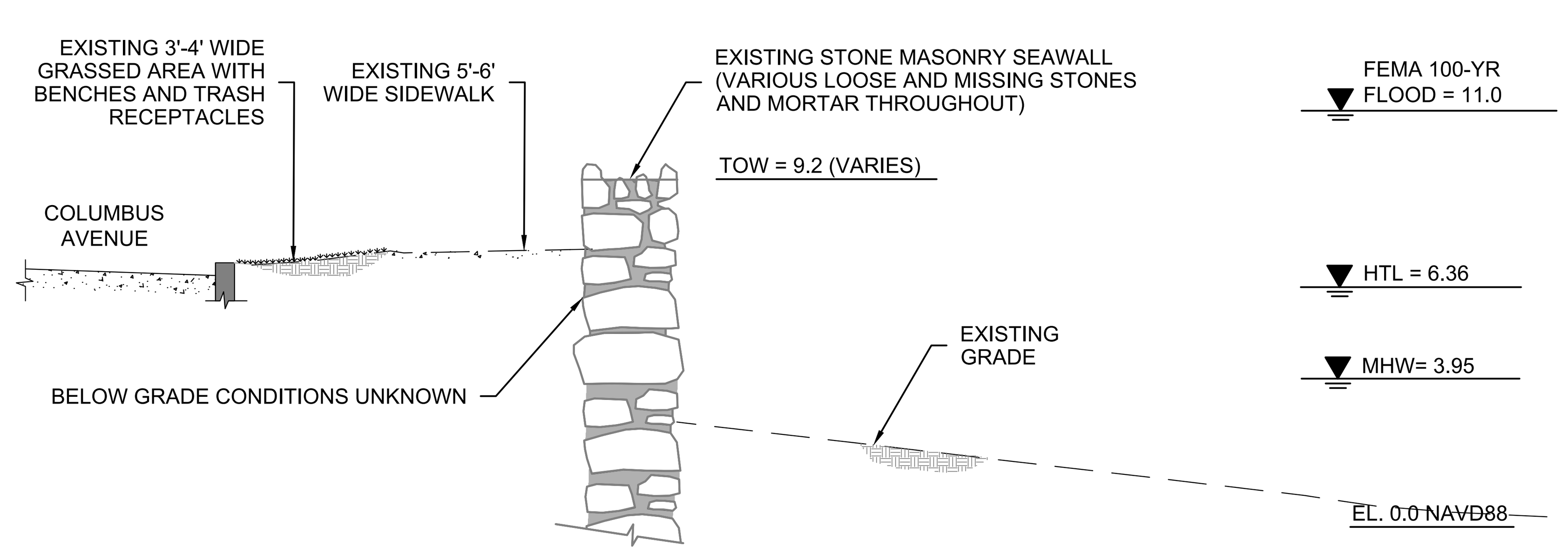
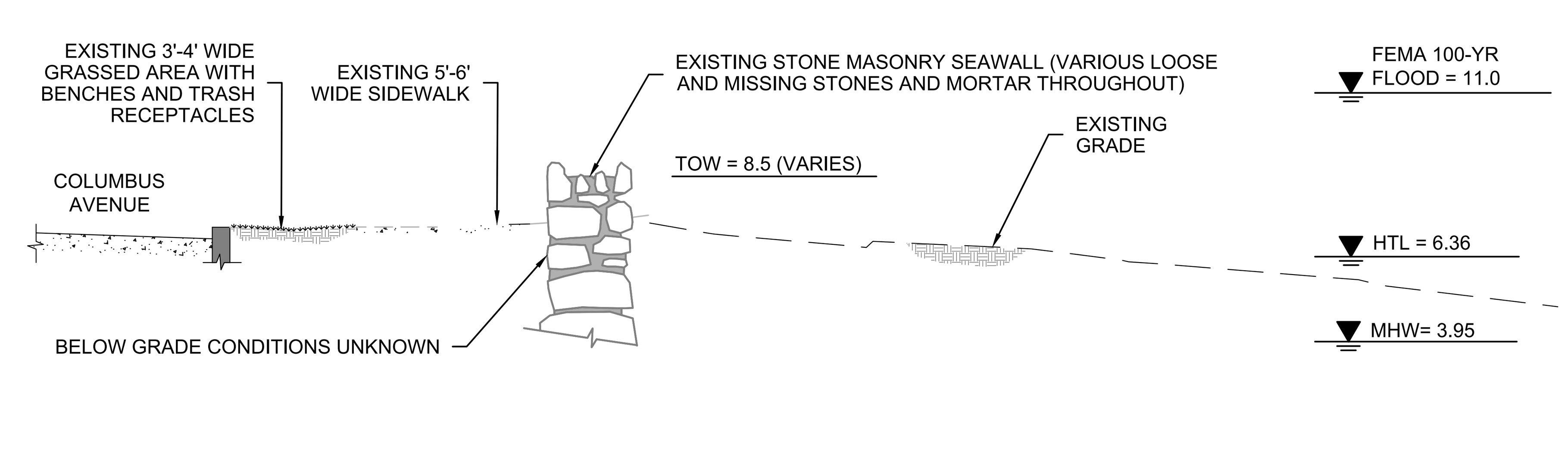


EXISTING SECTION D - D': STA 3+59

SCALE: 1" = 4'



EXISTING SECTION E - E': STA 4+70

SCALE: 1" = 4'

NO.	ISSUE/DESCRIPTION	BY	DATE

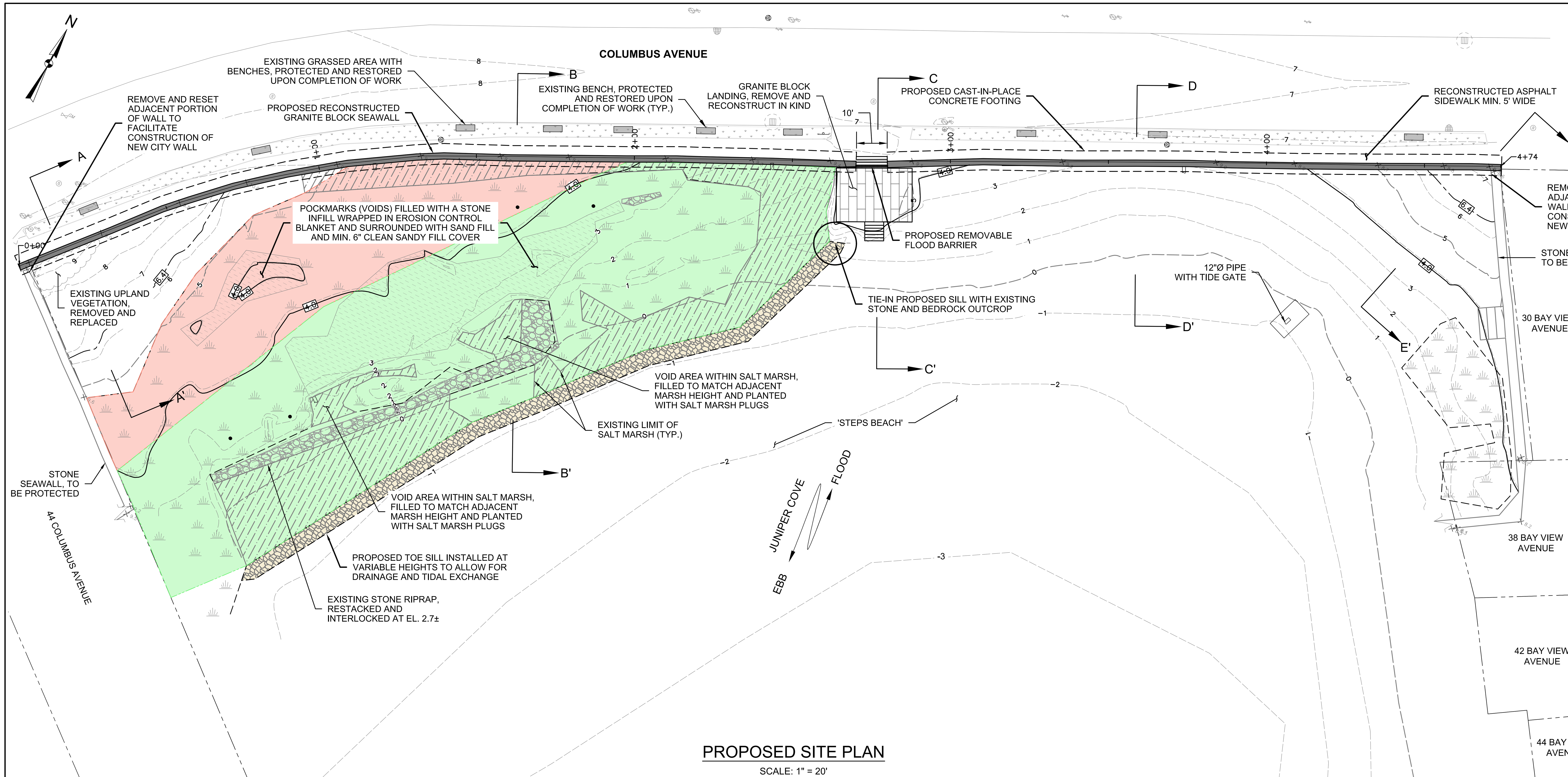
COLUMBUS AVENUE SEAWALL RECONSTRUCTION
SALEM, MASSACHUSETTS
(EEA #258-2020-3)

EXISTING SECTIONS

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

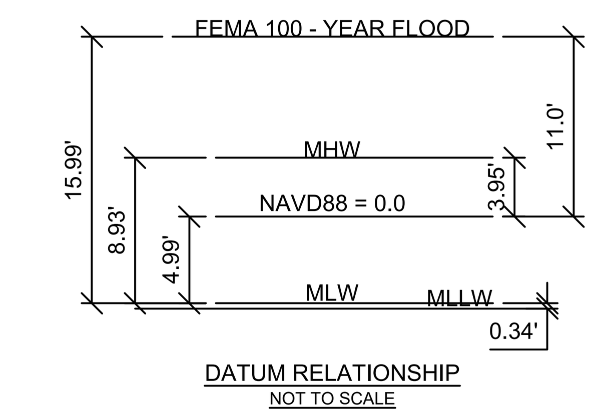
PREPARED FOR:
CITY OF SALEM
120 WASHINGTON STREET
SALEM, MASSACHUSETTS

PROJ MGR: DAS	REVIEWED BY: DAS	CHECKED BY: -	DRAWING
DESIGNED BY: DAS	DRAWN BY: LFT	SCALE: AS SHOWN	3
DATE: OCTOBER 2020	PROJECT NO. 18.0171674.04	REVISION NO. -	SHEET NO. 3 OF 6



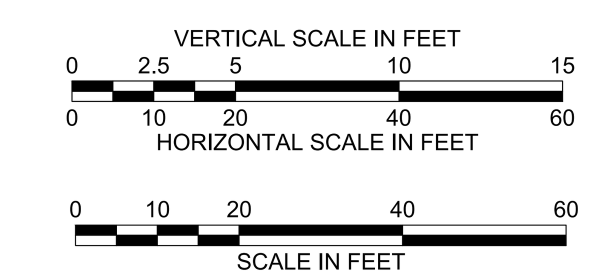
PROPOSED SITE PLAN

SCALE: 1" = 20'



DATUM RELATIONSHIP

NOT TO SCALE



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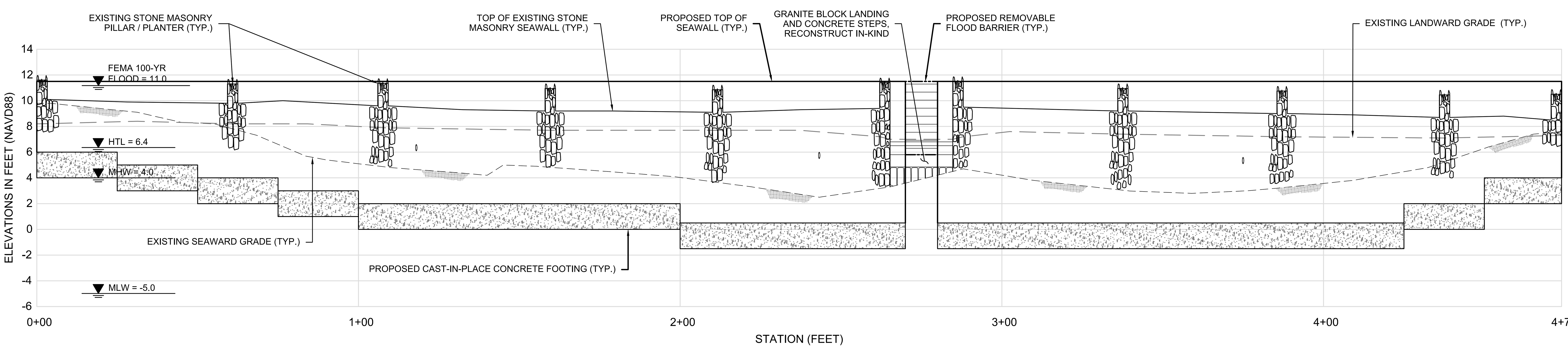
NOT FOR CONSTRUCTION



PROPOSED SEAWALL PROFILE

VERTICAL SCALE: 1" = 5'
HORIZONTAL SCALE: 1" = 20'

EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS
DAM, LEVEE AND COASTAL FORESHORE PROTECTION REPAIR AND REMOVAL

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COLUMBUS AVENUE SEAWALL RECONSTRUCTION
SALEM, MASSACHUSETTS
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PROPOSED CONDITIONS PLAN AND PROFILE

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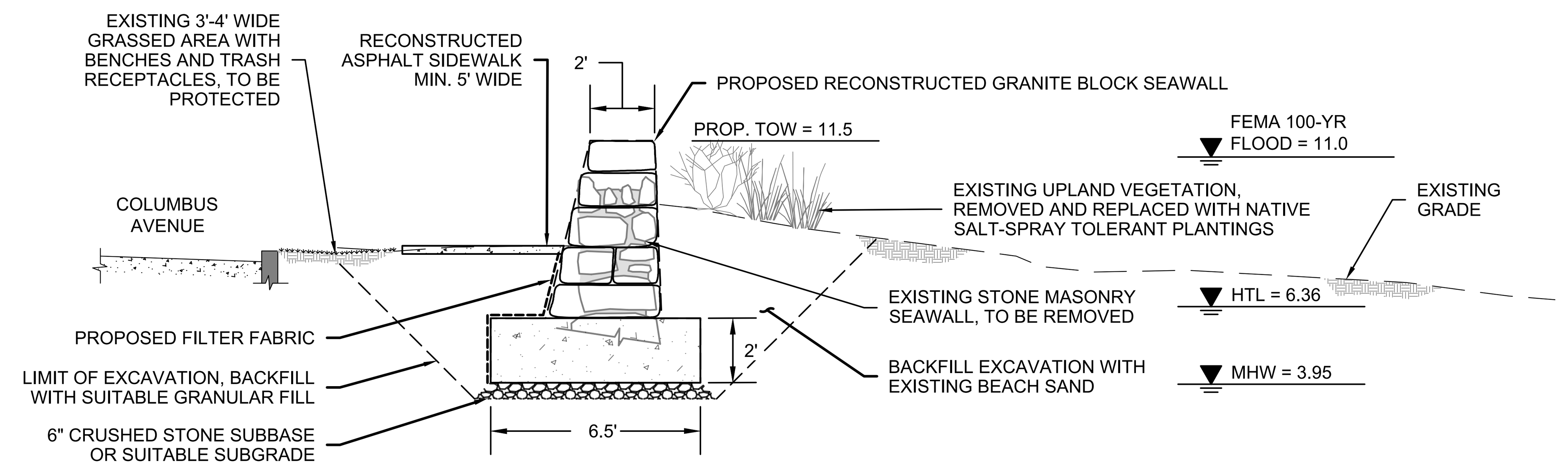
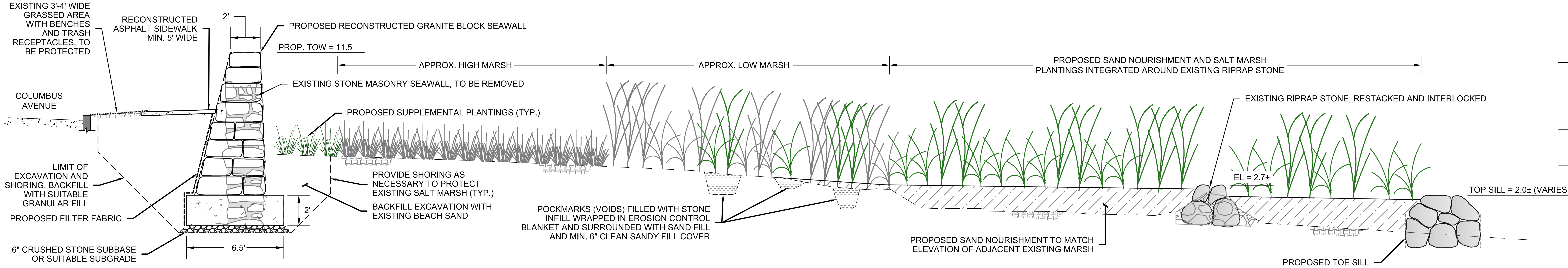
DESIGNED BY: DAS	DRAWN BY: LFT	SCALE: AS SHOWN	4
DATE: OCTOBER 2020	PROJECT NO. 18.0171674.04	REVISION NO. -	SHEET NO. 4 OF 6



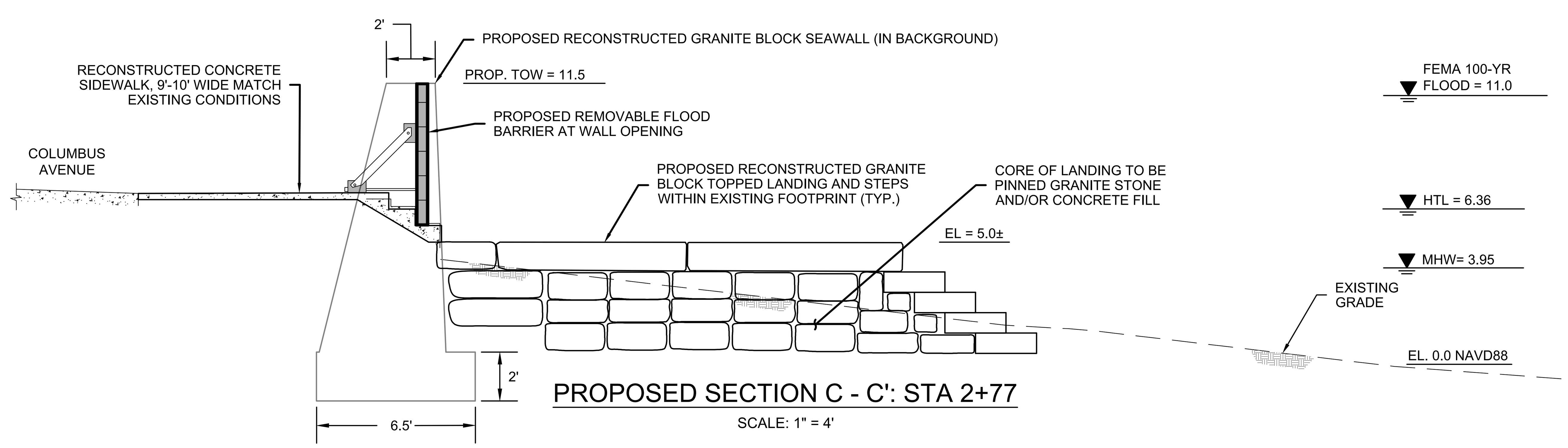
PROPOSED SECTION A - A': STA 0+14

SCALE: 1" = 4'



PROPOSED SECTION B - B': STA 1+63

SCALE: 1" = 4'



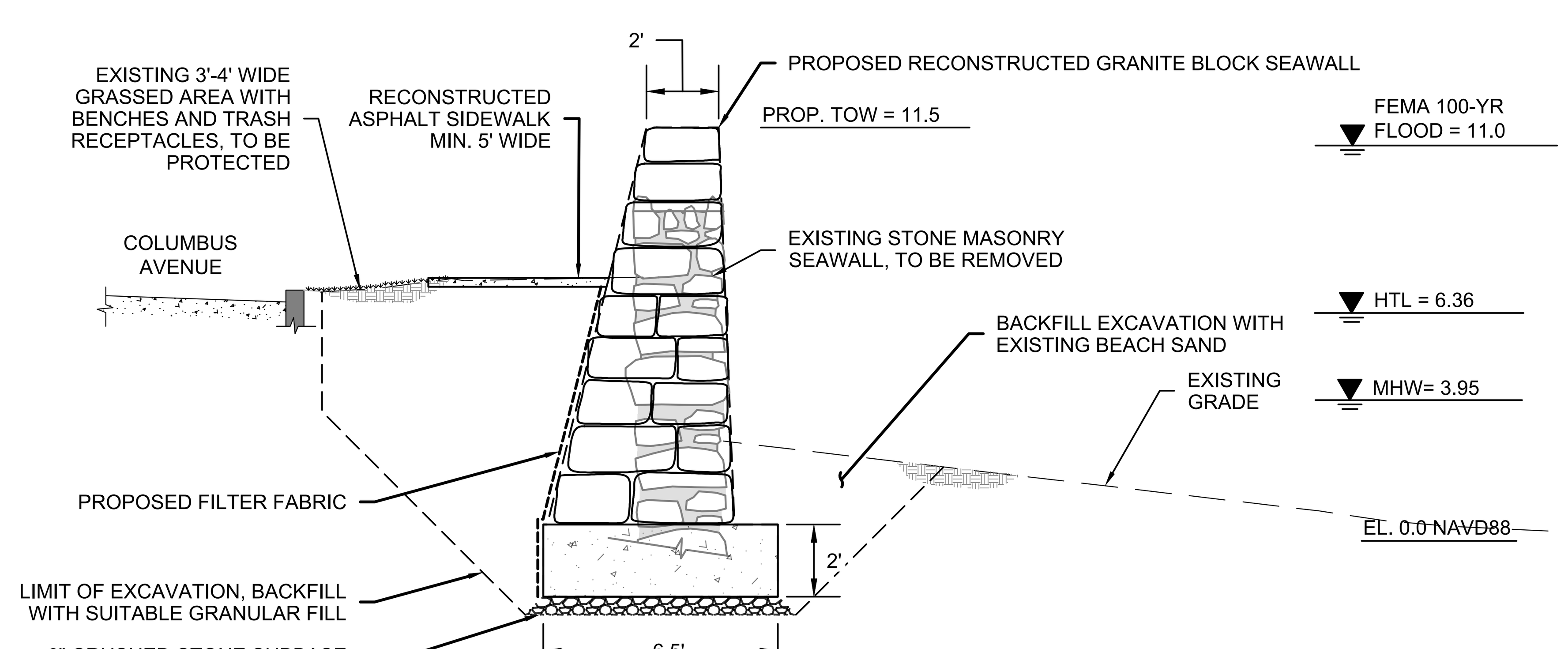
PROPOSED SECTION C - C': STA 2+77

SCALE: 1" = 4'

0 2 4 8 12

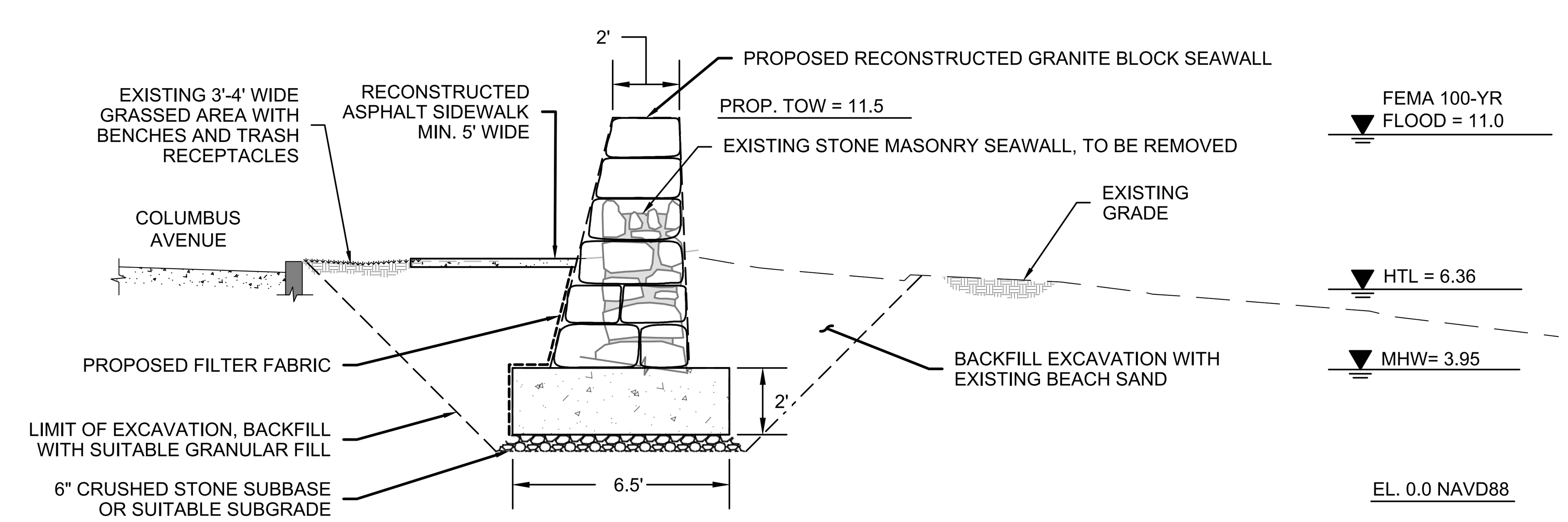
SCALE IN FEET

DRAFT COPY
NOT FOR CONSTRUCTION



PROPOSED SECTION D - D': STA 3+59

SCALE: 1" = 4'



PROPOSED SECTION E - E': STA 4+70

SCALE: 1" = 4'

EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS
DAM, LEVEE AND COASTAL FORESHORE PROTECTION REPAIR AND REMOVAL

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NO.	ISSUE/DESCRIPTION	BY	DATE

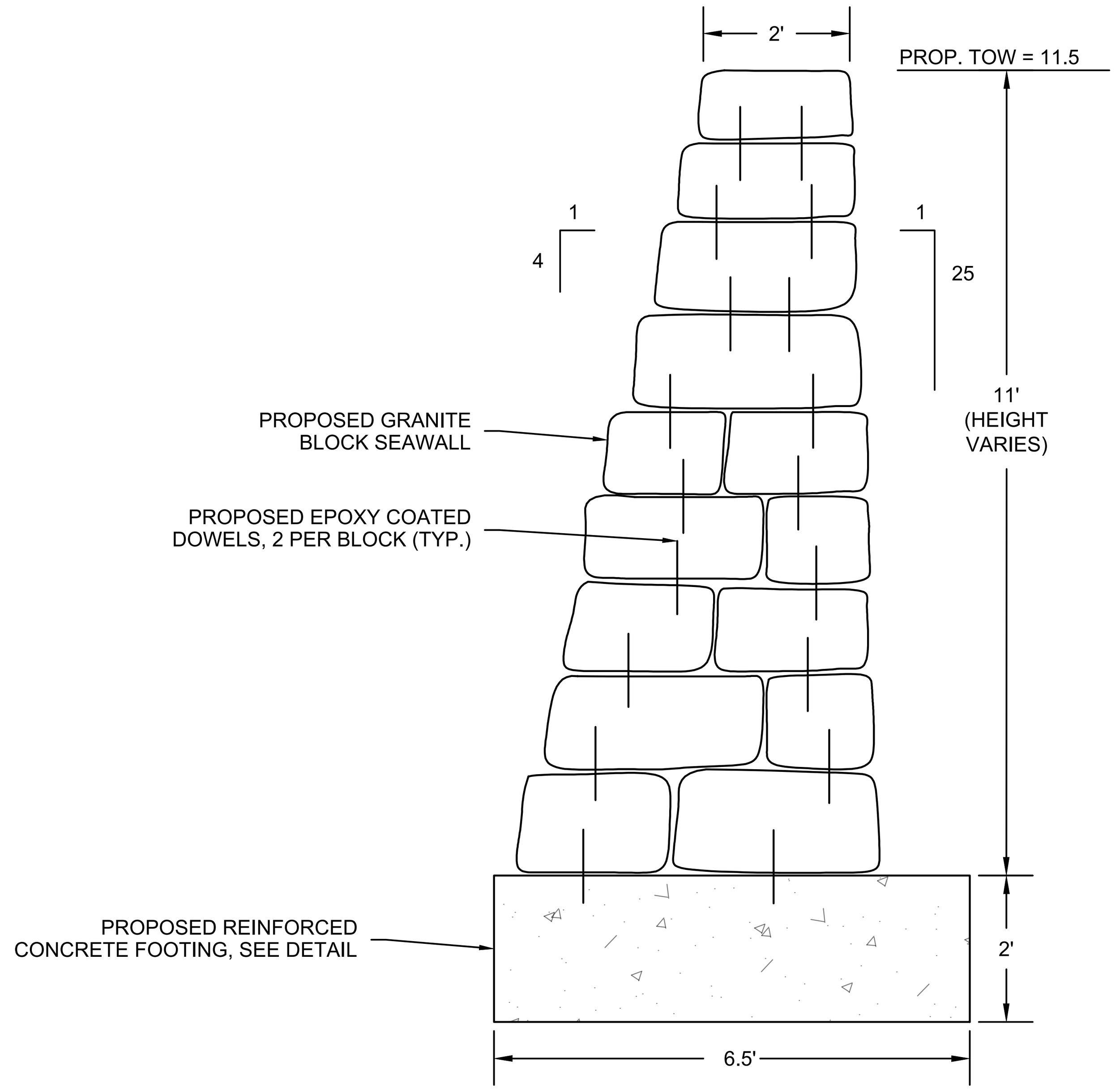
COLUMBUS AVENUE SEAWALL RECONSTRUCTION
SALEM, MASSACHUSETTS
(EEA #258-2020-3)

PROPOSED SECTIONS

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

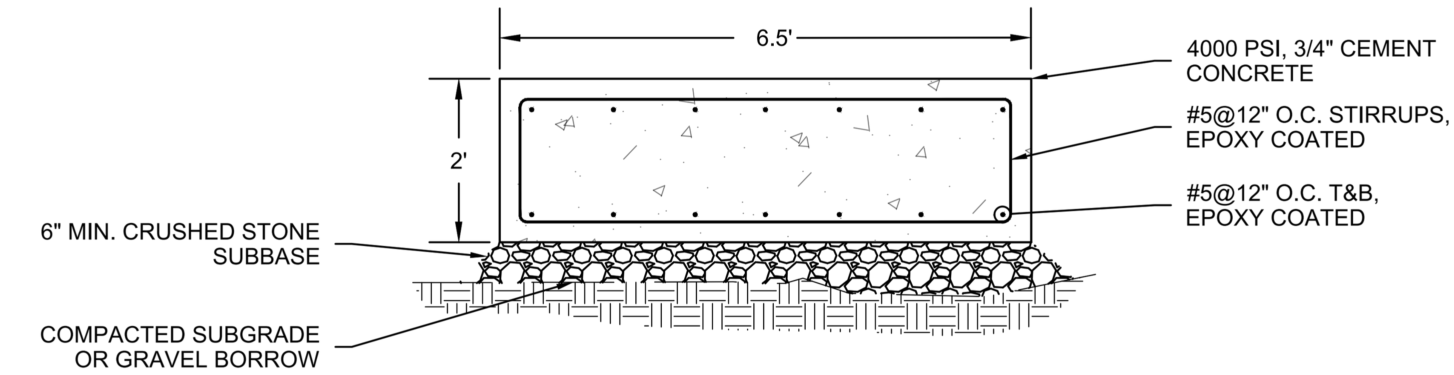
PREPARED FOR: CITY OF SALEM, 120 WASHINGTON STREET, SALEM, MASSACHUSETTS

PROJ MGR: DAS	REVIEWED BY: DAS	CHECKED BY: -	DRAWING
DESIGNED BY: DAS	DRAWN BY: LFT	SCALE: AS SHOWN	5
DATE: OCTOBER 2020	PROJECT NO. 18.0171674.04	REVISION NO. -	SHEET NO. 5 OF 6



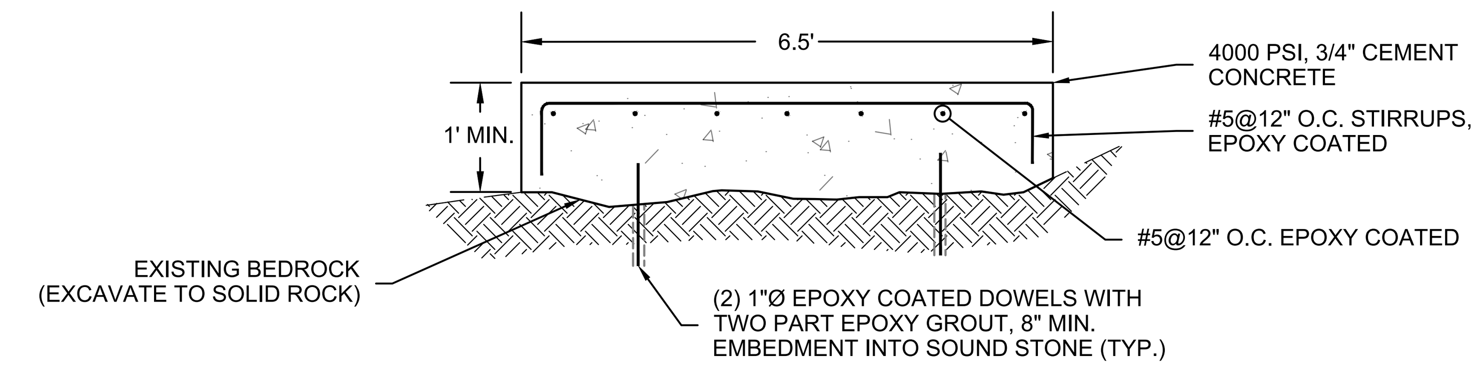
TYPICAL PROPOSED GRANITE BLOCK SEAWALL DETAIL

SCALE: 1" = 2'



TYPICAL PROPOSED FOOTING DETAIL ON GRADE

SCALE: 1" = 2'

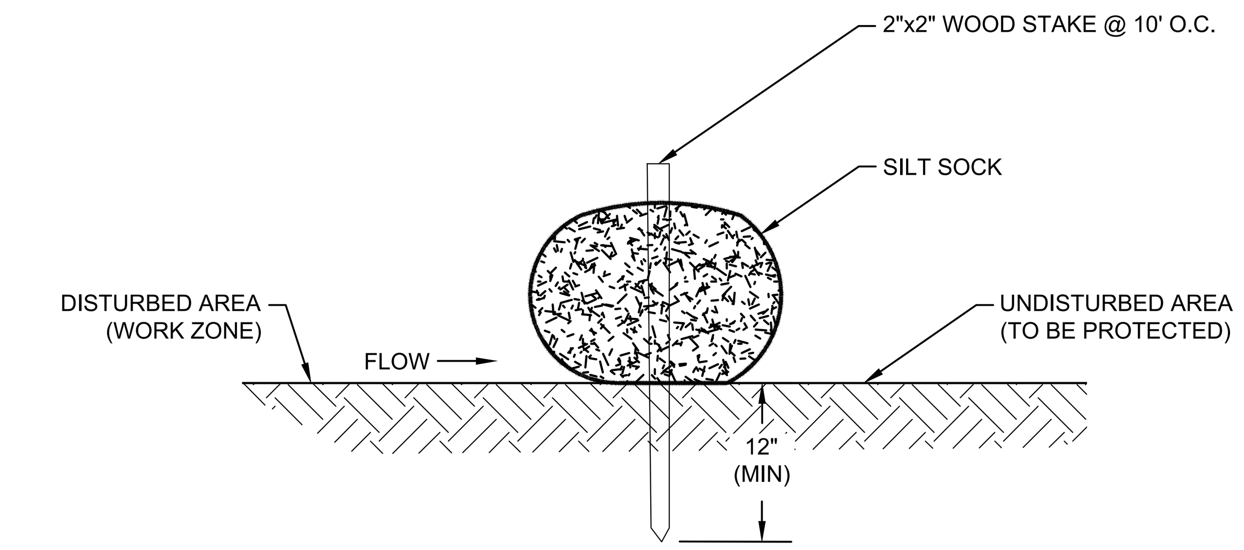


TYPICAL PROPOSED FOOTING DETAIL ON BEDROCK

SCALE: 1" = 2'

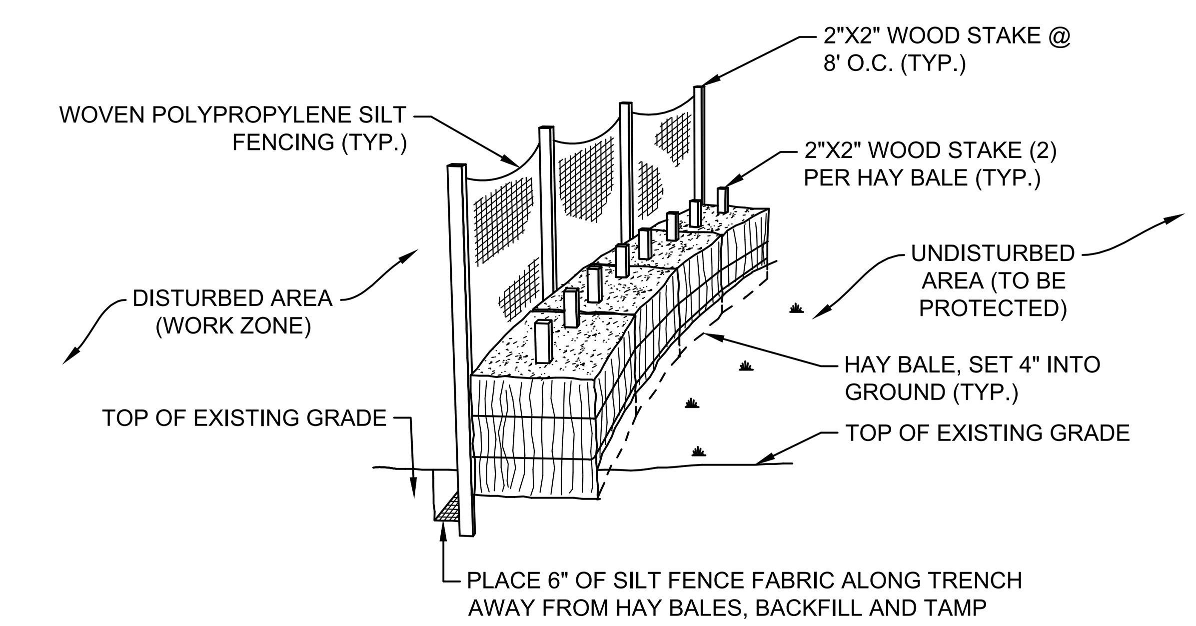
PROPOSED FOOTING NOTES:

1. CEMENT CONCRETE SHALL BE 4000 PSI, 3/4" AGGREGATE.
2. REINFORCING STEEL SHALL BE EPOXY COATED.
3. ALL REINFORCING BARS ARE TO BE A MINIMUM 3" CLEAR FROM FACE OF CONCRETE WHERE CONCRETE IS EXPOSED TO EARTH.
4. SITE CONDITIONS ENCOUNTERED DURING CONSTRUCTION DETERMINE FOOTING DETAIL USED.



TEMPORARY EROSION CONTROL - TYPICAL SILT SOCK DETAIL

SCALE: N.T.S.



TEMPORARY EROSION CONTROL - TYPICAL SILT FENCE WITH HAY BALES DETAIL

SCALE: N.T.S.

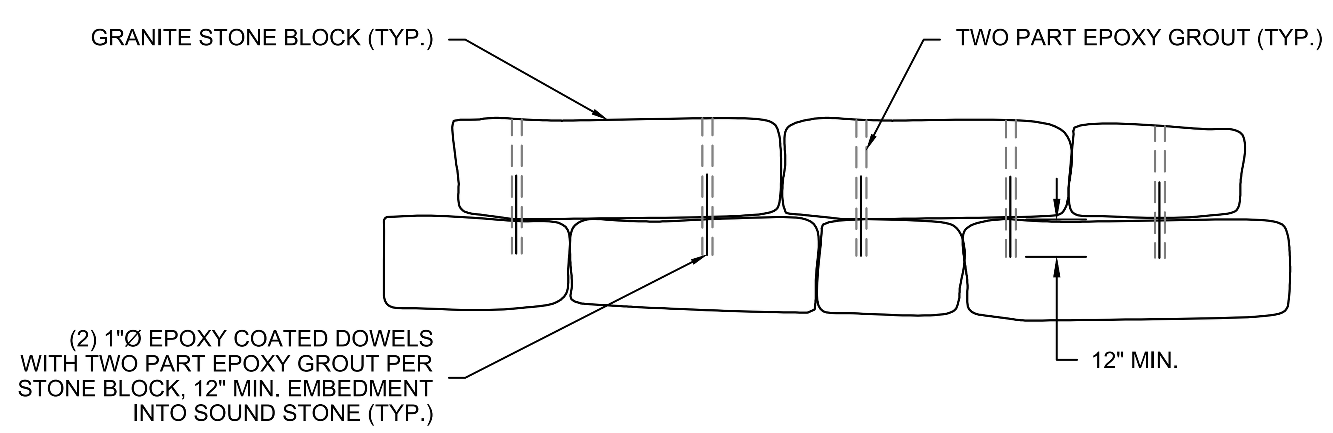
EROSION CONTROL NOTES:

1. EROSION CONTROLS SHALL BE INSTALLED BETWEEN THE LIMITS OF WORK AND BORDERING VEGETATED WETLANDS.
2. THE EROSION CONTROLS SHALL ALSO ACT AS A LIMIT OF DISTURBANCE, AND NO ALTERATION SHALL TAKE PLACE BEYOND IT.
3. EROSION CONTROLS SHALL BE INSPECTED DURING WORK AND MAINTAINED IN GOOD REPAIR.
4. EROSION CONTROLS SHALL REMAIN IN PROPER FUNCTIONING CONDITION UNTIL ALL DISTURBED AREAS HAVE BEEN STABILIZED WITH VEGETATION OR OTHER MEANS.
5. SILT SOCKS MUST BE PLACED PARALLEL TO CONTOUR WITH BOTH ENDS OF THE SOCK EXTENDED UPSLOPE AT A 45 DEGREE ANGLE TO THE REST OF THE SOCK TO PREVENT END-AROUNDS.
6. HAY BALES SHALL BUTT TOGETHER.

0 2 4 8 12

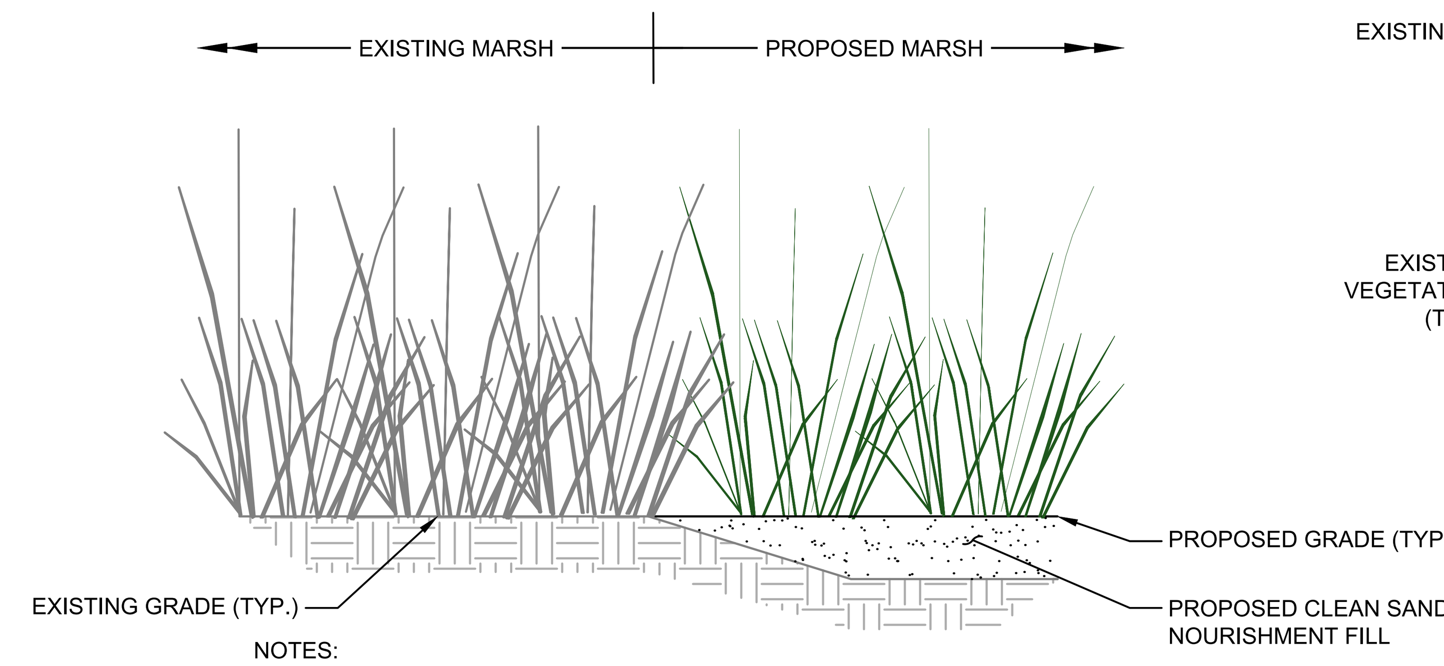
SCALE IN FEET

DRAFT COPY
NOT FOR CONSTRUCTION



STONE MASONRY ANCHORING DETAIL

SCALE: N.T.S.

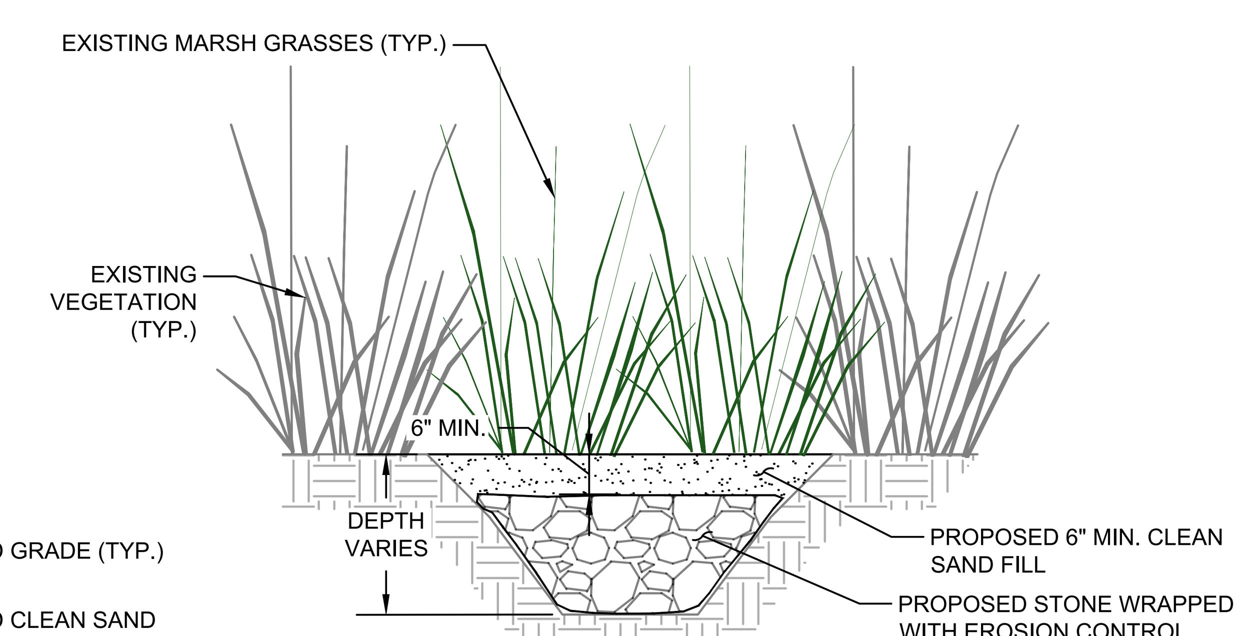


NOTES:

1. EXISTING SALT MARSH AREAS TO BE DELINEATED AND PROTECTED DURING CONSTRUCTION.
2. USE EXTREME CARE WHEN PLACING SALT MARSH ADJACENT TO EXISTING SALT MARSH AREAS.
3. MAXIMUM THICKNESS OF 4" OF CLEAN SAND NOURISHMENT FILL ALLOWED OVER EXISTING VEGETATION.
4. EXISTING VEGETATION SHALL EXTEND ABOVE PROPOSED SAND FILL AND SHALL NOT BE LAID FLAT AND BURIED.

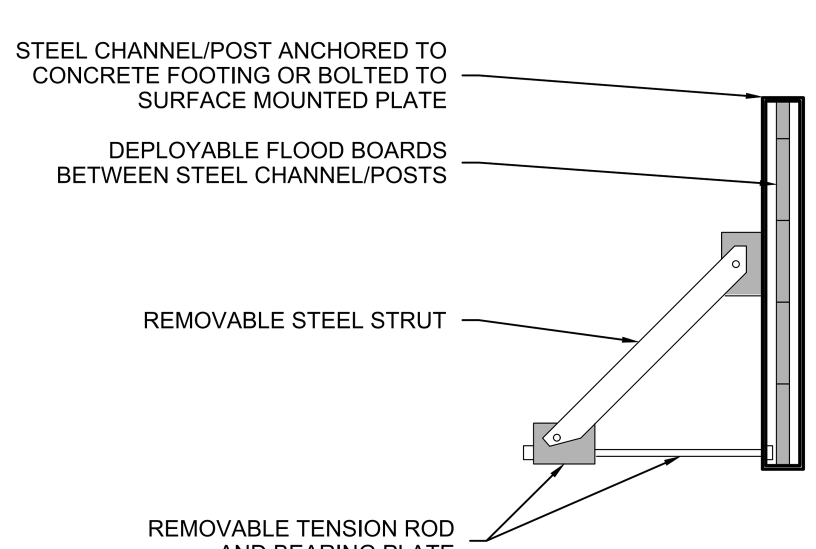
TIE-IN WITH EXISTING MARSH DETAIL

SCALE: N.T.S.



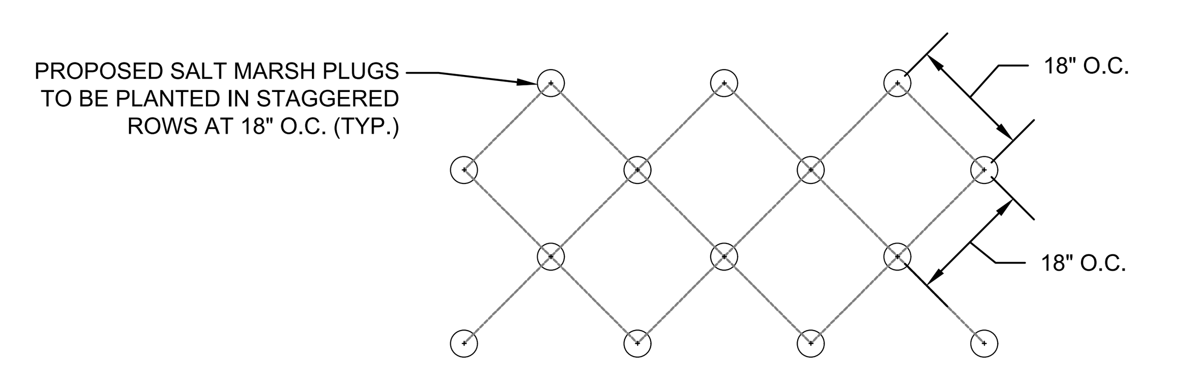
SALT MARSH VOID DETAIL

SCALE: N.T.S.



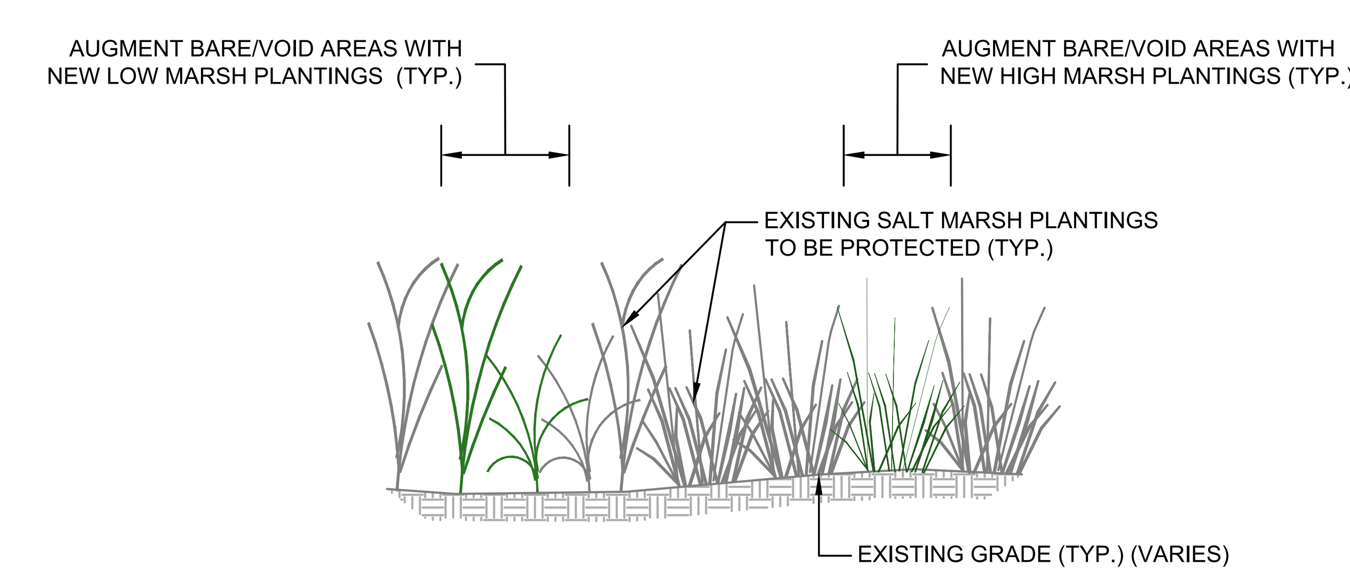
PROPOSED FLOOD BARRIER DETAIL

SCALE: 1" = 2'



TYPICAL SALT MARSH PLANTING DETAIL

SCALE: N.T.S.



SUPPLEMENTAL SALT MARSH PLANTINGS DETAIL

SCALE: N.T.S.

Executive Office of Energy and Environmental Affairs

EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS
DAM, LEVEE AND COASTAL FORESHORE PROTECTION REPAIR AND REMOVAL

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NO.	ISSUE/DESCRIPTION	BY	DATE

COLUMBUS AVENUE SEAWALL RECONSTRUCTION
SALEM, MASSACHUSETTS
(EEA #258-2020-3)

PROPOSED DETAILS

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

PREPARED FOR:
CITY OF SALEM
120 WASHINGTON STREET
SALEM, MASSACHUSETTS

PROJ MGR: DAS	REVIEWED BY: DAS	CHECKED BY: -	DRAWING
DESIGNED BY: DAS	DRAWN BY: LFT	SCALE: AS SHOWN	6
DATE: OCTOBER 2020	PROJECT NO. 18.0171674.04	REVISION NO. -	SHEET NO. 6 OF 6

Attachment A – Limitations

USE OF REPORT/STUDY

1. GZA GeoEnvironmental, Inc. (GZA) has completed a metocean data analysis at the Columbus Ave Seawall in Salem, MA. Use of this study, 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 identified in GZA's contract for services (with the exception of purposes of regulatory review), for any use, without our prior written permission, shall be at that party's risk, and without any liability to GZA.

STANDARD OF CARE

2. 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.

EXISTING CONDITIONS

3. The existing conditions described on the plans were made on the dates referenced. Conditions observed and reported by GZA reflect the conditions that existed at the time of our work. Such conditions are subject to change and conditions at the time of construction may differ from those shown on the plans.

COMPLIANCE WITH CODES AND REGULATIONS

4. GZA used reasonable care in identifying and interpreting applicable codes and regulations during project design. These codes and regulations are subject to various, and possibly contradictory, interpretations. Compliance with codes and regulations by other parties is beyond our control.

PROBABILITY AND UNCERTAINTY

5. Waves and water levels have been presented in terms of probability (annual exceedance probabilities). Values presented should be considered to be approximately "Best Estimate" values based on the available data. The Client shall be aware that these values have uncertainty with upper and lower bound values.

Attachment B – Metocean and Wave Analysis

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MEMORANDUM

To: Mr. David H. Knowlton, City Engineer/DPS Director, P.E.
City of Salem, MA
98 Washington Street, 2nd Floor
Salem, Massachusetts

From: David A. Smith, Project Manager
Tianyi Liu, Ph.D., P.E.
Daniel C. Stapleton, P.E.

Date: October 21, 2020

File No.: 18.0171674.04

Re: Metocean Analysis and Wave Analysis
Columbus Avenue Seawall Reconstruction Project (EEA #258-2020-3)
Salem, Massachusetts

This memorandum presents the results of GZA GeoEnvironmental, Inc. (GZA) metocean data and wave analysis for the Columbus Avenue Seawall Reconstruction Project located within Juniper Cove in Salem, MA. The existing seawall is proposed to be reconstructed with consideration to raise the height of the seawall for greater protection and resilience to wave surge/flooding conditions. The goals of this analysis were to evaluate:

- Wave height within the Cove and at the seawall based on the 10-year, 50-year, and 100-year recurrence interval flood events;
- Wave effects at the northeast corner where sand has been observed to be deposited;
- Effects of flooding in the presence of the seawall;
- Effects of the existing dumped stone breakwater at the Cove entrance on reducing wave heights;
- Effects of wave runup/overtopping at the wall.

This memorandum is subject to the Limitations indicated in **Attachment A.** Elevations provided are referenced to the North American Vertical Datum 1988 (NAVD88).

GZA's analysis included:

1. Evaluation of the coastal storm conditions (water levels and waves) associated with different probabilities of occurrence (up to the 500-year recurrence interval flood event) using available data sources including: a) FEMA Flood Insurance Study (FIS); and b) the USACE North Atlantic Coast Comprehensive Study (NACCS) ; and
2. 2D numerical wave model simulations using the SWAN (Simulating WAves Nearshore) model to evaluate the wave details at the Columbus Avenue Seawall and the effects of a breakwater located at the Cove entrance.

BACKGROUND

The Columbus Ave Seawall (CAS) is located within Juniper Cove in Salem, MA, and is exposed to ocean storm surge and wave action from the Atlantic Ocean (**Figure B-1**). The inlet width of Juniper Cove is approximately 200 to 400 feet and the water depth within the Cove varies and is less than 10 feet under mean sea level (**Figure B-2**). Therefore, the topographic feature of small inlet width and shallow water depth in Juniper Cove may help to dissipate large incoming waves from Atlantic Ocean and provides protection for the CAS from direct impacts by large wave actions. Storm surge generated by extreme winds during tropical or extratropical storms can enter the Juniper Cove and cause flooding and hydrodynamic impacts at the CAS.

TOPOGRAPHIC AND BATHYMETRIC DATA

GZA created a Digital Elevation Model (DEM) of the project area based on available Lidar, specifically the 2016 LiDAR DEM published by USGS (3-foot horizontal resolution, Reference 1) (**Figure B-3**). The vertical datum of the 2016 USGS LiDAR DEM is NAVD88. GZA also performed an updated limited topographic survey of the site on March 31, 2020. GZA's topographic survey indicated that the top elevation of the existing CAS varies from about elevation 8.5 feet NAVD88 at the northeast end to 10.1 feet NAVD88 at the southwest end. The grade elevation at the bottom of the existing wall is about elevation 3 to 5 feet NAVD88 and slopes down to about elevation -5 feet NAVD88 near the breakwater at the Cove entrance.

METOCEAN DATA

A metocean data analysis was performed to characterize the environmental conditions (combined tide, storm surge and waves) at CAS. The metocean characteristics (e.g., water level, wave height, wind) and wave model results are summarized herein and presented in **Attachment B**. The conditions pertinent to this project include:

- Tidal elevations;
- Stillwater flood elevations;
- Relative sea level rise;
- Wave heights; and
- Wind climatology.

TIDAL ELEVATIONS

The tidal datums at CAS are based on the NOAA tidal bench mark for Beverly Harbor, Station ID 8442417 (Reference 2) and are as follows:

- Mean Higher High Water (MHHW): 4.40 feet NAVD88
- Mean High Water (MHW): 3.95 feet NAVD88
- Mean Tide Level (MTL): -0.52 feet NAVD88
- Mean Low Water (MLW): -4.99 feet NAVD88
- Mean Lower Low Water (MLLW): -5.32 feet NAVD88

STILLWATER COASTAL FLOOD ELEVATION

Stillwater elevations represent flood level not including wave effects (wave amplitude and wave setup). The following includes a summary of stillwater elevations at the project site.

FEMA FLOOD ELEVATIONS

The current FEMA Flood Insurance Study (FIS) (Reference 3) presents the peak stillwater elevations. **Table B-1** presents the FEMA-predicted stillwater elevations at the CAS associated with the 10-year, 50-year, 100-year and 500-year recurrence interval flood events, based on coastal transect 30 (**Figure B-4**). The effective FEMA 100-year recurrence interval stillwater elevation at CAS is 10.0 feet NAVD88, and the Base Flood Elevation is 11 feet NAVD88 (**Figure B-4**). The CAS is located within the coastal AE zone, as shown in **Figures B-4**, indicating that it will be exposed to wave height less than 3 feet. Stillwater coastal elevations for different occurrence probabilities (based on FEMA Flood Insurance Study data) range from:

- 10-year: Elevation 8.4 feet NAVD88
- 50-year: Elevation 9.4 feet NAVD88
- 100-year: Elevation 10.0 feet NAVD88
- 500-year: Elevation 11.4 feet NAVD88

The 100-year Stillwater elevation of 10 feet NAVD88 exceeds the elevation of much of the existing CAS, indicating that significant flooding may occur for the 100-year recurrence interval flood event. The Stillwater elevation of the 10-year recurrence interval flood event is close to the top of wall elevation at the northeast corner, indicating that this higher probability flood event may also result in wall and street flooding due to wave effects. The 10-year recurrence interval flood event (currently, not considering sea level rise) has about a 10% chance of being met or exceeded in any given year.

USACE FLOOD ELEVATIONS

Predicted water level data statistics are also available from the US Army Corps of Engineers (USACE) North Atlantic Coast Comprehensive Study (NACCS) (Reference 4). As shown in **Figure B-5**, the NACCS save points 10709, 10710 and 69 are all located out of the Juniper Cove at water depths of 15 to 30 feet at Mean Sea Level and are approximately 2,500 feet away from CAS. The NACCS-predicted water levels at NACCS save points 10709, 10710 and 69 were presented in **Table B-1**. The 100-year recurrence interval mean peak water level predicted by NACCS is approximately 9.0 feet NAVD88 at CAS.

OBSERVED FLOOD ELEVATION

The highest observed water levels at the NOAA Boston gage (Reference 5, see **Figure B-6** for location) which is about 15 miles from CAS is presented in **Table B-2**, indicating that most historical extreme water levels in vicinity of the Boston gage were caused by extratropical storms (Nor'easters) occurring during astronomical high tide events. Peak water levels were observed at the NOAA Boston tide gage of Elevation 9.6 feet to 9.7 feet NAVD88 during the 1978 Blizzard and more recently during the January 4, 2018 Nor'easter.

RELATIVE SEA LEVEL RISE

The relative sea level rise at CAS was estimated using the USACE sea level rise calculator and the NOAA 2017 Intermediate sea level rise projection at NOAA Boston gage (see **Figure B-6** for location) (Reference 6). **Table B-3** presents relative sea level rise projections for the NOAA Boston tide station, which is representative of the project site. Assuming the NOAA 2017 Intermediate sea level rise projection, sea level rise for the year 2070, relative to 2020 is about 2 feet.

The relative sea level rise can be linearly added to the current tidal datums and the FEMA 100-year stillwater elevation to predict the future (2070) 100-year recurrence interval stillwater level of Elevation 12 feet NAVD88. Sea level rise will increase the wave and flood risks at the 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 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.

<u>WAVE OBSERVATION</u>

Wave observation data is not available at the coastline near CAS but is available at wave buoys that are located 15 to 20 miles offshore from the project site. The wave buoys include USACE WIS (Wave Information Studies) buoys 63050 (Reference 7) (**Figure B-7**, about 17 miles to the CAS at depth of 59 meters, data record: 1980 to 2014) and the NERACOOS (Northeastern Regional Association of Coastal Ocean Observing Systems) A01 buoy (Reference 8) (**Figure B-10**, located about 13 miles to CAS at depth of 65 meters, also named as NDBC Buoy 44029). The offshore waves recorded at the WIS and NERACOOS buoys are deep water waves 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 reveal the characteristics of deep-water wave (e.g., dominant wave direction, wave period) that propagates toward the project site under influence of local wind.

The wave rose at the WIS wave buoys is presented in **Figure B-8**, indicating that waves are predominantly from the southeast direction, and the extreme wave frequency curves are presented in **Figure B-9**, indicating the 100-year wave height at the WIS buoys is approximately 28 feet (about 8.5 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 January 2018 Nor'easter observed at the NERACOOS A01 buoy are presented in **Figure B-11**, indicating that wave heights reached approximately 24 feet at this buoy which is located about 13 miles away from CAS.

<u>USACE NACCS</u>

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 B-5** for location) out of the Juniper Cove in deep water are summarized in **Table B-1**. The 100-year significant wave height at NACCS save points 10709, 10710 and 69 are 15.8 feet, 13.2 feet and 16.7 feet, respectively, which indicate high incoming waves to the Juniper Cove under 100-year storm wave condition.

DEPTH-LIMITED WAVE HEIGHTS

The immediate vicinity of the project structure can be submerged or partially submerged during significant coastal flood events. Wave heights at the seaward toe of the structures can be depth-limited and are estimated using the following equation:

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

WIND CLIMATE ANALYSIS

To analyze the local wind patterns at CAS, GZA conducted statistical analyses of historical wind data (1943-2019) from the nearby Boston Logan International Airport. The GZA analyzed extreme winds were also compared with ASCE 7-16 design gusts (Reference 9) at CAS.

WIND OBSERVATIONS

The Boston Logan International Airport has a 77-year record (1943 to 2019) of hourly wind data (speed and direction). The data was plotted as a wind rose which shows wind frequency and magnitude throughout the historical record coming from 32 different directional bins (**Figure B-12**), indicating the prevailing, low velocity, winds are generally from the western quadrant. 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 to 10 mph to winds greater than 50 mph, and a wind rose was plotted for each category (**Figures B-13**). The results of the analysis indicate that most of the high winds with speed greater than 50 mph are from northeast direction which may represent a typical wind feature during a Nor'easter storm event.

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 (Reference 9). 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 10) based on assumed condition "onshore winds at a coastline", and the converted ASCE 7-16 1-minute sustained wind speed is presented in **Table B-4**.

GZA performed statistical analysis on wind data records (1-minute averaging duration) at Boston Logan International Airport. 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 curve for Logan International Airport is presented in **Figure B-14**. The wind speeds at 10-year, 50-year, 100-year and 500-year recurrence intervals from GZA statistical analysis are summarized in **Table B-4**.

The GZA wind statistics based on data at Logan Airport compare well with ASCE 7-16 wind speeds, as shown in **Table B-4**. Therefore, the ASCE 7-16 wind speeds presented in **Table B-4** are supported by the site specific-statistical analysis based on wind data at Logan Airport in the vicinity of CAS, and are therefore recommended to use for the wind climatology at the project site.

WAVE MODELING

Utilizing input from the metocean data analysis, GZA performed numerical wave analyses using the SWAN (Simulating WAves Nearshore) model to evaluate waves generated by wind and deep-water waves propagating toward the site (from the USACE WIS buoy 63050) for the 25-year, 50-year, and 100-year recurrence intervals. 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 represent significant wave heights, H_s, and breaking wave heights, H_b, (where depth limited wave conditions exist).

GZA's SWAN model, with variable resolution, is built based on the 2016 USGS LiDAR DEM (**Figure B-3**) and GZA's survey of CAS wall height. The model mesh has a high-resolution within the Juniper Cove and the immediate project area, which is presented in **Figure B-15** and **B-16**. The metocean inputs to the SWAN model for the 25-year, 50-year, and 100-year recurrence intervals are summarized in **Tables B-5, B-6 and B-7**, and two wind scenarios with Scenario 1 using east wind and Scenario 2 using northeast wind were applied. The simulated wave height and direction are presented in **Figures B-17** through **B-22**, and multiple output stations were specified for the model, as shown in **Figures B-19, B-22, B-23** and **B-24**. The Output Stations 10, 11, 12 and 13 are adjacent to the CAS (**Figure B-24**); the Output Stations 1, 2, 3 and 4 are located along the CAS and are about 50 feet from the wall; Output Station 5 and 6 are located on the land side of the breakwater which is indicated by Output Station 7 (**Figure B-23**); Output Station 8 is located within Juniper Cove on the ocean side of the breakwater; Output Station 9 is located at the approximate entrance to the Cove, and indicates incoming wave conditions to the Cove. The significant wave heights at the output stations are summarized in **Tables B-5, B-6 and B-7** for the 25-year, 50-year, and 100-year recurrence intervals.

The simulated wave height shows the large change in Juniper Cove from about 10 feet at the inlet entrance to about 1.5 feet to 2.6 feet at the CAS for the 100-year recurrence interval storm event, which is likely due to the topographic feature inside Juniper Cove that dissipates wave propagation toward the project site. The wave direction is generally westerly from the inlet entrance to the CAS, while wave refraction and shoaling take place at the northeast end of CAS. This is because the bathymetric feature of water depth under the 100-year stillwater elevation of 10 feet NAVD88 is generally uniform within the channel-like Cove, while the curved shoreline feature at the northeast end causes wave refraction and shoaling. FEMA FIRM shows that the limit of moderate wave action is at the Cove entrance (**Figure B-4**), indicating the wave heights within the Cove are less than 1.5 feet. This is inconsistent with the model results, probably because detailed 2D wave modeling was not performed in FEMA FIRM. Under 100-year stillwater elevation, a large portion of the area within the Cove have water depth greater than 10 feet, and large incoming waves from Atlantic Ocean can enter the Cove and propagate in these areas.

The 100-year wave height along the CAS increases from 1.5 feet at the northeast end to 2.6 feet in the middle section (Output Station 12 in **Figure B-24**) and remains above 2 feet to the southwest end. The variation of wave height along the CAS is probably because the southwest end is located straightly in the direction of wave propagation from the Cove entrance, while the northeast end is partly sheltered by the private walls at the northern shoreline of the Cove. The 100-year stillwater elevation of 10 feet NAVD88 is above the top elevation of 8.5 feet NAVD88 at the northeast end of CAS and is generally at the top level of the southwest end with elevation of 10.1 feet NAVD88. The wave crest elevation estimated by Stillwater elevation plus 70% of significant wave height) along the CAS is approximately 11 to 12 feet NAVD88. Therefore, the areas behind the CAS would be inundated by the 50-year and 100-year stillwater elevation plus wave actions.

BREAKWATER EFFECTS ON WAVES

Significant wave heights were estimated using the SWAN model for increased breakwater heights (**Figures B-25** through **B-33**). If the breakwater crest was raised 5 feet to elevation 5 feet NAVD88, the 100-year flood wave height at the seawall would be reduced by approximately 0 feet to 0.4 feet. The small reduction of wave height is likely because there would be a water depth of 5 feet above the breakwater under 100-year flood event of elevation 10 feet NAVD88, which does not cause significant wave breaking. If the breakwater height is increased to elevation 10 feet NAVD88 the wave heights at the seawall would be reduced by approximately 0.5 feet to 1.4 feet for the 100-year recurrence interval flood event. Refer to **Tables B-8**, **B-9**, and **B-10** for results of various output stations.

The existing rubble stone breakwater provides some, but minor, wave attenuation. The existing breakwater has a crest at approximate elevation 0 feet NAVD88 and the width varies from approximate 10 feet to 14 feet. Side slopes vary at approximately one vertical to three horizontal (1V:3H).

The breakwater provides approximately 25 percent to 30 percent wave attenuation within the Cove based on the SWAN wave model. For example, the simulated wave heights at the breakwater crest ranged from approximately 5.8 feet to 6.0 feet (Output Station 7) for the 100-year storm event, and wave heights immediately landward of the breakwater ranged from elevation 4.2 feet to 4.4 feet (Output Station 6) for the 100-year storm event. The 25 percent to 30 percent reduction is also consistent for the 10-year and 50-year storm events.

The simulated wave height is approximately 6 feet at the breakwater crest and the water depth under the FEMA 100-year Stillwater elevation is approximately 10 feet. The ratio of wave height to water depth is less than the breaking wave threshold of 0.78, indicating the breakwater does not cause wave breaking to reduce wave height under the 100-year recurrence interval flood event.

Shallow water depths within the Cove landward of the breakwater further attenuate wave heights. A significant reconstruction and raise in crest elevation would be required to increase wave attenuation due to the existing breakwater. Given that the Cove elevation increases toward the seawall (resulting in attenuated waves near the wall), the added wave attenuation benefit of reconstructing the breakwater is expected to be minor.

WAVE RUNUP/OVERTOPPING

An assessment of wave runup and overtopping was performed for an increased seawall height to elevations 11 feet NAVD88 and 12 feet NAVD88 for the FEMA 10-year, 50-year, and 100-year recurrence interval flood events (**Figures B-34** through **B-38**). Additionally, an assessment of wave runup at the northeast wall corner was performed for the existing topography and for the theoretical removal of the sand build-up. Refer to **Tables B-11, B-12,** and **B-13** for the results of wave runup and overtopping at the seawall for the predicted 10-year, 50-year, and 100-year recurrence interval flood events.

Wave runup heights along the seawall for the predicted 100-year recurrence interval flood event range from approximately 2.7 feet to 5.0 feet, corresponding to approximate elevations of 12.7 feet NAVD88 to 15.0 feet

NAVD88. These calculated wave runup heights would lead to significant wall overtopping. Wave runup heights along the seawall for the predicted 10-year recurrence interval flood event range from approximately 0 feet to 4.4 feet, corresponding to elevations of 8.4 feet NAVD88 to 12.8 feet NAVD88. Wall overtopping is expected even during a 10-year storm event.

An additional wave runup analysis was performed for the theoretical removal of sand build-up at the northeast corner, represented by output station 10. Removal of sand at the northeast corner reduces the wave runup height for the 100-year recurrence interval flood event at the seawall from 2.7 feet to 2.1 feet.

WAVE REFLECTION/REDIRECTION

The following includes a summary of the qualitative analysis for the wave reflection/redirection caused by an increased seawall height on adjacent structures. For stillwater induced flooding, raising the seawall is unlikely to affect the inundation in the adjacent properties, because storm surge can enter this area over the low adjacent structures (ie 'back-door flooding' effects). Raising the seawall would not affect the flood depth or flood zone on the adjacent properties and along Columbus Avenue (currently both categorized as AE zone), although the wave heights and overtopping behind the seawall would be reduced.

Raising the seawall could potentially affect the reflected wave height (e.g., overtopping condition), because with a raised wall, the ocean water (mass and momentum) that may previously have gone over the seawall and splash the street, may be redirected or fall back to the Cove or to the adjacent property at the seawall corner (see yellow arrows in **Figure 1**). The influence of such redirected water to the adjacent property is uncertain and cannot be fully estimated, however those areas may have already experienced overtopping directly during the storm event.

Overtopping to the adjacent properties is mostly due to waves directly impacting the adjacent wall (see purple line in **Figure 1**), with some possible increase from redirected water. It is difficult to quantify the redirected water impacts within the Cove due to erratic and turbulent conditions that could occur. The influence of such redirected water to the adjacent property is uncertain and cannot be fully estimated, however those areas may have already experienced overtopping directly during the storm event.

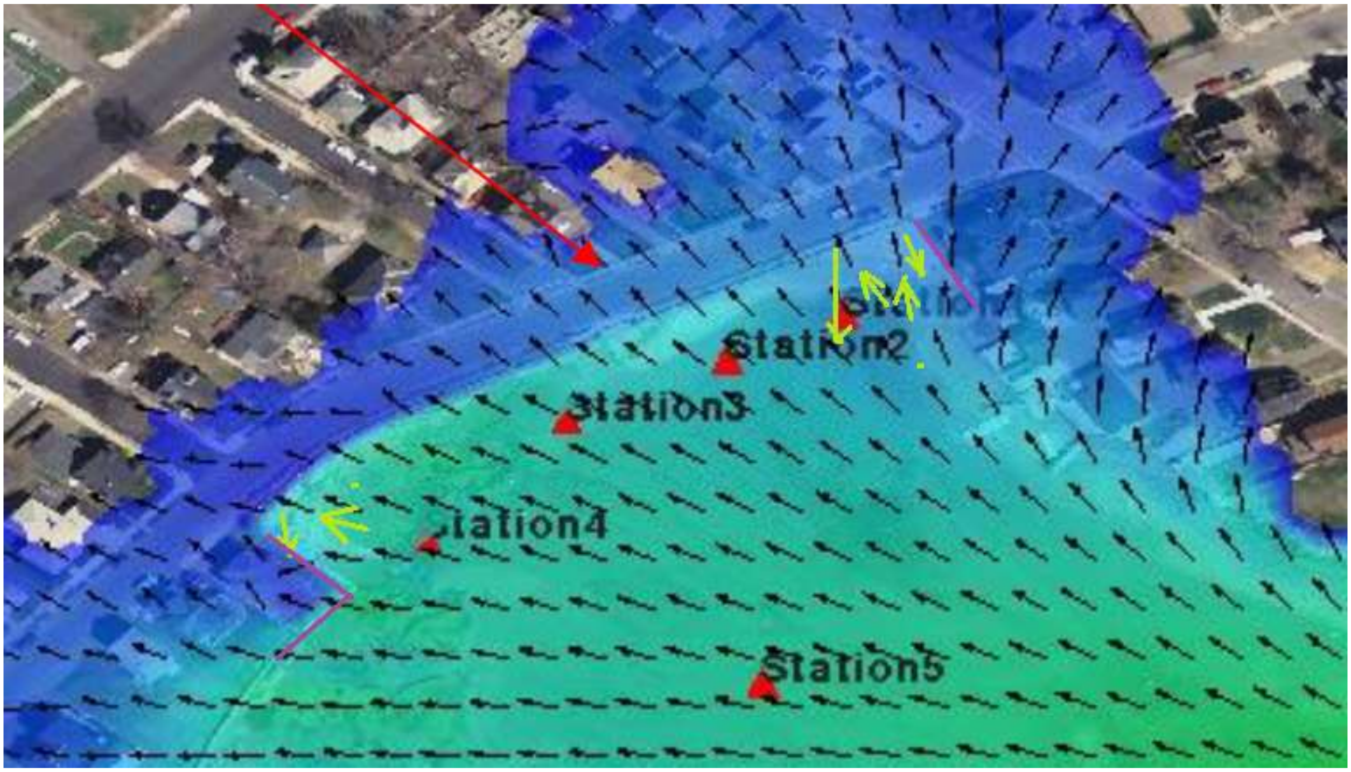

Figure 1: Schematic Analysis of Wave Reflection from the Columbus Avenue Seawall

At the southwest corner, the redirected water seems to partially affect the adjacent wall during the 100-year flood event. The elevation close to the toe of the seawall is approximately 8 to 10 feet NAVD88, indicating a breaking wave condition during the 100-year storm event. The breaking wave condition is highly turbulent and chaotic, so the influence of redirected water in this highly turbulent environment is difficult to estimate. The adjacent wall would likely experience the most impulsive condition from the breaking waves nearby, instead of the redirected water due to the raise in seawall height. During 50-year or weaker storms, the stillwater level is less than or equal to the elevation of the seawall toe, indicating stillwater may not reach the seawall, and most waves would break over the shoreline slope, leading to relatively minor wave overtopping the seawall and even lesser influences from redirected water whether the seawall is raised or not.

SUMMARY

The simulated wave heights indicated significant wave attenuation within Juniper Cove from about 10 feet at the Cove inlet to about 1.4 feet to 2.6 feet at the seawall for the predicted 100-year recurrence interval flood event. Waves along the CAS range from approximately 1.4 feet to 2.6 feet in height for the 100-year storm event. Comparatively, for the 10-year storm event, waves along the seawall range from no waves at the southwest corner to approximately 2.3 feet towards the center of the seawall.

Generally, the largest predicted waves occur towards the center of the seawall and the smallest predicted waves occur at the northeast corner, likely due to the topographic difference and natural sheltering. Although significant wave attenuation occurs within the Cove, the wave heights would still likely overtop the existing seawall based on the existing conditions.

The predicted wave crest elevations along the CAS for the 100-year recurrence interval flood event ranges from approximately 10.8 to 11.8 feet NAVD88, which is generally consistent with the FEMA Base Flood Elevation. Comparatively, the predicted wave crest elevations along the CAS for the 10-year recurrence interval flood event ranges from approximately 8.4 to 10.0 feet NAVD88 at the approximate top of CAS elevation.

Wave runup elevations along the seawall for the predicted 100-year recurrence interval flood event range from approximately 12.7 feet NAVD88 to 15.0 feet NAVD88, which would lead to significant wall overtopping. Wave runup elevations along the seawall for the predicted 10-year recurrence interval flood event range from approximately 8.4 feet NAVD88 to 12.8 feet NAVD88. Wall overtopping is expected even during a 10-year storm event.

Flooding at the CAS wall is due to stillwater flood inundation, wave amplitude (greenwater overtopping) and wave wall run-up and overtopping during significant storm events. Increasing the wall elevation to above the stillwater elevation may still have some flood vulnerability due to run-up and overtopping and certainly from 'back-door' flooding effects.

REFERENCES

1. USGS, https://inport.nmfs.noaa.gov/inport/item/49419
2. NOAA/NOS's Tides and Currents, https://tidesandcurrents.noaa.gov/
3. FEMA FIS, https://msc.fema.gov/portal/advanceSearch
4. USACE, NACCS, https://www.nad.usace.army.mil/CompStudy/
5. NOAA, Center for Operational Oceanographic Products and Services, https://tidesandcurrents.noaa.gov/
6. NOAA et al. 2017, Global and Regional Sea Level Rise Scenarios for the United States, https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf
7. WIS (Wave Information Studies), http://wis.usace.army.mil/
8. NERACOOS, http://www.neracoos.org/
9. Applied Technology Council, https://hazards.atcouncil.org
10. World Meteorological Organization, Guidelines for Converting between Various Wind Averaging Periods in Tropical Cyclone Conditions, https://www.wmo.int/pages/prog/www/tcp/Meetings/HC31/documents/Doc.3.part2.pdf

Attachment A

USE OF PLANS

1. GZA GeoEnvironmental, Inc. (GZA) has completed a metocean data analysis at the Columbus Ave Seawall in Salem, MA. Use of this study, 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 identified in GZA's contract for services (with the exception of purposes of regulatory review), for any use, without our prior written permission, shall be at that party's risk, and without any liability to GZA.

STANDARD OF CARE

2. 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.

EXISTING CONDITIONS

3. The existing conditions described on the plans were made on the dates referenced. Conditions observed and reported by GZA reflect the conditions that existed at the time of our work. Such conditions are subject to change and conditions at the time of construction may differ from those shown on the plans.

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4. GZA used reasonable care in identifying and interpreting applicable codes and regulations during project design. These codes and regulations are subject to various, and possibly contradictory, interpretations. Compliance with codes and regulations by other parties is beyond our control.

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5. Waves and water levels have been presented in terms of probability (annual exceedance probabilities). Values presented should be considered to be approximately "Best Estimate" values based on the available data. The Client shall be aware that these values have uncertainty with upper and lower bound values.

Attachment B

Table B-1: Metocean Characteristics in the vicinity of the Columbus Ave Seawall.

Return Period	FEMA		USACE[3]					
	Stillwater Elevation[1] (ft, NAVD88)	Base Flood Elevation[2] (ft, NAVD88)	Stillwater Elevation (ft, NAVD88)			Wave Height (ft)		
			#10709	#10710	#69	#10709	#10710	#69
1-year			6.1	6.1	6.1	8.7	7.0	9.7
2-year			6.7	6.7	6.7	12.8	9.8	13.8
5-year			7.3	7.4	7.3	14.4	11.3	15.3
10-year	8.4		7.7	7.8	7.7	15.0	11.8	15.8
50-year	9.4		8.7	8.7	8.6	15.6	12.6	16.4
100-year	10.0	11	9.1	9.1	9.0	15.8	12.8	16.5
500-year	11.4		9.9	9.9	9.8	15.9	13.2	16.7

Note:

1. Stillwater Elevation is based on FEMA FIS at Transect 30 in project site vicinity;
2. Base Flood Elevation is based on FEMA FIRM presented in Figure B-4.
3. See Figure B-5 for locations of USACE NACCS save points 10709, 10710 and 69;

Table B-2: Top Ten Highest Water Levels[1] at NOAA Boston Gage.

Time	Water Level[2] (ft, NAVD88)	Storm Type
1/4/2018	9.7	Nor'Easter
2/7/1978	9.6	Nor'Easter
3/2/2018	9.1	Nor'Easter
1/2/1987	8.7	Nor'Easter
10/30/1991	8.6	Nor'Easter
1/25/1979	8.5	Nor'Easter
12/12/1992	8.5	Nor'Easter
12/29/1959	8.5	Nor'Easter
2/19/1972	8.4	Nor'Easter
1/3/2014	8.3	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 B-3. Sea Level Rise Projections (using the USACE Relative Sea Level Change Calculator for NOAA et. al. 2017 projections; relative to the year 2020) for Boston, MA, NOAA2017 VLM (vertical land movement): 0.00259 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
2020	--	--	--	--	--	--	--
2040	0.05	0.26	0.36	0.62	0.92	1.32	1.48
2050	0.08	0.42	0.56	1.05	1.51	2.14	2.49
2070	0.13	0.78	0.99	1.96	2.92	4.17	5.12
2100	0.21	1.05	1.45	3.54	5.55	8.08	10.14

Table B-4. Wind Speed Statistics (1-min, 10-meter) based on ASCE 7-16 and GZA wind statistical analysis based on wind data of all directions at Logan Airport.

Analysis	Wind Speed (mph) Statistics			
	10-year	50-year	100-year	500-year
ASCE 7-16	61	75	80	--
GZA Statistical Analysis	56	68	74	87

Table B-5. SWAN Wave Modeling for 100-year recurrence interval.

SWAN Model Input	Stillwater Elevation (ft, NAVD88)		10.0
	Wave Input at eastern open boundary	Significant Wave Height[1] (ft)	28
		Wave Period[2] (sec)	11
		Wave Direction	From due east
	Wind	Speed[3] (mph)	80
		Direction (Scenario 1)	From due east
		Direction (Scenario 2)	From northeast
SWAN Model Output[4] of Significant Wave Height (ft)	Stations	Scenario 1	Scenario 2
	Output Station 1	1.6	1.2
	Output Station 2	2.3	1.8
	Output Station 3	2.7	2.3
	Output Station 4	2.9	3.2
	Output Station 5	3.1	3.2
	Output Station 6	4.4	4.2
	Output Station 7	6.0	5.8
	Output Station 8	7.4	7.1
	Output Station 9	10.0	9.6
	Output Station 10	1.4	1.2
	Output Station 11	2.2	1.7
	Output Station 12	2.6	2.2
	Output Station 13	2.0	1.8

Note:

1. Based on wave data at WIS buoy 63050 (see **Figure B-7**);
2. Estimated based on wave period measurement at NERACOOS Buoy A01 (see **Figure B-10**);
3. 1-min sustained wind speed;
4. See **Figures B-23** and **B-24** for locations of output stations.

Table B-6. SWAN Wave Modeling for 50-year recurrence interval.

SWAN Model Input	Stillwater Elevation (ft, NAVD88)		9.4
	Wave Input at eastern open boundary	Significant Wave Height[1] (ft)	26.2
		Wave Period[2] (sec)	11
		Wave Direction	From due east
	Wind	Speed[3] (mph)	75
		Direction (Scenario 1)	From due east
SWAN Model Output[4] of Significant Wave Height (ft)	Stations		Scenario 1
	Output Station 1		1.5
	Output Station 2		2.2
	Output Station 3		2.6
	Output Station 4		2.8
	Output Station 5		3.0
	Output Station 6		4.2
	Output Station 7		5.8
	Output Station 8		7.1
	Output Station 9		9.6
	Output Station 10		1.3
	Output Station 11		2.0
	Output Station 12		2.5
	Output Station 13		1.6

Note:

1. Based on wave data at WIS buoy 63050 (see **Figure B-7**);
2. Estimated based on wave period measurement at NERACOOS Buoy A01 (see **Figure B-10**);
3. 1-min sustained wind speed;
4. See **Figures B-23** and **B-24** for locations of output stations.

Table B-7. SWAN Wave Modeling for 10-year recurrence interval.

SWAN Model Input	Stillwater Elevation (ft, NAVD88)		8.4
	Wave Input at eastern open boundary	Significant Wave Height[1] (ft)	21.2
		Wave Period[2] (sec)	11
		Wave Direction	From due east
	Wind	Speed[3] (mph)	61
		Direction (Scenario 1)	From due east
SWAN Model Output[4] of Significant Wave Height (ft)	Stations		Scenario 1
	Output Station 1		1.2
	Output Station 2		1.8
	Output Station 3		2.4
	Output Station 4		2.7
	Output Station 5		2.8
	Output Station 6		3.8
	Output Station 7		5.4
	Output Station 8		6.6
	Output Station 9		8.9
	Output Station 10		1.1
	Output Station 11		1.8
	Output Station 12		2.3
	Output Station 13		0.0

Note:

1. Based on wave data at WIS buoy 63050 (see **Figure B-7**);
2. Estimated based on wave period measurement at NERACOOS Buoy A01 (see **Figure B-10**);
3. 1-min sustained wind speed;
4. See **Figures B-23** and **B-24** for locations of output stations.

Table B-8. SWAN Simulated Significant Wave Height (ft) for 100-year recurrence interval.

Output Stations	Breakwater Height based on LiDAR		Breakwater Height El. 0’		Breakwater Height El. 5’		Breakwater Height El. 8’		Breakwater Height El. 10’	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2
#1	1.6	1.2	1.7	1.3	1.7	1.1	1.5	0.7	1.4	0.6
#2	2.3	1.8	2.3	1.9	2.3	1.6	2.1	0.9	2.0	0.8
#3	2.7	2.3	2.7	2.4	2.5	2.0	2.1	1.1	2.1	1.1
#4	2.9	3.2	2.9	3.1	2.5	2.8	2.3	1.7	2.3	1.9
#5	3.1	3.2	3.1	3.2	2.6	2.6	2.7	1.9	2.8	2.1
#6	4.4	4.2	4.2	4.0	3.3	3.2	2.2	2.0	2.6	2.4
#7	6.0	5.8	6.2	6.0	6.7	6.4	3.0	3.0	N/A	N/A
#8	7.4	7.1	7.4	7.1	7.4	7.1	7.4	7.1	7.4	7.1
#9	10.0	9.6	10.0	9.6	10.0	9.6	10.0	9.6	10.0	9.6
#10	1.4	1.2	1.5	1.3	1.4	1.2	1.0	0.7	0.8	0.6
#11	2.2	1.7	2.3	1.8	2.2	1.6	1.8	0.8	1.7	0.7
#12	2.6	2.2	2.6	2.3	2.4	1.9	1.9	0.9	1.8	0.8
#13	2.0	1.8	1.9	1.8	1.6	1.5	1.3	1.2	1.4	1.3

Table B-9. SWAN Simulated Significant Wave Height (ft) for 50-year recurrence interval.

Output Stations	Breakwater Height based on LiDAR	Breakwater Height El. 0’	Breakwater Height El. 5’	Breakwater Height El. 8’	Breakwater Height El. 10’
#1	1.5	1.5	1.4	1.0	1.0
#2	2.2	2.2	2.0	1.8	1.7
#3	2.6	2.6	2.3	2.2	2.2
#4	2.8	2.8	2.3	2.2	2.3
#5	3.0	2.9	2.5	2.7	2.9
#6	4.2	4.0	3.1	1.9	2.5
#7	5.8	6.0	6.4	2.2	N/A
#8	7.1	7.1	7.1	7.1	7.1
#9	9.6	9.6	9.6	9.6	9.6
#10	1.3	1.4	1.2	0.6	0.6
#11	2.0	2.1	1.9	1.5	1.4
#12	2.5	2.5	2.2	1.9	1.9
#13	1.6	1.5	1.3	1.0	1.1

Table B-10. SWAN Simulated Significant Wave Height (ft) for 10-year recurrence interval.

Output Stations	Breakwater Height based on LiDAR	Breakwater Height El. 0’	Breakwater Height El. 5’	Breakwater Height El. 8’	Breakwater Height El. 10’
#1	1.2	1.2	0.9	0.4	0.4
#2	1.8	1.9	1.4	0.6	0.7
#3	2.4	2.4	1.8	0.9	1.1
#4	2.7	2.6	2.0	1.4	1.7
#5	2.8	2.6	1.8	1.2	1.6
#6	3.8	3.6	2.4	1.5	2.2
#7	5.4	5.6	5.0	0.7	N/A
#8	6.6	6.6	6.6	6.6	6.6
#9	8.9	8.9	8.9	8.9	8.9
#10	1.1	1.2	0.8	0.3	0.3
#11	1.8	1.8	1.3	0.5	0.6
#12	2.3	2.4	1.8	0.9	1.1
#13	0.0	0.0	0.0	0.0	0.0

Table B-11. Assessment of Wave Runup and Overtopping at the Columbus Avenue Seawall during 100-year storm.

Output Station[1]	Wall Height (ft, NAVD88)	Bed Condition		Wave Condition					Wave Runup[2]	Overtopping Flowrate[2]
		Sand Removal	Bed Level[1] (ft, NAVD88)	Significant Wave Height[1] (ft)	Peak Wave Period[1] (s)	Wave Crest Elevation[3] (ft, NAVD88)	Wave Breaking?	Wave Runup on Seawall (ft)	Wave Runup Elevation (ft, NAVD88)	Per LF (gal./min.)
Station 10 (Northeast Corner)	11	No Sand Removal	7	1.4	11.1	11.0	No	2.7	12.7	41
		After Sand Removal	4	1.1	11.1	10.8	No	2.1	12.1	17
	12	No Sand Removal	7	1.4	11.1	11.0	No	2.7	12.7	6
		After Sand Removal	4	1.1	11.1	10.8	No	2.1	12.1	2
Station 11	11	N/A	2.7	2.2	11.1	11.5	No	4.2	14.2	157
	12	N/A	2.7	2.2	11.1	11.5	No	4.2	14.2	48
Station 12	11	N/A	3.6	2.6	11.1	11.8	No	5.0	15.0	243
	12	N/A	3.6	2.6	11.1	11.8	No	5.0	15.0	89
Station 13	11	N/A	8.3	2.0	11.1	11.4	Yes	3.9	13.9	121
	12	N/A	8.3	2.0	11.1	11.4	Yes	3.9	13.9	33

Note:
1. See **Figures B-34** through **B-38** for results of runup and overtopping analysis;
2. Calculated based on EurOtop Manual (2018);
3. Estimated simply by stillwater elevation plus 70% of significant wave height;
4. Height of wall located on neighbor properties was not increased in modeling.

Table B-12. Assessment of Wave Runup and Overtopping at the Columbus Avenue Seawall during 50-year storm.

Output Station[1]	Wall Height (ft, NAVD88)	Bed Condition		Wave Condition					Wave Runup[2]	Overtopping Flowrate[2]
		Sand Removal	Bed Level[1] (ft, NAVD88)	Significant Wave Height[1] (ft)	Peak Wave Period[1] (s)	Wave Crest Elevation[3] (ft, NAVD88)	Wave Breaking?	Wave Runup on Seawall (ft)	Wave Runup Elevation (ft, NAVD88)	Per LF (gal./min.)
Station 10 (Northeast Corner)	11	N/A	7	1.3	11.1	10.3	No	2.5	11.9	6
	12	N/A	7	1.3	11.1	10.3	No	2.5	11.9	0
Station 11	11	N/A	2.7	2.0	11.1	10.8	No	3.9	13.3	53
	12	N/A	2.7	2.0	11.1	10.8	No	3.9	13.3	9
Station 12	11	N/A	3.6	2.5	11.1	11.2	No	4.8	14.2	123
	12	N/A	3.6	2.5	11.1	11.2	No	4.8	14.2	33
Station 13	11	N/A	8.3	1.6	11.1	10.5	Yes	3.1	12.5	20
	12	N/A	8.3	1.6	11.1	10.5	Yes	3.1	12.5	2

Note:

1. See **Figures B-34** through **B-38** for results of runup and overtopping analysis;
2. Calculated based on EurOtop Manual (2018);
3. Estimated simply by stillwater elevation plus 70% of significant wave height;
4. Height of wall located on neighbor properties was not increased in modeling.

Table B-13. Assessment of Wave Runup and Overtopping at the Columbus Avenue Seawall during 10-year storm.

Output Station[1]	Wall Height (ft, NAVD88)	Bed Condition		Wave Condition					Wave Runup[2]	Overtopping Flowrate[2]
		Sand Removal	Bed Level[1] (ft, NAVD88)	Significant Wave Height[1] (ft)	Peak Wave Period[1] (s)	Wave Crest Elevation[3] (ft, NAVD88)	Wave Breaking?	Wave Runup on Seawall (ft)	Wave Runup Elevation (ft, NAVD88)	Per LF (gal./min.)
Station 10 (Northeast Corner)	11	N/A	7	1.1	11.1	9.2	Yes	2.1	10.5	0
	12	N/A	7	1.1	11.1	9.2	Yes	2.1	10.5	0
Station 11	11	N/A	2.7	1.8	11.1	9.7	No	3.5	11.9	5
	12	N/A	2.7	1.8	11.1	9.7	No	3.5	11.9	0
Station 12	11	N/A	3.6	2.3	11.1	10.0	No	4.4	12.8	21
	12	N/A	3.6	2.3	11.1	10.0	No	4.4	12.8	4
Station 13	11	N/A	8.3	0.0	11.1	8.4	No	0.0	8.4	0
	12	N/A	8.3	0.0	11.1	8.4	No	0.0	8.4	0

Note:

1. See **Figures B-34** through **B-38** for results of runup and overtopping analysis;
2. Calculated based on EurOtop Manual (2018);
3. Estimated simply by stillwater elevation plus 70% of significant wave height;
4. Height of wall located on neighbor properties was not increased in modeling.

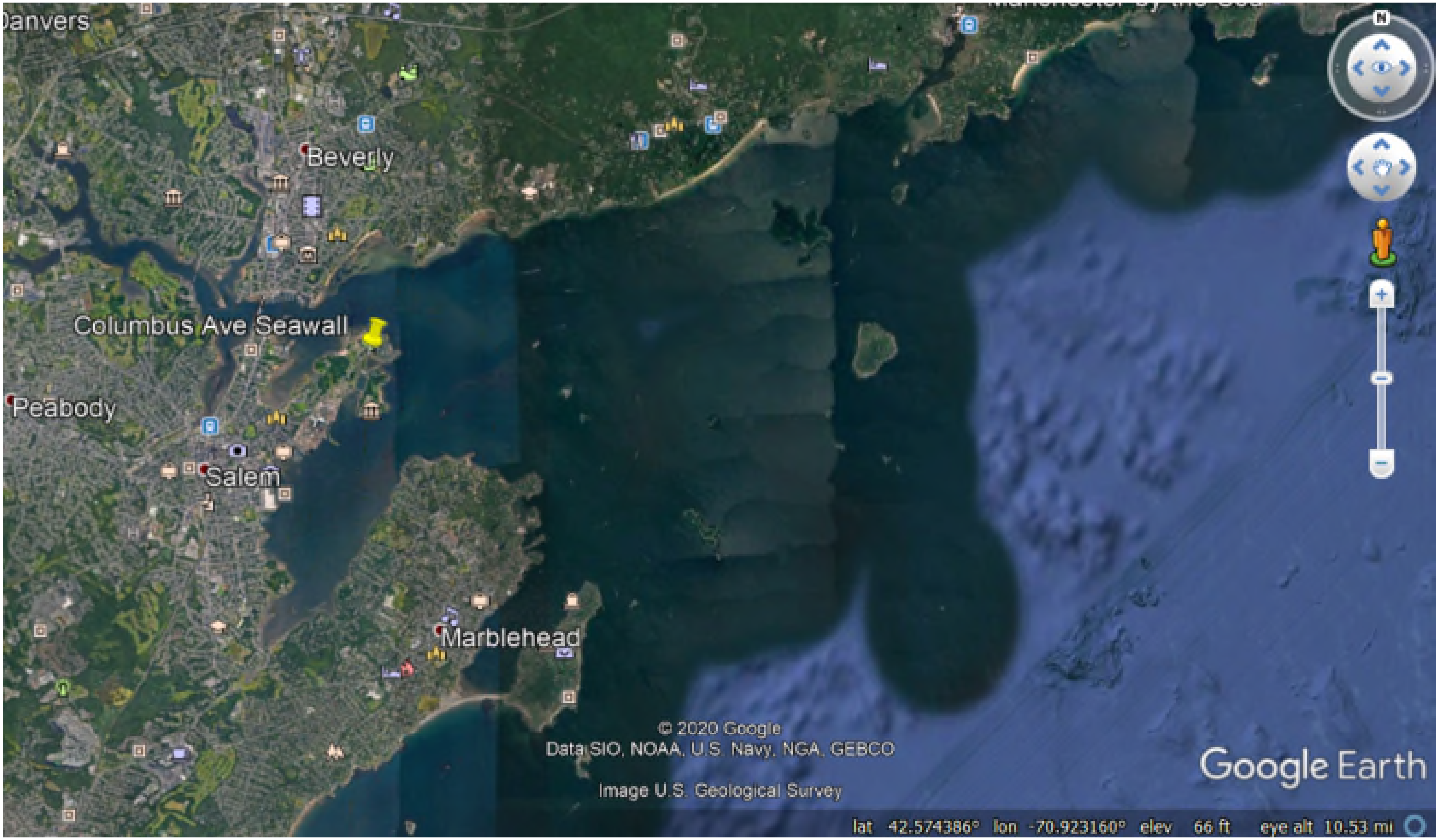


Figure B-1: Location of Columbus Ave Seawall (CAS).

Figure B-2: Location of Columbus Ave Seawall (CAS) – zoomed view.

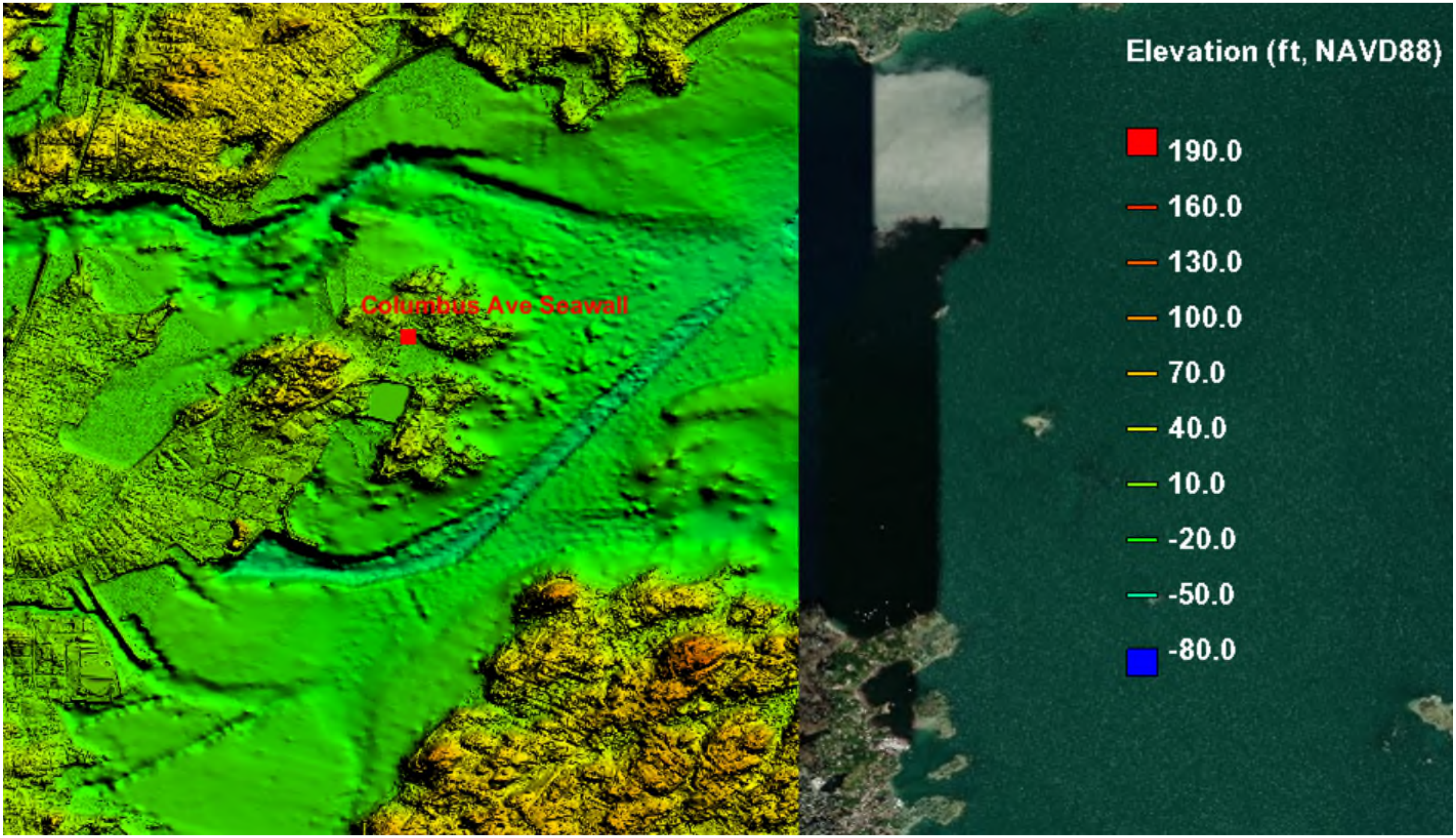


Figure B-3: Topography and Bathymetry at CAS (2016 **USGS LiDAR DEM, Reference 1**).

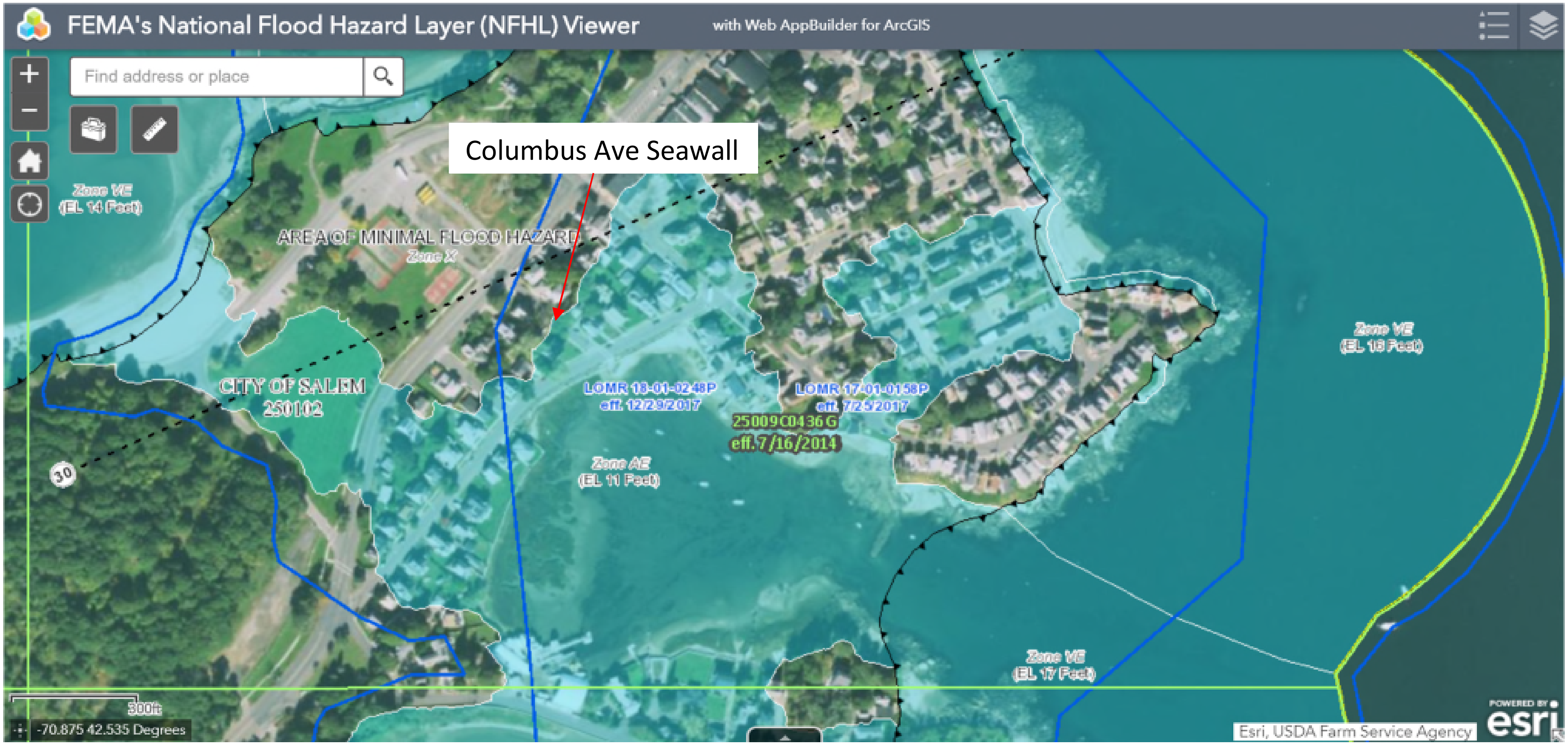


Figure B-4: Coastal flood zones and coastal transects in vicinity of CAS.

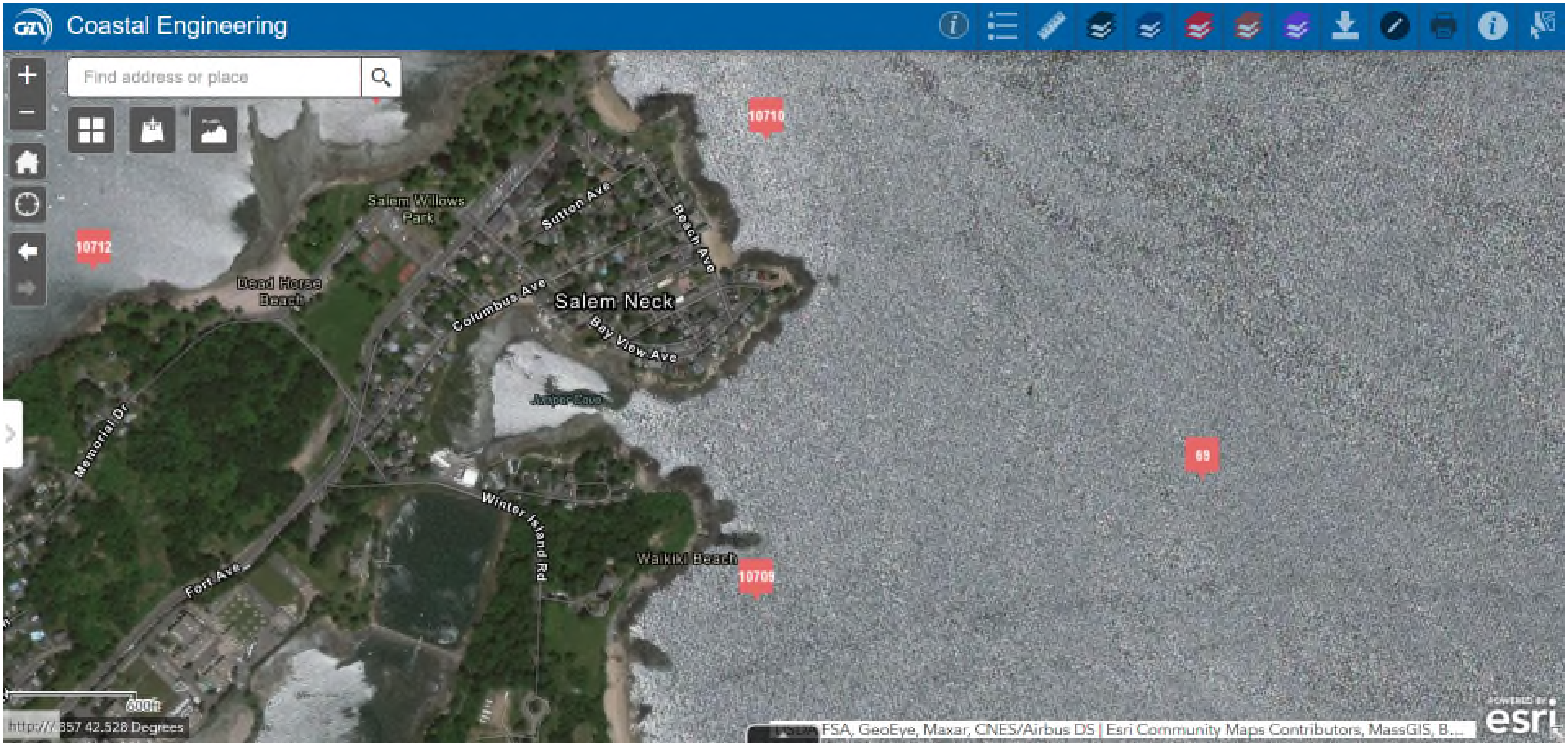


Figure B-5: USACE NACCS save points in vicinity of CAS.

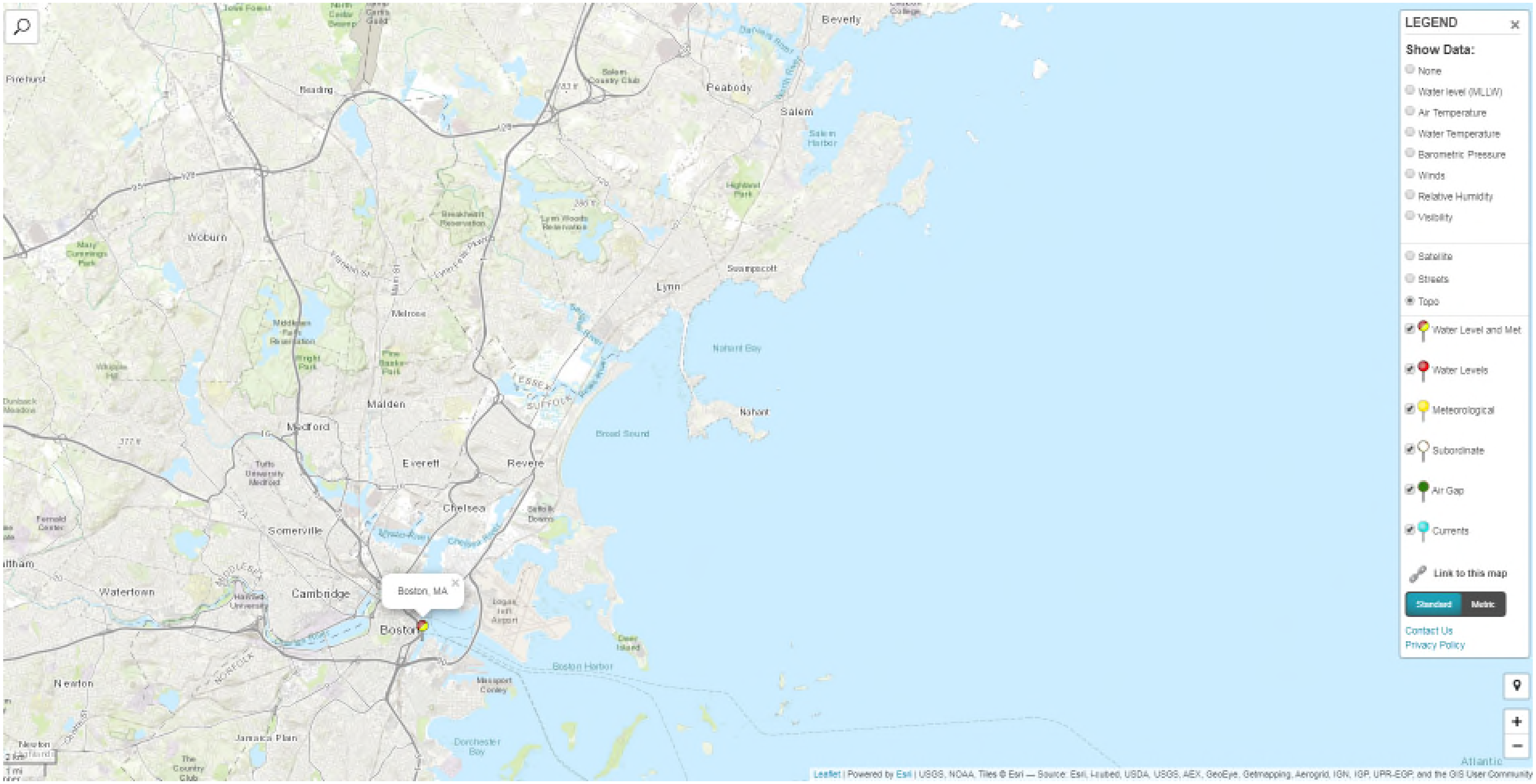


Figure B-6: Location of NOAA Boston gage.

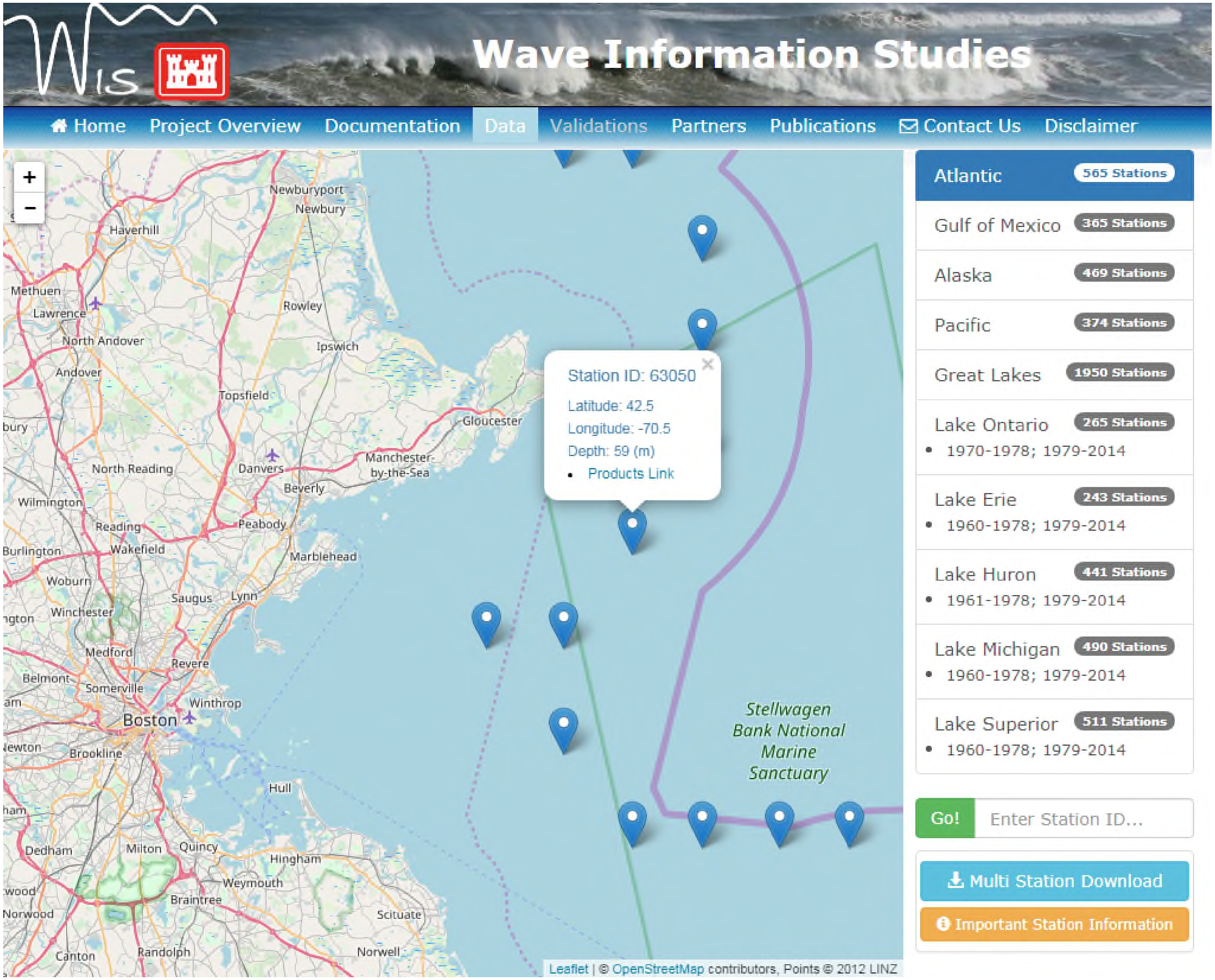
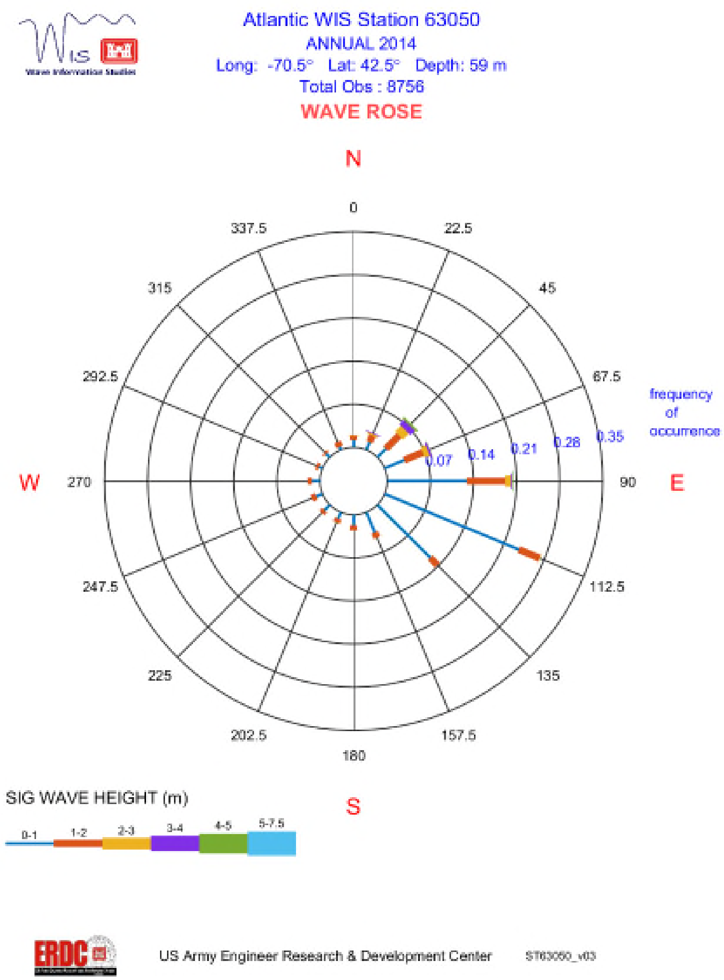


Figure B-7: Location of WIS wave buoy 63050.



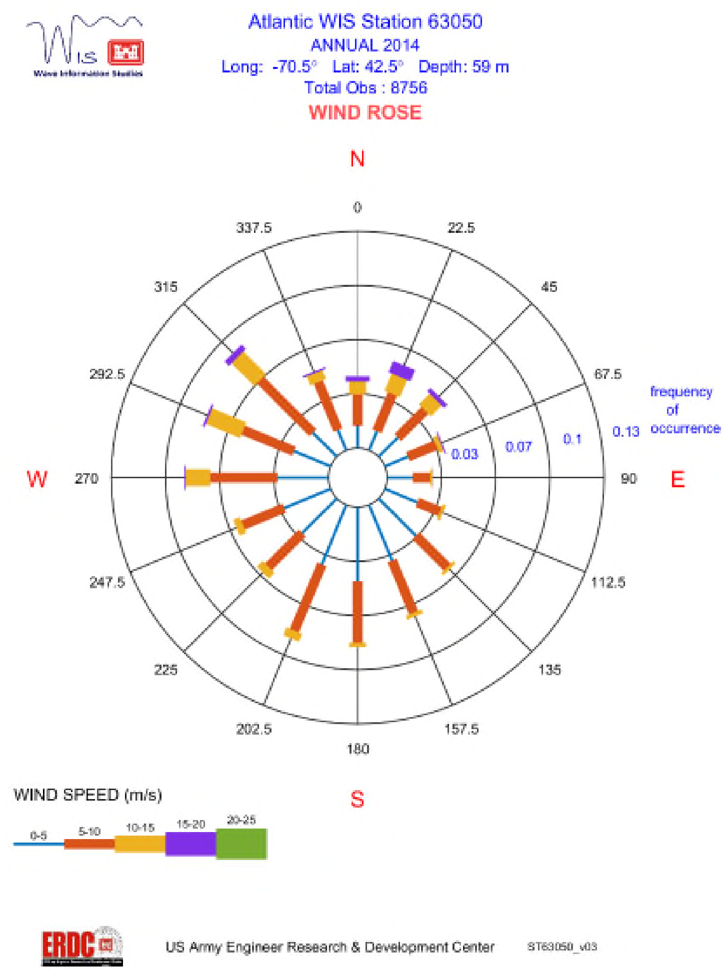
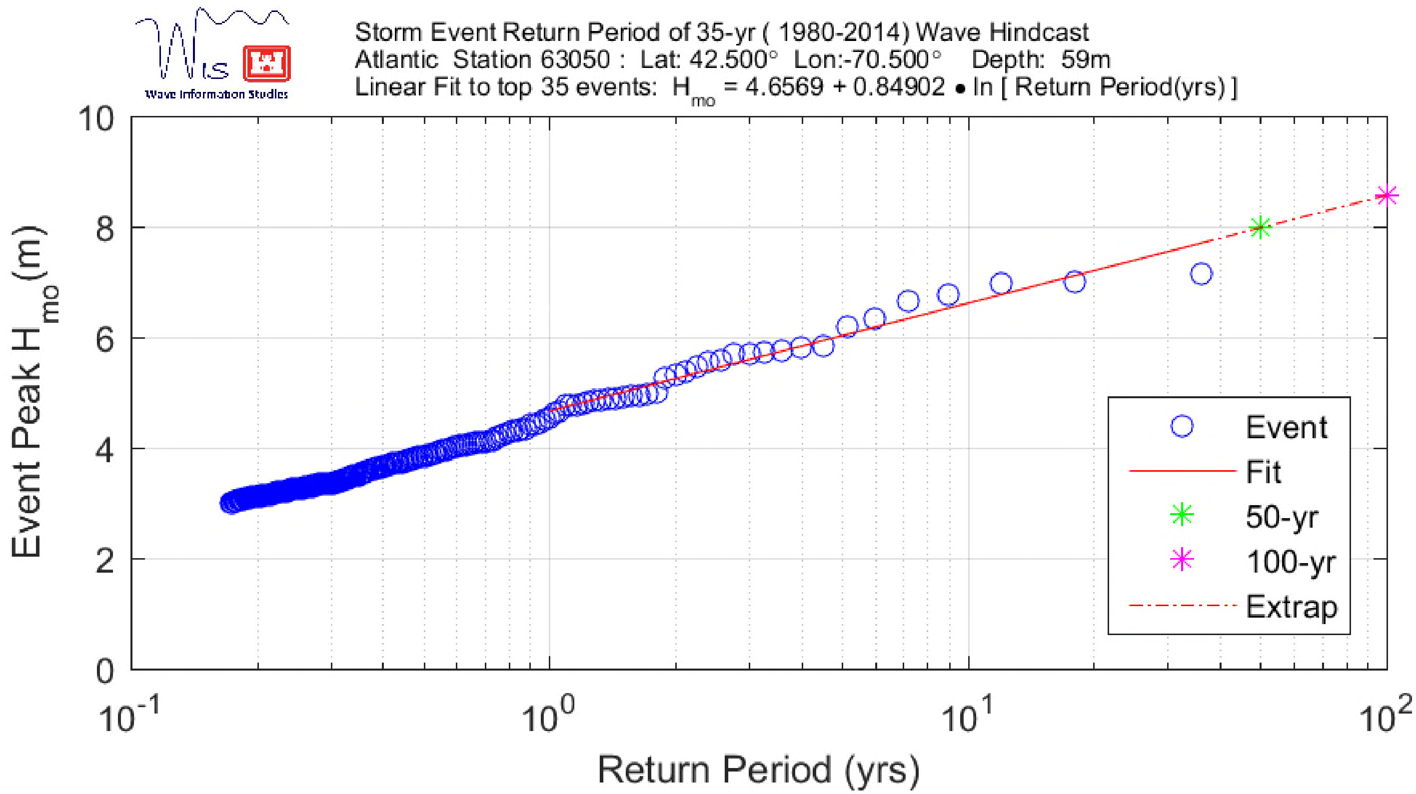


Figure B-8: Wave and wind rose at WIS wave buoy 63050.



Top 10 events based on Peak H_{mo}

Event	Date/Time(UTC)	H_{mo}	T_p	θ_{mean}	Event	Date/Time(UTC)	H_{mo}	T_p	θ_{mean}
1	2012/10/29 23:00	7.13	12.48	88.0	6	2013/02/09 03:00	6.33	10.77	49.0
2	1991/10/31 04:00	6.99	16.83	74.0	7	1991/08/19 20:00	6.18	8.70	116.0
3	1980/01/16 12:00	6.96	12.41	68.0	8	2010/03/14 14:00	5.84	11.73	89.0
4	2010/02/26 06:00	6.76	12.44	89.0	9	1981/12/06 15:00	5.82	10.82	41.0
5	1992/12/13 00:00	6.66	13.24	75.0	10	2003/12/07 03:00	5.76	11.00	58.0

An event is defined as any period when $H_{mo} > 3.00$m θ_{mean} is direction that waves are arriving from

ERDC US Army Engineer Research & Development Center   ST63050_v03

Figure B-9: Wave height statistics at WIS wave buoy 63050.

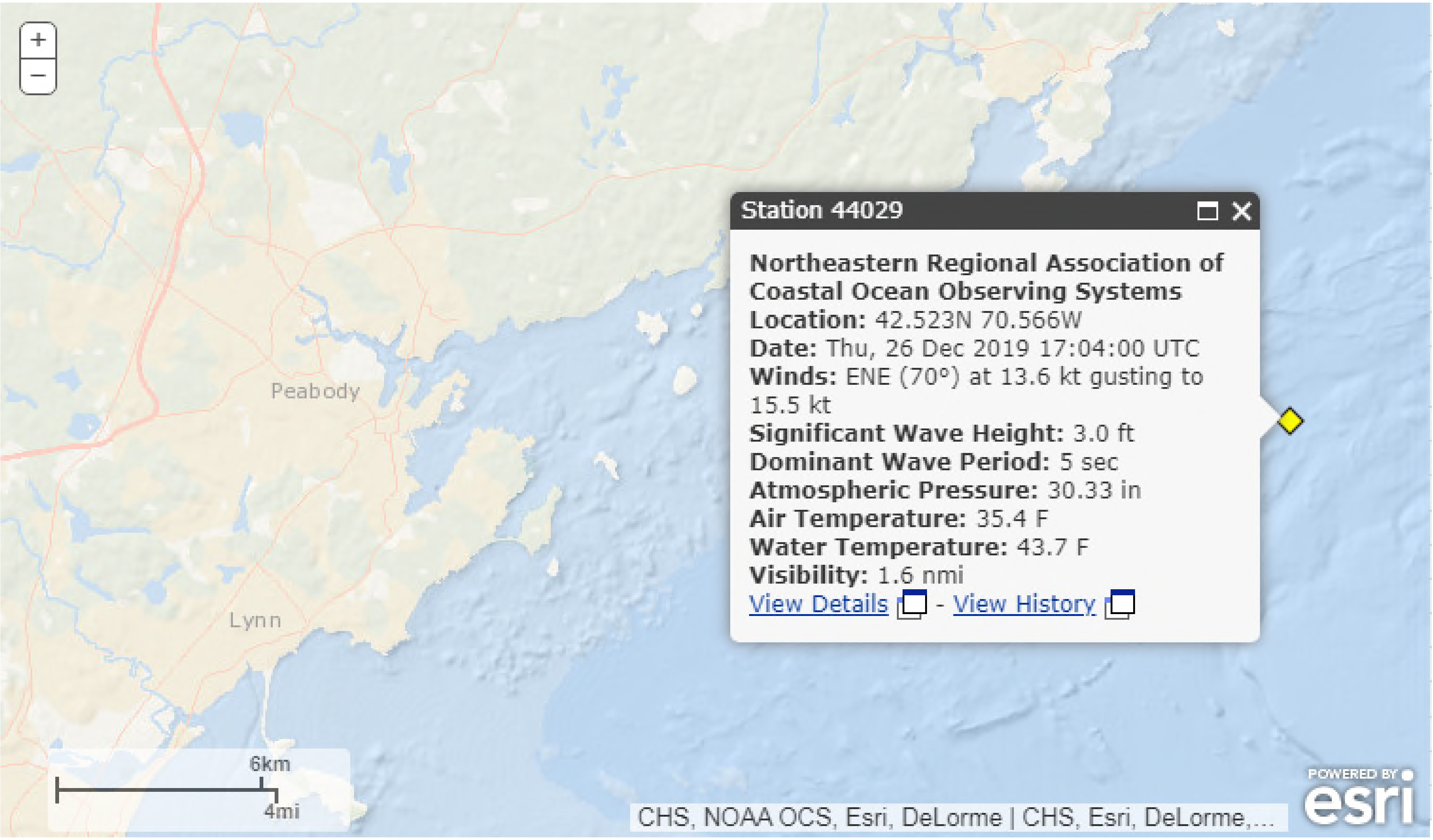


Figure B-10: Location of NERACOOS A01 buoy (or NDBC Wave Buoy 44029).

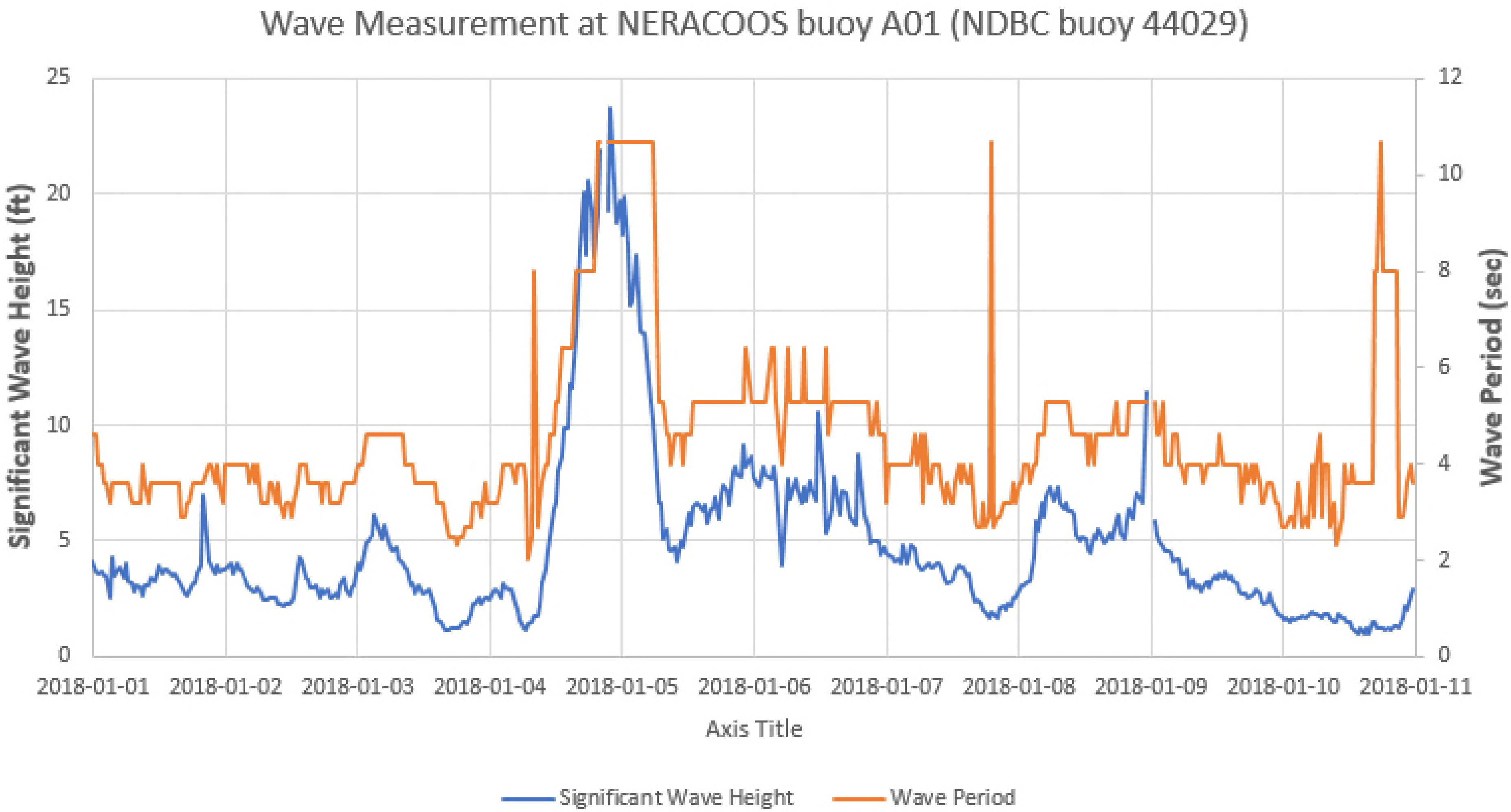


Figure B-11: Location of NERACOOS A01 buoy (or NDBC Wave Buoy 44029).

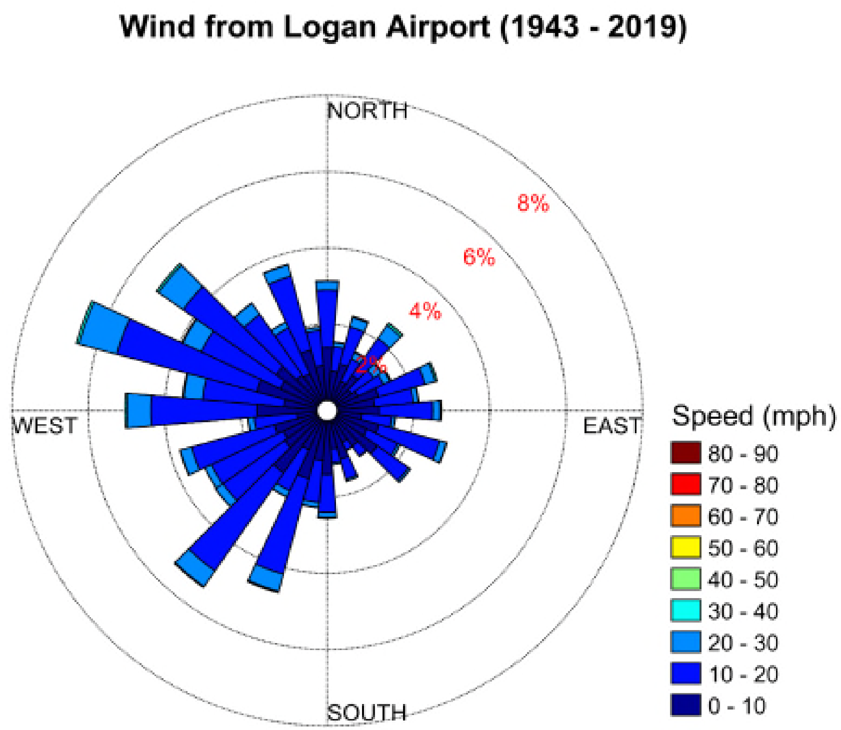


Figure B-12: Wind rose at the nearby Boston Logan Airport.

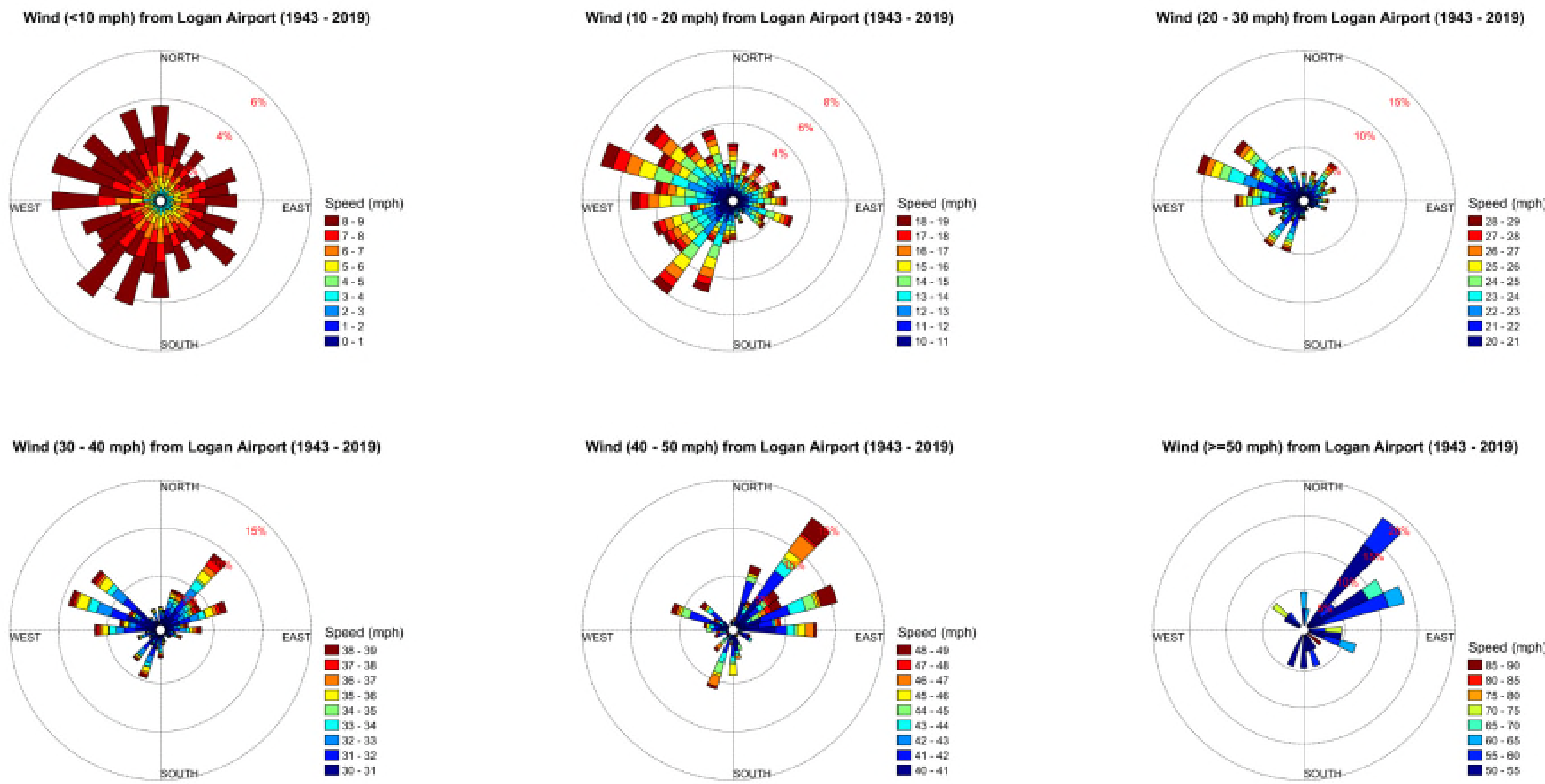


Figure B-13: Wind rose for various speed ranges at the nearby Boston Logan Airport.

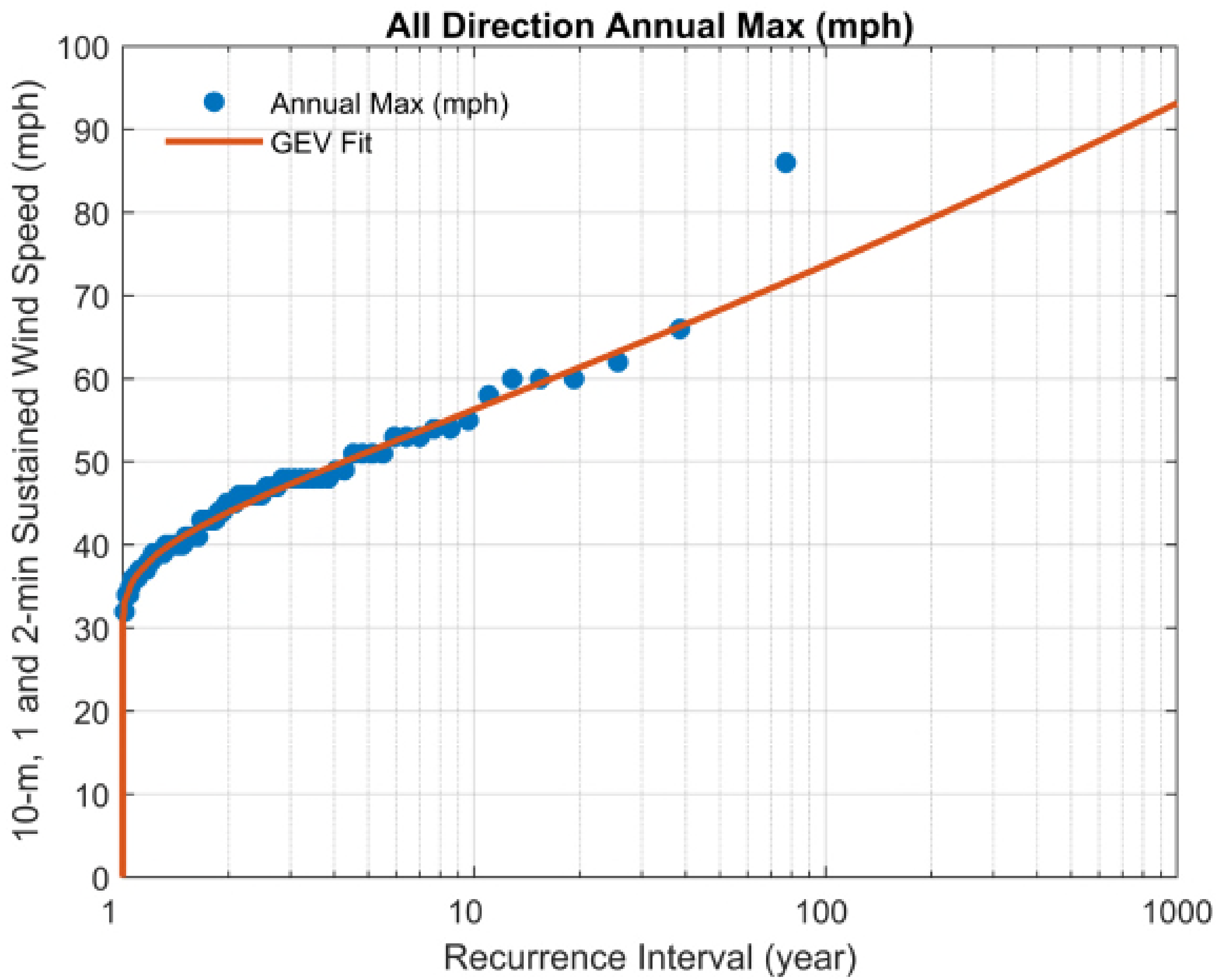


Figure B-14: GZA statistical analysis on extreme winds at Boston Logan Airport.

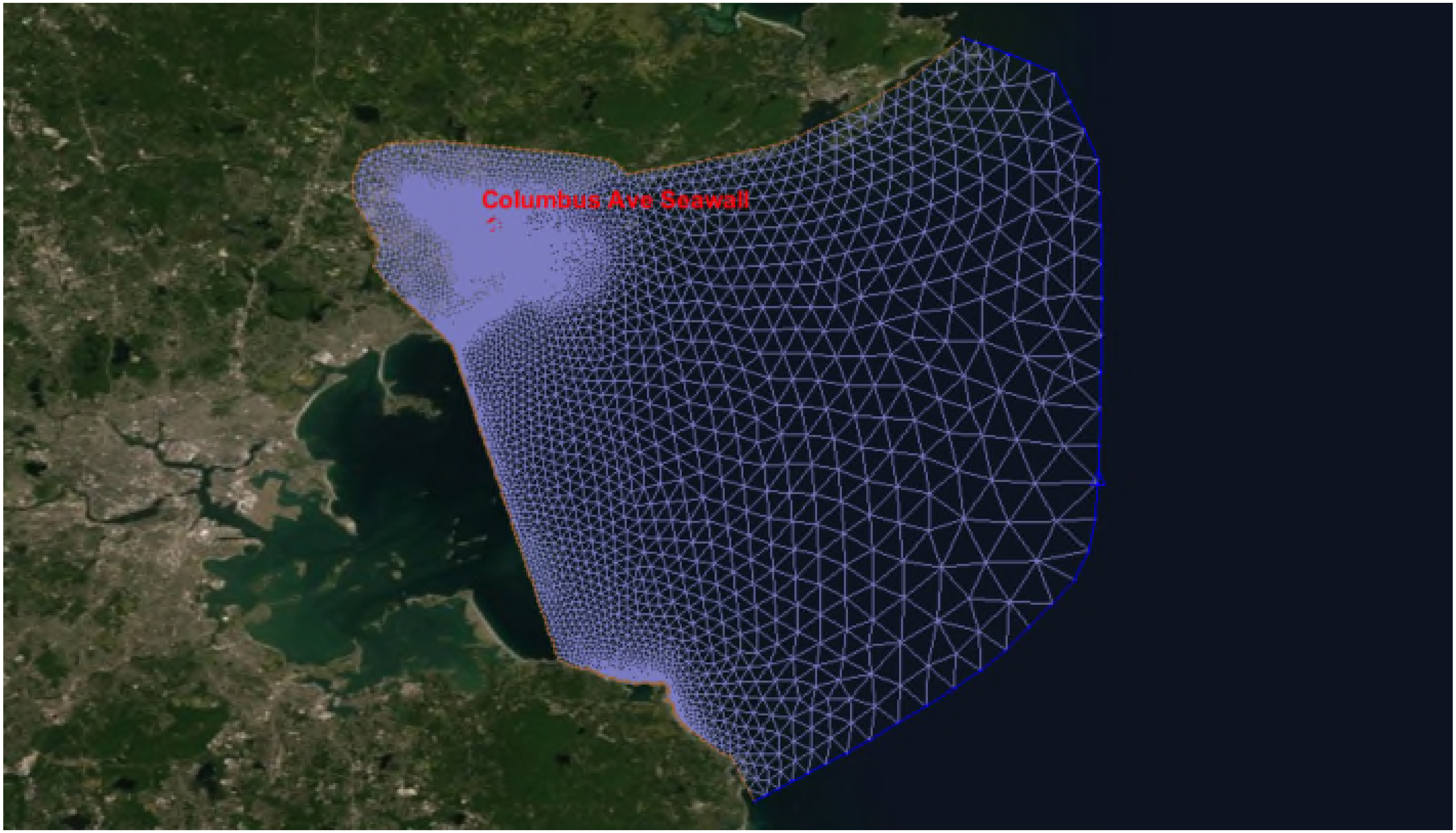


Figure B-15: SWAN model mesh.

Figure B-16: SWAN model mesh – zoomed view.

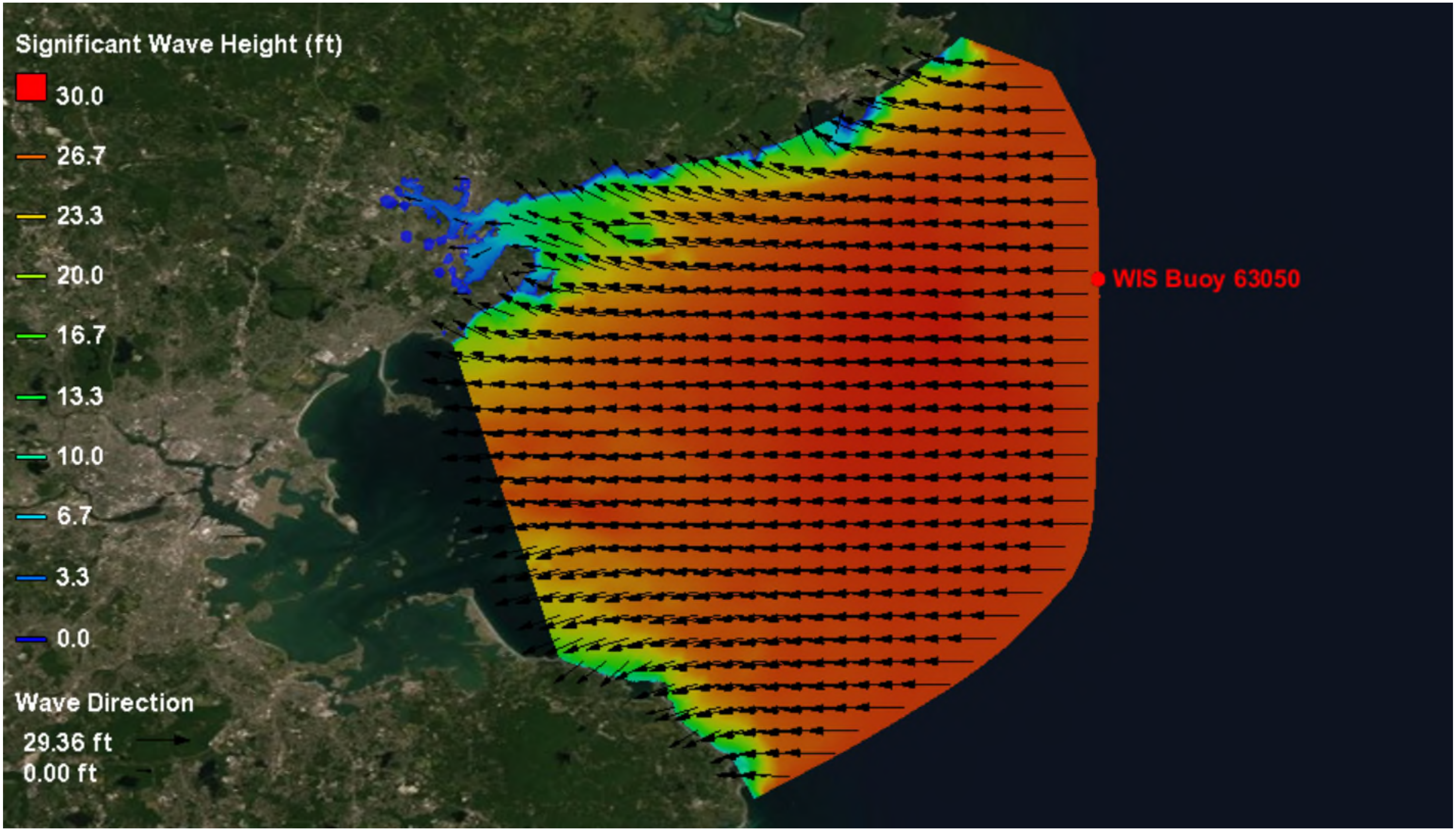


Figure B-17: SWAN simulated significant wave height for 100-year recurrence interval – scenario 1.

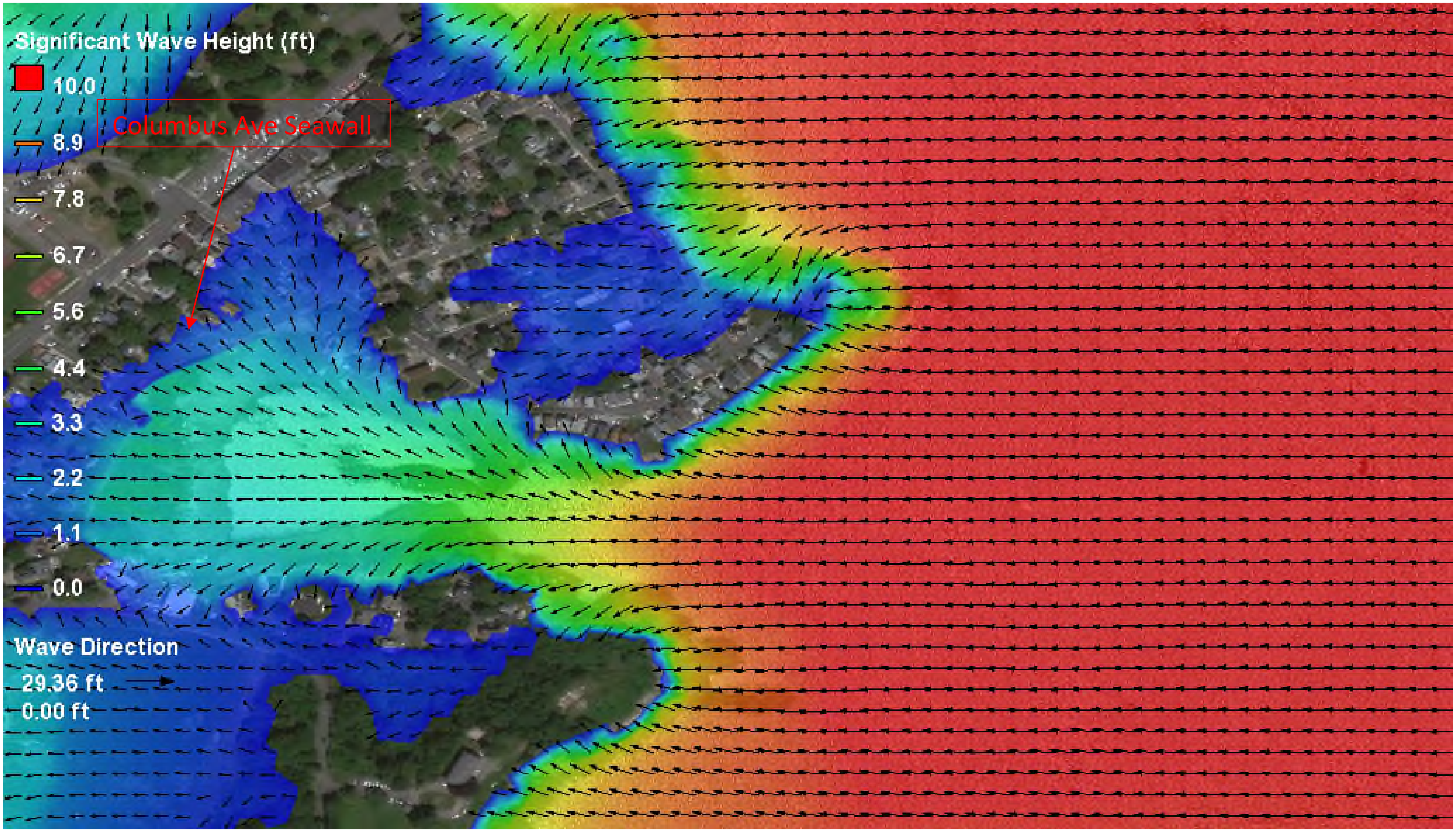


Figure B-18: SWAN simulated significant wave height for 100-year recurrence interval – scenario 1 (zoomed view).

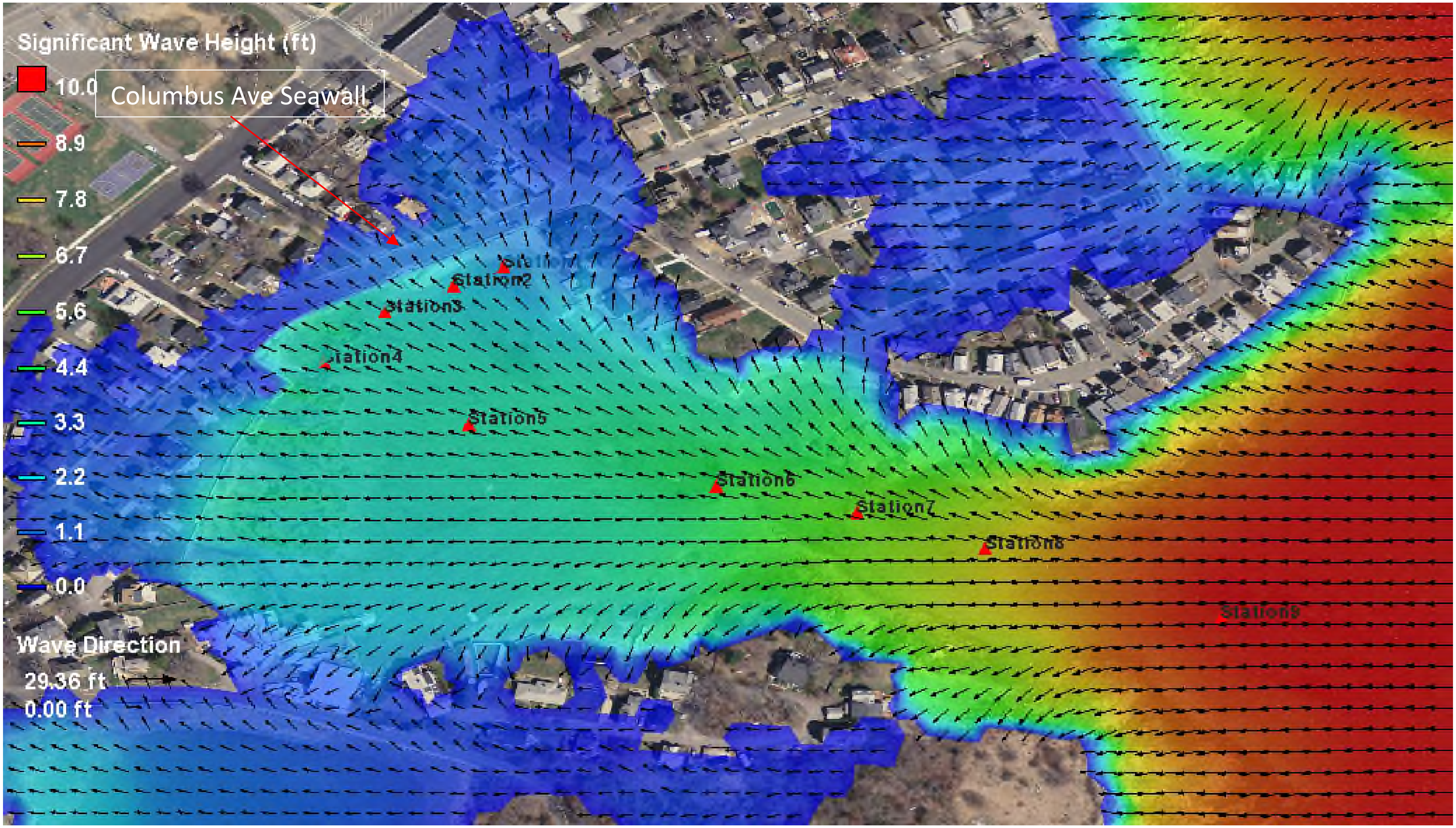


Figure B-19: SWAN simulated significant wave height for 100-year recurrence interval – Scenario 1 (site vicinity).

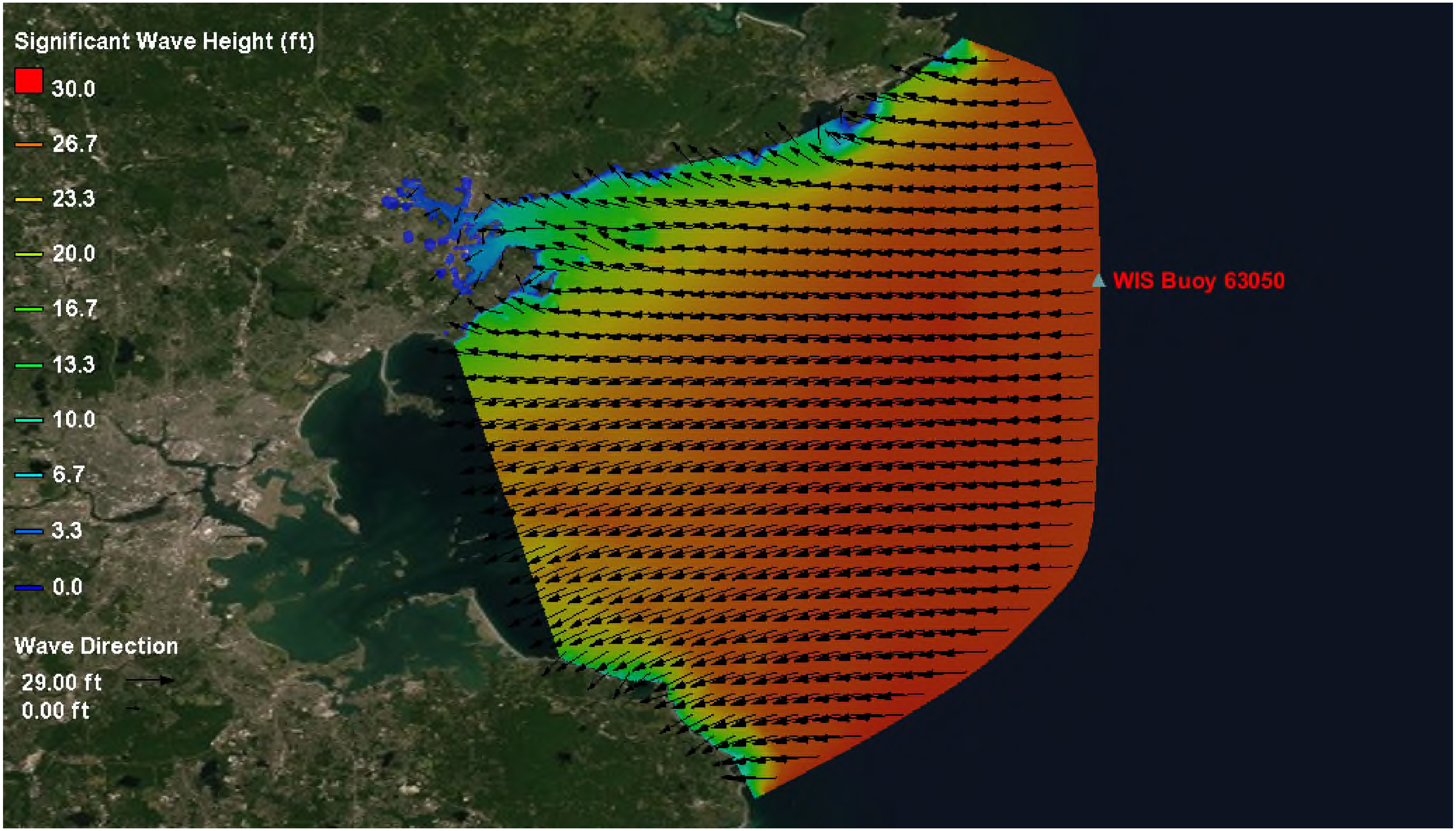


Figure B-20: SWAN simulated significant wave height for 100-year recurrence interval – scenario 2.

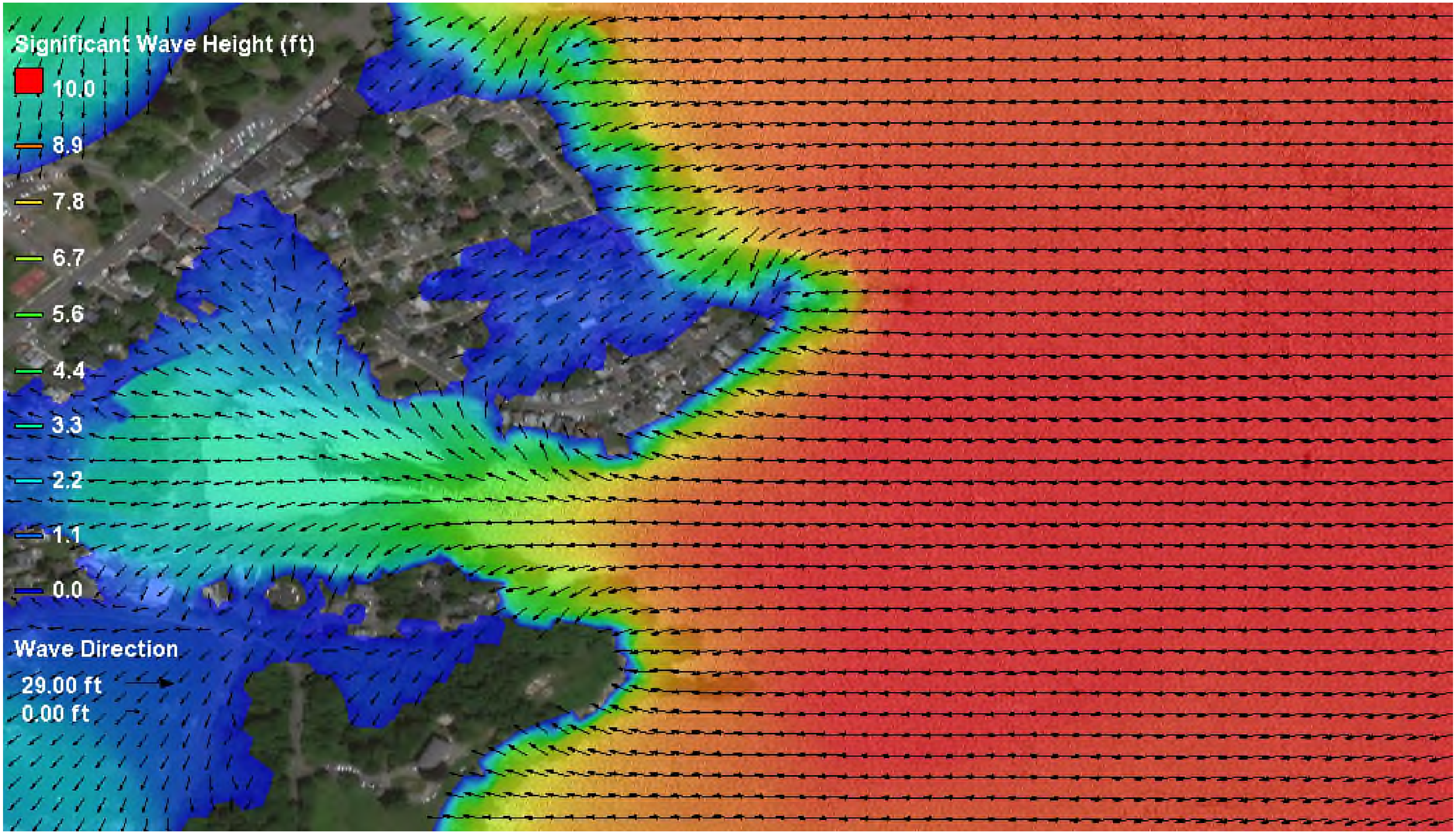


Figure B-21: SWAN simulated significant wave height for 100-year recurrence interval – scenario 2 (zoomed view).

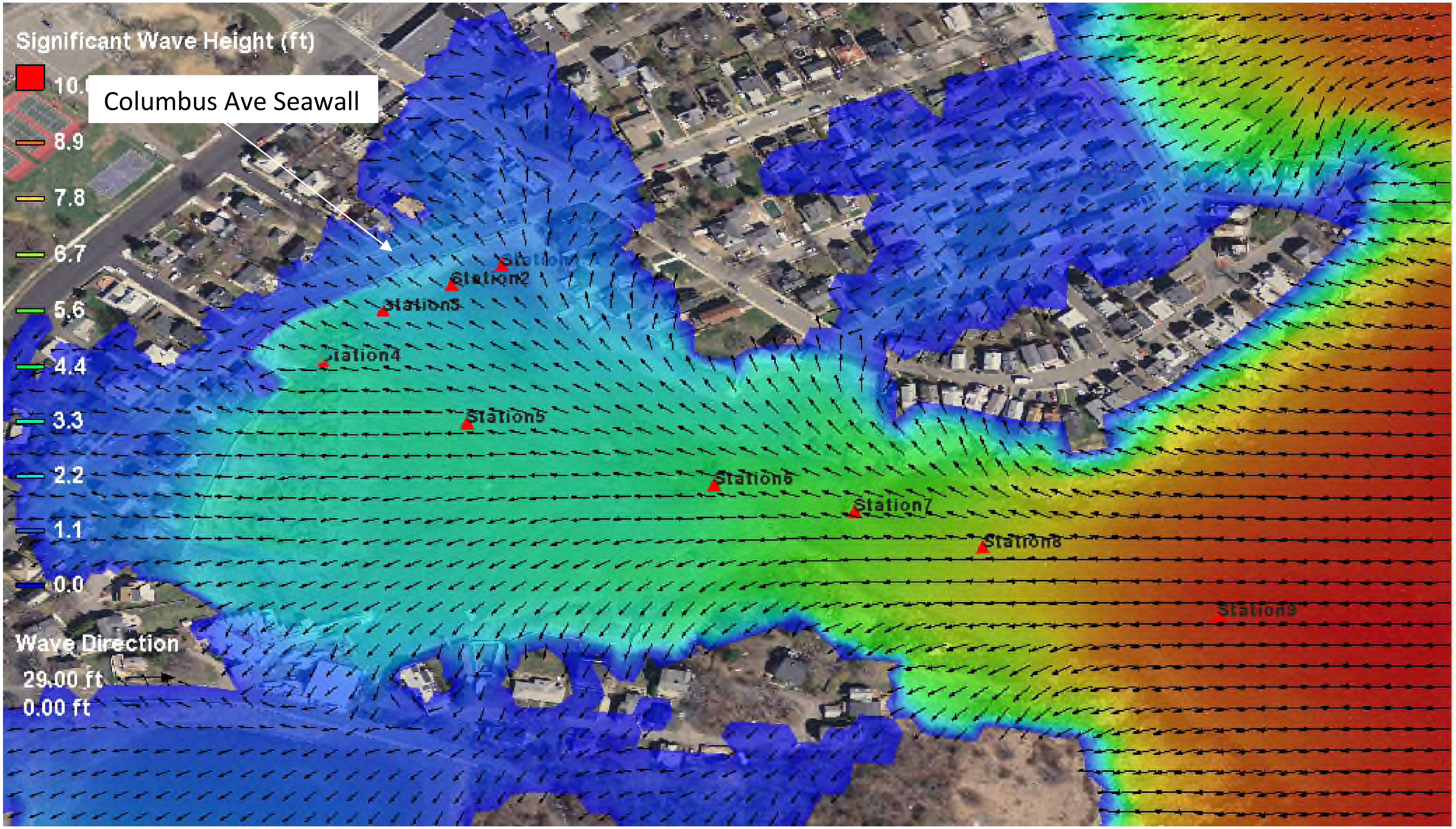


Figure B-22: SWAN simulated significant wave height for 100-year recurrence interval – Scenario 2 (site vicinity).

Figure B-23: Output Stations for SWAN Model Results.

Figure B-24: Output Stations 10 to 13 adjacent to the CAS for SWAN Model Results.

Figure B-25: Output Station ID and location of the breakwater (orange color).

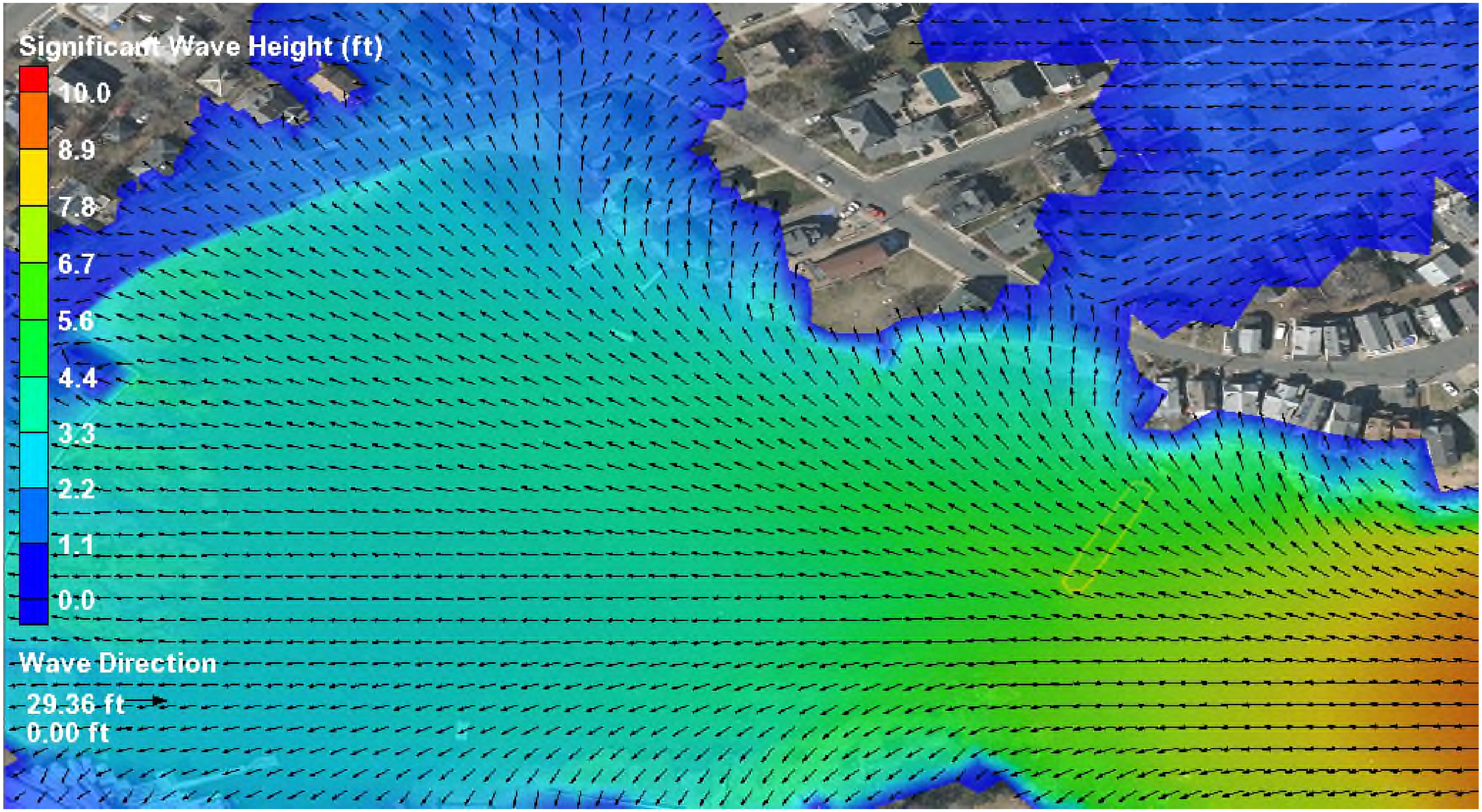


Figure B-26: 100-yr Storm Event Breakwater height: El. 0' – Scenario 1

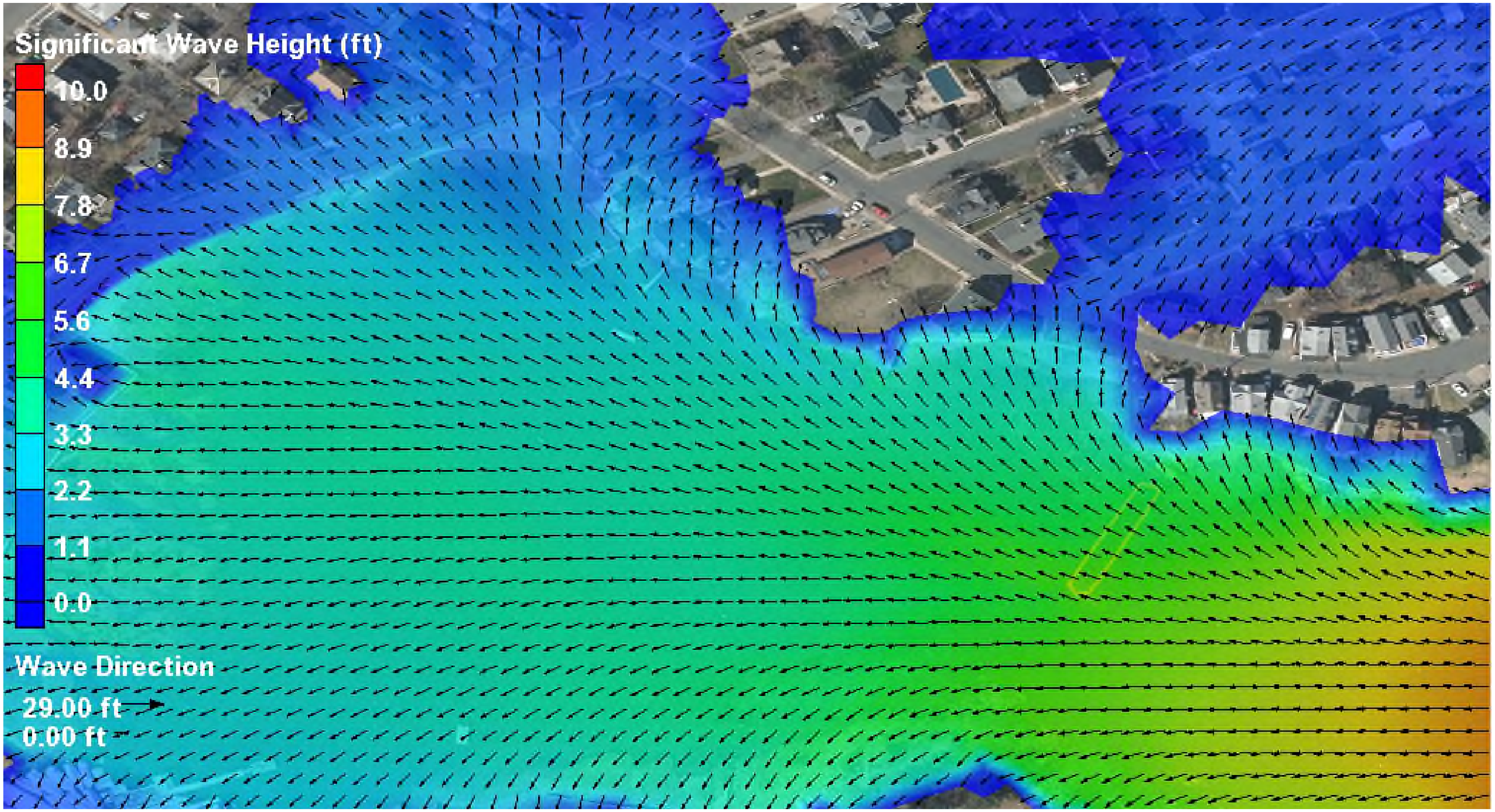


Figure B-27: 100-yr Storm Event Breakwater height: El. 0' – Scenario 2

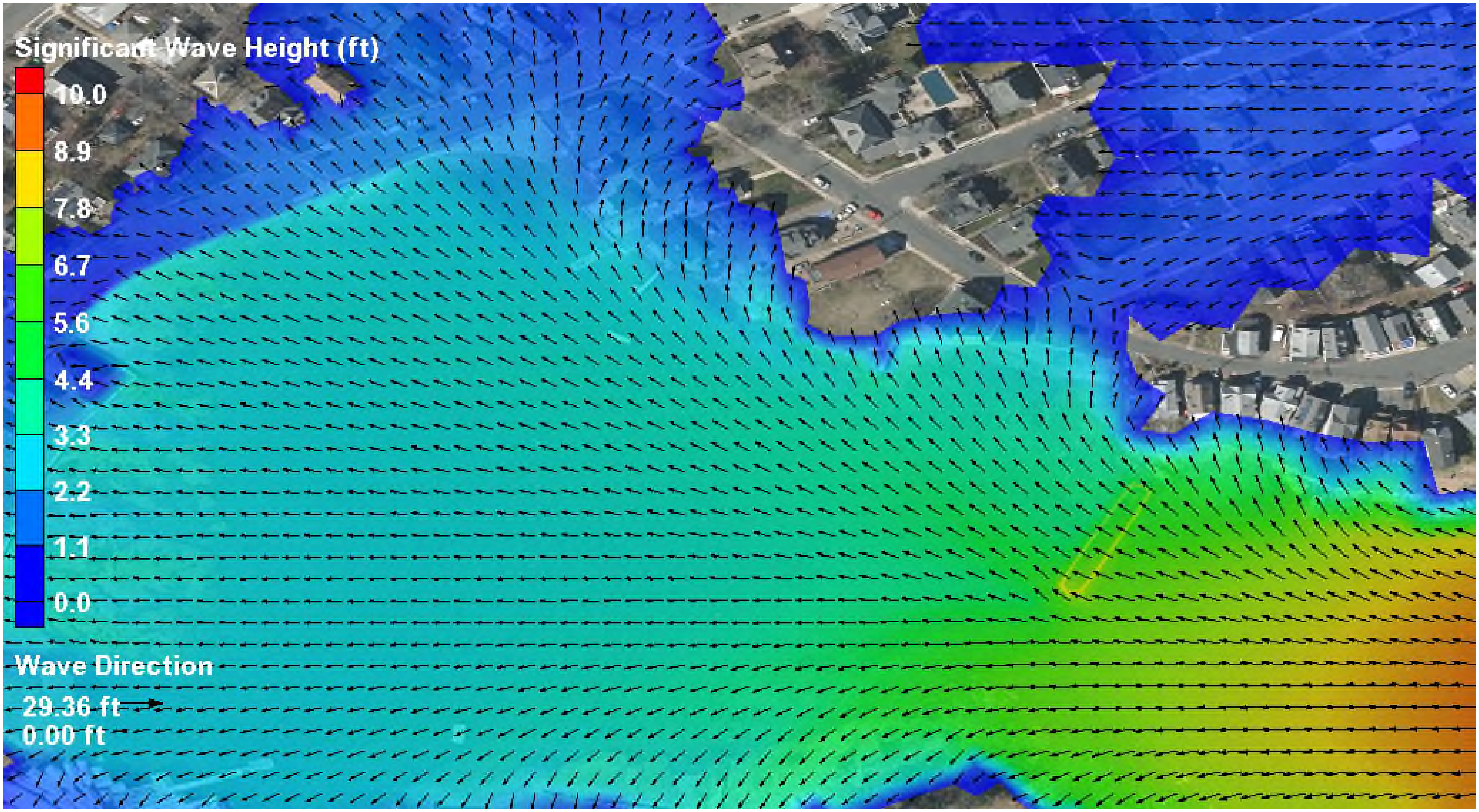


Figure B-28: 100-yr Storm Event Breakwater height: El. 5' – Scenario 1

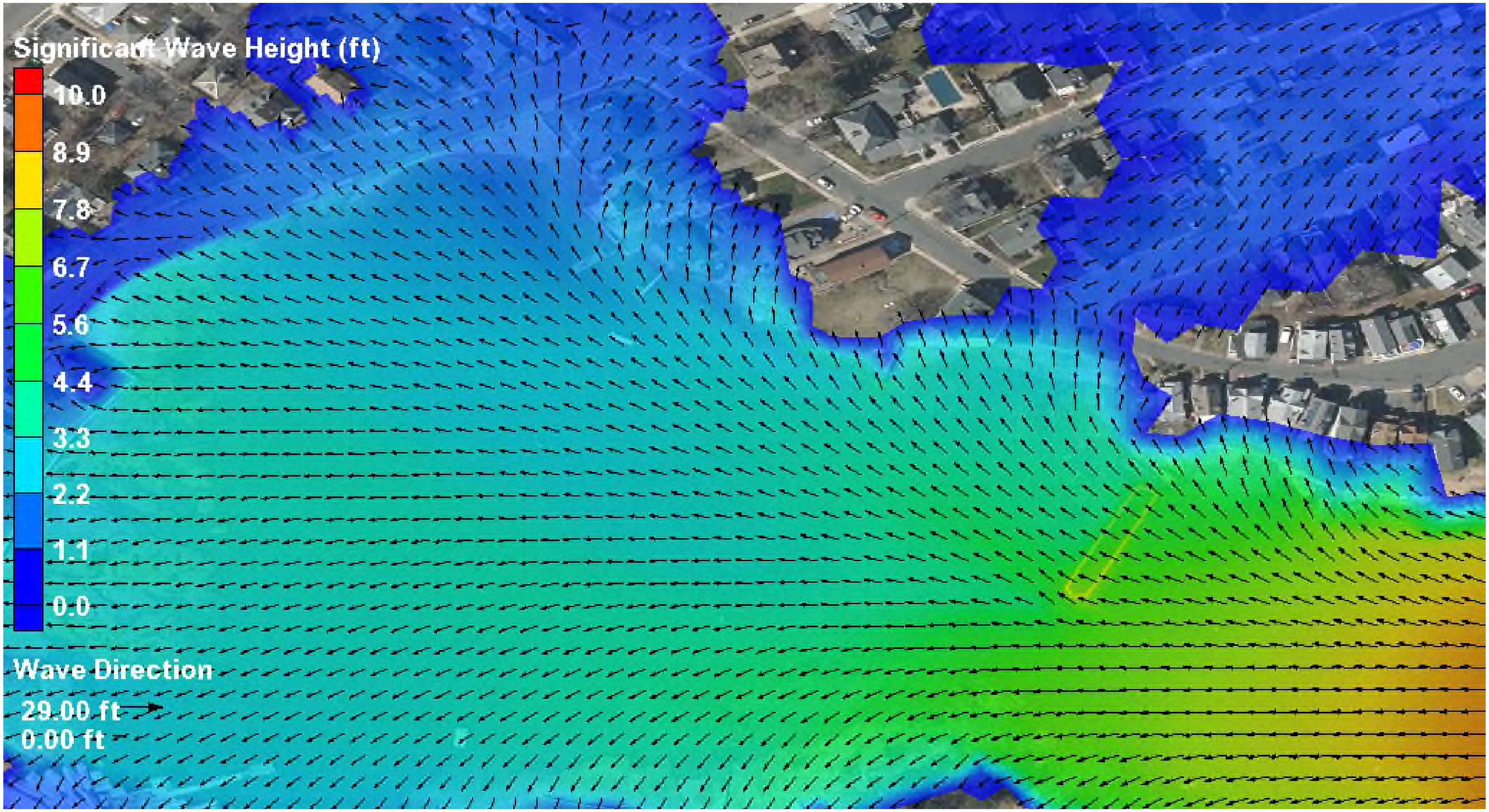


Figure B-29: 100-yr Storm Event Breakwater height: El. 5' – Scenario 2

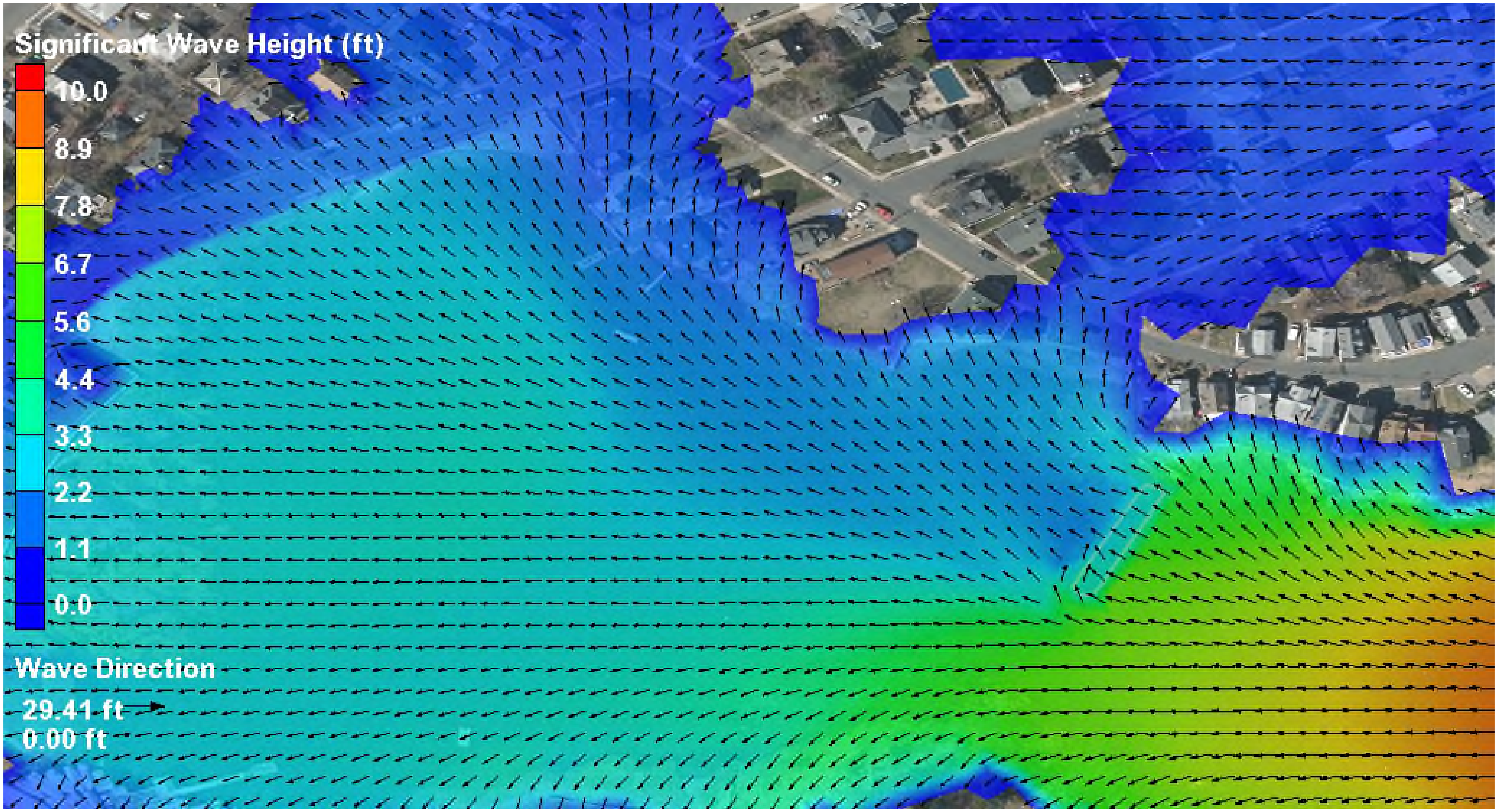


Figure B-30: 100-yr Storm Event Breakwater height: El. 8' – Scenario 1

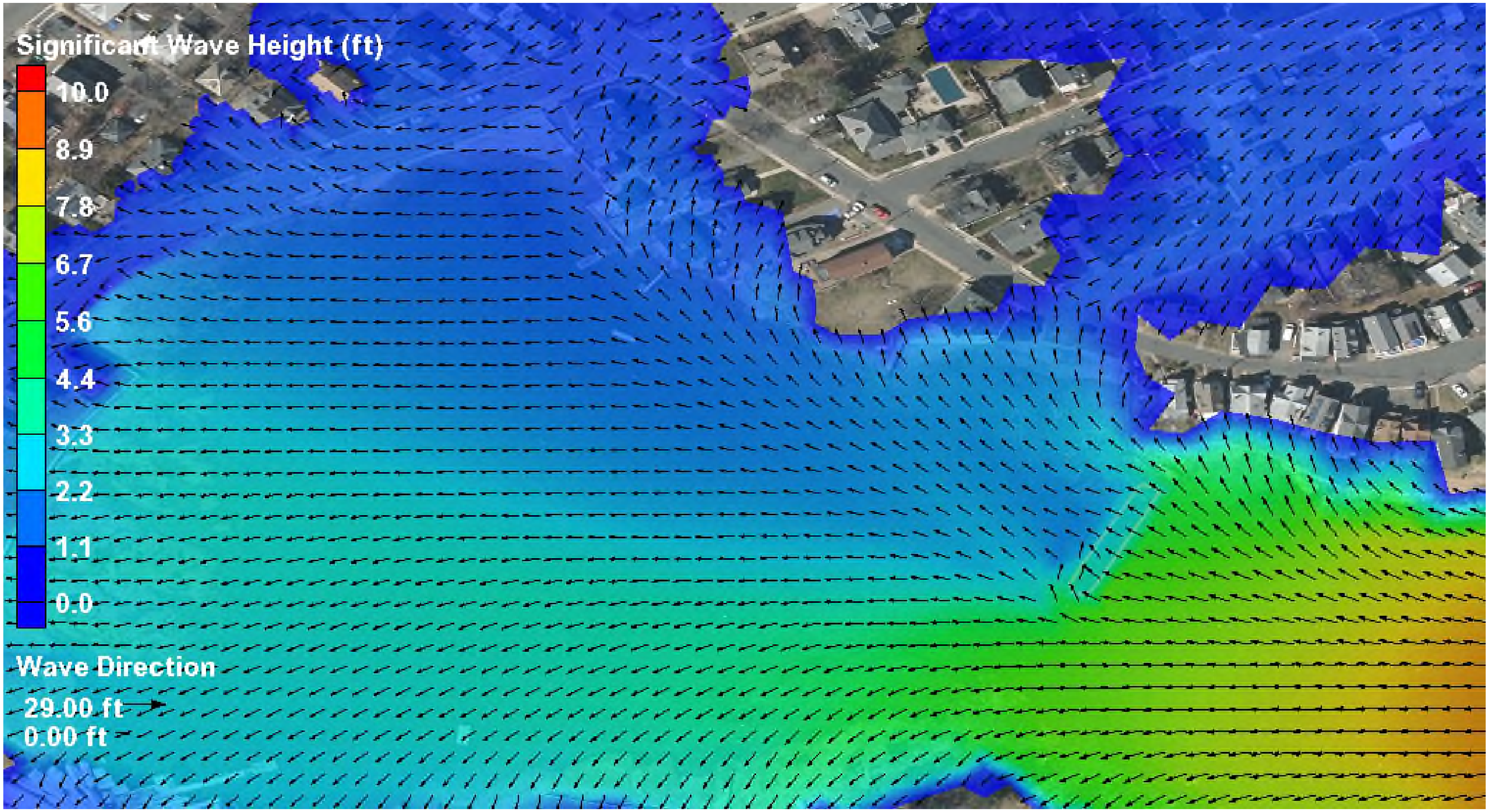


Figure B-31: 100-yr Storm Event Breakwater height: El. 8' – Scenario 2

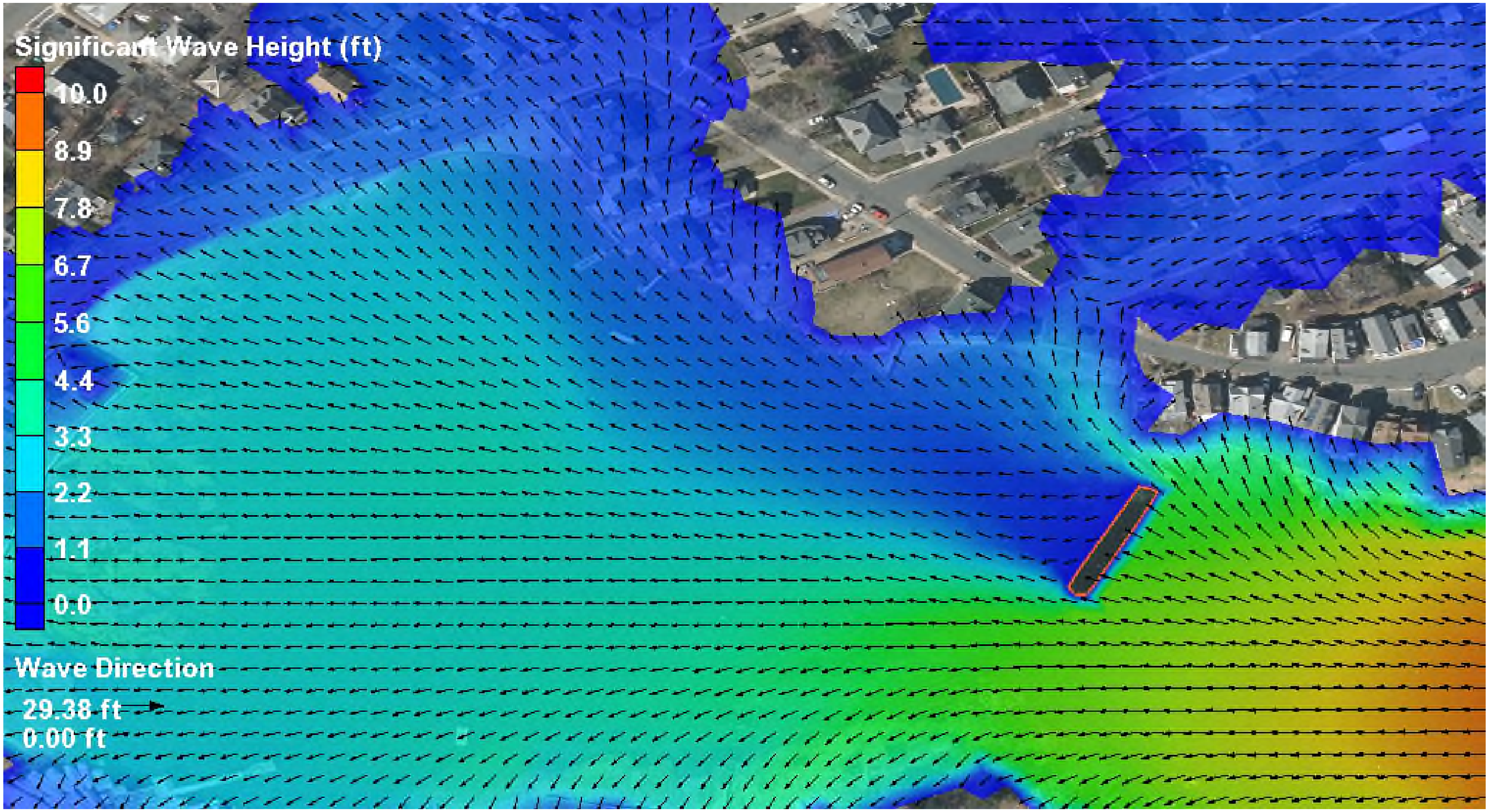


Figure B-32: 100-yr Storm Event Breakwater height: El. 10' – Scenario 1

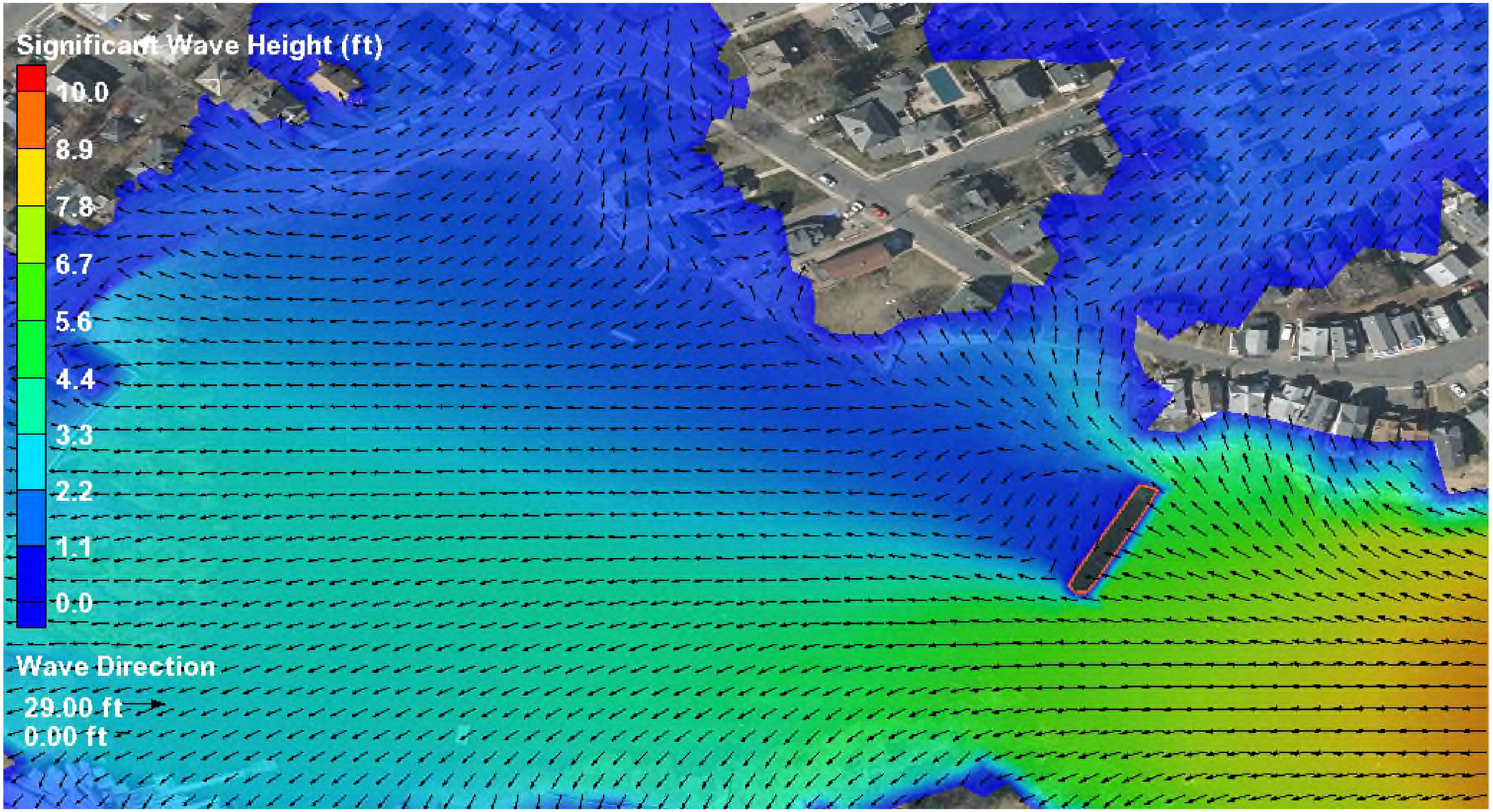


Figure B-33: 100-yr Storm Event Breakwater height: El. 10' – Scenario 2

Figure B-34: Wave Runup / Overtopping - Location of output station.

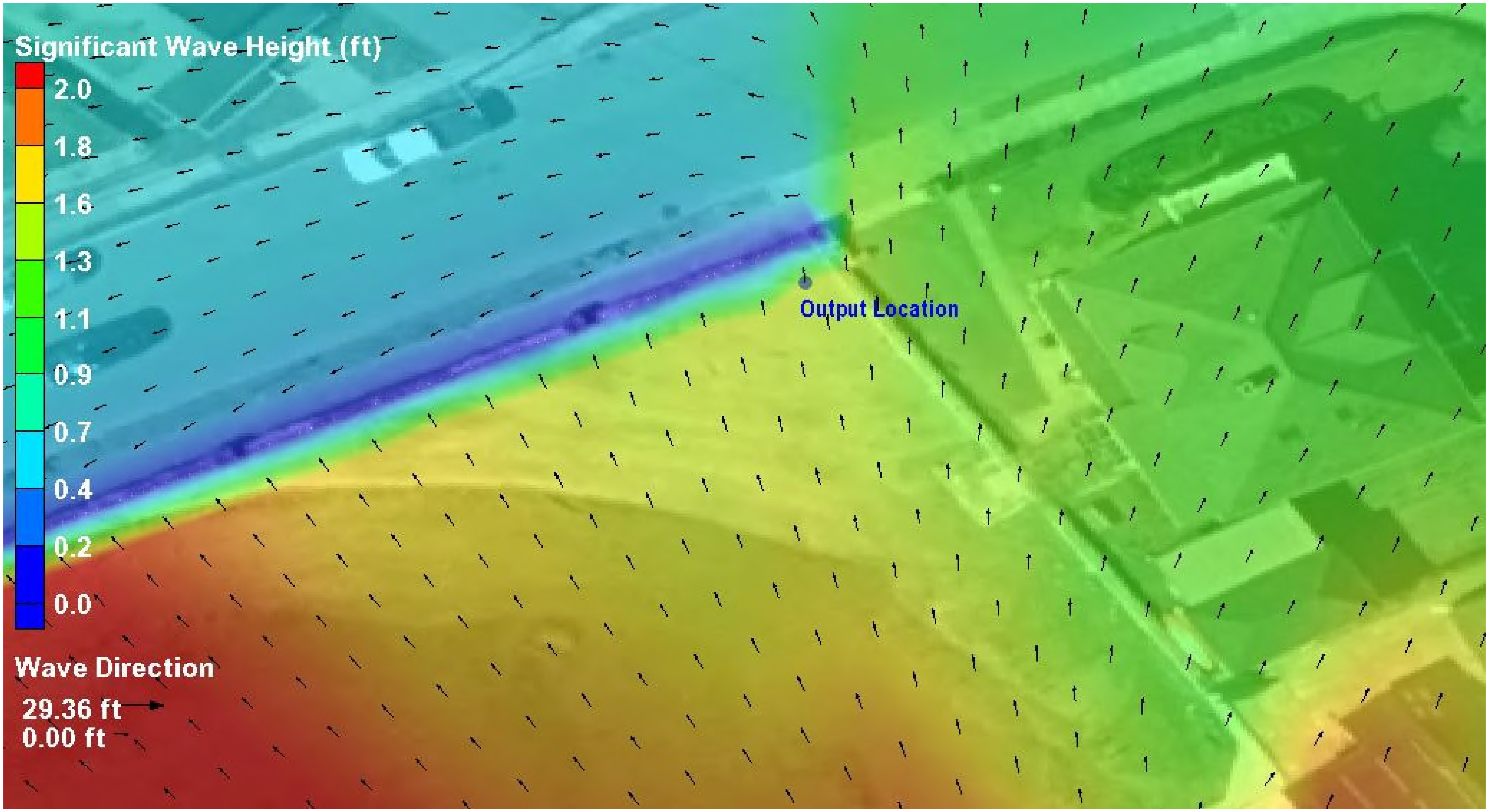


Figure B-35: 100-yr Storm Event Wave Runup / Overtopping - Wall height: El. 11’ – before sand removal.

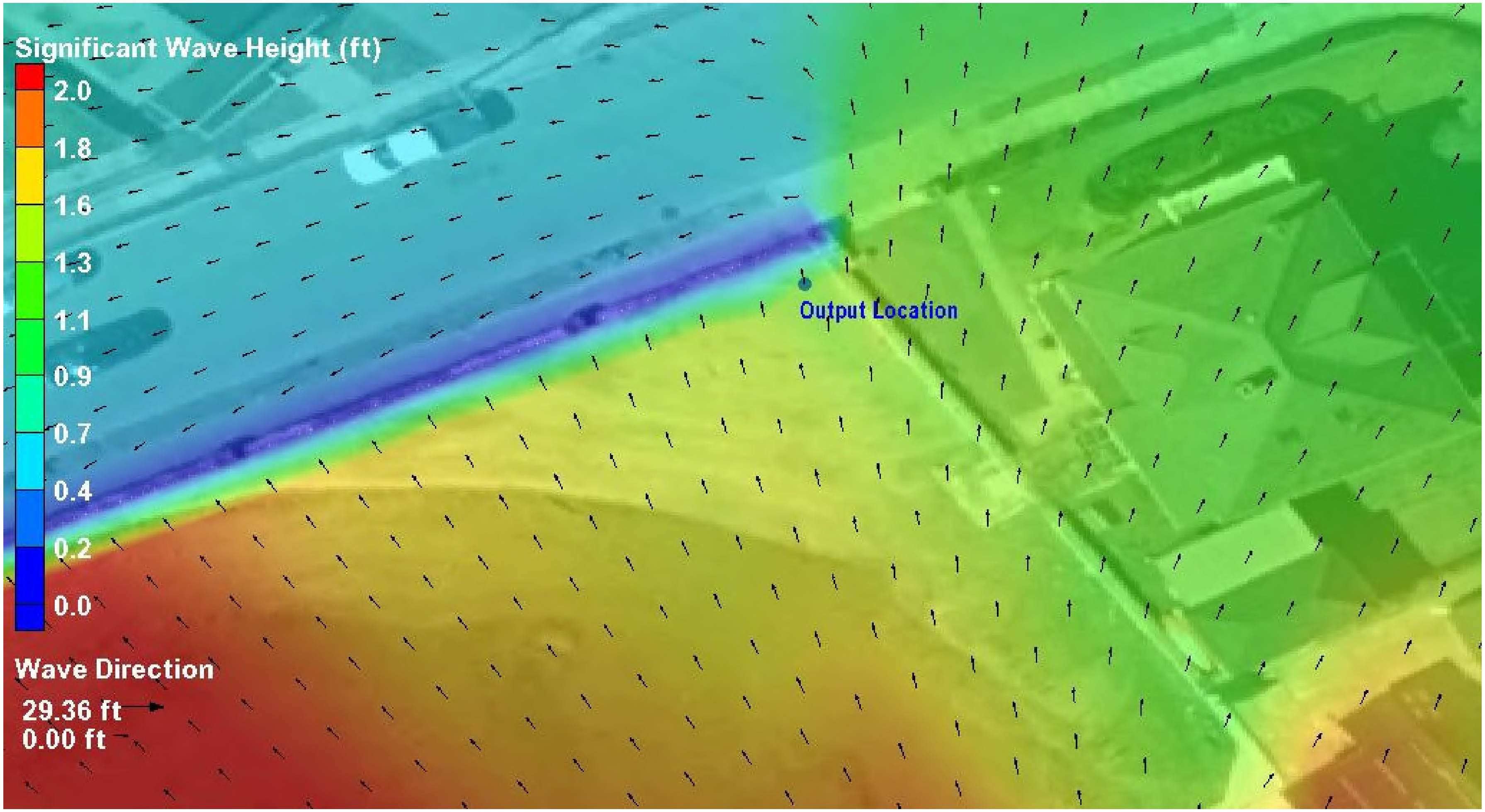


Figure B-36: 100-yr Storm Event Wave Runup / Overtopping - Wall height: El. 11' – after sand removal.

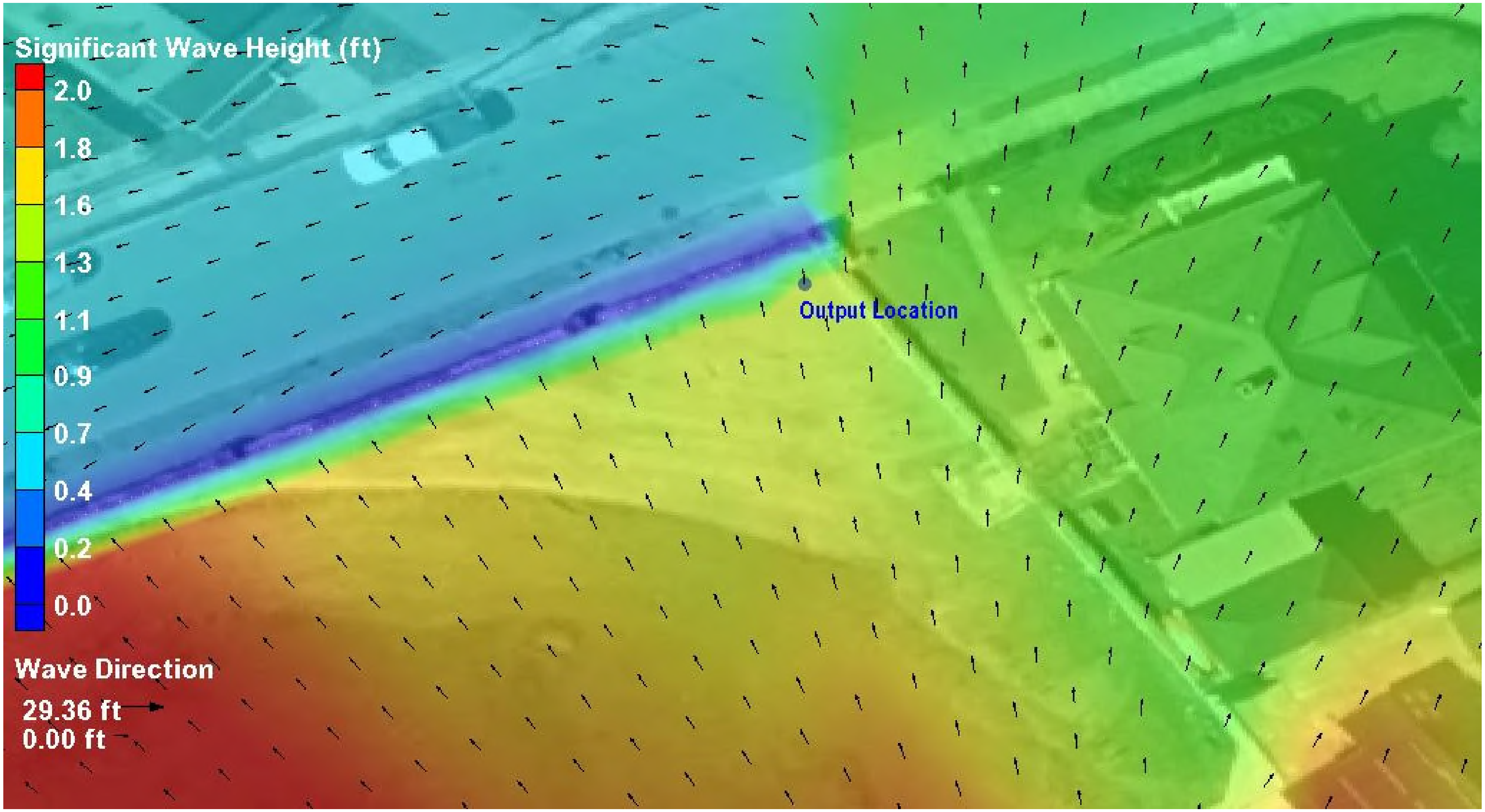


Figure B-37: 100-yr Storm Event Wave Runup / Overtopping - Wall height: El. 12' – before sand removal.

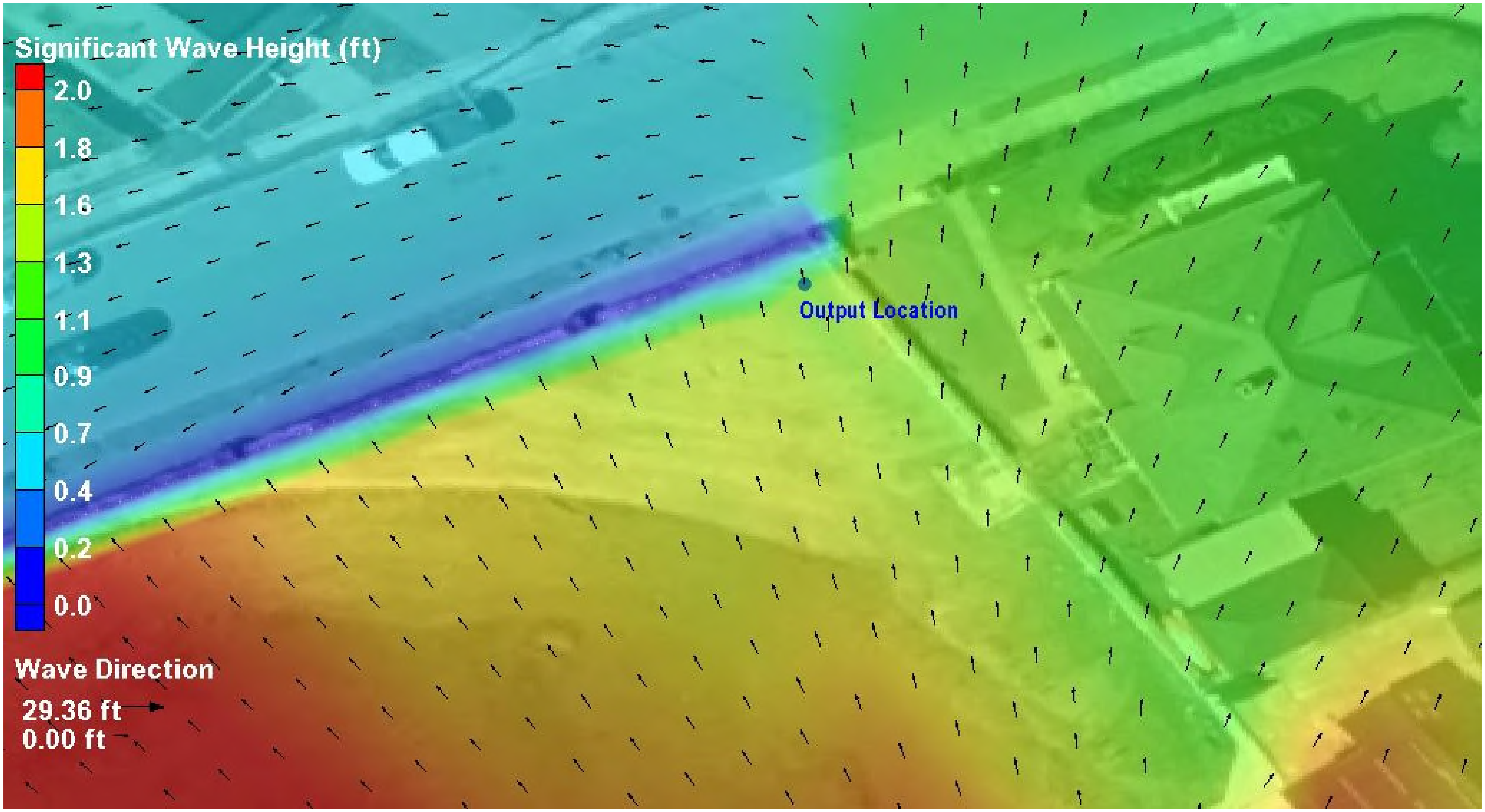


Figure B-38: 100-yr Storm Event Wave Runup / Overtopping - Wall height: El. 12' – after sand removal.

Attachment C – Preliminary Budgetary Cost Estimate

COLUMBUS AVENUE SEAWALL RECONSTRUCTION PROJECT
COLUMBUS AVENUE, SALEM, MA
ENGINEER'S COST ESTIMATE

Item No.	Description	QTY	Unit	Unit Price	Total
1	Mobilization and Demobilization	1	LS	$35,000	$35,000
2	Demolition, Removal and Disposal	1	LS	$25,000	$25,000
3	Site Restoration (benches, grass, etc.)	1	LS	$20,000	$20,000
4	Bituminous Paved Sidewalk	260	SY	$50	$13,000
5	Concrete Sidewalk/Steps	10	CY	$600	$6,000
6	Crushed Stone	350	CY	$150	$52,500
7	Filter Fabric	4700	SY	$8	$37,600
8	Granite Stone Wall	580	CY	$600	$348,000
9	Reinforced Concrete Footing	230	CY	$1,200	$276,000
10	Granite Block Landing Remove/Reset	1	LS	$30,000	$30,000
11	Storm Boards/Stop Log	1	LS	$8,000	$8,000
12	High Marsh Plantings - *S. patens*	1000	PLUG	$1.50	$1,500
13	Low Marsh Plantings - *S. alterniflora*	4500	PLUG	$1.50	$6,750
14	Salt Marsh Sand	200	CY	$80	$16,000
15	Sill Construction	222	LF	$100	$22,200
16	Salt Marsh Maintenance	1	LS	$3,000	$3,000
				Subtotal	$900,550
				Contingency 15%	$135,083
				Total Estimated Base Work	$1,035,633
					Engineer/Consultant Services
				Engineer Construction Support /Closeout Services 15%	$135,083
				TOTAL ESTIMATED PROJECT COST	**$1,170,715**