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June 10, 2024
GZA File No. 01.0177440.00

Town of Islesboro
Islesboro Sea Level Rise Committee
Islesboro, ME 04848
c/o Shri A. Verrill, Project Manager
Shri@SunriseEcologic.com

Re: Alternative Analysis and 15% Preliminary Design Memorandum - DRAFT
The Narrows – Islesboro, Maine

Dear Shri,

In accordance with the project agreement, GZA is providing this Alternative Analysis and 15% Preliminary Design Memorandum for the coastal resilience project along The Narrows in Islesboro, Maine. This memorandum summarizes the work completed under Tasks 1 through 3 consisting of project coordination with the Sea Level Rise Committee (SLRC), a site visit, existing document review, metocean data analysis, and an alternatives analysis for potential approaches to incorporate coastal resiliency for the subject roadway. An overview of this memorandum, with a focus on the alternatives, will be presented to the SLRC at a June meeting. This memorandum is subject to the Marine Design Limitations in Appendix A.

PROJECT OVERVIEW

The Town of Islesboro is an island community of approximately 600 year-round residents. It is located approximately three miles from the mainland in Penobscot Bay in Maine. The island has a north-south orientation with a narrow isthmus, The Narrows, connecting the northern and southern portions of the island. (See **Image 1**.) The Maine Department of Transportation's ferry service for the island, the town office, community center, and most of the emergency response services are located on the southern portion of the island. As such, Main Road, as the only road that passes along The Narrows, is critical to daily life on the island and for access to services during emergency conditions.

Image 1: Aerial imagery – Islesboro, Maine

Essentially, there are three sections of Main Road that have coastal exposure along The Narrows. In this report, the "North" Narrows refers to the section of Main Road north of the Oak - Pine Forest and has a main exposure to the west with Crow Cove. The "Middle" Narrows refers to the section of Main Road along the Oak - Pine Forest and has an eastern exposure to Penobscot Bay. The "South" Narrows refers to the section of Main Road south of the Oak - Pine Forest and has a western exposure to Crow Cove and an eastern exposure to Penobscot Bay. (See **Image 2**.)

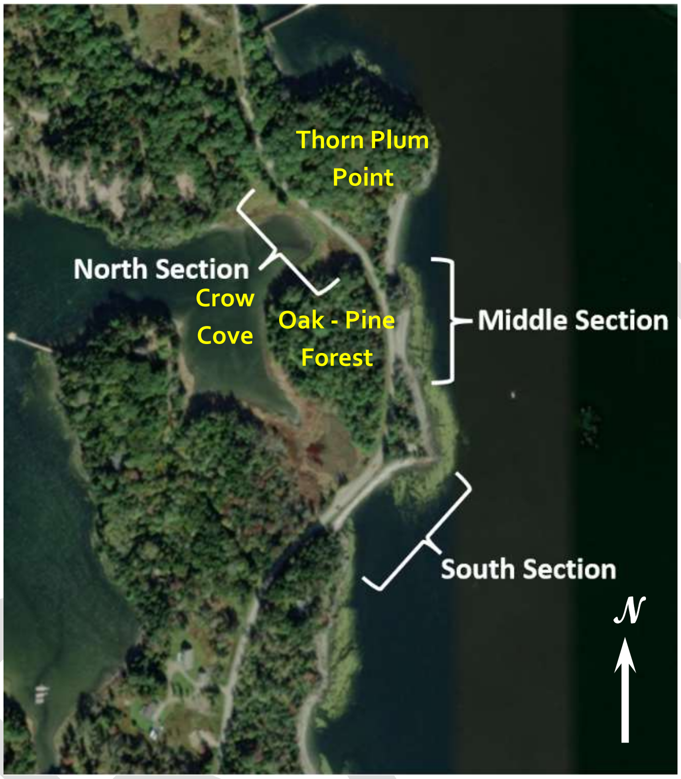


Image 2: North, Middle, and South Sections of The Narrows

During the winter storms of 23 December 2022, 10 January 2024, and 13 January 2024, the storm surge, wave action, and roadway debris at The Narrows closed Main Road for several hours during each event. Roadway flooding, wave overtopping, and debris created hazardous conditions and isolated the northern part of the island from the ferry terminal and town services headquartered in the southern portion of the island. (See **Photographs 1 and 2**.) As the frequency and intensity of coastal storms increase and the island connectivity at The Narrows is threatened, the Town is developing adaptive alternatives for improving the resilience of Main Road through The Narrows, including potential incorporation of nature-based approaches.

Photograph 1: The Narrows, January 10, 2024 Storm Conditions (Photo curtesy of the Town of Islesboro)

Photograph 2: The Narrows, January 13, 2024 Storm Conditions (Photo curtesy of the Town of Islesboro)

The following summarizes our work for characterizing the coastal site conditions at The Narrows and the 15% preliminary design of alternatives for improving resilience of Main Road along the North, Middle, and South Narrows.

EXISTING DOCUMENTS REVIEW

GZA reviewed the following documents made available to us by the Town Manager and the SLRC on The Narrows.

A. 2023 Gartley & Dorsky, East Shore Drive Shoreline Stabilization Plans (2 drawing sheets)

   The East Shore Drive Shoreline Stabilization project is located south of The Narrows on the east side of the island. While it is not directly related to The Narrows, it is representative of a recent project completed by the Town to address impacts to a roadway with direct exposure to Penobscot Bay. It consisted of stone slope stabilization using stone of 2-ft to 3-ft in size with 3-ft to 4-ft toe stones.

B. 2020 CES, Inc. The Narrows, Main Road Reconstruction Report and Draft Plans

   The Main Road Draft Reconstruction Plans provide roadway details for raising Main Road along The Narrows to Elevation 12 feet (minimum) to 13 feet (maximum) (NAVD88 vertical datum). In addition to draft plans, the project included a Project Summary discussing potential construction methods, anticipated permitting requirements, potential construction schedule, and estimated material quantities.

   The project plans were based on a 2019 topographic survey completed by CES, Inc. The Town provided a copy of the AutoCAD file with the topographic survey for use on the current project.

C. 2017 Ransom Consulting, Inc. study: *Present and Future Vulnerability to Coastal Flooding at Grindle Point and the Narrows*

   The report for this study provided detailed coastal flood hazard information for Grindle Point and The Narrows. The study was based on numerical storm surge and wave modeling with local probabilistic sea level change projections and included a Monte Carlo simulation that combined probabilistic sea level change projections with coastal flooding hazard information. The report discusses relevant consequences from Total Water Level (TWL) exceeding the roadway elevations and classified the level of consequences as Minor, Moderate, or Severe based on the depth of flooding and wave action for projections out to year 2100. The report did not include potential hazards resulting from wave run-up or overtopping, potential erosion of unprotected areas of the roadway, or stability assessment of existing coastal protection structures along the roadway. The report provides a summary for considering adaptation planning as related to accommodate, protect, and retreat. For The Narrows, the report indicates adaptation as a reasonable option for 20-30 years "until the likelihood of moderate to severe flooding at the Narrows becomes too great."

D. 1983 Army Corps of Engineers' Preliminary Design Drawing, a 1983 Design Drawing, and a 1984 As-Built Drawing for the southern end of The Narrows

The 1983 preliminary design drawing consists of a site plan depicting the limits of the then-proposed stone slope protection and the approximate limits of exposed bedrock. (See **Figure 1**.) The design drawing consists of cross-sections detailing the stone composition and the geometry of the slope protection. The 1984 as-built drawing provides the as-constructed modifications to the design cross-sections. (See **Figure 2**.). The slope protection geometry included a 7-foot wide stone crest with a stone slope (2 horizontal to 1 vertical) on the ocean side to a 10-foot to 13-foot wide stone berm at the toe of the slope that was either keyed into the exposed bedrock or had a sloped face to match the existing harbor bottom. While the stone size is not specified, the cross-sections detail a 3-foot thick outer stone layer over a 1.25-foot thick stone bedding over a 1-foot gravel base on compacted fill and bedrock.

It is noted that the geometry of the slope protection based on the 2019 topographic survey is similar to the 1984 as-built cross-section but appears to have some differences along the sloped shoulder and crest width. The berm at the toe of the slope appears to have a shallow slope rather than a defined level "bench" geometry shown in the 1984 plans. (See **Figure 3**.) However, in general, the revetment geometry has fared well over the 40 years since its construction. It is noted that the stone berm at the toe of the slope was not visually evident during GZA's 2024 site visit.

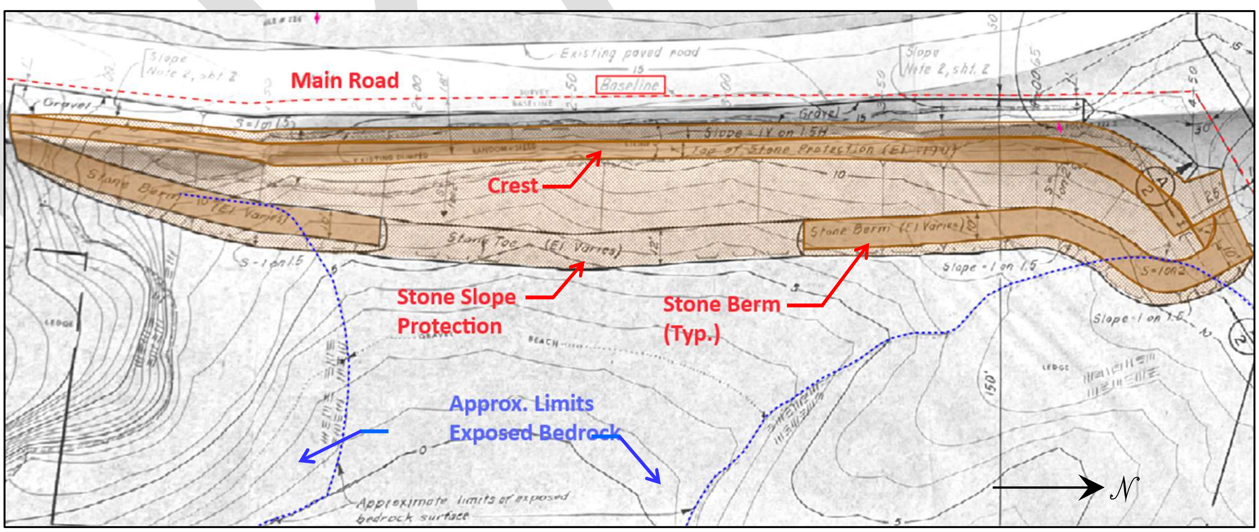


Figure 1: **Excerpt from 1983 Preliminary Design Site Plan and Index Drawing, Emergency Shoreline Protection, The Narrows, Islesboro, Maine, Army Corps of Engineers, dated August 2983.**

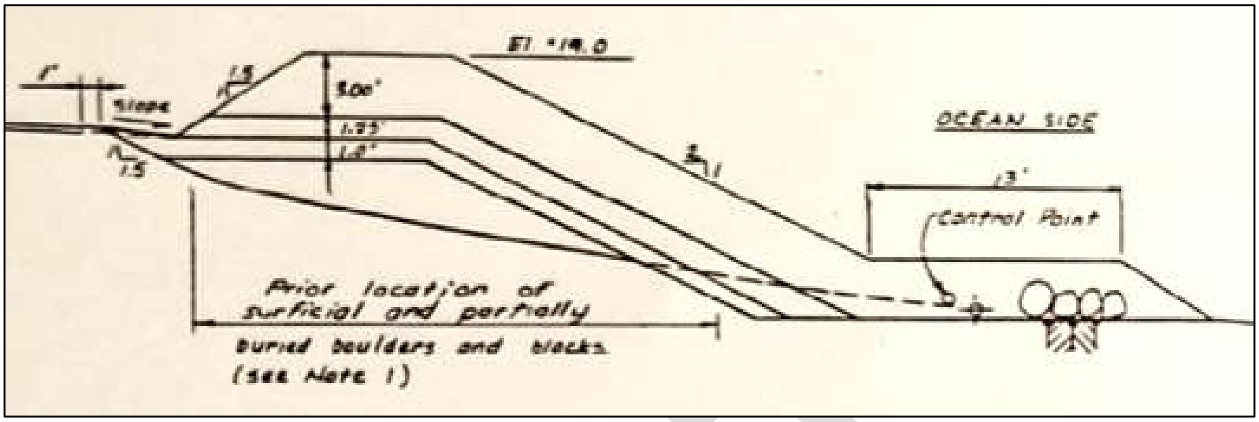


Figure 2: Representative Stone Slope Protection Cross-Section, Excerpt from As-Built Drawing, Emergency Shoreline Protection, The Narrows, Islesboro, Maine, Army Corps of Engineers, dated 9-17-84. (Vertical Datum = Mean Low Water, 1948)

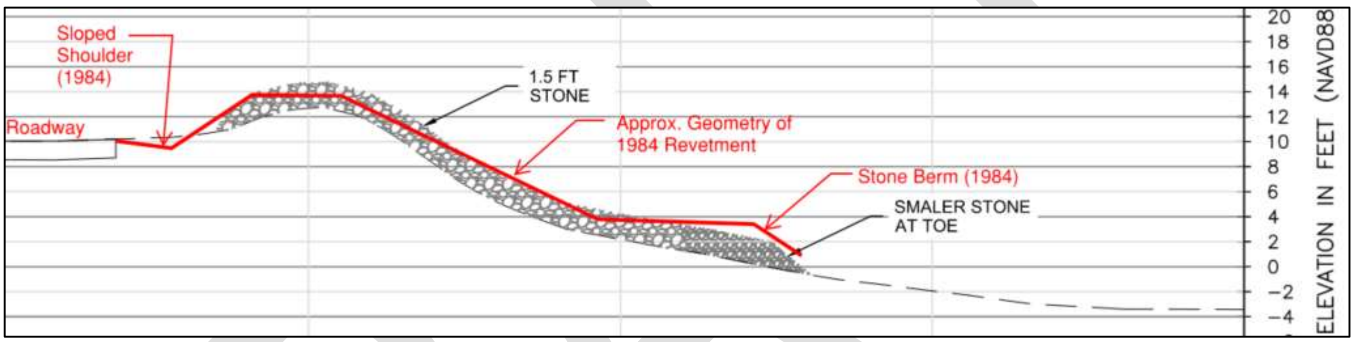


Figure 3: Example Existing Conditions Cross-Section with an Approximate Overlay of the 1984 Representative Cross-Section (shown in red). (Vertical Datum for Existing Conditions = NAVD 88)

METOCEAN DATA ANALYSIS

GZA completed a metocean data analysis specific to the Site. (See **Appendix B**). A summary of the analysis is presented below.

100-year, 1-minute wind .... 90 mph

Mean Lower Low Water Elevation................................. -5.3 feet NAVD88 vertical datum

Mean Higher High Water Elevation .... 4.7 feet NAVD88 vertical datum

100-year Stillwater Elevation .... 9.4 feet NAVD88 vertical datum

100-year Significant Wave Height.................................. 7.8 feet (east-southeast direction, approx. 12-mile fetch)

2050 Relative Sea Level Rise Projections .... 1.5 feet State of Maine “Commit to Manage”
1.2 feet to 1.3 feet NOAA 2022 (Portland – Bar Harbor)

3.0 feet State of Maine “Prepare to Manage”
1.4 feet to 1.5 feet NOAA 2022 (Portland – Bar Harbor)

2100 Relative Sea Level Rise Projections .... 3.9 feet State of Maine "Commit to Manage"
3.5 feet to 3.7 feet NOAA 2022 (Portland – Bar Harbor)

8.8 feet State of Maine "Prepare to Manage"
6.0 feet to 6.1 feet NOAA 2022 (Portland – Bar Harbor)

The December 2022 storm event and the two January 2024 storm events ranked within the top four highest water levels recorded at the Portland, Maine tide station since the gauge was installed in 1901. The 9.3 ft (NAVD88) water level recorded during the 13 January 2024 event is the highest water level recorded and is 0.4 feet higher than the second highest water level recorded (8.9 feet NAVD 88 on 7 February 1978). (See Appendix A for the top ten recorded water levels for the Portland, Maine tide station.) While these recent water levels were historic, they do not include wave heights.

SITE CHARACTERIZATION AND HAZARDS

Based on our review of available documents, our site reconnaissance, discussion with SLRC, and our metocean data analysis, the coastal hazards at the Islesboro Narrows are attributed to inundation due to the elevation of the roadway and to hazards due to the size of the existing stone comprising the coastal protection at the South and Middle Narrows.

Existing Coastal Protection

Main Road along the Middle and South Narrows has stone protection of the easterly shoreline with exposure to Penobscot Bay. The South Narrows stone protection is the revetment constructed by the USACE in 1984. During GZA's January 2024 site visit, it was observed to consist of an average stone size, D_{50}, of approximately 1.5 feet with maximum sized stones of approximately 4 feet. Per the 2019 topographic survey, it has an average crest elevation of 14 feet ± NAVD88 and an approximate 1:3 (vertical: horizontal) slope on the ocean side. The crest elevation is approximately 3.5 feet higher than Main Road. (See **Photograph 3**.)

Photograph 3: South Narrows Looking South, 18 January 2024

The Middle Narrows coastal protection is less robust than the South Narrows protection and appears to consist of stone protection (rather than an engineered revetement). During GZA's January 2024 site visit, it was observed to consist of an average stone size, D_{50}, of approximately 1.5 feet with maximum sized stones of approximately 3 feet. Per the 2019 topographic survey, it has an average crest elevation of 12.5 feet ± NAVD88 and an approximate 1:5 (vertical: horizontal) slope on the ocean side. The crest elevation is approximately 1 foot higher than Main Road. (See **Photograph 4**.)

Main Road along the North Narrows does not have augmented shore protection. The east side of the roadway is mostly shielded from Penobscot Bay by trees, vegetation and the higher topography of Thorn Plum Point. The west side of the roadway abuts a marsh within Crow Cove. (See **Photograph 5**.) While the wave exposure is limited by the fetch and buffered by the marsh, the roadway elevation is only approximately 1 foot higher than the FEMA 100-year water level.

Photograph 4: Middle Narrows Looking North, 18 January 2024

Photograph 5: North Narrows Looking North, 18 January 2024

<u>Existing Roadway Elevation and Inundation Hazard</u>

Main Road, along the North, Middle, and South Narrows, has average centerline of roadway elevations between 10.5 feet and 11.5 feet NAVD88. With the 100-year FEMA water level at 9.4 feet NAVD88, the roadway is vulnerable to inundation during high storm surges. (See **Table 1**.)

TABLE 1: MAIN ROAD ELEVATION VS FEMA 100-YR WATER LEVEL

Location	Main Road Average Elevation (ft, NAVD 88 Datum)	FEMA 100-yr Water Level (ft, NAVD 88 Datum)
North Narrows	10.5	9.4
Middle Narrows	11.5	9.4
South Narrows	10.5	9.4

The storm events in December 2022 and January 10 and 13, 2024 had recorded water levels similar to the 100-yr event. The NOAA Station for Portland, Maine recorded water levels of 8.3 feet, 8.4 feet, and 9.3 feet for the three storm events, respectively, placing them within the top four storm water levels recorded since the gauge was installed in 1910. The January 13th event is the top water level at both the Portland and Bar Harbor tide gauges. These recorded water levels do not include the wave crest elevations. Therefore, with the crest of the existing revetment on the east side of Main Road at Middle and South Narrows approximately at an average elevation of 10.5 feet and 14 feet respectively, Main Road was subjected to the effects of overtopping and storm debris from the record high water levels and wave action during these storm events.

<u>Existing Coastal Protection Elevation and Wave Runup & Overtopping Hazard</u>

With the existing elevations of Main Road and of the crest of the stone protection/revetment along the Middle and South Narrows, wave runup and overtopping are hazards for the use of Main Road during significant current-day storms and for projected sea level rise scenarios. Wave runup is the mechanism of a wave breaking and "running up" a slope or structure.

The wave runup elevation depends on the wave height and steepness, and the slope angle, roughness, and permeability/ porosity of the slope or structure. Wave overtopping occurs when the crest of the slope or height of a structure is lower than the wave runup elevation. It is quantified as a discharge volume and can pose hazards to both vehicular and pedestrian uses of a roadway adjacent to a shoreline with overtopping. The USACE Coastal Engineering Manual (CEM) provides critical discharge volumes for safe to unsafe vehicular and pedestrian uses of a roadway and for types of structures that may be along the shoreline. (See **Appendix C**.)

Using these critical discharge volumes with the site topography and metocean analysis wave data, the Middle and South Narrows were evaluated to estimate the additional crest height necessary of the slope protection/revetment under various sea level rise scenarios. The evaluation considered vehicular use at any speed (i.e. no overtopping) and at low speed with overtopping not exceeding the safe discharge volume as indicated by the CEM.

Using wave data from the metocean data analysis, topographic features, and structure dimensions gathered from available data and our site reconnaissance, GZA completed an analysis to estimate wave runup elevations and overtopping discharge volumes for the current slope protection/revetment conditions at the Middle and South Narrows. The analysis was performed for the current 100-yr storm water level and for various projected sea level rise conditions. (See **Table 2**.) Based on the analysis, the existing slope protection at Middle Narrows requires an increase in the crest elevation of approximately 1.5 to 2 feet for current-day conditions; approximately 3 to 5.5 feet for 2050 conditions; and approximately 5.5 to 10.5 feet for 2100 conditions. The existing revetment at South Narrows requires an increase in the crest elevation of approximately 2 to 2.5 feet for current-day conditions; approximately 3.5 to 6 feet for 2050 conditions; and approximately 6 to 11 feet for 2100 conditions.

TABLE 2: MIDDLE AND SOUTH NARROWS: SLOPE PROTECTION/REVETMENT CREST ELEVATION FOR VEHICLE USE AT LOW SPEED AND ALL SPEEDS FOR SEA LEVEL RISE SCENARIOS

Existing Slope Protection/Revetment		Stillwater		Driving at Low speed		Driving at Any Speed	
Narrows Location	Average Crest EL	Scenario	Elevation	Additional Crest Height	Estimated Crest Elevation	Additional Crest Height	Estimated Crest Elevation
	(ft, NAVD88)		(ft, NAVD88)	(ft)	(ft, NAVD88)	(ft)	(ft, NAVD88)
Middle	12.5	Current 100-yr	9.4	1.6	14.1	1.9	14.4
		2050 100-yr					
		1.5' SLR	10.9	3.1	15.6	3.4	15.9
		3.0' SLR	12.4	5.1	17.6	5.4	17.9
		2100 100-yr					
		3.9' SLR	13.3	5.5	18.0	5.8	18.3
		8.8' SLR	18.2	10.3	22.8	10.6	23.1
South	14.0	Current 100-yr	9.4	1.9	15.9	2.3	16.3
		2050 100-yr					
		1.5' SLR	10.9	3.4	17.4	3.8	17.8
		3.0' SLR	12.4	5.4	19.4	5.8	19.8
		2100 100-yr					
		3.9' SLR	13.3	5.8	19.8	6.2	20.2
		8.8' SLR	18.2	10.7	24.7	11.0	25.0

<u>Existing Coastal Protection Stone Size and Stability Hazard</u>

The system of stones comprising a coastal revetment provides the structure's stability and performance during storm events. The size of the stone is a function of the shoreline's slope, coastal exposure and wave environment for the design storm conditions. Results of GZA's analysis of the existing stone protection at Middle Narrows and the revetment at South Narrows indicate that the stone at both locations is undersized not only for sea level rise projections but also for the current-day water levels with an easterly to southeasterly storm consistent with the FEMA 100-yr recurrence interval storm. (See **Table 3**.) Based on the analysis, the stone protection at Middle Narrows requires an increase in the average stone size of approximately 0.5-foot for current-day conditions; approximately 1-foot to 2-foot for 2050 conditions; and approximately 2.5-foot to 5.5-foot for 2100 conditions. The revetment at South Narrows requires an increase in the average stone size of approximately 1-foot for current-day conditions; approximately 1.5-foot to 3-foot for 2050 conditions; and approximately 3-foot to 6-foot for 2100 conditions.

TABLE 3: MIDDLE AND SOUTH NARROWS: AVERAGE STONE SIZE REQUIRED FOR MAXIMUM FETCH AND 100-YR RECURRENCE INTERVAL STORM WITH CURRENT-DAY WATER LEVELS AND SLR SCENARIOS

Existing Slope Protection/Revetment		Stillwater Scenario	Average Stone Size Required	Average Stone Size Increase Compared to Existing
Narrows Location	Average Ext. Stone* (ft)		(ft)	(ft)
Middle	1.5	Current 100-yr	1.8	0.3
		2050 100-yr 1.5' SLR	2.7	1.2
		3.0' SLR	3.8	2.3
		2100 100-yr 3.9' SLR	4.1	2.6
		8.8' SLR	6.9	5.4
South	1.5	Current 100-yr	2.3	0.8
		2050 100-yr 1.5' SLR	3.2	1.7
		3.0' SLR	4.4	2.9
		2100 100-yr 3.9' SLR	4.6	3.1
		8.8' SLR	7.4	5.9

* As estimated during GZA's January 2024 site visit.

15% PRELIMINARY DESIGN SEA LEVEL RISE VALUES

As coordinated with the SLRC, the design sea level rise values for the project are 3.9 feet for shoreline/slope protection alternatives and 6.6 feet for consideration of a bridge alternative. The different SLR design values are in recognition that shoreline/slope protection has a shorter design life than a bridge and provides a different approach to coastal resiliency than a bridge.

The 3.9 feet of SLR corresponds to the State of Maine "Commit to Manage" recommendation for year 2100. When superimposed with the FEMA 100-year flood elevation, it results in a design Stillwater Elevation of 13.3 feet NAVD88. This design Stillwater Elevation provides a buffer of approximately 1 foot to 2.5 feet for the stillwater levels corresponding to the 2050 sea level rise projections. (See **Table 4**.)

TABLE 4: SHORELINE/SLOPE PROTECTION DESIGN STILLWATER ELEVATION WITH SEA LEVEL RISE COMPARED TO 2050 SEA LEVEL RISE PROJECTIONS

Water Level Component	Design Stillwater	2050 "Commit to Manage"/Intermediate SLR Scenario		2050 "Prepare to Manage"/High SLR Scenario	
		Maine Guidance	NOAA 2022	Maine Guidance	NOAA 2022
FEMA 100-yr Flood Elevation (ft, NAVD88)	9.4	9.4	9.4	9.4	9.4
SLR Projection (Ft)	3.9	1.5	1.3	3.0	1.5
SLR 100-yr Stillwater Elevation (ft, NAVD88)	**13.3**	**10.9**	**10.7**	**12.4**	**10.9**
Comparison to Design Stillwater (ft)		*- 2.4*	*- 2.6*	*-0.9*	*- 2.4*

The 6.6 feet of SLR approximately corresponds to the average of the State of Maine recommendations for "Commit to Manage" and "Prepare to Manage" for year 2100. When superimposed with the FEMA 100-year flood elevation, it results in a design Stillwater Elevation of 16.0 feet NAVD88, which was considered a reasonable design value in consideration of the inherent uncertainty of the projections and island-wide implications if such projections are realized. (See **Table 5**.)

TABLE 5: POTENTIAL BRIDGE ALTERNATIVE - DESIGN STILLWATER ELEVATION WITH SEA LEVEL RISE COMPARED TO 2100 SEA LEVEL RISE PROJECTIONS

Water Level Component	Design Stillwater	2100 "Commit to Manage"/Intermediate SLR Scenario		2100 "Prepare to Manage"/High SLR Scenario	
		Maine Guidance	NOAA 2022	Maine Guidance	NOAA 2022
FEMA 100-yr Flood Elevation (ft, NAVD88)	9.4	9.4	9.4	9.4	9.4
SLR Projection (Ft)	6.6	3.9	3.5	8.8	6.0
SLR 100-yr Stillwater Elevation (ft, NAVD88)	**16.0**	**13.3**	**12.9**	**18.2**	**15.4**
Comparison to Design Stillwater (ft)		*- 2.7*	*- 3.1*	*+2.2*	*-0.6*

15% PRELIMINARY DESIGN ALTERNATIVES - ROADWAY

There are two options for reducing the inundation hazard of Main Road along The Narrows: increase the roadway elevation or replace the roadway with a bridge.

INCREASE ROADWAY ELEVATION

The objective of increasing the elevation of Main Road is to minimize the flood water depth on the roadway to allow for emergency response vehicles to traverse The Narrows during the peak water levels of the design storm event. As established by the SLRC, a maximum water depth on the roadway of 2 feet is permissible for emergency response vehicles. This maximum water depth would be anticipated for a few hours during the period of the peak tide and the subsequent drainage during the receding tide.

Superimposing the 3.9-foot design sea level rise projection with the current FEMA 100-year Stillwater elevation results in a design future 100-yr stillwater elevation of 13.3 feet NAVD88. To limit the water depth on the roadway to no greater than 2-feet, the Main Road requires a minimum elevation of 11.3 feet NAVD88. This minimum elevation would be for the edge of the roadway and the roadway would have a crown to promote drainage.

In reviewing the 2020 Main Road Draft Reconstruction Plans by CES, Inc., the project elevated the crest of Main Road through The Narrows to a minimum centerline elevation of 12.0 feet ± NAVD88. The draft plans detail a 2% cross slope from the centerline, which results in an edge of pavement elevation of approximately 11.8 feet NAVD88 minimum. This minimum elevation is 0.5-foot higher than the elevation corresponding to 2 feet of water on the roadway for the future 100-yr stillwater condition. As such, the 2020 draft plans provide a reasonable approach for elevating Main Road.

Per the 2020 Project Summary for the draft plans, the design incorporated a new vertical alignment (profile). The draft plans show the proposed centerline of roadway elevations between approximately 12.0 feet and 13.3 feet NAVD88 along the South, Middle and North Narrows with transitions at the project limits to tie into the exiting roadway elevations (approx. elevation 15.4 feet NAVD88 at the southern limit and approx. elevation 15.7 feet NAVD88 at the northern limit). The draft plans also detail 3:1 (horizontal : vertical) typical side slopes from the edge of the elevated roadway down to existing grade and limited sections of roadway with 2:1 side slopes to minimize wetland impacts. It is noted that a 3:1 slope is a typical embankment for receiving loam and seed. Steeper embankments may be possible to further limit the project footprint.

For the Middle and South Narrows, raising the roadway per the 2020 Main Road Draft Reconstruction Plans would reduce the water depth on the road for the design storm event. However, it does not address the storm hazards from overtopping and debris.

15% PRELIMINARY DESIGN ALTERNATIVES – COASTAL PROTECTION

In terms of coastal protection from wave action and overtopping, the basic concept is to reduce the wave energy either at the shoreline or offshore. The following presents overviews of conceptual coastal protection options considered for The Narrows.

Stone Revetment

Full replacement of the stone protection at Middle Narrows and of the stone revetment at South Narrows with an engineered stone revetment allows for reconstructing the coastal protection for the future 100-yr design storm event. To provide protection for the 3.9-foot design sea level rise projection, the crests of the revetments require an approximate elevation of 18 to 20 feet NAVD88 (Middle Narrows and South Narrows, respectively) for vehicular use of Main Road at low speed with overtopping and at any speed without overtopping. (Refer to Table 2 under Site Characterizations and Hazards). These crest elevations are 6.5 feet to 9.5 feet higher than the average centerline elevation of the existing road or approximately 4.5 feet to 8 feet higher than the average proposed centerline roadway crest elevation detailed in the 2020 Main Road Draft Reconstruction Plans.

If the existing stone is suitable for reuse and meets technical requirements for stone aspect ratio and soundness, it may be incorporated into the reconstruction. Supplemental larger armor stone would be required to meet the average stone size for wave energy absorption and revetment stability. For the future 100-yr design storm event with the 3.9-foot design sea level rise projection, an average armor stone size of 4-foot to 4.5-foot is required for both locations. (Refer to Table 3 under Site Characterizations and Hazards.) Assuming a granite density of 162 pounds per cubic foot, the armor stone size corresponds to 4.5-ton to 6.0-ton stones. The armor stone would be placed over bedding stone and a geotextile with larger toe stones to anchor the revetment slope. Similar to the 1984 design, incorporation of a stepped berm at the lower portion of the revetment will aid in reducing the wave energy and runup.

An alternative approach includes reconstructing for the 2050 100-yr scenario with 1.5 feet of sea level rise. For this scenario, the crests of the revetments require an approximate elevation of 15.5 feet to 18 feet NAVD88 (Middle Narrows and South Narrows, respectively) for vehicular use of Main Road at low speed with overtopping and at any speed without overtopping. (Refer to Table 2 under Site Characterizations and Hazards). These crest elevations are 4 feet to 7 feet higher than the average elevation of the exiting road or approximately 2.5 feet to 6 feet higher than the average proposed roadway crest elevation detailed in the 2020 Main Road Draft Reconstruction Plans. This alternative reduces the armor stone size to 3.0-foot to 3.5-foot stones (2-ton to 3-ton) and would consist of similar components with bedding stone, geotextile, toe stone and a stepped berm at the lower portion of the revetment.

Wire Mesh TECCO® CELL System

Recognizing the additional construction aspects that are inherent to an island community and the SLRC's interest in a coastal protection option that could potentially be repaired by the Towns' public works crew, GZA explored a gabion-type system for the revetment composition. Specifically, we coordinated with Geobrugg North America on their TECCO® CELL system. The system consists of high-tensile stainless-steel wire mesh cells filled with rock placed on a geotextile. (See **Photograph 6**.) The cells are fabricated on-site for the specific site conditions and filled with smaller sized stone. Dissipation of wave energy is achieved by the water passing through the cells. The system has been used in riverine bank stabilization applications in Europe and New Hampshire and for cliff rock fall protection and coastal environments in the United Kingdom. It has been tested in high energy wave environments, but, not necessarily similar to the shoreline conditions at The Narrows. In addition to it being a new product to the U.S. and the potential aesthetics, further coordination with Geobrugg is necessary, if the SLRC is interested in this system. Additional aspects to coordinate include: excavating for stability of the system and potential need for rock anchors to secure the cells on bedrock/limited fill; potentially higher crest elevations in comparison to typical stone revetements; potential anchoring of the toe against waves; and potential mesh lifespan considerations.

Photograph 6: Geobrugg's TECCO® CELL System Installed Beside a Traditional Rock Revetment (Photograph curtesy of Geobrugg).

<u>Wave Return Seawall</u>

An option for mitigating wave overtopping is a wave return seawall at the top of the revetment. A wave return seawall has a concave curve that redirects waves back towards the water. Incorporation of a wave return seawall with the stone revetment at the South and Middle Narrows would allow for a lower overall crest elevation because the seawall acts as a solid barrier redirecting the waves. The wave return seawall would be at the top of the revetment slope with the revetment abutting the face of the wall. (See **Photograph 7**.) Depending on the depth to bedrock, the wall may require bedrock dowels or rock anchors to develop the wall capacity for the wave loading. In addition, the energy of the redirected wave back onto the revetment requires consideration during the design of the revetment and for potential impacts to the nearby natural resources. While wave return seawalls are used in areas requiring protection from severe wave action, based on feedback from the SLRC, it is not a favored approach for The Narrows with its nearby natural resources.

Photograph 7: Example Wave Return Seawall with Revetment (Marshfield, MA)

<u>Offshore breakwater</u>

Offshore breakwaters reduce wave runup and overtopping along a shore or shoreline structure by attenuating the wave offshore. Offshore breakwaters can be floating structures that rise and fall with tidal and storm water levels or rubble mound structures founded on the ocean bottom. Siting of floating breakwaters requires water depths that allow for water flow under the breakwater at the lowest water levels; consideration of the wave pattern that wraps around the ends of the floating breakwater; and feasibility of the ocean bottom conditions for anchorage by guide piles or bottom anchors with chains to the breakwater. Siting of the rubble mound breakwater is a function of the desired reduction in wave energy; water depths; and the contours of the ocean bottom. For both types of breakwaters, minimizing environmental impacts to the resource area and navigation must be balanced with the intended performance of the breakwater.

The water depths off The Narrows would set a floating breakwater significantly offshore for it to not bottom out at lower tidal conditions. Being so far offshore would require a long floating breakwater. As such, a floating breakwater was deemed not practical from a constructability standpoint and for likely environmental permitting challenges.

Based on an initial review of the site conditions, a rubble mound breakwater located approximately 50 feet offshore from the seaward toe of the existing stone protection at Middle Narrows and the existing revetment at South Narrows would reduce the wave environment and wave runup. At this location, the rubble mound breakwater approximately reduces the wave height by 50%. To achieve the fundamental objective of improving safety along Main Road for SLR and storms, the rubble mound breakwater option also requires reconstruction of the stone protection/revetment for the reduced waves that will reach the shoreline. The revetment would not need to be as robust as one without the breakwater, but, it would be more robust than the existing stone protection/revetment to reduce the potential debris hazard that the existing smaller stone poses.

With its proximity to the shore, the rubble mound breakwater provides a higher potential for the addition of Nature Based Solutions (NBS) to the project. Its presence may allow for sediment accretion between the breakwater and the shore and thereby provide more favorable conditions for organisms and marine life in the nearshore environment. The extent to which sediment accretion may occur requires additional evaluation to identify potential sediment transport.

<u>Nature Based Solutions</u>

Given that Nature Based Solutions (NBS) have the ability to enhance shorelines and coastal resiliency, GZA explored NBS concepts that are potentially compatible with the limitations of the site conditions along The Narrows.

At North Narrows, where wave action is limited naturally by Crow Cove, a marsh ecosystem exists. The marsh, while providing environmental benefits, also mitigates erosion from small waves and storm surge by buffering wave action and trapping sediment. With the mitigation alternative that raises the roadway elevation, the associated new embankment on the west side of the roadway may allow for the marsh to naturally migrate as sea levels rise. In the interim, the embankment allows for incorporation of resilient coastal shrubs on the upper portion of the embankment. The plantings would provide slope stability and additional protection of the roadway from potential debris. *The Coastal Planting Guide* published by The Maine Coastal Program and Department of Agriculture provides useful information for coastal planting for slope stabilization. The reference is available at: Attachment-E2-Maine-Coastal-Planting-Guide-November-2017-For-Booklet-Printing-Release-Version-1.1.pdf (northeastoceancouncil.org).

At Middle and South Narrows, where the coastal exposure to Penobscot Bay is greater, marsh plantings and living shoreline type approaches are not feasible options due to the wave energy. However, other NBS options may be incorporated within the revetment to provide a semi-hybrid shoreline option. Concrete “tide pool” elements could be integrated into the stone matrix of the revetment and/or breakwater. Companies such as ECOncrete® design molds to cast “tide pools” using bio-enhanced concrete and texture agents to promote marine growth. (See **Photographs 8 and 9**.) The tide pools are located within the intertidal zone of the structures and can support biodiversity and habitat.

Photograph 8: Concrete "Tide Pools" integrated in a Stone Coastal Structure (Photograph Source: Nearshore habitats for marine life and coastal birds during coastal construction - ECOncrete (econcretetech.com))

Photograph 9: Concrete "Tide Pook" supporting intertidal vegetation (Photograph Source: https://www.monmouth.edu/uci/wp-content/uploads/sites/58/2021/09/ECOncrete-Technical-Pages.pdf

The TECCO® CELL coastal protection option may also provide some opportunity for NBS. From discussion with the manufacturer, Geobrugg, the voids in the wire mesh rock slope trap sediment and can allow for natural or supplemental vegetation growth. (See **Photograph 10**.) However, additional evaluation is needed to access this potential. Based on an initial review of the area, there appears to be limited longshore drift and sediment sources for The Narrows.

Photograph 10: Vegetation Establishing through a TECCO CELL Installation (Photograph curtesy of Geobrugg)

As discussed under the Offshore Breakwater section, a rubble mound breakwater provides a potential for the addition of Nature Based Solutions (NBS) to the project within the tidal zone between the breakwater and the shoreline. This zone may be allowed to naturally develop or plannings and other enhanced habitat may be incorporated to promote marine life.

Another potential NBS approach is the incorporation of reef balls at Middle and South Narrows. Reef Balls are molded concrete structures that use bio-enhanced materials similar to the concrete tide pools. They are hollow with openings that allow for habitat areas by mimicking natural reef structures. The openings are also integral to the design as they absorb wave energy and stabilize the structure from wave action. They are most commonly used in areas where shellfish or coral species are readily available to inhabit the structures.

Reef balls are typically used as stand-alone structures acting as small breakwaters. Generally, they are placed in rows along the shoreline near Mean Low Water with the top of the landward-most row just submerged at high tide or 1 foot exposed at high tide. At this elevation, the reef balls provide some protection against storm surge by reducing wave action and trapping sediment.

Reef Balls work best when placed on sandy bottoms where they have a stable base. On shallow bedrock, such as seen at some areas of both the Middle and South Narrows, reef balls may require anchoring. If the slope of the hard bottom is too steep, they may not be feasible. GZA has discussed potential options with the Reef Ball Foundation for the site. They have installed reef balls from Florida to Alaska and have experience with a range of site conditions. As a conceptual level, the Goliath Ball is recommended for the conditions at The Narrows. (See **Figure 4**.) Additional information is available at the following link https://reefballfoundation.org/sizes/

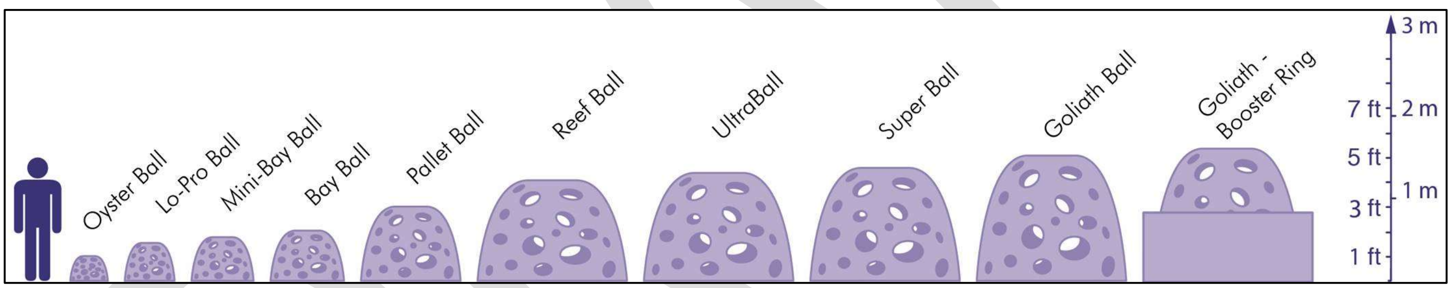


Figure 4: Reef Ball Sizes (Curtesy of The Reef Ball Foundation)

15% PRELIMINARY BRIDGE CONCEPT

The SLRC requested that the alternatives for the South Narrow include a bridge option with 6.6' of sea level rise. While GZA provides geotechnical engineering and other services for bridges, we are not bridge engineers. However, one of our industry partners who specializes in bridge design provided us a professional curtesy and discussed the bridge concept for The Narrows. Based on their insights and the coastal hazards that we discussed with them, incorporating a bridge at the South Narrows along the existing Main Road alignment is not advisable. Rather a realignment of Main Road to the west from the South Narrows through North Narrows was recommended to provide more distance from the main exposures from Penobscot Bat to the east. The concept includes the new roadway following a similar alignment as the existing road, but more westward and with a shallower curve through the Middle Narrows. It also includes the reconstructed revetments at Middle and South Narrows for wave reduction. See the schematic plan view included in the Recommendations section.

The following are considerations for this option.

- Offset the bridge approximately 75 feet minimum from the existing road to provide clearance for construction with Main Road remaining in-service and for separation from the storm waves from the east.
- Low profile bridge superstructure to reduce potential impacts from storm surge.
- Potential bridge constructed of galvanized steel beams with precast deck panels and cast-in-place concrete closure.
  - Bridge width of approximately 30 feet to accommodate a 26 to 28-foot wide roadway.
  - Bridge length of approximately 300 feet comprised of four equal spans to span the marsh.
  - Elevation of the bottom of the bridge superstructure at 16 feet NAVD88 (minimum).
  - Elevation of the roadway approximately at 18 feet NAVD88.
  - Bridge foundation assumed on shallow bedrock and may require micropiles with corrosion protection jackets, shallow spread footing foundations with rock dowels or a combination, depending on bedrock elevation and quality.
- Relocated roadway constructed on fill through the Oak Pine Forest to the North Narrows. If a second bridge is desired at North Narrows, it would have similar design considerations as those listed above for the South Narrows bridge.
- Permitting would be similar to that for the revetment and offshore breakwater. It would include, but not necessarily be limited to permitting approvals through the U.S. Army Corps of Engineers, the Maine Department of Environmental Protection, Maine Department of Agriculture, Conservation & Forestry, and the state Bridge Maintenance program to attain a bridge number. As part of the supporting information for these applications, an environmental assessment will likely be necessary as well as a National Environmental Protection Act (NEPA) review through any federal agency providing funding for the project.
- It is recommended that this alternative be constructed in phases. A potential approach may be as follows:

Phase 1:	Construction of the revetments with berm and reef balls at Middle and South Narrows to protect the current roadway, construction area, and future bridge.
Phase 2:	South Narrows bridge construction
Phase 3:	Elevated fill roadway though the Oak Pine Forest
Phase 4:	Elevated fill roadway or bridge over North Narrows

A conceptual order of magnitude construction cost for the South Narrows bridge is in the $10-$12 million range with an additional $3 million for the bridge approach and realigned roadway. For conceptual purposes, this alternative will likely total around $20 million.

15% PRELIMINARY DESIGN RECOMMENDATIONS

In considering the various alternatives discussed above for potential approaches to mitigate the coastal hazards at The Narrows, we have compiled the following recommendations for North, Middle and South Narrows. The recommendations are consistent with the design sea level rise value of 3.9 feet and the SLRC's goal of Main Road remaining passible by emergency response vehicles during storm events.

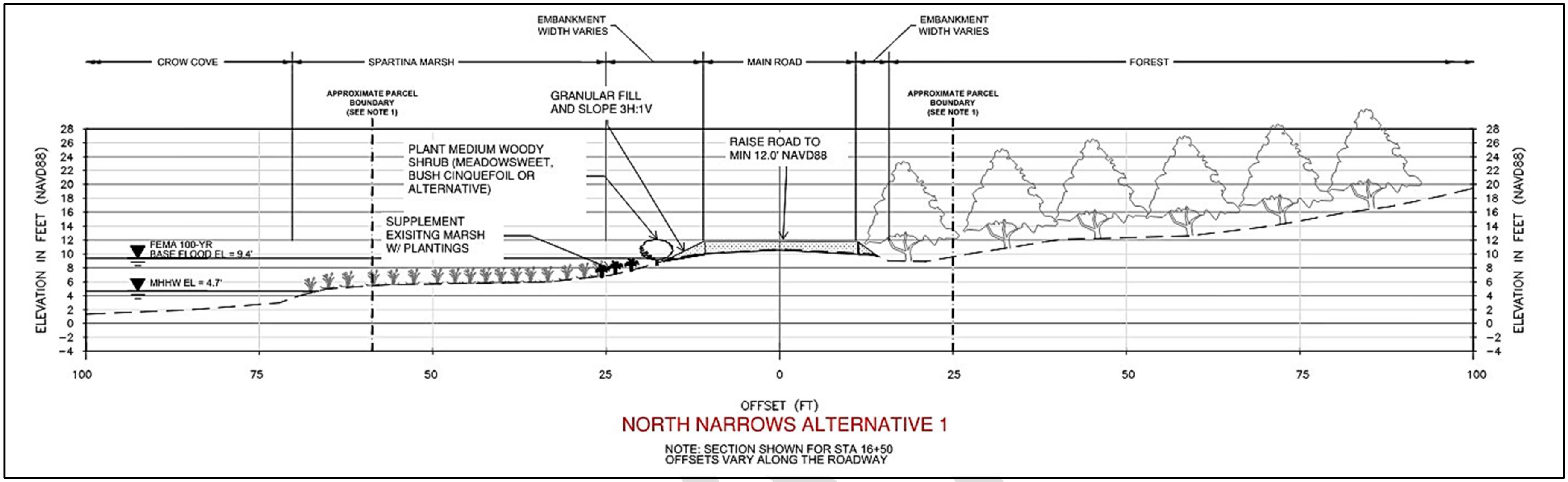
NORTH NARROWS

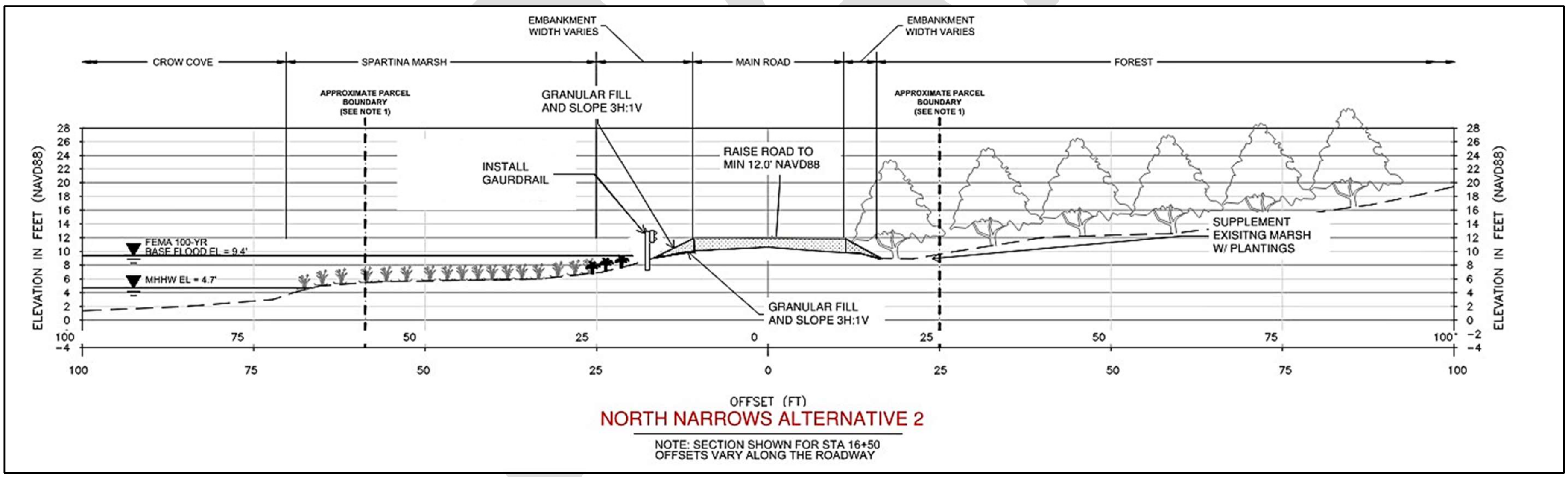
North Narrows is generally protected by Crow Cove to the west with wave exposure limited by the fetch and buffered by the marsh. However, the elevation of the existing road is subject to inundation during storm events. Methods to mitigate hazards at North Narrows include reducing inundation, promoting existing natural systems, and incorporating nature-based solutions as much as practical. It is recommended that the roadway be raised in elevation with the embankments planted with marine shrubbery. Where the construction has temporary impacts to the east and west of the roadway, the project should include marsh restoration and vegetation replacement.

Recommendations:

1. Raise the roadway with fill per the 2020 Main Road Draft Reconstruction Plans (approximately 12.0 to 12.9 feet NAVD88 along the centerline of roadway); revegetate disturbed marsh areas on the west side; and incorporate marine plantings and shrubbery on the upper west embankment, east embankment and areas disturbed by construction on the east side.
2. The same as Recommendation 1 with the incorporate of a guardrail on the west side as an additional measure to inhibit storm debris from Crow Cove onto the roadway.

See the following page for schematic cross-sections for the recommendations.





Schematic Cross-Sections for 15% Preliminary Design Recommendations – North Narrows

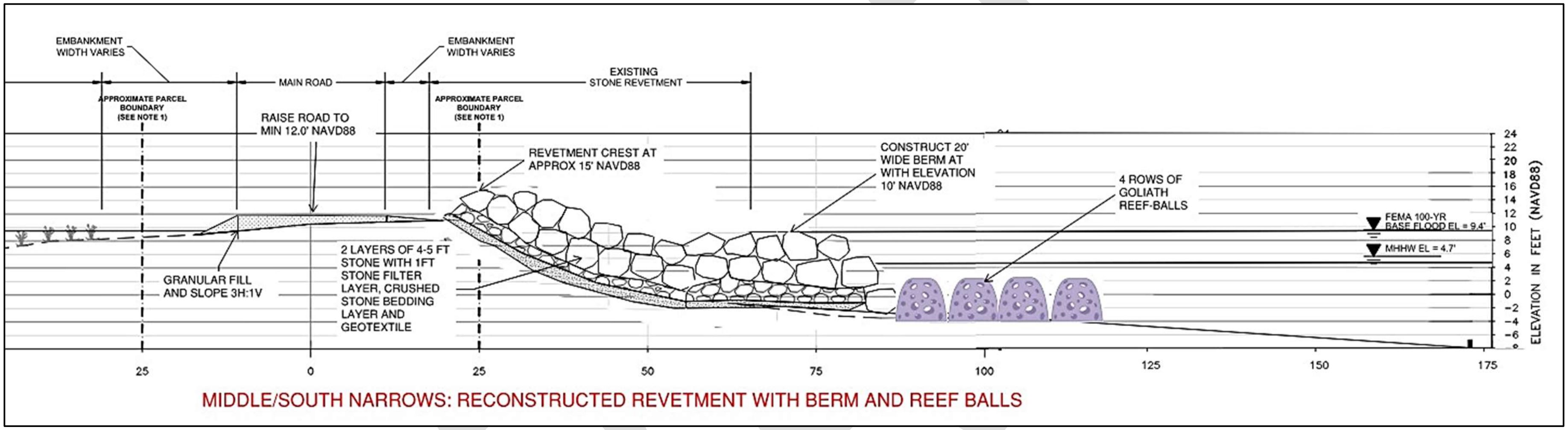
MIDDLE AND SOUTH NARROWS

Middle and South Narrows have similar types of coastal hazards, namely direct east to southeasterly exposure to Penobscot Bay with wave inundation, wave overtopping, storm debris, and eastern shores with stone protection that is inadequate for the design storm conditions under water levels scenarios for current-day and SLR projections. Methods to mitigate hazards at Middle and South Narrows include raising the roadway; replacing the existing stone protection on the east shore with an engineered stone revetment; incorporating a wave return seawall, offshore breakwater, reef balls and/or NBS enhancements.

Recommendations:

1. Stone Revetment: Raise the roadway with fill per the 2020 Main Road Draft Reconstruction Plans (approximately 12.0 to 13.3 feet NAVD88 along the centerline of roadway).
    a. Reconstruct revetment to a crest elevation of 18.3 ft NAVD88 and with two layers of armor stone (average stone size of 4.1 to 4.6 feet) on a filter stone layer and geotextile.
    b. Reconstruct the revetment to a crest elevation of 15 ft NAVD88 and with two layers of armor stone (average stone size of 4.1 to 4.6 feet) on a filter stone layer and geotextile and with a 20-foot wide “berm” at elevation 10 ft NAVD88.
2. Wire Mesh TECCO® CELL System: Raise the roadway with fill per the 2020 Main Road Draft Reconstruction Plans (approximately 12.0 to 13.3 feet NAVD88 along the centerline of roadway).
    a. Replace the shore protection with the TECCO® CELL Mesh Rock Armor system with a crest elevation of 18.3 ft NAVD88.
    b. Replace the shore protection with the TECCO® CELL Mesh Rock Armor system with a crest elevation of 15 ft NAVD88 and a 20-foot wide “berm” at elevation 10 NAVD88.
3. Wave Return Seawall: Raise the roadway with fill per the 2020 Main Road Draft Reconstruction Plans (approximately 12.0 to 13.3 feet NAVD88 along the centerline of roadway). Along the road at the top of the shoreline slope, construct a concrete seawall with a wave return and top of wall elevation at 18.5 ft NAVD88.
    a. Reconstruct the revetment to a crest elevation of 15 ft NAVD88 and with one layer of armor stone (average stone size of 4.1 to 4.6 feet) on a filter stone layer and geotextile.
    b. Replace the shore protection with TECCO® CELL Mesh Rock Armor system with a crest elevation of 15 ft NAVD88.
4. Offshore Breakwater: Raise the roadway with fill per the 2020 Main Road Draft Reconstruction Plans (approximately 12.0 to 13.3 feet NAVD88 along the centerline of roadway). Reconstruct the revetment to a crest elevation of 15 ft NAVD88 and with one layer of armor stone (average stone size of 4.1 to 4.6 feet) on a filter stone layer and geotextile. Construct a rubble mound breakwater located offshore near the -1 ft NAVD88 contour with a base width of 50 feet and a crest at elevation 10 ft NAVD88.
5. Nature Based Solutions
    a. Integrate concrete “tide pool” elements into the intertidal zone along the stone revetment or rubble mound breakwater alternatives.
    b. Incorporate reef balls near Mean Low Water with the stone revetment alternative.

The following page provide a schematic cross section for a recommendation at Middle and South Narrows that combines the raising of Main Road with a reconstructed revetment, berm and reef balls. This recommendation increases the coastal resiliency and provides potential opportunities for added habitat and marine growth.

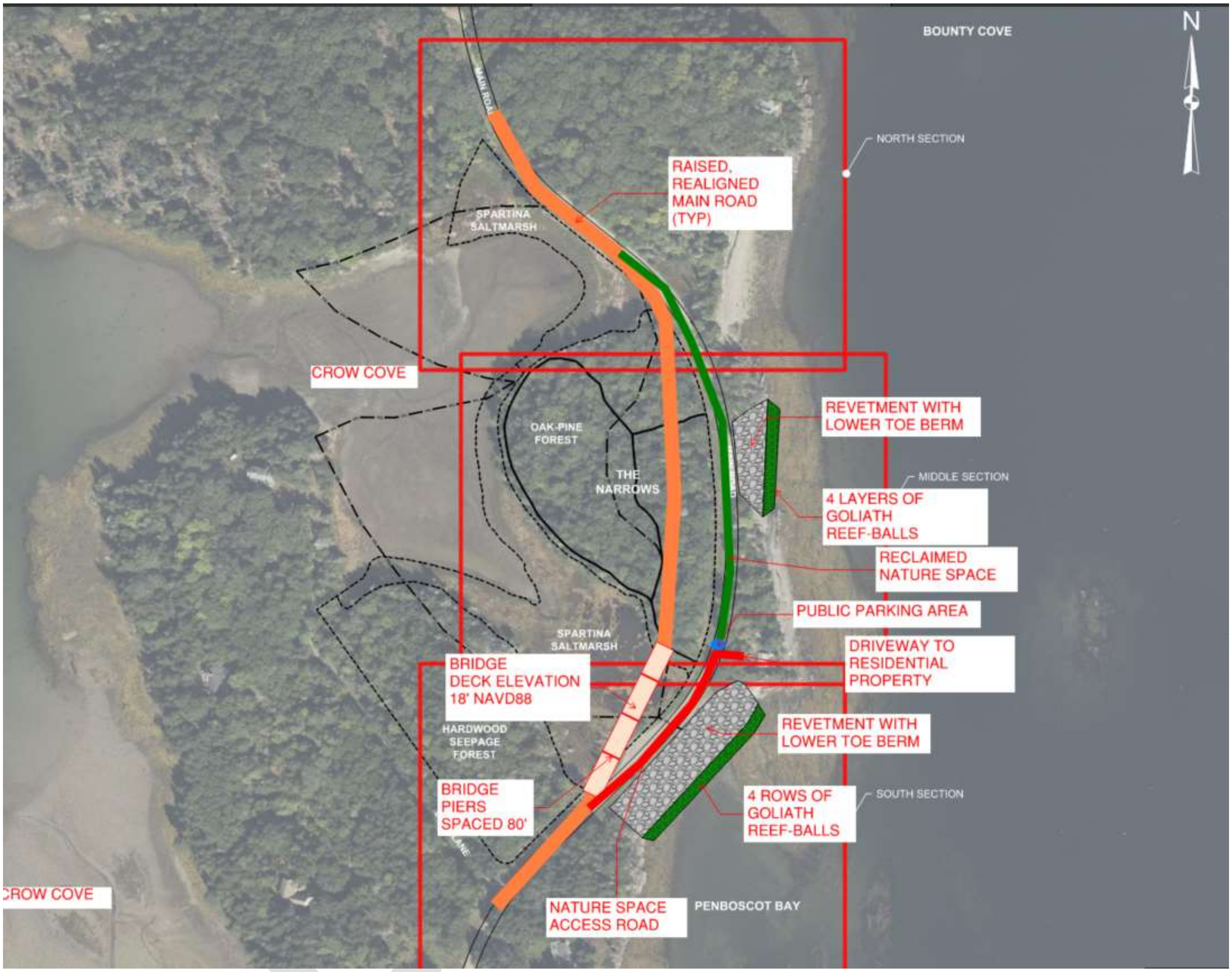


Schematic Cross-Sections for 15% Preliminary Design Recommendations – Middle and South Narrows

<u>BRIDGE OPTION WITH ROADWAY RE-ALIGNMENT</u>

If Main Road can be relocated toward the west, the coastal resiliency could be further improved along The Narrows by constructing a bridge through South Narrows and a roadway through the Oak Pine Forest to the north of North Narrows. This alternative provides a longer-term approach that incorporates the near-term mitigation solutions to allow for a phased implementation of coastal resilience.

See the following page for a plan view depicting the general concept of the Main Road Realignment.



Schematic Plan for 15% Preliminary Design Alternative – Main Road Realignment with Bridge at South Narrows

15% PRELIMINARY DESIGN ALTERNATIVES COMPARISON

Each of the recommendations presented for the North, Middle and South Narrows are rated against the evaluation criteria. The ratings are intended to provide a relative comparison. The ratings range from 1 to 5 with 5 being the most beneficial for the specific criteria. A higher overall total can be thought as a more favorable alternative. However, it is important to note that some criteria may have a greater importance than other criteria, which is note reflected in the total rating. See **Appendix D** for a description of the criteria.

Location	Alternative	Service Life	Construction Cost	Future Adaptability	Emergency Access	Envir. Impact	Permitting	Construction Considerations	Engineering Constraints	Property Impact	Total
North Narrows	*Raise Roadway with revegetated slope and marsh supplement*	3	5	5	4	5	4	4	4	4	38
	Raise Roadway with guardrail (debris deterrent)	3	4	5	4	4	4	4	4	4	36

Location	Alternative	Service Life	Construction Cost	Future Adaptability	Emergency Access	Envir. Impact	Permitting	Construction Considerations	Engineering Constraints	Property Impact	Total
Middle and South Narrows	*Reconstruct Stone Revetment*	4	3.5	3	3.5	4.5	4.5	4	4	5	36
	Wire Mesh TECCO® CELL System	3.5	3.5	3	3.5	4.5	4.5	3.5	4	5	35
	Reconstruct Revetment with Return Seawall	3.5	2.5	3	3.5	4.5	4.5	3	3	4	31.5
	Reconstruct Revetment and Construct Offshore Breakwater	4	2	3	3.5	3	3	3	4	4	29.5
	Reconstruct Revetment with Berm and Reef Balls	4	3	3.5	3.5	4	4	4	4	5	35
	Bridge and Raised Causeway	5	1	5	5	2	3	4	3	2	30

Appendix A: Marine Design Limitations

MARINE DESIGN LIMITATIONS

Use of Report

1. GeoEnvironmental, Inc. (GZA) prepared this Design and/or Report on behalf of, and for the exclusive use of the Client for the stated purpose(s) and location(s) identified in the letter. Use of this work product, 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 the agreement, for any use, without our prior written permission, shall be at that party's sole risk, and without any liability to GZA.

Standard of Care

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

3. GZA's services were performed using the degree of skill and care ordinarily exercised by qualified professionals performing the same type of services, at the same time, under similar conditions, at the same or a similar property. No warranty, expressed or implied, is made.
4. In conducting our work, GZA relied upon certain information made available by public agencies, Client and/or others. GZA did not attempt to independently verify the accuracy or completeness of that information. Inconsistencies in this information which we have noted, if any, are discussed in the Report.

Design Conditions

5. The Design conditions including generalized soil profile(s) provided in our Report and/or used in our calculations are based on widely-spaced subsurface explorations and are intended only to convey trends in subsurface conditions. The boundaries between strata are approximate and idealized, and were based on our assessment of subsurface conditions. The composition of strata, and the transitions between strata, may be more variable and more complex than indicated. For more specific information on soil conditions at a specific location refer to the exploration logs. The nature and extent of variations between these explorations may not become evident until further exploration or construction. If variations or other latent conditions then become evident, it will be necessary to reevaluate the conclusions and recommendations of this report.

6. In preparing this report and/or design, GZA relied on certain information provided by the

Client, state and local officials, and other parties referenced therein which were made available to GZA at the time of our evaluation. This information includes, but is not limited to, facility elevations, facility uses, maintenance schedules, and loading. GZA did not attempt to independently verify the accuracy or completeness of all information reviewed or received during the course of this evaluation.

7. In preparing this Report and/or design GZA developed environmental loading for the storm return frequency indicated in the Report, project plans, and/or design calculations. This return frequency was developed based on information provided by the Client. GZA should be notified if the selected return frequency is not appropriate for the project and GZA will revise the design accordingly.

Compliance with Codes and Regulations

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

Cost Estimates

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

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

experienced professional cost estimators to evaluate actual costs. The opinions of cost in the Report should not be interpreted as a bid or offer to perform the work. Unless stated otherwise, all costs are based on present value.

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

Additional Information

12. In the event that the Client or others authorized to use this Letter obtain information on conditions at the site(s) not contained in this Letter, such information shall be brought to GZA's attention forthwith. GZA will evaluate such information and, on the basis of this evaluation, may modify the opinions stated in this report.

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

Appendix B: Metocean Data Analysis

METOCEAN DATA ANALYSIS

GZA completed a Metocean Data Analysis to develop site characteristics relative to coastal exposure including, wind, water level, wave heights, and sea level rise projections for the site.

DIGITAL ELEVATION MODEL

GZA identified and acquired recent topographic and bathymetric data for the Site, using the NOAA Data Access Viewer (DAV), and created a Digital Elevation Model (DEM). See **Figure 1**. The NOAA DAV is a national repository for available elevation (LiDAR), imagery and land cover data for the coastal U.S. and its territories. The data, hosted by the NOAA Office for Coastal Management, is customized to a selected area and provided as a downloadable file. The specific data sources included:

- The NOAA NCEI Continuously Updated Digital Elevation Model (CUDEM) - 1/9 Arc-Second Resolution Bathymetric-Topographic Tiles. Database attributes include:
    - Data Source: Raster Digital Elevation Model
    - Cell size (m): 3.00
    - Vertical Accuracy (cm): 50 - Not tested
    - Horizontal Accuracy (cm): 100 - Not tested
    - Vertical Datum: NAVD88
- 2021-2-22 USGS Lidar for Midcoast Maine. Database attributes include:
    - Data Source: U.S. 3D Elevation Program Point Cloud
    - Estimated Point Spacing (m): 0.3
    - Vertical Accuracy (cm): 3.6 - Tested
    - Horizontal Accuracy (cm): 12 – Compiled

The DEM was combined with the 2019 limited topographic survey completed by CES, Inc. to establish the bathymetry and topography for the site and to develop the coastal hazards for the approaches to incorporate coastal resiliency for the subject roadway.

Figure 1: Site Digital Elevation Model (1-foot contours)

WIND CHARACTERIZATION

The site is located between the airports in Portland and Bar Harbor. Both airports have historic wind data over a time period adequate for statistical analyses. The Portland Airport data was used for this project because its wind speeds are slightly higher than at Bar Harbor and considered a reasonable conservative approach for 15% to 30% preliminary design. In addition, per NOAA, tidal processes at Islesboro are better reflected by the Portland tidal station than the Bar Harbor tidal stations. Therefore, using Portland airport data for wind provides consistency between the basis for the wind and water level data.

Extreme winds were evaluated based on statistical analysis of the Portland Airport data (1948 to 2022) and comparison to the American Society of Civil Engineers' *Minimum Design Loads and Associated Criteria for Buildings and other Structures* (ASCE 7-22) wind speeds at the site. Based on GZA's statistical analysis of the Portland Airport's wind data, the all-direction 1-minute sustained wind speed ranges from about 29 mph (1-year recurrence interval) to 90 mph (100-year recurrence interval). Inferred all-direction wind intensities for other recurrence intervals are summarized in **Table 1**. The ASEC 7-22 wind speeds are from the associated ASCE Hazard Tool and are 3-second gusts at 10 meters, which GZA transformed to 1-minute and 2-minute sustained wind speeds for comparison with the Portland Airport data. It is noted that the Portland Airport data is generally consistent with the ASCE 7-22 wind speeds, as transformed to the same wind duration, for the 10-yr and 20-yr recurrence intervals. The Portland Airport wind speed for the 100-year recurrence interval event is higher than the ASCE 7-22 value. The Portland Airport data is considered more conservative and representative of Islesboro and, therefore, is used for the project. A wind rose developed from the Portland Airport data is shown in **Figure 2**.

TABLE 1: WIND DATA SUMMARY

Recurrence Event Probability	Portland Airport Wind Speed All-Direction 1-2 minute at 10m (mph)	ASCE 7-22 Wind Speed All-Direction 3s gust at 10m (mph)	ASCE 7-22 Transformed Wind Speed All-Direction 1-2 minute at 10m (mph)
1-Year	28.9	Not provided	-
2-Year	38.0	Not provided	-
10-Year	60.0	72	59(1-min)/56(2-min)
20-Year	62.0	80	65(1-min)/63(2-min)
100-Year	90	90	73(1-min)/70(2-min)

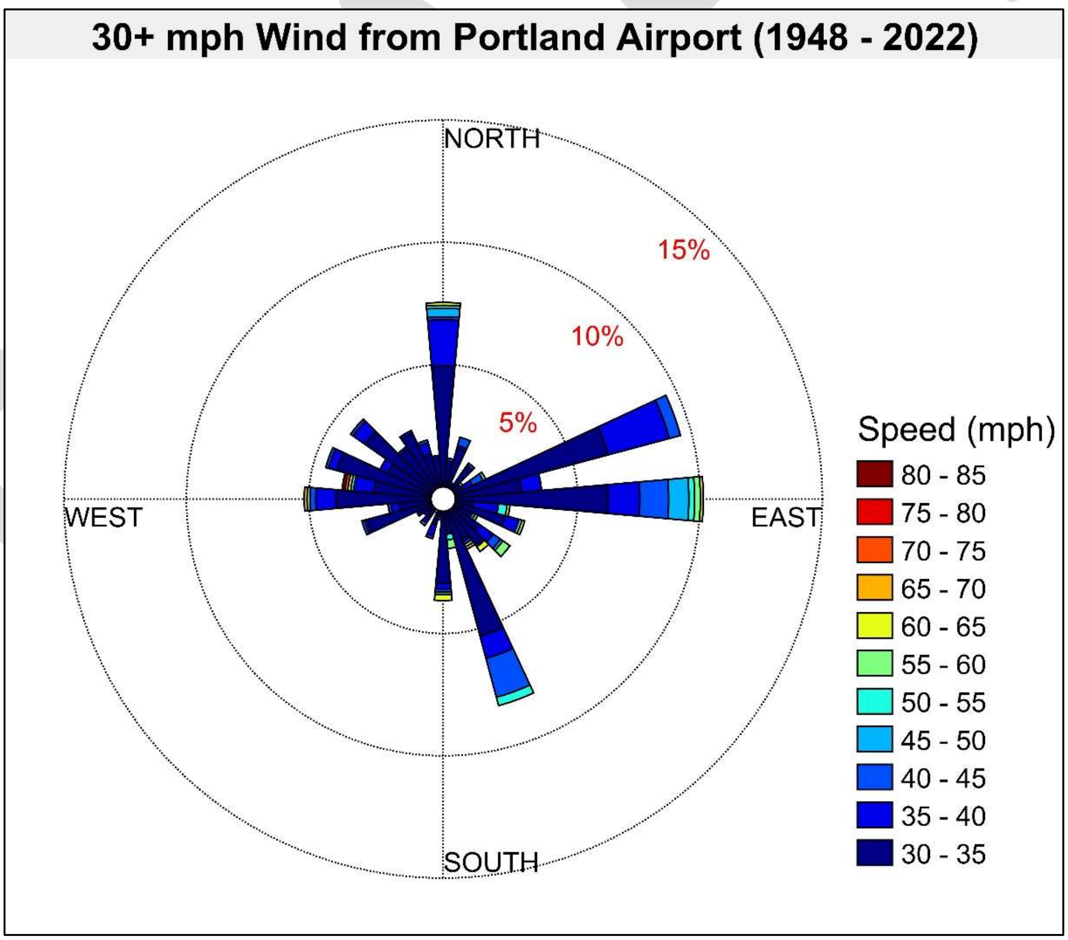


Figure 2: Wind Rose for Portland, Maine (Winds greater than 30mph)

WATER LEVELS: EXTREME WATER LEVELS (COASTAL STORM SURGE)

NOAA's Tides and Currents website is developed and supported by the Center for Operational Oceanographic Products and Services (CO-OPS). NOAA tidal datums are local datums referenced to fixed base elevations and are established for National Tidal Datum Epochs (NTDE), which are updated to reflect periodic and apparent secular trends in sea level approximately every 20 to 25 years. The specific 19-year NTDE period was adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values for tidal datums (e.g., Mean Lower Low Water). Tidal datums in certain regions with anomalous sea level changes (Alaska, Gulf of Mexico) are calculated on a Modified 5-Year Epoch.

Although the NOAA Bar Harbor tidal station is closest to the Site, the reference gauge for the area is the Portland NOAA tidal station. This is verified by the closest harmonic gauge, Pulpit Harbor - Penobscot Bay gauge [8414888], which identifies Portland, ME as its control station. The present NTDE for the NOAA Portland tide gage is the period of 1983 through 2001. See **Figure 3** for the mean water levels relative to the North American Vertical Datum of 1988 (NAVD88) for the NOAA Portland tide gage.

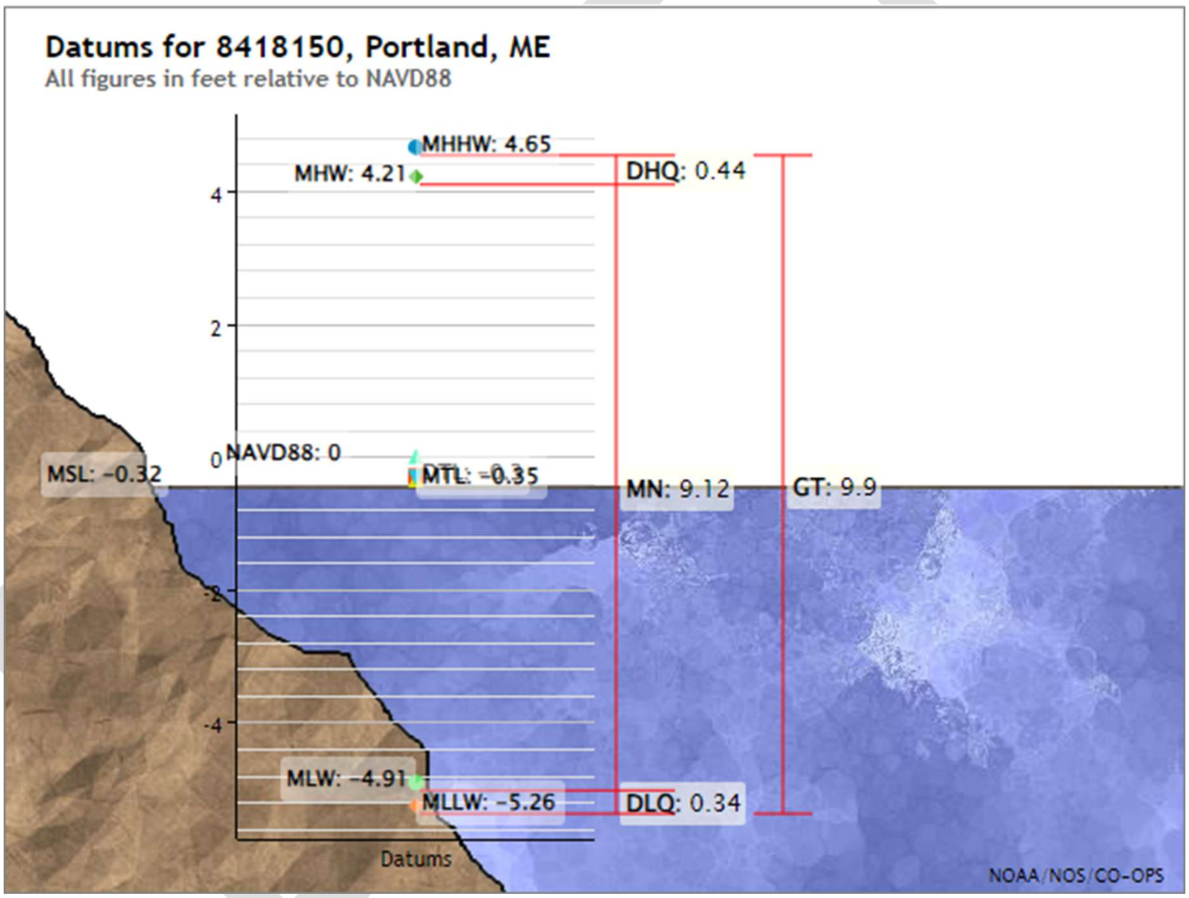


Figure 3: NOAA Tidal Datums for Portland, ME Relative to NAVD88

Various federal agencies provide Extreme Stillwater levels that are predicted to occur during coastal storms under the current climate and sea level. **Table 2** summarizes the Stillwater elevation for the range of recurrence intervals as developed by NOAA, FEMA, and the North Atlantic Coast Comprehensive Study (NACCS).

- NOAA provides exceedance probability statistics on extreme water levels, including annual exceedance probability levels for select CO-OPS water level stations with at least 30 years of data. When used in conjunction with real time station data, exceedance probability levels can be used to evaluate current conditions and determine whether a rare event is occurring.

- FEMA Flood Insurance Rate Maps (FIRMS) and Flood Insurance Studies (FIS) present flood-frequency information. The effective FIS and FIRM applicable to this study include:
  - FEMA Flood Insurance Study, Waldo County, Maine; FIS Number 23027CV000A; effective July 6, 2015
  - FEMA Flood Insurance Rate Map Panels 23027C0634E; effective date July 6, 2015
  - For the areas of Waldo County that are impacted by coastal flooding processes, FEMA's coastal flood hazard analyses provide estimates of coastal Base Flood Elevations (BFEs). Coastal BFEs reflect the increase in water levels during a flood event due to extreme tides and storm surge as well as overland wave effects.
  - The FEMA 100-year recurrence interval flood Stillwater elevation is 9.4 feet NAVD88 based on Transect 67 located just north of the North Narrows.
- The North Atlantic Coast Comprehensive Study (NACCS) was completed by the US Army Corps of Engineers (USACE) after Hurricane Sandy to address coastal storm and flood risk to vulnerable populations, property, ecosystems, and infrastructure. The study was conducted to provide information for computing the joint probability of coastal storm environmental forcing parameters for the U.S. North Atlantic Coast (NAC) coastal regions from Virginia to Maine. NACCS included the application of a suite of high-fidelity numerical models within the Coastal Storm Modeling System (CSTORM-MS). The statistical analysis of the response of the 1,150 simulated storms (1,050 tropical cyclones and 100 extra-tropical cyclones) was conducted at nearly 19,000 save point locations to produce response statistics including Annual Exceedance Probability (AEP) and average recurrence interval (ARI).
  - NACCS Point 17946 is located approximately 1/3 of a mile from The Narrows (to the East) and has an estimated mean 100-year Stillwater elevation of 8.4 feet NAVD88.

TABLE 2: STILLWATER LEVEL DATA SUMMARY

Recurrence Event Probability	NOAA Water Level Gauge PORTLAND (feet, NAVD88)	FEMA FIS Water Level Transect 67 (feet, NAVD88)	NACCS Point 17946 (feet, NAVD88)
1-Year	6	-	6.4
2-Year	7	-	6.9
10-Year	7.9	-	7.6
20-Year	-	-	7.7
100-Year	8.72	9.4	8.4

Due to its geographic location, Islesboro is susceptible to flooding from northeasters (Nor'easters) and occasionally hurricanes and post-tropical storms. Nor'easters are high frequency events, although with variable intensity. The top ten highest water levels observed as of April 2024 at the NOAA Portland tidal station are shown in **Table 3**. Nor-easters were the storm typology representing the top 10 flood high water levels at the NOAA tidal station, with 6 of the top 10 occurring in the past 6 years.

TABLE 3: TOP TEN HIGHEST WATER LEVELS AT NOAA PORTLAND TIDE STATION 8418150

Rank	Water Level (ft, NAVD88)	Date
1	9.3	1/13/2024
2	8.9	2/7/1978
3	8.4	1/10/2024
4	8.3	12/23/2022
5	8.3	01/01/2018
6	8.1	3/10/2024
7	8.0	12/04/1990
8	8.0	11/30/1944
9	8.0	11/20/1945
10	7.9	03/02/2018

GZA conducted an in-house flood frequency analysis of the NOAA data through 3/25/2024 for the Portland, Maine tide gage. The analysis used the generalized extreme value (GEV) method on annual maximum water levels to calculate likelihood of water level events. **Figure 4** presents the findings with the GEV curve compared to NOAA's generated recurrence intervals and to the FEMA 100-Year water level for Transect 67 at Islesboro. It is important to note that the FEMA 100-Year Water Level falls above the GEV curve, but within the upper confidence interval. Therefore, the design for resilience measures at The Narrows should be based on the FEMA 100-Year Water Level for the Transect near The Narrows.

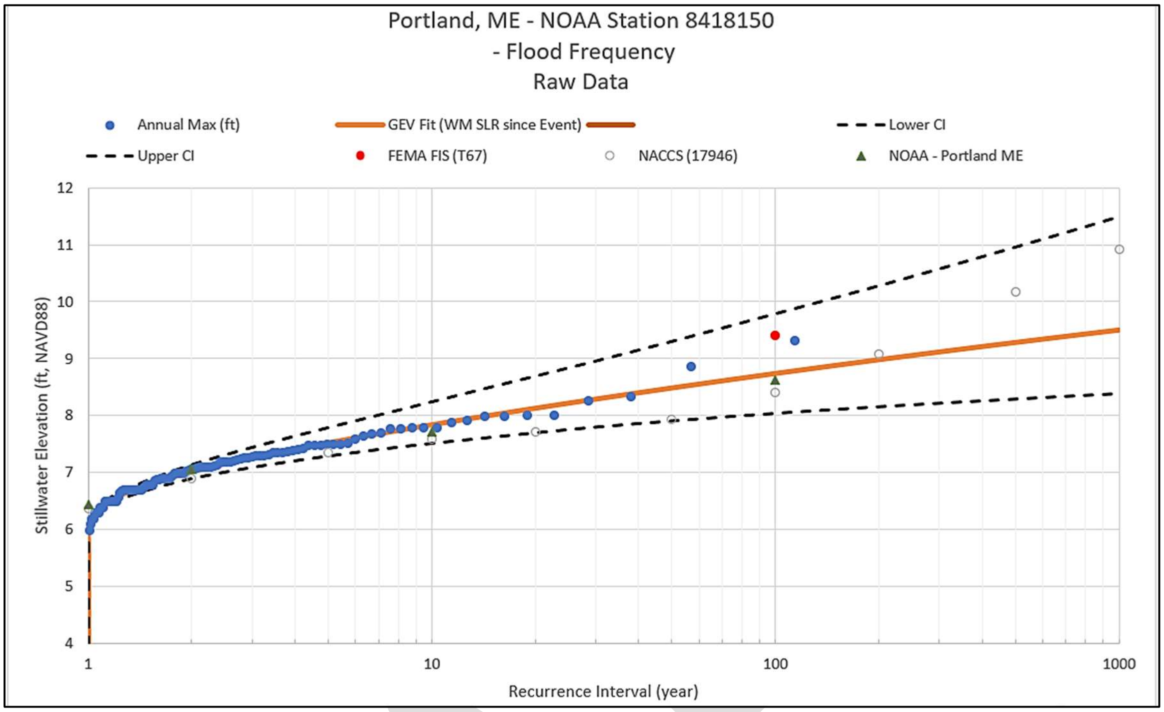


Figure 4: GEV Flood Frequency Analysis of NOAA Station 8418150 Portland, ME

SEA LEVEL RISE

Relative sea level change (RSLC) is the combination of water level change and landform change at a specific location. Landform change can be due to glacial rebound, tectonic changes, sediment redistribution, etc. The observed RSLC at the NOAA Portland tide station, over the last 112 years, indicates a historical mean sea level rise trend of 1.95 mm/year with a 95% confidence interval of +/- 0.14 mm. See **Figure 5**.

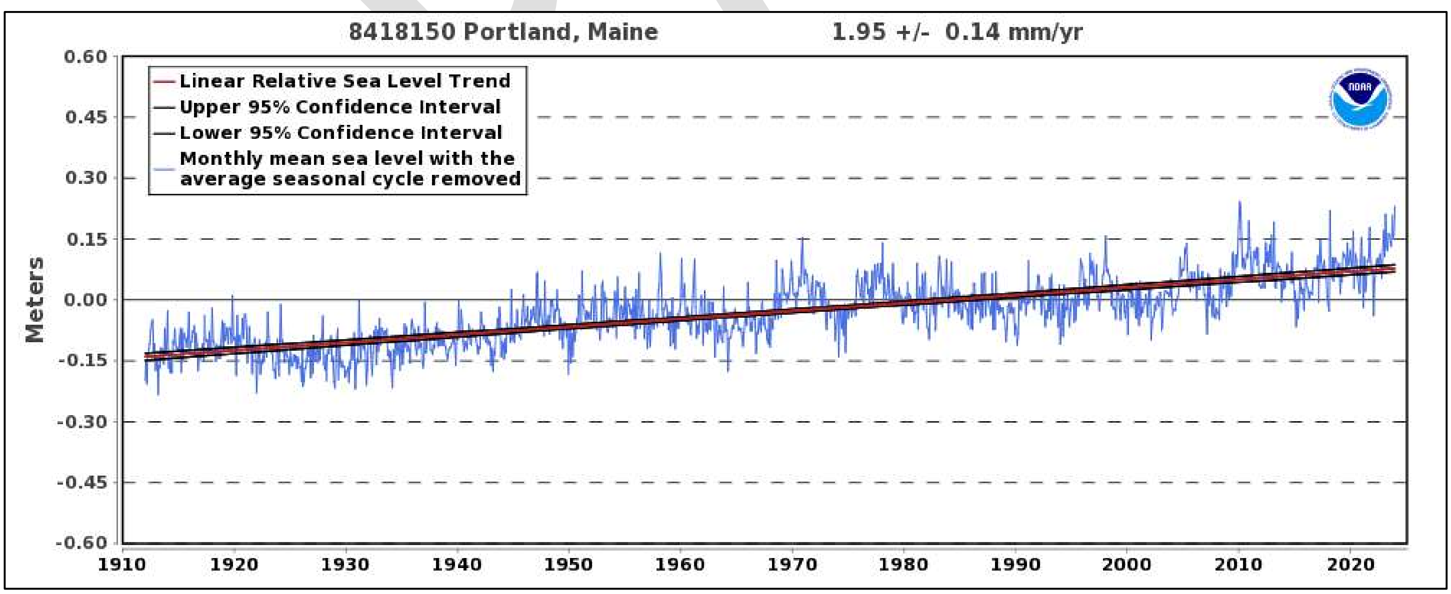


Figure 5: Observed Relative Sea Level Change, NOAA Portland, ME Station

Sea level rise projections were reviewed from NOAA's 2022 Sea Level Rise Technical Report - "*Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines*" (NOAA 2022) and U.S. Army Corps of Engineers' 2013 predictions from the USACE Sea Level Analysis Tool (SLAT). See **Tables 4 and 5 and Figure 6.** The five NOAA projections for global sea level rise are associated with estimated exceedance probabilities under three Representative Concentration Pathway (RCP) scenarios for greenhouse gas emissions (Kopp et al., 2014). The USACE 2013 report provides projections for three scenarios of Low (the linear extrapolation of historic sea-level rise), Intermediate (which references the Intergovernmental Panel on Climate Change (IPCC) AR4), and High (which references a higher IPCC AR4 curve and accommodates the rapid loss of ice from Antarctica and Greenland).

TABLE 4: PORTLAND, MAINE SEA LEVEL RISE PROJECTIONS: NOAA 2022

Year	Sea Level Rise Prediction (ft)				
	Low	Intermediate-Low	Intermediate	Intermediate-High	High
2050	0.59	0.72	0.85	1.01	1.11
2100	1.08	1.7	3.21	4.29	5.64
2150	1.57	2.85	6.23	7.34	10.39

TABLE 5: PORTLAND, MAINE SEA LEVEL RISE PROJECTIONS: USACE 2013

Year	Sea Level Rise Prediction (ft)		
	Low	Intermediate	High
2050	0.29	0.59	1.54
2100	0.82	1.85	5.14
2150	1.34	3.56	10.6

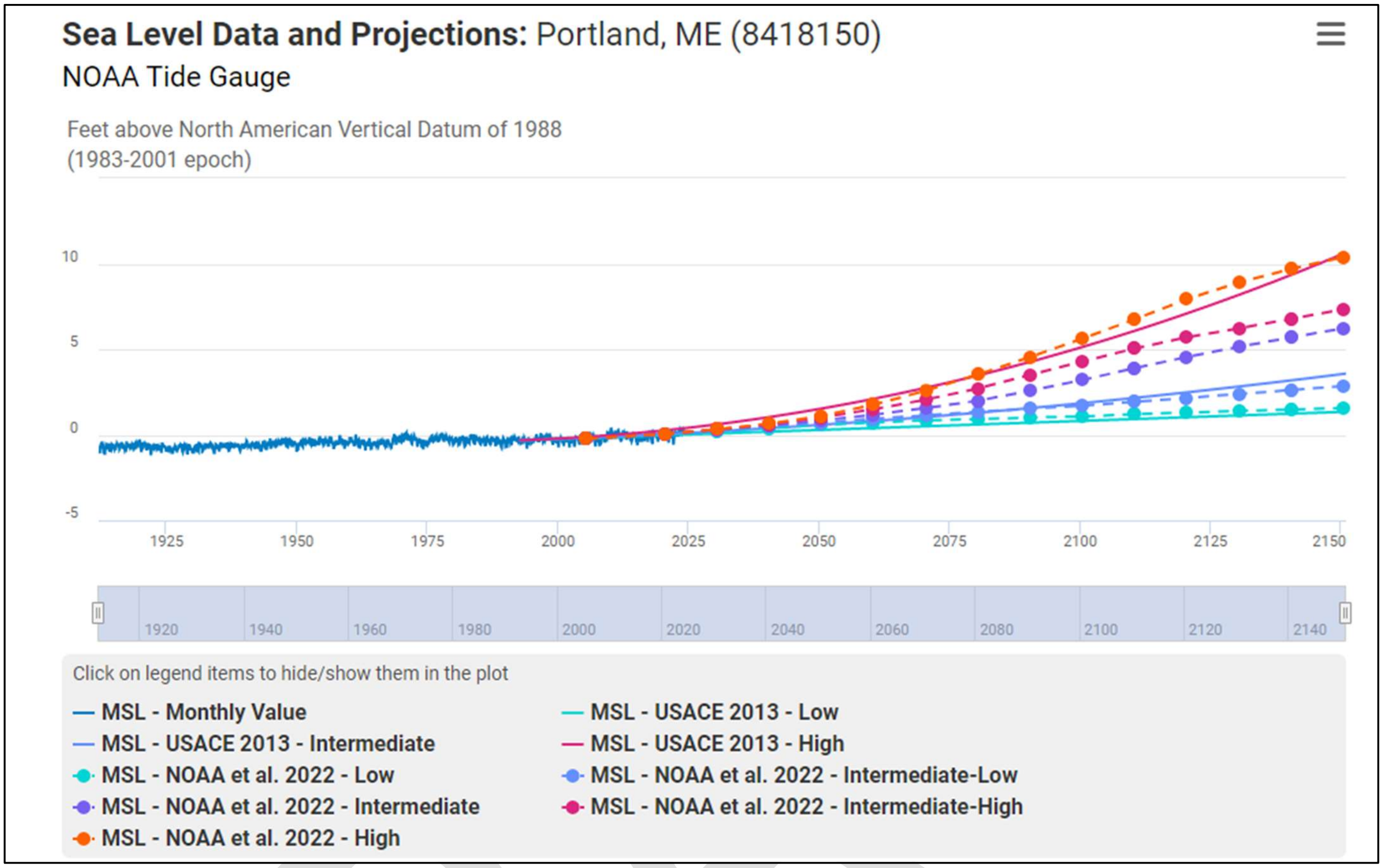
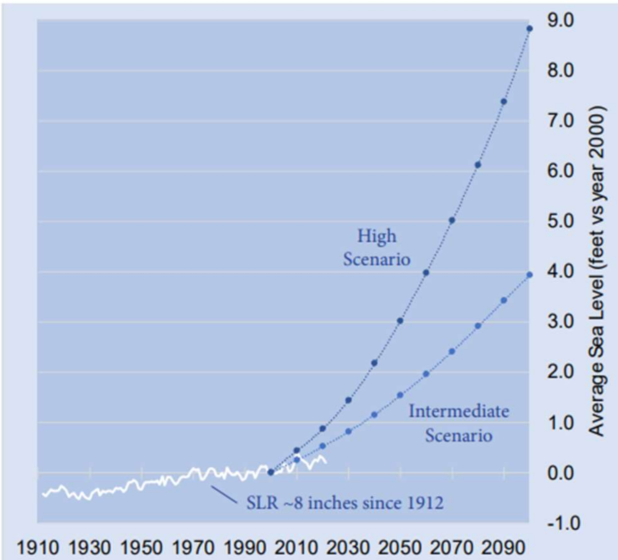


Figure 6: Sea Level Rise Curves from USACE SLAT Tool for NOAA Station 8418150 Portland, ME

In collaboration with the Maine Department of Environmental Protection, the Maine Governor's Office Policy on Innovation and the Future has published guidance on sea level rise for the state of Maine. The guidance provides recommended projections for the years 2050 and 2100 for two scenarios. The "Commit to Manage" scenario corresponds to intermediate sea level rise projections. The "Prepare to Manage" scenario corresponds to high sea level rise projections. The recommended sea level rise value for each scenario is the average of the average NOAA 2017 (NOAA Technical Report NOS CO-OPS 083 - "Global and Regional Sea Level Rise Scenarios for The United States") projections for the Portland, Bar Harbor, and Eastport NOAA Tide Gauges. See **Figure 7** for the recommended sea level rise projections.



Historical annual average sea level in Maine and intermediate and high projections of Maine's future SLR.

Maine Guidance Scenario	Sea Level Rise Projection (ft)
Year 2050	
"Commit to Manage"	1.5
"Prepare to Manage"	3.0
Year 2100	
"Commit to Manage"	3.9
"Prepare to Manage"	8.8

Figure 7: State of Maine Guidance for Sea Level Rise

It is important to note that Maine's Guidance is based on the NOAA 2017 projections and that the subsequent NOAA 2022 report lowered the SLR projections for the Maine NOAA Tide Gauges. **Table 6** provides a comparison of the Maine Guidance recommendations and the NOAA 2022 guidance for Portland, Bar Harbor, and Eastport.

TABLE 6: COMPARISON OF STATE OF MAINE GUIDANCE SLR RECOMMENDATIONS WITH NOAA 2022 SLR PROJECTIONS FOR MAINE NOAA STATIONS

Sea Level Rise Scenario	State of Maine Guidance (ft)	NOAA 2022 SLR Guidance		
		Portland Tide Gauge (ft)	Bar Harbor Tide Gauge (ft)	Eastport Tide Gauge (ft)
2050 "Commit to Manage" Intermediate	1.5	1.2	1.3	1.0
2050 "Prepare to Manage" High	3.0	1.4	1.5	1.3
2100 "Commit to Manage" Intermediate	3.9	3.5	3.7	3.4
2100 "Prepare to Manage" High	8.8	6.0	6.1	5.7

The Maine Coastwise Manual (MCM), developed by the Maine Coastal Program, presents guidance and tools for design of tidal crossings incorporating climate resiliency. Likewise, the New Hampshire Coastal Flood Risk Summary (NHCFRS), developed by New Hampshire Department of Environmental Services, presents guidance for incorporation of coastal flood risk projections for coastal resilience projects. Both of these state-level manuals present sea-level rise guidance for practitioners. As shown in **Figure 8**, the MCM presents SLR predictions in accordance with the risk consequence associated with the project. Note that these SLR predictions are presentations of the NOAA 2017 and NOAA 2022 average predictions for the three Maine NOAA tide gauges.

	LOW RISK CONSEQUENCE[1]	MEDIUM RISK CONSEQUENCE[2]	HIGH RISK CONSEQUENCE[3]	VERY HIGH RISK CONSEQUENCE[4]
	CORRESPONDING SEA LEVEL RISE SCENARIO ESTIMATES (FT) Compared to sea level in the year 2000			
	INTERMEDIATE	INTERMEDIATE	INTERMEDIATE-HIGH	HIGH
TIMEFRAME	Source: **NOAA 2017** *(NOAA 2022)*	Source: **NOAA 2017** *(NOAA 2022)*	Source: **NOAA 2017** *(NOAA 2022)*	Source: **NOAA 2017** *(NOAA 2022)*
2050	**1.5** *(1.2)*	**1.5** *(1.2)*	**2.2** *(1.3)*	**3.0** *(1.4)*
2070	**2.4** *(1.9)*	**2.4** *(1.9)*	**3.5** *(2.4)*	**5.0** *(2.9)*
2100	**3.9** *(3.6)*	**3.9** *(3.6)*	**6.1** *(4.6)*	**8.8** *(5.9)*

[1] Corresponds with the Intermediate scenario, central estimate (50% probability of exceedance)
[2] Corresponds with the Intermediate scenario, central estimate (50% probability of exceedance)
[3] Corresponds with the Intermediate High scenario, central estimate (50% probability of exceedance)
[4] Corresponds with the High scenario, central estimate (50% probability of exceedance)

Figure 8: Maine Coastwise Manual Sea-Level Rise Estimates

The NHCFRS presents many sea-level rise tables based on the RCPs (Kopp et al, 2014) and averages from NOAA gauges in Portland, ME, Seavey Island, ME, and Boston, MA. **Figure 9** is the NHCFRS's recommended relative sea level rise values in accordance with risk tolerance for the RCP 4.5 projections for Coastal New Hampshire.

STEP 3 TABLE A. RECOMMENDED DECADAL RSLR ESTIMATES (IN FEET ABOVE 2000 LEVELS) BASED ON RCP 4.5, PROJECT TIMEFRAME, AND TOLERANCE FOR FLOOD RISK.

TIMEFRAME	HIGH TOLERANCE FOR FLOOD RISK	MEDIUM TOLERANCE FOR FLOOD RISK	LOW TOLERANCE FOR FLOOD RISK	VERY LOW TOLERANCE FOR FLOOD RISK
	Plan for the following RSLR estimate (ft)* *compared to sea level in the year 2000*			
	Lower magnitude, Higher probability	⟷		Higher magnitude, Lower probability
2030	0.7	0.9	1.0	1.1
2040	1.0	1.2	1.5	1.6
2050	1.3	1.6	2.0	2.3
2060	1.6	2.1	2.6	3.0
2070	2.0	2.5	3.3	3.7
2080	2.3	3.0	3.9	4.5
2090	2.6	3.4	4.6	5.3
2100	2.9	3.8	5.3	6.2
2110	3.3	4.4	6.1	7.3
2120	3.6	4.9	7.0	8.3
2130	3.9	5.4	7.9	9.3
2140	4.3	5.9	8.9	10.5
2150	4.6	6.4	9.9	11.7

Figure 9: NHCFRS RSLR Estimates Based on RCP 4.5

<u>OFFSHORE AND NEARSHORE WAVES</u>

The Islesboro Narrows is somewhat sheltered from larger oceanic waves by the presence of Hewes Point to the southeast (which partially forms Islesboro Harbor), as well as Vinalhaven and North Haven to the south and several small islands in Penobscot Bay. See **Figure 10**. Despite this, high wave energy within Penobscot Bay can reach The Narrows from the east-southeast direction where the open water fetch is approximately 12 miles. See **Figure 11**.

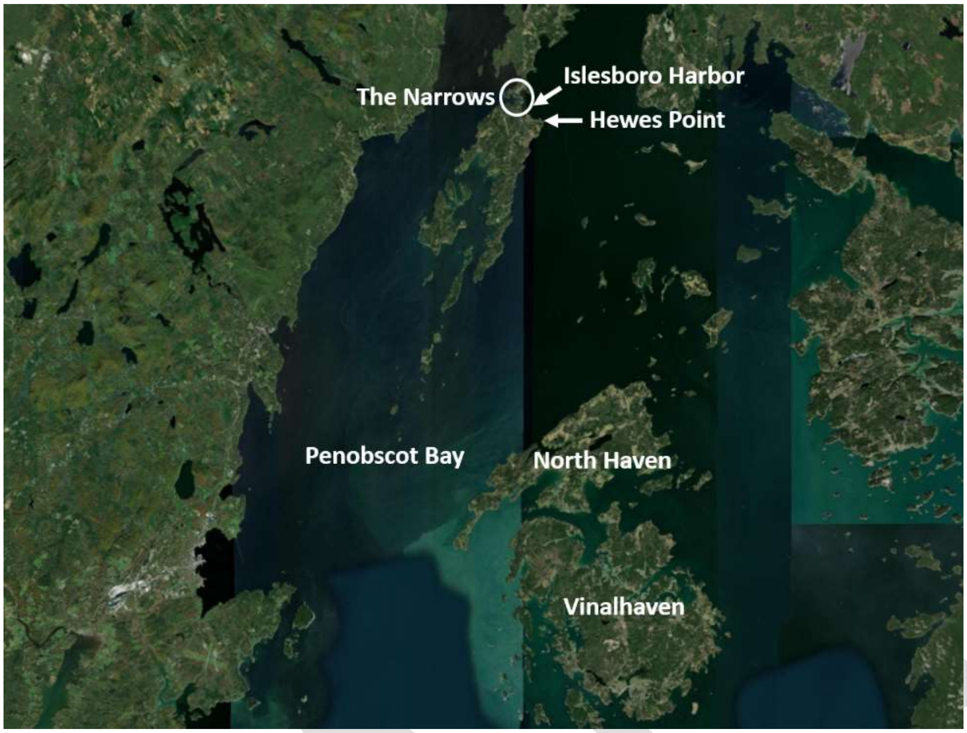


Figure 10: The Narrows and Surrounding Islands and Penobscot Bay

Figure 11: Approximate East-Southeast Open Water Fetch for The Narrows

The effective FEMA Flood Insurance Study (FIS) defines the area of The Narrows as a coastal VE flood hazard zone with a Base Flood Elevations (BFE) of 16 feet NAVD88. The VE flood hazard zone indicates an area of coastal flood with velocity that has wave heights greater than 3 feet, but the FIS does not provide the estimated wave height. To estimate, wave heights, GZA completed a wind-wave analysis and compared the findings against results from the Coastal Engineering

Design & Analysis System (CEDAS) Automated Coastal Engineering System (ACES) wave estimation tool and the USACE NAACS study results for the save point near The Narrows. See **Table 7** for the comparison.

TABLE 7: THE NARROWS – WAVE DATA SUMMARY

Recurrence Event Probability	GZA Wind Wave Analysis*		Results from CEDAS/ACES†		USACE NACCS‡ Point 17946
	Significant Wave Height (ft)	Wave Period (s)	Significant Wave Height (ft)	Wave Period (s)	Significant Wave Height (ft)
1-Year	2.0	2.6	1.8	2.9	4.1
2-Year	2.8	2.9	2.6	3.3	5.4
10-Year	4.7	3.5	4.6	4.3	7.6
20-Year	4.9	3.5	4.8	4.4	8.1
100-Year	7.7	4.1	7.9	5.4	8.9

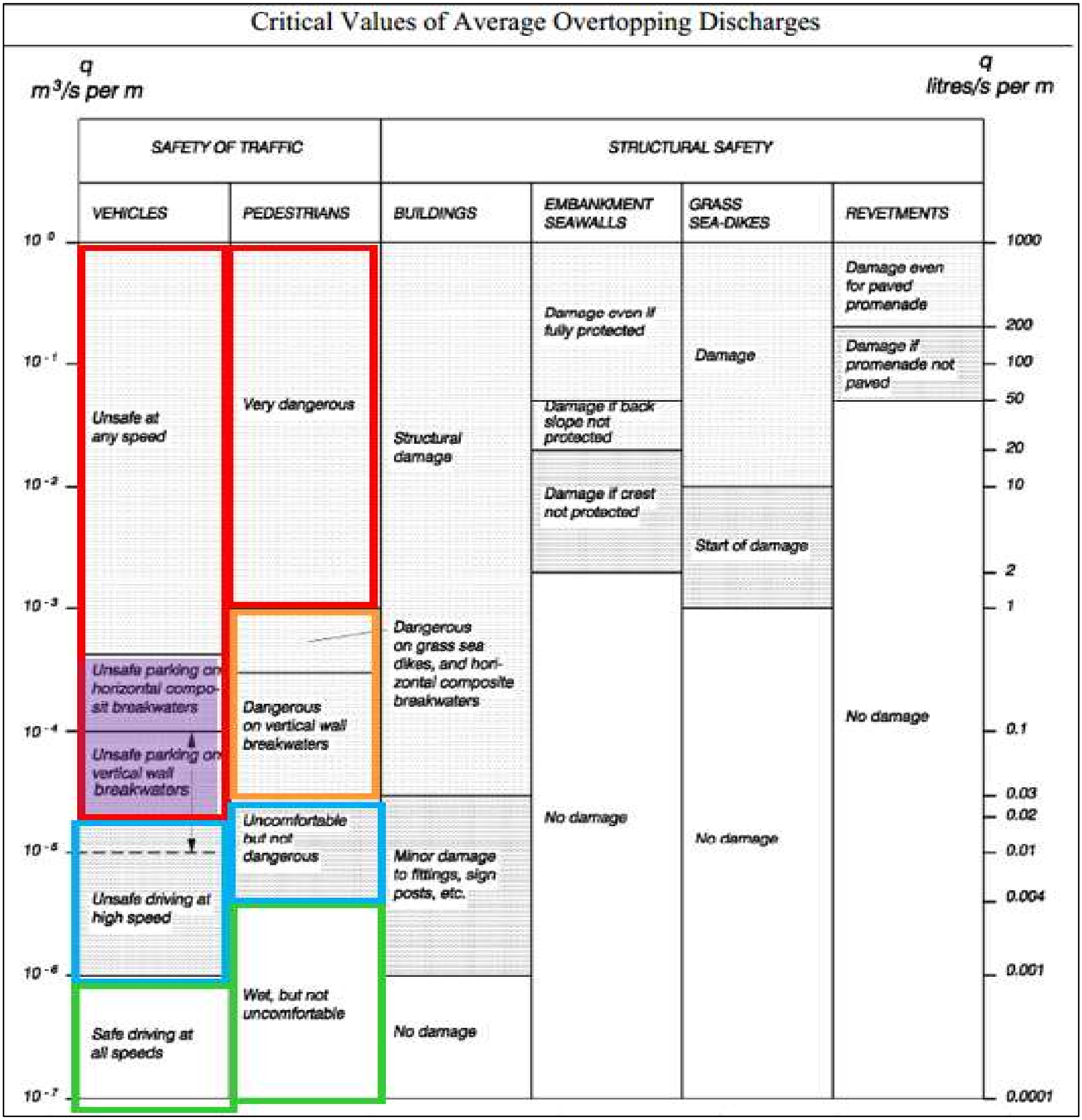
* Results for the maximum fetch distance of 65,200 ft in the east-southeast direction from The Narrows to Northwest Harbor at Deer Isle and the associated wind speed for the indicated annual exceedance probability event.

† Results for ACES for the associated wind speed for the indicated annual exceedance probability event.

‡ Wave height is at the NACCS point location approximately 1/3 mile offshore. Wave vector not indicated in the study. It is assumed the results are for the greatest fetch out of the east-southeast direction.

For this project, the average 100-year significant wave height of the wind-wave analysis and the CEDAS/ACES result for the nearshore wave was used, e.g. 7.8 feet. The wave height for the NACCS Point represents waves offshore in deeper water than along the shore of The Narrows.

Appendix C: USACE Coastal Engineering Manual Critical Values of Average Overtopping Discharges



Excerpt from USACE Coastal Engineering Manual

Appendix C: 15% Preliminary Design Alternatives Evaluation Criteria

Criteria Factors	**Concerns/Alternative Performance**
Design Service Life	• Hard structure design life (e.g. 75 Years for bridge) • Revetment design life (25 years) • Nature-based design life (5-10 years typ.)
Cost	• Design, Permitting, Construction • Maintenance • Adaptation • Grant funding
Future Adaptability/Expansion	• Roadway modification • Structure resilience
Public Function/Safety	• Pedestrian, commercial access • Value of accessible assets • Emergency response route
Flood Capacity	• SLR Resilience • Inundation Period • FEMA Flood Zone
Tidal Exchange	• Crossing opening size • Maintaining tidal flow
Environmental Impact	• Sunlight for vegetation • Tidal and storm inundation period • Marsh migration potential • Habitat substitution
Permitting	• Regulatory authorities (local, state, and federal) • Permittable action • Federal grant funding requirements (National Environmental Policy Act – NEPA environmental assessment)
Construction Constraints	• Road Closure • Time of year restrictions • Constructability • Phased construction suitability
Engineering Considerations	• Scour sensitivity/potential • Geotechnical subsurface conditions • Stone sizing, stability, sourcing
Property Impact	• Construction impact (temporary, permanent • Construction period • Noise