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Subject: Penobscot Bay Vulnerability Assessment and Resilience Planning – Draft Summary Report
Maine Coastal Program, Maine Department of Marine Resources

Wood Environment & Infrastructure Solutions, Inc. (Wood) is pleased to provide the Maine Department of Marine Resources (DMR) this summary report on the baseline characterization, vulnerability assessment and resilience planning for ten sites included in DMR's Penobscot Bay Working Waterfront Resiliency Analysis project. Our work was performed in general accordance with the scope of work and the terms and conditions included in Wood's proposal dated 1 March 2019.

1.0 INTRODUCTION

The DMR, Maine Coastal Program (MCP) contracted with Wood to provide resiliency and vulnerability analyses and recommendations for adaptation measures for ten distinct and pre-selected working waterfront sites in Penobscot Bay, Maine This working waterfront-focused project was funded by the National Oceanic and Atmospheric Administration (NOAA) to examine the resiliency of working waterfront sites in Penobscot Bay given current and projected impacts of storm surge, flooding and sea-level rise. A goal of the project was to highlight future climate risks to Maine's working waterfronts, and to provide a range of adaptation options for waterfront assets. The project sites and associated evaluation focus are listed below and shown on the overview map in **Figure 1;** aerial overviews of each site are provided in **Appendix A**.

Baseline Characterization & Vulnerability Assessment

- Middle Pier, Rockland (pier and adjacent public park)
- Municipal Fishing Pier, Lincolnville
- Public Landing, Camden (landing and adjacent public park)
- Public Landing, Belfast
- Hamilton Wharf, Searsport
- Ferry Terminal, Vinalhaven
- Lobster Co-op, Stonington
- Town Dock, Castine

Road Inundation Evaluation

- Island Road, South Thomaston

Alternative Waterfront Access Site Evaluation

- Four Alternate Sites, North Haven

Wood submitted to DMR a separate report for each study site. This summary report is intended as a high-level review of the general approach and principal findings of the project. The individual site reports should be referenced for details on and findings at each study location.

2.0 SCOPE OF WORK

2.1 Baseline Characterization and Vulnerability Analysis: Eight Working Waterfront Sites

Baseline characterization and vulnerability analysis were conducted for all but the South Thomaston and North Haven sites. The scope of work for the eight sites included:

- Baseline characterization including a review of available site documents, interviews with community representatives, survey of site topography and elevations of key site features, and review of the general condition of existing site structures by a Wood structural engineer;
- Vulnerability analyses based on the baseline survey data, condition of structures, and modelling of potential tidal, storm surge and wave-induced inundation under three sea-level rise (SLR) scenarios; and
- Development of recommended resilience measures, including strategies for incremental adaptation under the modelled scenarios.

The vulnerability analysis was based on the surveyed elevation and structural condition of working waterfront features (e.g., piers, buildings, utilities) and the inundation modelling conducted by Woods Hole Group (WHG). The inundation modelling by WHG included the tidal, storm surge and wave-induced flooding for the three SLR scenarios. Wood provided findings in separate reports for each of the eight sites which included recommendations and estimated costs for improved resilience of vulnerable waterfront features.

2.2 Road Inundation Evaluation: Island Road, South Thomaston

Over the past several years, the Town of South Thomaston has observed hazards associated with inundation and icing of Island Road, primarily in the two low-lying areas. In addition to public safety concerns, Island Road provides the only means of egress between the mainland and Spruce Head Island, and loss of access could severely impact the working waterfront and island commerce. Given the importance of maintaining access to Spruce Island, the town has obtained funding from the Northern Border Regional Commission (NBRC) to improve a portion of Island Road that is in poor condition and prone to flooding. Based on the importance of Island road for working waterfront access and public safety, DMR approved a request by the town that the Penobscot Bay waterfront resilience project include an evaluation of the vulnerability of Island Road to storm and tidal flooding, and to provide recommendations for improved resilience. The town intends to incorporate the findings of the vulnerability assessment and resilience measures into the road improvement project to the extent feasible.

To meet the town's need for an evaluation of the vulnerability of Island Road to inundation from storm, tide and seal level rise, Wood completed the work detailed below.

- Review of readily-available information on coastal vulnerability and the economic, geologic and physiographic setting of South Thomaston, focusing on Island Road.
- A site visit on 18 June 2019 with Owen Casas, Town Administrator; Cheryl Waterman, Select Board member; Betty Gray, Knox County Emergency Management Agency; and Gerry Grierson, Road Commissioner; observed and photographed existing condition of Island Road.
- Review of information provided by the town on road right-of-way, past flood events, road improvement grant application and the cost estimate for road improvements.
- A topographic survey of Island Road for evaluation of vulnerability to flood hazards and SLR.
- Modelling by WHG of potential inundation of Island Road from storm surge, waves, and tide under the three SLR scenarios.

The findings were summarized in a separate report which included the methodology, inundation evaluation results, and recommendations for improved resilience of Island Road.

2.3 Working Waterfront Access Site Evaluation: North Haven

The Town of North Haven is planning growth of commercial and recreational used of its harbors, and has identified several limitations of its existing working waterfront access sites, including access, parking, dock space and utilities, among others. As a result, DMR approved a request by the town that the Penobscot Bay waterfront resilience project include an evaluation of four potential sites for improved waterfront access and associated facilities. Accordingly, Wood's scope of work included:

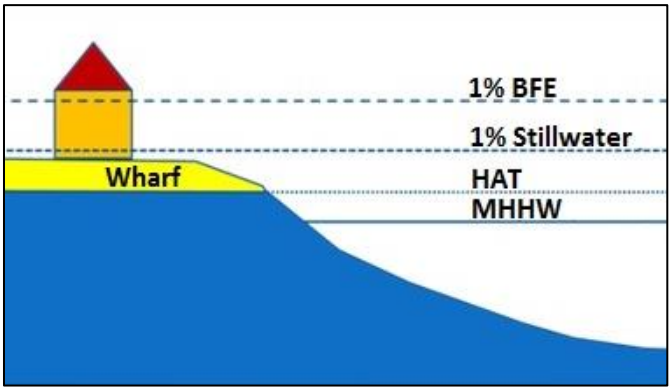
- Review of readily-available information for the four site options (Pulpit Harbor, Izzy's Beach, Town waterfront and Mullen Head), including background information provided by the town;
- A site visit on September 26, 2019 to the prospective sites and participated in a meeting with the Rick Lattimer, Town Administrator, Tammy Brown, Tax Assessor, and Linda Darling, a representative of the Board of Selectmen to discuss Wood's initial findings, and to obtain perspectives of the town regarding the site options; and
- Evaluation of each of the four site options and ranking of each based on relative favorability with respect to proximity to the town centre, road access, available acreage, harbor congestion, proximity to all tide access, storm vulnerability, environmental impact and relative cost.

The findings were synthesized into a report documenting the methodology, findings, and recommendations for improving waterfront access for commercial and recreational boating.

3.0 INUNDATION MODELLING

As a basis for the vulnerability analysis at the eight working waterfront sites and Island Road in South Thomaston, water surface elevation (WSE) exposure profiles were developed by WHG which summarize current and potential future tidal, storm surge and wave-induced inundation impacts. The key flood elevation profiles included the Mean Higher High Water (MHHW), the Highest Astronomical Tide (HAT), the 1% Still Water Level, and the 1% Base Flood Elevation (BFE), which includes wave action. Site-specific survey topographic survey data obtained by Wood served as the basis for flood inundation modelling.

The present day MHHW and HAT tidal datums were sourced from the nearest long-term NOAA tide station and from spatial files developed by Maine Geological Survey (MGS)[1]. The present day 1%-annual-chance still water level was obtained from the 2016 Federal Emergency Management Agency (FEMA) Flood Insurance Study for Knox County. Site-specific wave modelling was conducted for existing and future sea levels to better quantify wave hazards and potential increases in wave heights at the site. Wave modelling was conducted using FEMA's overland wave modelling approach for consistency in providing an estimate of the 1% BFE for the future scenarios. The relative positions of the reference elevations are shown on the adjacent figure insert.



For potential future flood impacts, relative SLR scenarios were reviewed using the U.S. Army Corps of Engineers' Sea-Level Change Curve Calculator (Version 2017.55), specifying the Bar Harbor long-term tide gauge, a regionally-informed vertical land movement rate (from NOAA), and the NOAA et. al (2017)[2] SLR curves.

In collaboration with DMR and the MGS, SLR scenarios of 1 ft, 2 ft and 4 ft were identified for evaluating short-term, mid-term, and long-term impacts, respectively. These projected increases in sea level roughly correspond with NOAA's Intermediate scenario for the years 2030, 2050, and 2085 with a relatively low exceedance probability (17%) and are consistent with the range of SLR values considered by the Maine Department of Transportation for planning and design of transportation infrastructure.

[1] https://www.maine.gov/dacf/mgs/hazards/highest_tide_line/index.shtml
[2] https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

4.0 FINDINGS

Table 1 includes a summary of the ten sites, including primary features and key vulnerabilities to storm events. In many instances, vulnerabilities relate to present day deficiencies, such as highly weathered timbers and decking, or unprotected utilities. The individual site reports provide details on the present day deficiencies and vulnerabilities over each flood scenario modelled.

The plots on **Figures 2A through 2C** depict the relationships between critical infrastructure elevations and existing and potential future modelled flood elevations for the eight sites where working waterfront vulnerability assessments were completed, and the two locations on Island Road in South Thomaston. The plot on **Figure 3** includes a summary of estimated budgets for recommended resilience measures for the eight working water front sites where vulnerability assessments were conducted. **Attachment B** includes flood zone maps for the present day and each SLR scenario developed by WHG.

4.1 Baseline Characterization and Vulnerability Analysis: Eight Working Waterfront Sites

Vulnerability Overview

As shown on **Table 1**, key site features vulnerable to inundation and wave action at multiple working waterfront sites include wharves, piers, hoists and utilities. These vulnerabilities appear to be exacerbated by present day structural or mechanical deficiencies resulting from storm damage, daily wear and tear, and pending maintenance or upgrades. Typical deficiencies observed by Wood include:

- Corrosion of dock attachments and fasteners on piers/wharves;
- Deterioration of wood pilings and other support structures on piers/wharves;
- Settlement or washing out of material around wharf/pier support structures, breakwaters and culverts;
- Lack of sufficient structural support members on piers/wharves, and insufficient attachment of floating docks to piers/wharves;
- Utilities lacking weather-proof enclosures; and
- Cracking and deterioration of pavement in parking lots and along access roads.

Apparent deficiencies, combined with the vulnerability of each site to flood and wave impacts, were considered when developing recommendations for improved resilience.

Inundation Modelling

The inundation modeling plots on **Figures 2A and 2B** include water level elevations (NAVD 88) for MHHW, HAT, 1% Still Water and 1% BFE. The 1% BFE incorporates wave heights which range from 1 (present day) to 7 feet (long term). Average wave heights were used for each SLR scenario on the plots. The site-specific elevation of a pier or wharf was included on each plot as a benchmark for interpreting the extent of potential inundation. Key findings based on the modeling data include:

- The sites with the highest risk of inundation under the MHHW, HAT and 1% Still Water Flood scenarios include Camden, Belfast, Searsport and Castine because of the relatively low elevation at these wharves (i.e., around 8 ft). For example, the wharves at these locations may also be inundated under daily MHHW in the Long Term scenario.
- Sites with lower risk of inundation under the MHHW, HAT and 1% Still Water Flood scenarios include Rockland, Lincolnville, Vinalhaven and Stonington, reflecting the relatively higher elevation of wharves or buildings at these locations (ranging from about 9 to 12 ft).
- Modeling data indicates wharves/piers at all eight sites will be inundated under the 1% BFE, which includes storm-induced waves, for all scenarios. Inundation under the 1% BFE is predicted to range from about 2 to 5 ft for Present Day scenario, to about 7 to 13 ft for the Long Term scenario.
- The most extensive inundation under the 1% BFE scenarios is predicted for Searsport and Lincolnville, due to the combination of relatively low wharf elevations and exposure to off-shore wind and waves.

Table 1. Site Summary
Penobscot Bay Resiliency Project

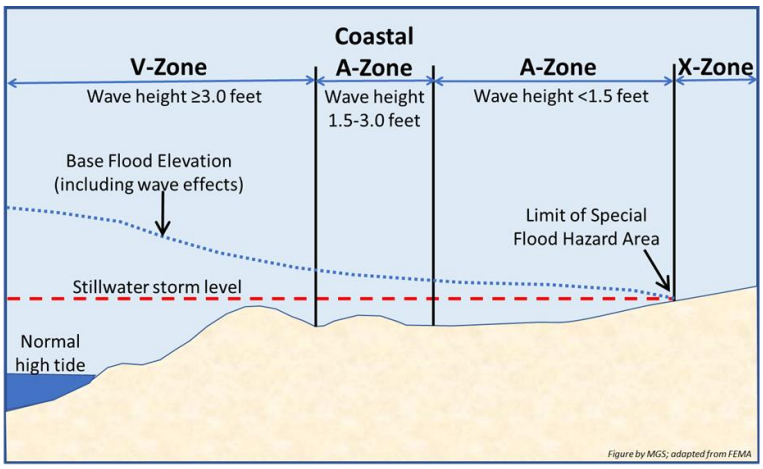
Location	Features												Key Vulnerabilities
	Wharf/Pier/Terminal	Floating Dock(s)	Boat Ramp	Access Road/Parking	Buildings	Utilities	Pump Station	Fuel Storage/Dispensers	Hoist	Shoreline Revetment	Breakwater	Public Park	
Structural Vulnerability Assessment Sites													
Middle Pier, Rockland	•	•		•	•	•	•			•		•	Wharf, buildings, pump station, utilities
Public Landing, Camden	•	•		•	•	•			•	•		•	Wharf, buildings, utilities, hoist
Municipal Fishing Pier, Lincolnville	•	•	•	•		•			•	•			Wharf, utilities, hoist
Public Landing, Belfast	•	•	•	•	•	•		•	•	•	•		Wharf, buildings, fuel tank/dispenser, utilities, shoreline
Hamilton Wharf, Searsport	•	•	•	•		•				•			Wharf, utilities, shoreline
Ferry Terminal, Vinalhaven	•	•		•	•	•				•	•		Terminal, building, breakwater/attenuator, utilities
Lobster Co-op, Stonington	•	•		•	•	•		•		•			Wharf, buildings, fuel tanks/dispenser, utilities, shoreline
Town Dock, Castine	•	•	•	•	•	•				•			Wharf, building, utilities
Road Inundation Evaluation													
South Thomaston Road Inundation				•		•				•			Island Road (two low-lying locations)
Working Waterfront Access Evaluation													
North Haven Waterfront Access	•	•	•	•	•	•			•	•	•		Terminal pier, parking, shoreline/coastal slopes

Based on modelling by WHG, the flood maps in **Appendix B** reference FEMA 's Flood Zone Classification system described below.

Zone X: Area of moderate flood hazard, outside the 100-year limit.

Zone AE: Coastal flood zone with a 1% annual chance of flooding; base flood elevations are provided (values in parentheses on the flood maps).

Zone VE: Coastal flood zone with a 1% or greater chance of flooding and an additional hazard associated with storm waves; base flood elevations are provided (values in parentheses on the flood maps).



FEMA flood zones with associated wave heights are illustrated on the adjacent figure insert. A-Zones are not distinguished on the flood maps in Appendix B, and the "E" designation for Zones AE and VE indicates flood elevation data is provided on the maps. For example, Zone VE(El7), indicates a flood elevation of 17 feet.

As broadly indicated by the maps for each site, flood zones predicted for the 1% flood event (including wave action) extend progressively landward with increasing SLR. The result is an increase in inundation depth for vulnerable waterfront structures as SLR increases. It should be noted that wave heights attenuate rapidly once flood water meets the shore (i.e., typically within 100 ft for most storm scenarios).

Resilience Measures

Recommended resilience measures for each site vary depending on the SLR scenario and associated vulnerability to flooding and wave action. The primary recommendations applicable to several of the study sites are summarized below.

Compliance with ASCE 24: At a minimum, each site must comply with the American Society of Civil Engineers/Structural Engineering Institute Standard 24 – Flood Resistant Design and Construction (ASCE 24). This standard applies to new construction and existing structures that sustain substantial damage, or that are substantially improved. Under ASCE 24, the design elevation varies depending on the type of structure and its associated Flood Design Class.[3] For example, buildings and structures that pose a moderate risk to the public or moderate disruption to the community should they be damaged or fail due to flooding are categorized as Flood Design Class 2, and include most residential, commercial and industrial buildings not otherwise classified. The design requirements for Flood Design Class 2 specify BFE +1 ft or community-specific Design Flood Elevations (DFE), whichever is higher, for the lowest floor. **However, in light of the forecasted increase in water levels and the schedule for these events in relationship to the life of the structure, design should be based on the either BFE plus 2 feet of freeboard, the DFE, or 500-year event, whichever is higher.**

Wharves/Piers: Several sites included wharfs/piers with structural deficiencies due to weathering, storm damage and daily wear and tear, such as structures as Lincolnville and Stonington. Recommendations included:

- Confirm positive attachment of all structural members to their substrate or load-bearing elements. Incorporate redundancies in design as needed based on a detailed structural analysis. Recommend a destructive investigation to confirm the presence of shipworms/marine borers and determine the need for any corrective action per a Structural Engineer Licensed in the State of Maine.

[3] https://www.fema.gov/media-library-data/1436288616344-93e90f72a5e4ba75bac2c5bb0c92d251/ASCE24-14_Highlights_Jan2015_revise2.pdf

- Structural improvements to accommodate the risks associated with rising water levels and increased wave height such as weatherizing vulnerable assets and properly securing structures (e.g., chains, anchors, tie-backs, supplementary lateral bracing, etc.).
- Consider raising the wharf/pier in response to rising water levels and into flood zone of less impact, and reconstruction incorporating a sustainable design at the current location.

It should be noted that while raising a wharf/pier may reduce the impact of rising sea levels and storm events, such construction is expensive, particularly considering the need to accommodate impacts to adjacent parking lots, roads and utilities. A cost-benefit analysis should be conducted which considers the impacts of wharf reconstruction and the lifecycle of the structure relative to sea level trends, among other factors. It may be more feasible to invest in proactive wharf maintenance and assuring that the structures are properly secured against anticipated design forces with the understanding that waterfront structures may not be accessible during certain flood events.

Floating Docks: All eight sites had floating docks, and general recommendations for improvements included:

- Clean and coat all corroded steel framing members and replace corroded hardware. Confirm that all members are positively connected and the substrate is in decent condition to resist the intended design loading.
- Confirm the gangway attachments ability to resist the design loading and repair or replace as needed.
- Moor all floats to independent float piles or using mooring chains/ropes anchored to the seabed.
- Consider raising the gangway and gangway platform to accommodate SLR. This alternative would provide an elevated gangway platform above the deck elevation, and greater resilience during future extreme high tide and storm events.

Buildings: All but the sites in Lincolnville and Searsport had fixed buildings vulnerable to flooding based on proximity to the shore. Three primary recommendations apply to the buildings; these recommendations may be used independently or in combination, depending on building purpose and vulnerability to flooding. Design standards under ASCE 24 should be followed.

- Reconstruction of buildings with weather-resistant material with openings sealed against moisture intrusion.
- Raising buildings above a design flood elevation based on building use, vulnerability, building lifecycle and SLR.
- Relocation of buildings further inland to the design flood elevation.

Utilities: All eight sites included various utilities, typically electrical and water service to wharves/piers and docks. Wharves at Belfast and Stonington had motor fuel storage tanks, supply lines and pump dispensers. Electric hoists were observed at all sites but Rockland, Vinalhaven and Castine. General recommendations for resilience of utilities included:

- Utilities, fuel supply lines and equipment should be properly secured to resist design wind and water loading or relocated above the flood elevation as specified in ASCE 24. Watertight and stainless-steel electrical fixtures should be incorporated.
- Perform an assessment of fuel storage tanks and containment relative to hydrostatic loading, and repair or replace damaged or insufficient elements under direction of a qualified design professional registered in the State of Maine in accordance with ASCE 24.

Boat Ramps: Four of the eight sites had ramps (Lincolnville, Belfast, Searsport and Castine). Based on the projected SLR scenarios, the following recommendations were provided for maintaining boat ramp access and ease of use:

- Raising ramps commensurate with projected SLR and providing the recommended slope of between 12% and 15%. Depending on available space, options which incorporate varying slopes may be necessary to transition from the parking lot to the shore.
- For longer term SLR scenarios, consider options for relocation of ramps to accommodate higher sea level elevations.

These options require evaluation of the optimal timing for improvements to assure maximum usability over the lifecycle of the structure.

Shoreline Protection: Shoreline protection measures (e.g., stone revetment) appeared to be generally effective at the eight sites. In Searsport, some undermining of the parking lot adjacent to the shore was apparent, and in Belfast erosion was observed around a culvert discharging to the shore. General recommendations for improved shoreline resilience include:

- Consider localized re-grading and raising top-of-bank elevations to accommodate rising water levels and increased wave height above the top of riprap.
- Evaluate current shoreline protection measures and implement improved design (e.g., appropriately sized stone) that takes into account structure lifecycle and resilience under projected SLR and storm events.

4.2 Road Inundation Evaluation, South Thomaston

Overview of Road Vulnerabilities

Wood conducted visits to the two low-lying areas of concern to the South Thomaston community. Area A, located near the intersection of Island Road and Village Road, crosses a narrow neck of land bordered by tidal inlets to the north and south. The road lies within about 10 ft of the shore to the south and is separated from the shore to the north by about 180 ft of saltmarsh. Key observations during the visit to Area A include:

- Island Road dips downward and is close to the elevation of the adjacent tidal marsh;
- The southern edge of Island Road lies within a few feet of riprap used to protect the shoreline to the south, and some of the riprap along the shoreline south of Island Road appears to have been dislodge seaward, apparently due to wave and tide action; and
- Culverts beneath Island Road and Village Road appear are obstructed, limiting the effectiveness for stormwater drainage.

Town officials noted that during extreme high tides and storm surge events, waves overtop Island Road, and freezing ocean spray occurs on the road during the winter months. Town officials did not recall a storm event that resulted in closure of Island Road, but that inundation of the road resulted in safety concerns.

At Area B, Island Road dips downward from the lobster pound toward Elwell Point Road and the Spruce Head Island causeway to the east. At its lowest elevation, Island Road lies within about 10 ft of a cove (former lobster pound) to the north-northeast, and within about 275 ft of the shoreline to the south-southwest. Key observations at Area B include:

- The shoreline of the cove north of Island Road is protected by riprap, and the cove inlet is protected by a stone block dam and pier;
- Erosion of the shoreline south of Island Road was observed southeast of Elwell Point Road; riprap placed along the shore in this area does not extend to the road shoulder; and
- No obvious evidence of road bed erosion or washout was observed in Area B other than the area noted above southeast of Elwell Point Road.

Town officials noted that storm surge has resulted in flooding of Island Road in the vicinity of the cove where the road is at its lowest elevation in Area B. The operator of the lobster pound provided photos of this flood event during the winter of 2018-2019. The town is considering straightening the curve in Island Road adjacent to the lobster pound, resulting in relocation of the lobster pound parking lot to the northeast (opposite) side of Island Road.

Inundation Modelling

WHG conducted modelling of inundation at Areas A and B on Island Road using similar methodology as the eight working waterfront sites discussed above. The results of flood modelling are summarized on **Figure 2C** and provided in **Appendix B** which includes maps depicting the 1%-annual-chance flood zones and BFEs for each SLR scenario. The South Thomaston site

report also includes profiles of modelled flood elevations along the two transects for Areas A and B for visualization of road inundation. The principal findings are summarized below.

Area A

- The elevation of Island Road (about 9 ft) lies above MHHW and HAT elevations for all scenarios except the long term SLR of +4 ft.
- The road elevation is at or below the 1%-annual-chance still water elevation for all scenarios.
- The BFE, which considers wave action, lies about 2 ft. above the road elevation for the present day scenario, and ranges from 4 ft to 8 ft. above the road elevation for the short term to long term SLR scenarios modelled.

Area B

- The elevation of Island Road (about 10 ft) lies above MHHW and HAT elevations for all scenarios except the long term SLR scenario of +4 ft.
- The road elevation is at or below the 1%-annual-chance still water elevation for all scenarios accept the present day.
- The BFE, which considers wave action, is at the road elevation for the present day scenario, and ranges from 1 ft to 6 ft above the road elevation for the short term to long term SLR scenarios modelled.

The flood maps in **Appendix B** depict progressive shrinking of areas outside the 1%-annul-chance flood zone (Zone X) and expansion of areas impacted by flooding in Zone AE (coastal flood zone) and Zone VE (coastal flood zone with velocity/wave hazard).

Resilience Measures

The Town has been awarded a grant to improve an 800-ft section of Island Road that includes work in Areas A and B. This work includes, among others, raising the road elevation 2 to 3 ft and stabilizing the adjacent shoreline.

Based on the assessment by Wood, the proposed reconstruction effort should consider:

- A geotechnical evaluation of the proposed road reconstruction areas to evaluate the potential settlement and other design considerations;
- Repair or replacement of road culverts to improve drainage and reduce flooding of Island Road in Area A, and evaluate the benefit of adding road culverts at Area B;
- Raising the roadbed of Island Road at least 3 ft in Area A and 2 ft in Area B to reduced flooding potential for improved resilience through the current and short term scenarios;
- Design and construction of shore protection measures (e.g., riprap) that considers the inundation and wave modelling data and accommodates the long term storm flood scenario to the extent feasible (i.e., wave heights of 3 to 4 ft);
- Placement of a geogrid to stabilize the road base and help prevent washout due to flood events; and
- Evaluation of the benefits of geocomposite drains beneath the road bed to help prevent instability from hydrostatic pressure following potential flood events.

4.3 Working Waterfront Access Evaluation, North Haven

Wood conducted a qualitative ranking of each of the four waterfront access site options based on the relative strengths and weaknesses for each; the sites included: Pulpit Harbor, Izzy's Beach, the town waterfront and Mullen Head. The ranking criteria included proximity to the town centre, road access, available acreage, harbor congestion, proximity to all tide access, storm vulnerability, environmental impact and relative cost. The environmental impact criterion considered proximity of the site to mapped wading bird habitat, eel grass and extent of coastal wetlands. An evaluation of relative cost was based on the general complexity of planning, permitting and constructing a proposed waterfront access facility including parking, a launch ramp, and multi-use commercial pier and dock structures.

The highest ranking alternative was the Pulpit Harbor Town Dock, based on its current use for water access, an existing pier and docks, and dedicated parking, although limited. However, improvements to this site would be required to meet the Town's goals

for a multi-use recreational and commercial facility, including installation of a boat ramp, expanded parking, reconstruction of the pier to accommodate vehicle access and addition of utilities such as water, power and power lifts. Even though this location ranked highest, it faces significant challenges in achieving the town's goals including a relatively steep shoreline complicating construction of a boat ramp, lack of town-owned land for parking and access, a residential setting, and a narrow harbor which limits available mooring capacity for future growth. The complexity and cost of improving the Pulpit Harbor Town Dock site could be reduced if adjacent land were available to the town through acquisition or land exchange – such as the land owned by a conservation group to the east.

The limitations for each of the four sites and associated ranking indicates no one site is ideal for development to meet the town's goals. Izzy's Beach lacks the available land for parking and access and is very close private residences; the town waterfront is close to village amenities, but lacks land for parking and access and is located in a congested harbor front area; Mullen Head has substantial land, but is complicated by improvements needed to the narrow gravel access road, is vulnerable to storms due to its northeast exposure, and is valued for its scenic coves and beaches.

Assessment of the four alternative sites indicated that the town may consider a multi-site solution for improved commercial and recreational waterfront access and facilities focusing on the Pulpit Harbor Town Dock, Town Pier, and Mullin Head. Examples are provided below.

Pulpit Harbor Town Dock: Improvements could enhance recreational boating and limited commercial use experienced at this location. Upgrades for consideration could include:

- Levelling and resurfacing the parking area to improve access and reduce erosion;
- Working with NHCP to identify potential adjacent land for expanded parking;
- Implementing stormwater runoff controls in association with improved landscaping for buffering noise and maintaining scenic quality;
- Coastal slope protection (e.g., riprap)
- Water and power service;
- Expanding the pier width and adding one or more finger docks for added tie up capacity; and
- A mooring layout plan that identifies the optimum number and location of moorings for safety and ease of access.

Town Pier and Dock: Improvements at the pier and town dock on the town waterfront could focus on commercial boating needs based on current heavy use by fishermen and proximity to commercial boatyards, fuel and supplies. Examples of improvements for consideration:

- Expanding the concrete deck for added parking and loading space;
- Water and power service to the pier and dock;
- Adding a power lift for loading/unloading gear; and
- Expanding length and number of floating docks.

Mullen Head: Improvements at Mullen Head could focus on recreational and limited commercial use to help preserve the scenic qualities of this area. Improvements could include:

- A public boat ramp at a suitable location, such as at the picnic area where existing roads and relatively flat access area could accommodate parking and launching;
- Landscaping and associated erosion control and storm water runoff minimization;
- Modest widening and levelling of roads; and
- Water and power service.

5.0 ESTIMATED COSTS

Evaluation of the eight working waterfront sites included budget estimates for implementation of resilience measures for various flood and sea level rise scenarios. A summary of the budgets is provided on **Figure 3**. As shown, the budget estimates range from around $300K for improvements under the Present Day scenario at Rockland, to about $10M for improvements relating to the Long Term scenario at Vinalhaven, driven largely by the cost of ferry terminal resilience measures. The estimated budgets are intended as a planning tool for helping inform preliminary resilience measure prioritization. Actual budgets will vary based on options selected, timing, results of engineering studies and contractor-derived quotes, among other factors.

5.0 CONCLUSIONS

5.1 Eight Working Waterfront Sites

Evaluation of eight working waterfront sites indicated that each has structures with deficiencies related to day-to-day wear and tear, past storm damage and pending maintenance. These deficiencies increase the vulnerability of structures to damage from potential tidal, storm surge and wave-induced flooding. Structures common to the eight sites included wharves/piers, buildings, utilities, access roads/parking areas and shoreline revetment.

Modelling of the BFE under three projected SLR scenarios, ranging from 1 to 4 ft, indicated the highest risk of inundation at Camden, Belfast , Searsport and Castine where wharves/piers lie at a relatively low elevation of about 8 ft. Lower risk of inundation is projected for Rockland, Lincolnville, Vinalhaven and Stonington where the wharves/piers are at elevations ranging from about 9 to 12 ft. Modeling data indicates wharves/piers at all eight sites will be inundated under the 1% BFE which includes storm-induced waves predicted to range from about 2 to 5 ft for Present Day scenario, to about 7 to 13 ft for the Long Term scenario (4 ft SLR). The most extensive inundation under the 1% Still Water and 1% BFE events is predicted for Searsport and Lincolnville, due to the combination of relatively low wharf elevations and exposure to off-shore wind and waves.

Despite structural deficiencies and vulnerability to flooding and wave impacts, effective resilience measures can be implemented to reduce the impact of storm or extreme high tide events. Shorter term, readily implemented measures include improving weather resistance of vulnerable utilities, replacement of highly weathered wharf planking, and repair or replacement of corroded fasteners. More costly resilience measures for longer-term vulnerabilities include weatherization, raising or relocating critical structures such as buildings, wharves and tanks (e.g., motor fuel). Communities should consider the impacts of projected SLR, and plan for resilience improvements based on the lifecycle of the structure and updated SLR trends. Additional studies are recommended to refine the scope and budget for improved resilience measures.

5.2 Road Inundation Evaluation, South Thomaston

In South Thomaston, an evaluation of two low-lying areas indicates vulnerability to inundation by storm surge and wave action. Erosion of the road shoulder and part of the adjacent shoreline was observed, and riprap placed for shore protection appears to be undersized in some areas. Resilience measures can be incorporated into a proposed road reconstruction project which include, among others, completing a geotechnical evaluation to better characterize unknown historical fill materials, use of a geogrid in the road base to improve stability, shoreline protection measures based on the flood and wave modelling data, and raising of the road bed 2 to 3+ ft to reduce the risk of inundation. The proposed resilience measures are likely to substantially reduce the risk of road closure for the present day and short term flood scenarios (i.e., over the next ~10 years). The performance of the road over the next decade can be evaluated in association with updated SLR data to evaluate the need for future improvements or alternate egress design, such as bridge crossings.

5.3 Working Waterfront Access Evaluation, North Haven

An evaluation four potential sites for improved waterfront access and associated facilities indicated that none of the four sites is ideal for meeting the Town's goals for a commercial and recreational boating access site, primarily due to the limitation of available land for access and parking (Pulpit Harbor Town Dock, Izzy's Beach and town waterfront). At the one site where land is available, Mullen Head, the northeast exposure of the two coves (Banks and Mullen Coves) pose the risk of high storm impact. Each of the four sites would require environmental permitting and consideration of coastal wetlands and wildlife habitat.

A potential solution to the limitations posed by each of the four site options is to consider improvements to multiple sites, where collectively, the waterfront access goals of the town can be met. For example, improved public access and facilities at the Pulpit Harbor Town Dock and Mullen Head (e.g., picnic area) with a focus on enhancing recreational boating. At the town dock and ferry terminal pier along the Town waterfront, improvements could prioritize commercial boating with addition of parking, loading space and power lift equipment.

7.0 CLOSING

Wood appreciates the opportunity to support the Maine Coastal Program on this important project.

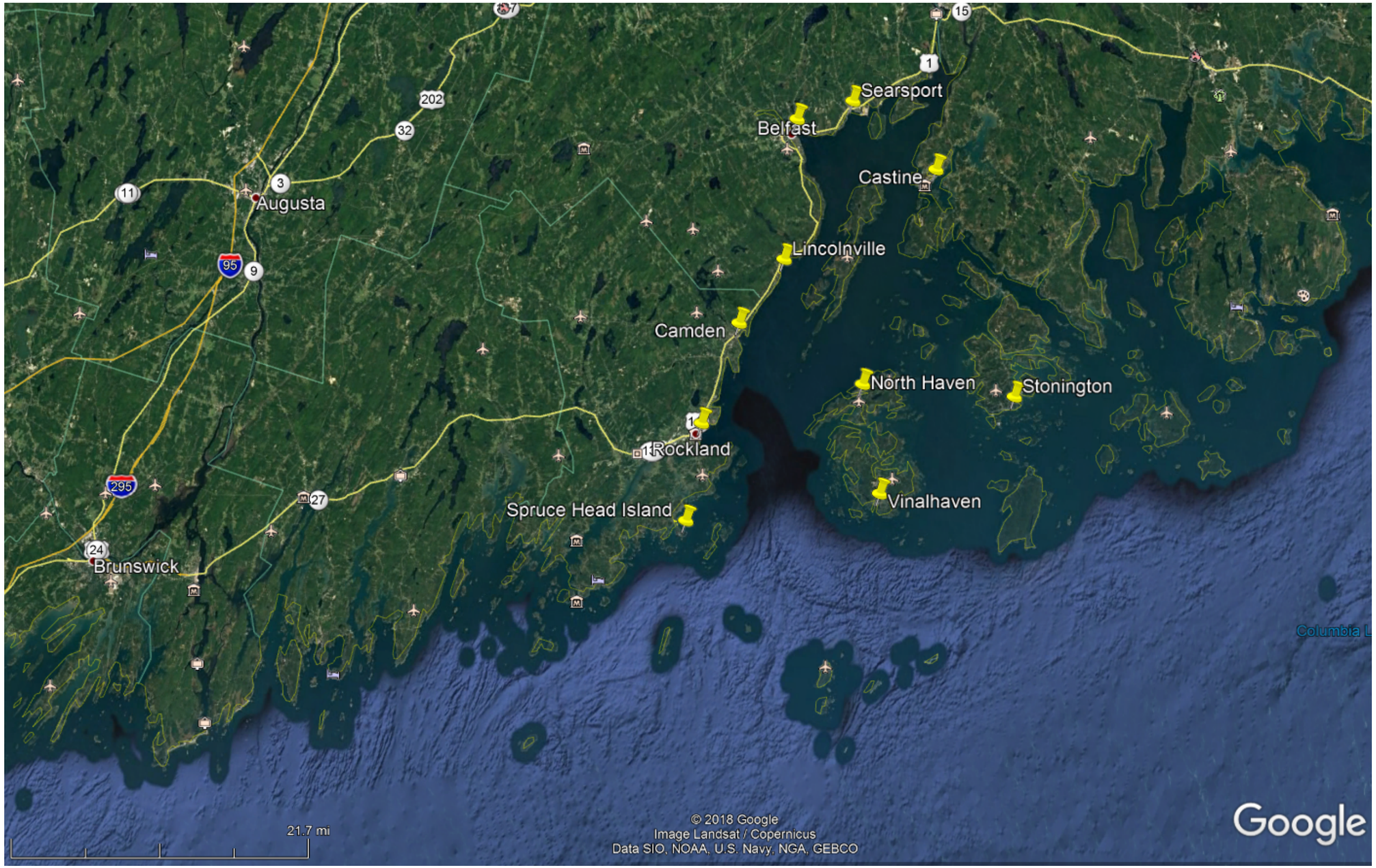
Sincerely,
Wood Environment & Infrastructure Solutions, Inc.

D. Todd Coffin
Associate Project Manager

Peter J. Hall
Global Manager - Climate, Resilience and Sustainability

Attachments: Table 1 - Site Summary
Figure 1 – Project Site Locations
Figures 2A through 2C - Water Level Elevation Summaries
Figure 3 – Budget Summary
Appendix A – Site Location Plans
Appendix B – Flood Maps

FIGURES



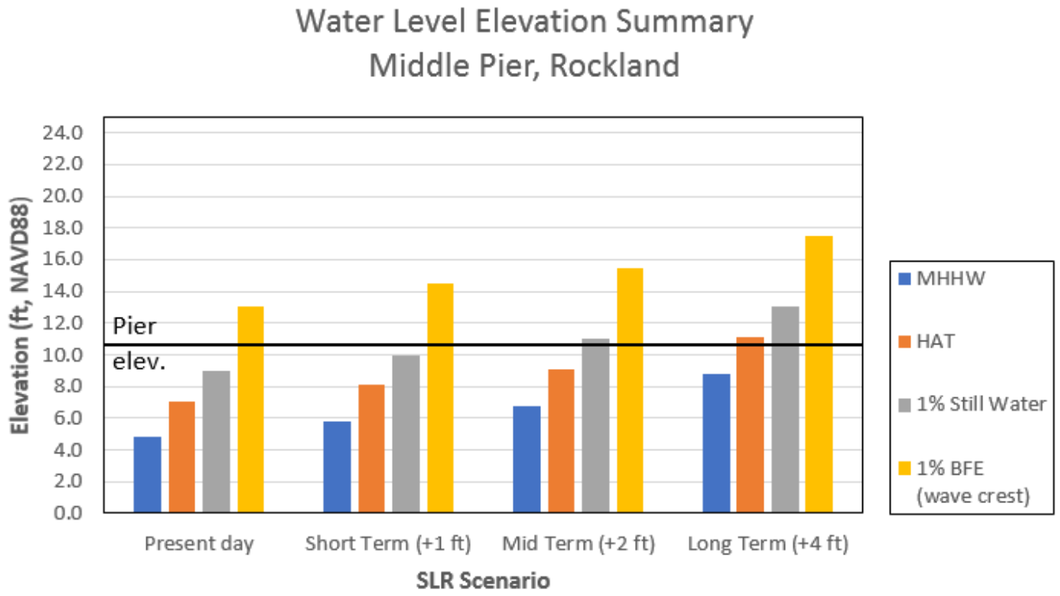
wood.

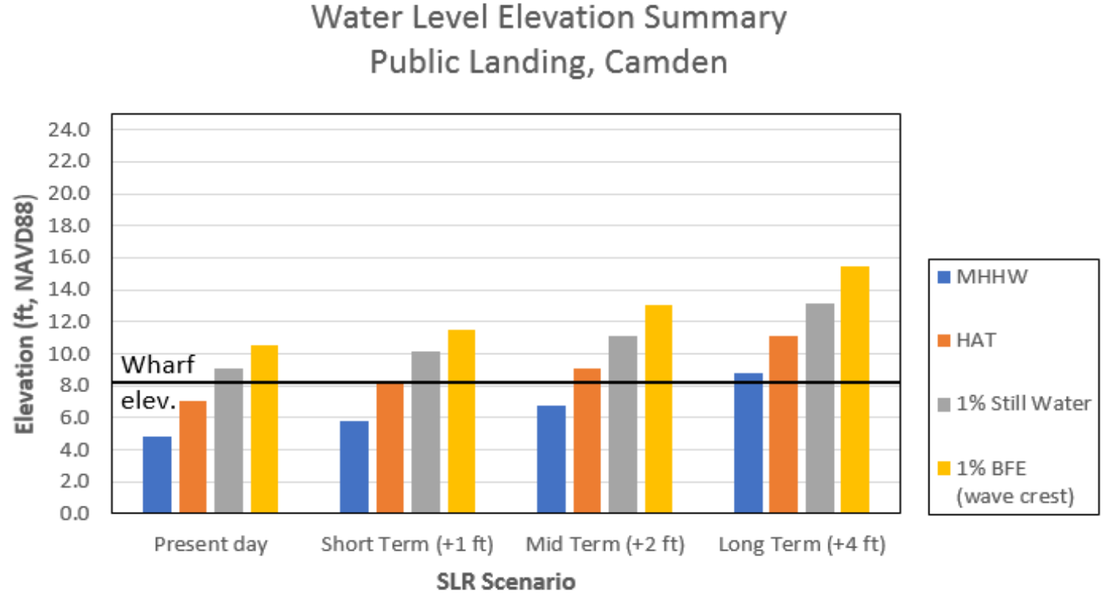
N

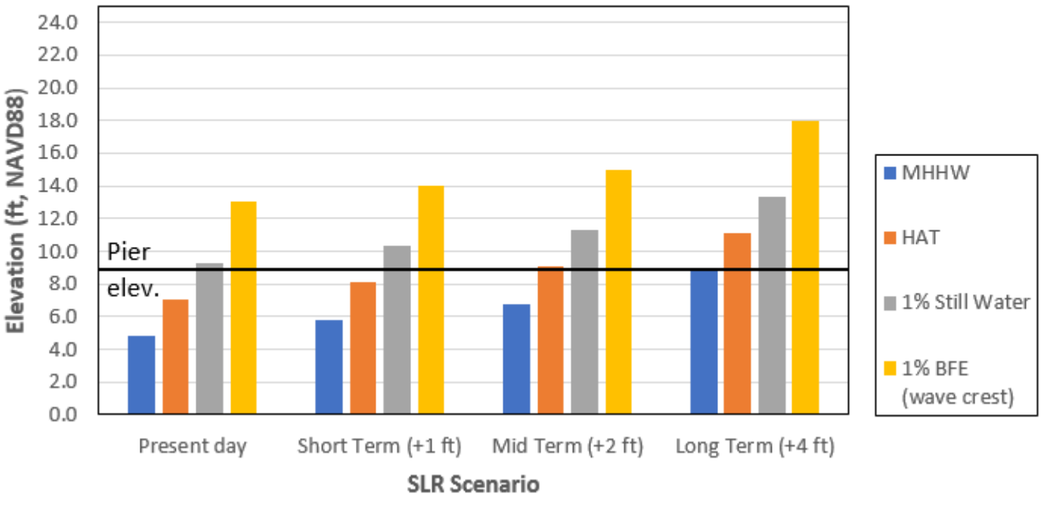
Prepared/Date: DTC 11/19/19	Checked/Date: PH 09/22/19

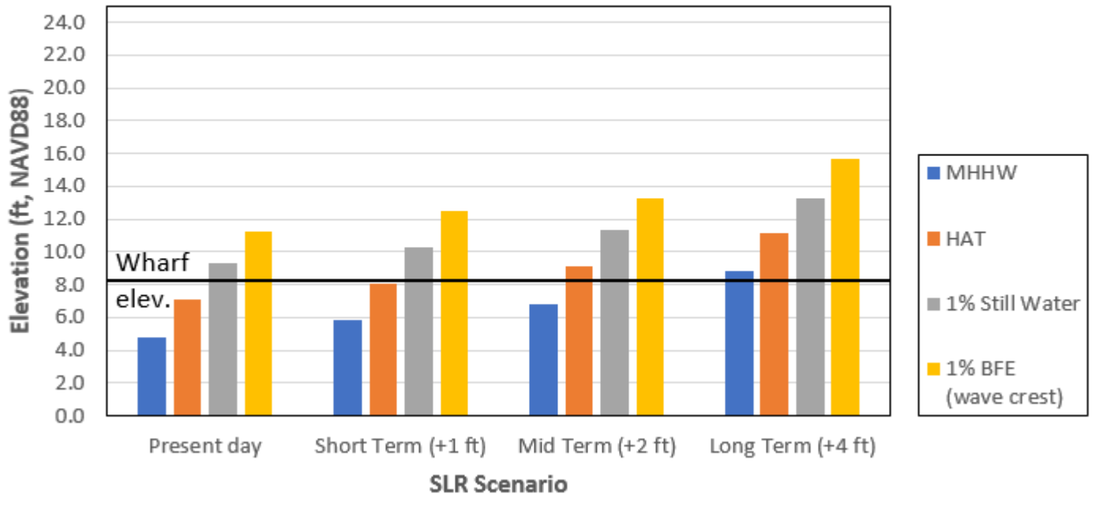
Figure 1
Project Site Locations

Penobscot Bay Working Waterfront Resiliency Analysis
Maine Coastal Program
Maine Department of Marine Resources









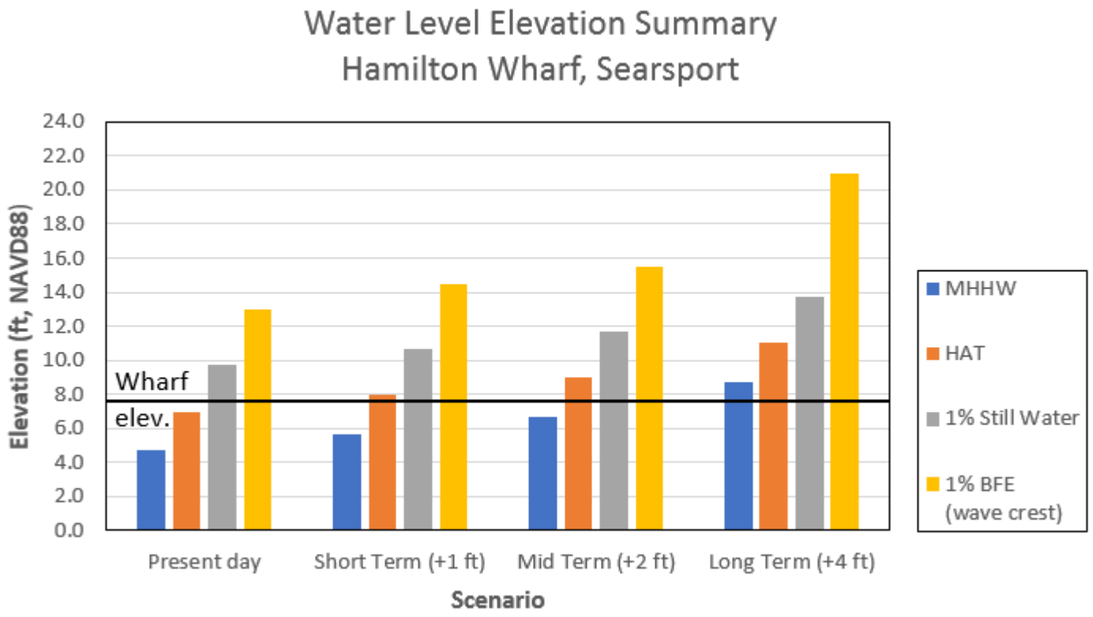
wood.

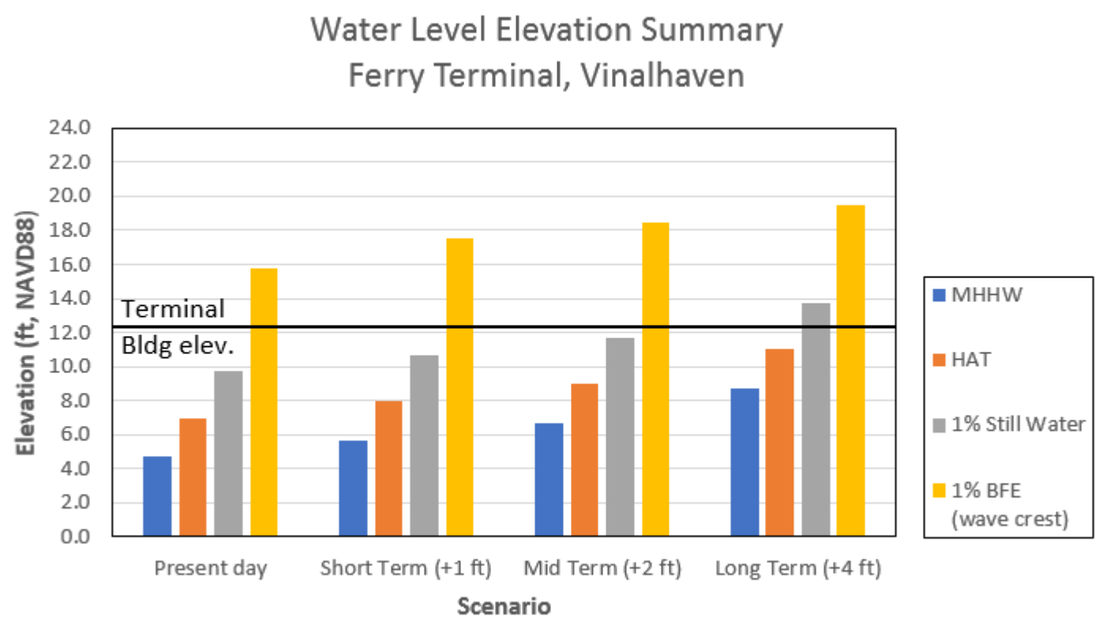
N

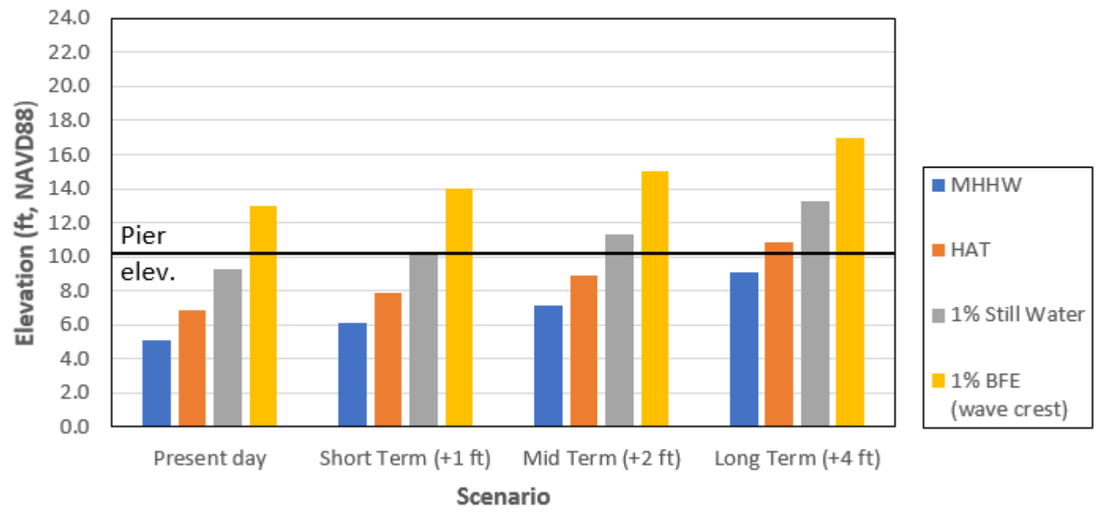
Prepared/Date: DTC 11/19/19 | Checked/Date: PH 09/22/19

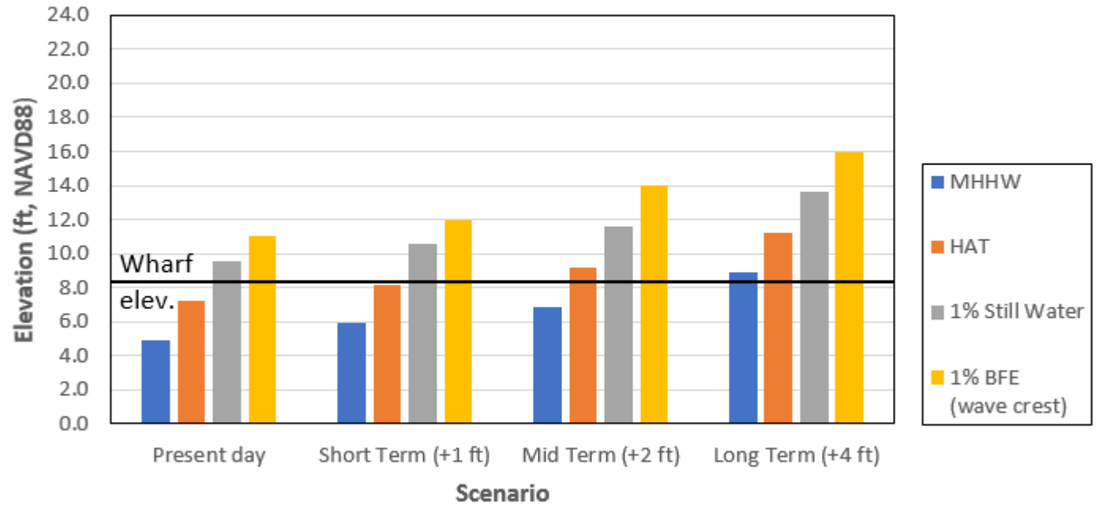
Figure 2A
Water Level Elevation Summaries

Penobscot Bay Working Waterfront Resiliency Analysis
Maine Coastal Program
Maine Department of Marine Resources









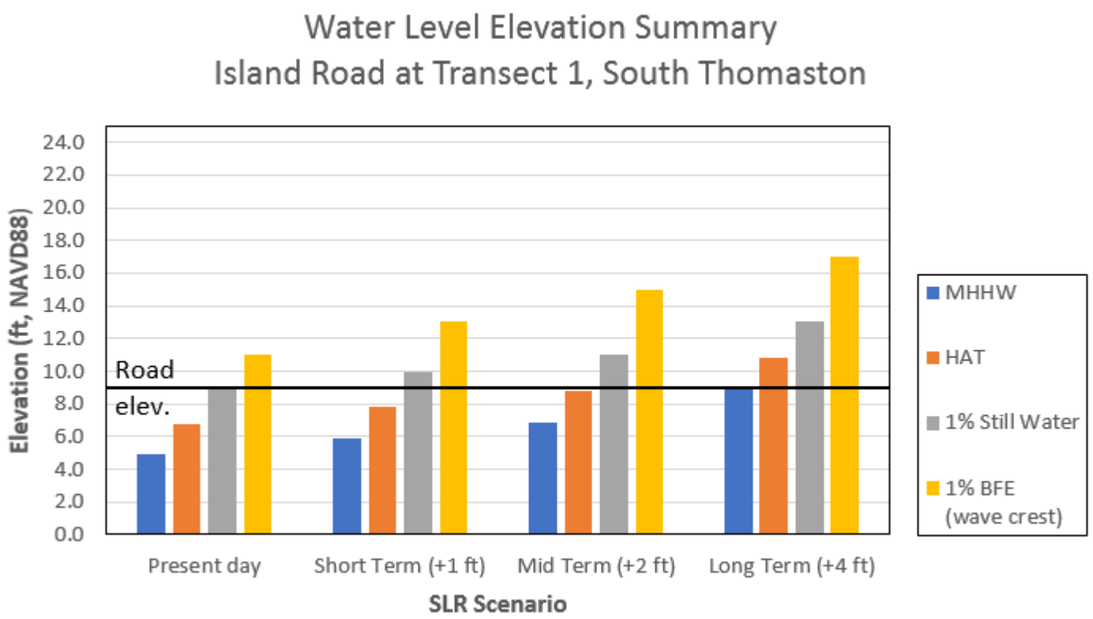
wood.

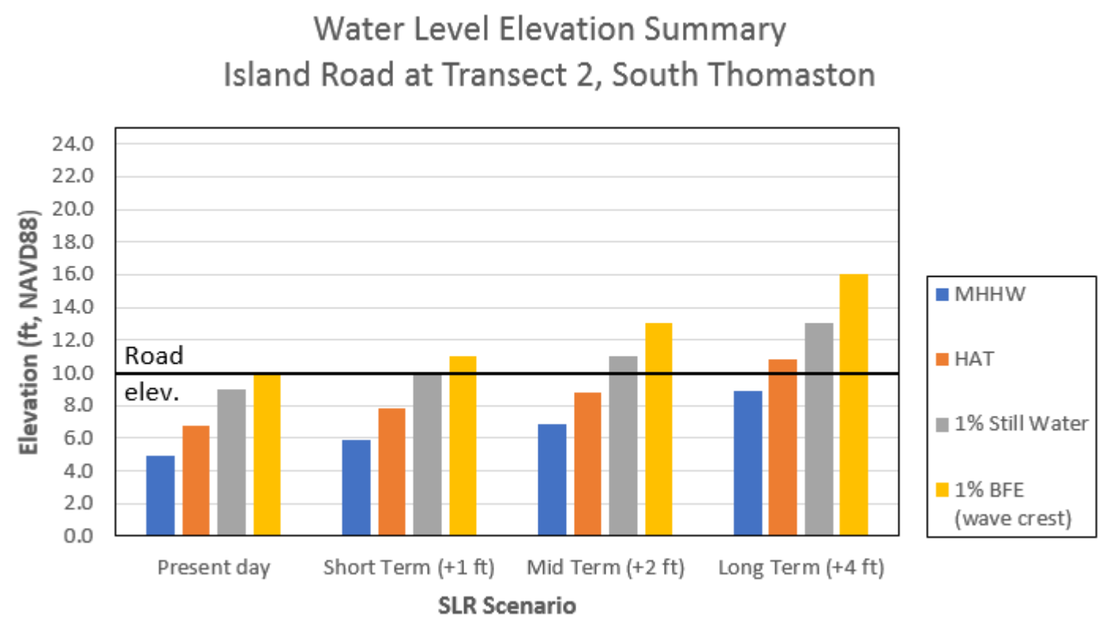
N

Prepared/Date: DTC 11/19/19 | Checked/Date: PH 09/22/19

Figure 2B
Water Level Elevation Summaries

Penobscot Bay Working Waterfront Resiliency Analysis
Maine Coastal Program
Maine Department of Marine Resources





wood.

N

Prepared/Date: DTC 11/19/19	Checked/Date: PH 09/22/19

Figure 2C
Water Level Elevation Summaries

Penobscot Bay Working Waterfront Resiliency Analysis
Maine Coastal Program
Maine Department of Marine Resources

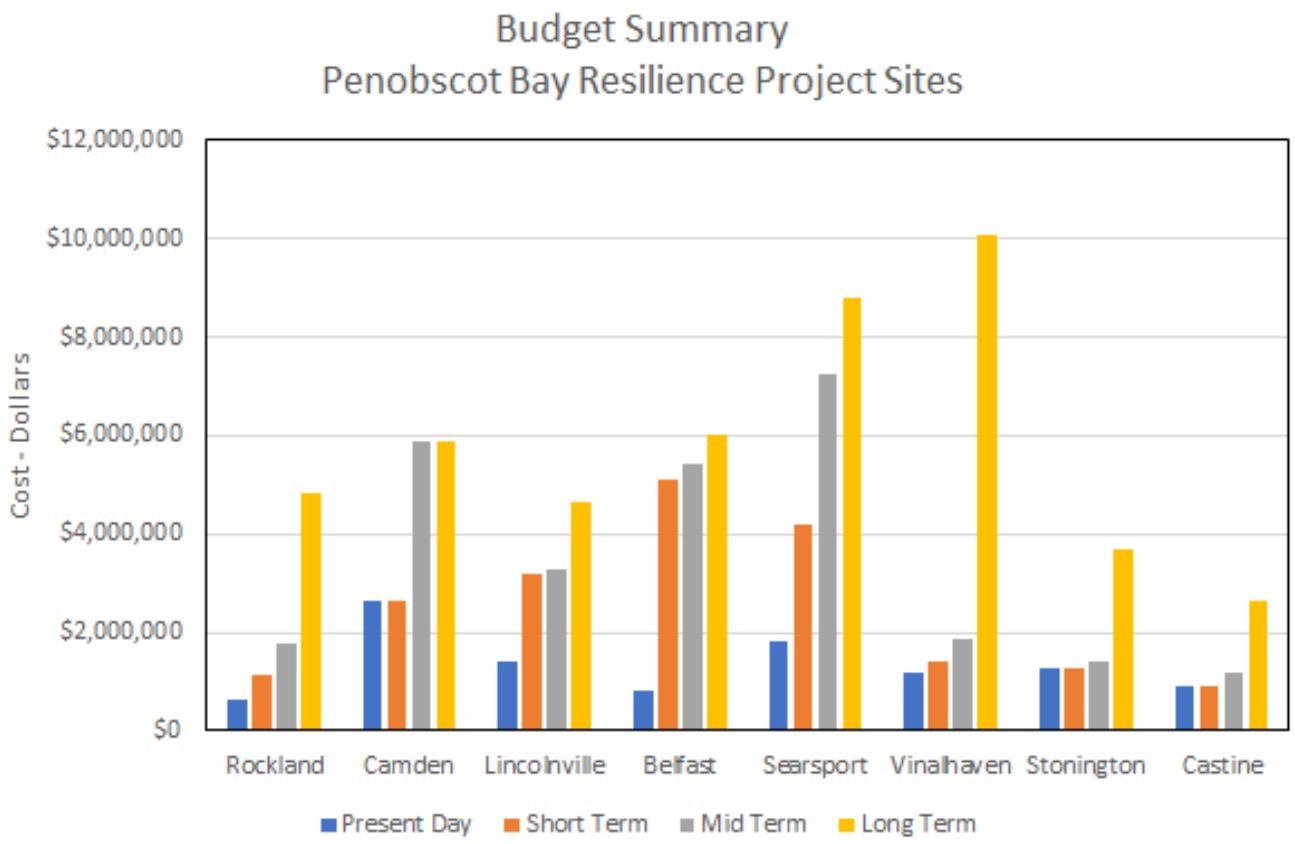


Figure 3
Budget Summary

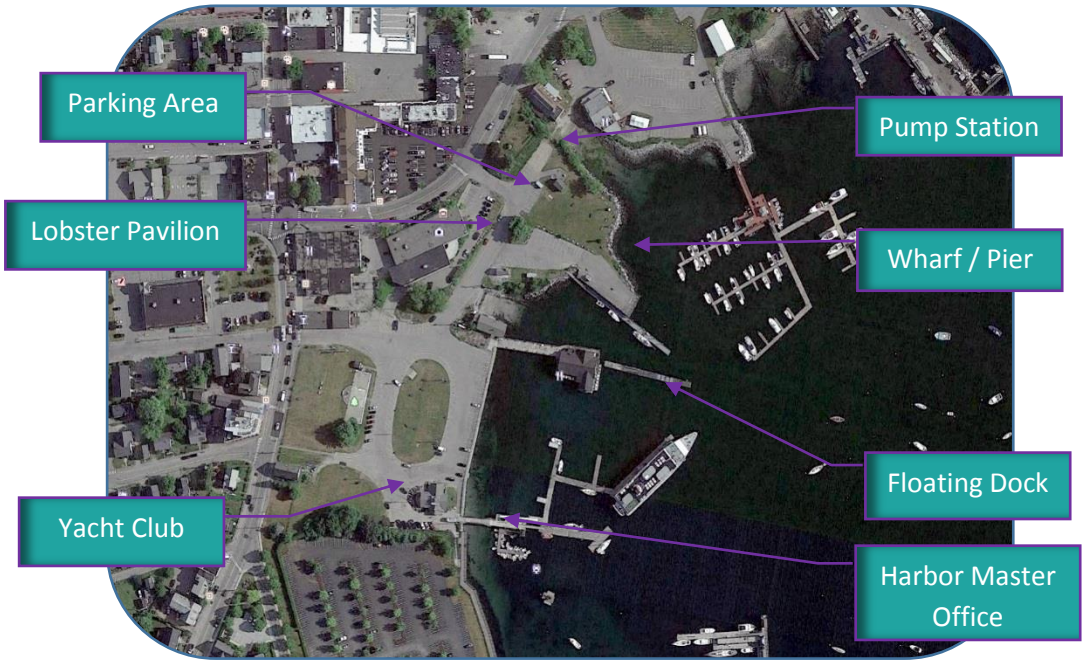
Penobscot Bay Working Waterfront
Resiliency Analysis
Maine Coastal Program
Maine Department of Marine Resources

Prepared/Date: DTC 11/21/19	Checked/Date: PH 11/22/19

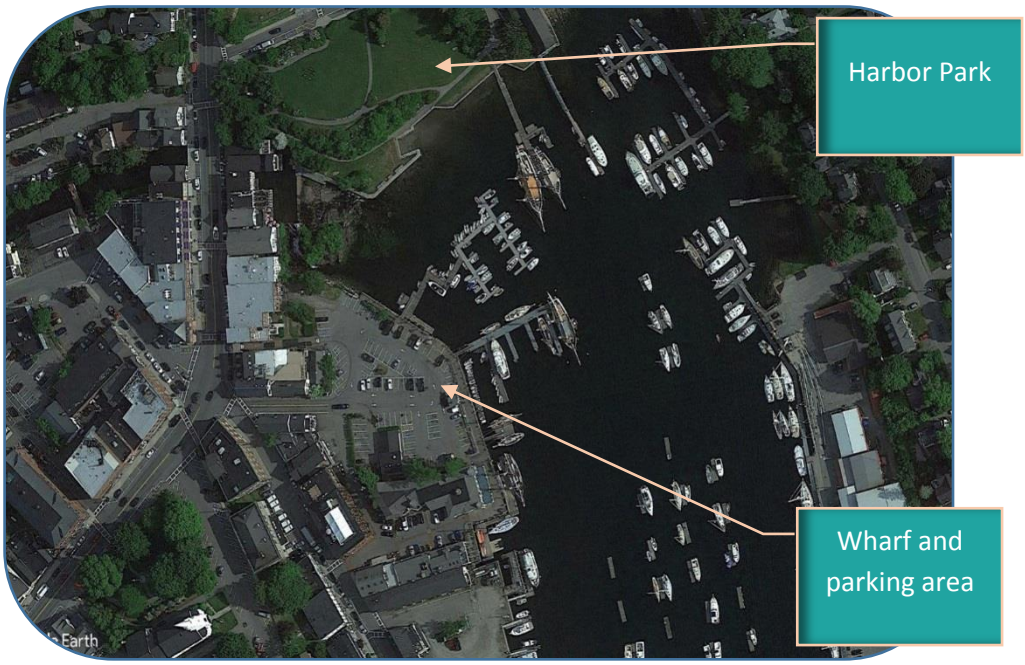
Appendix A

Site Location Plans

Middle Pier, Rockland

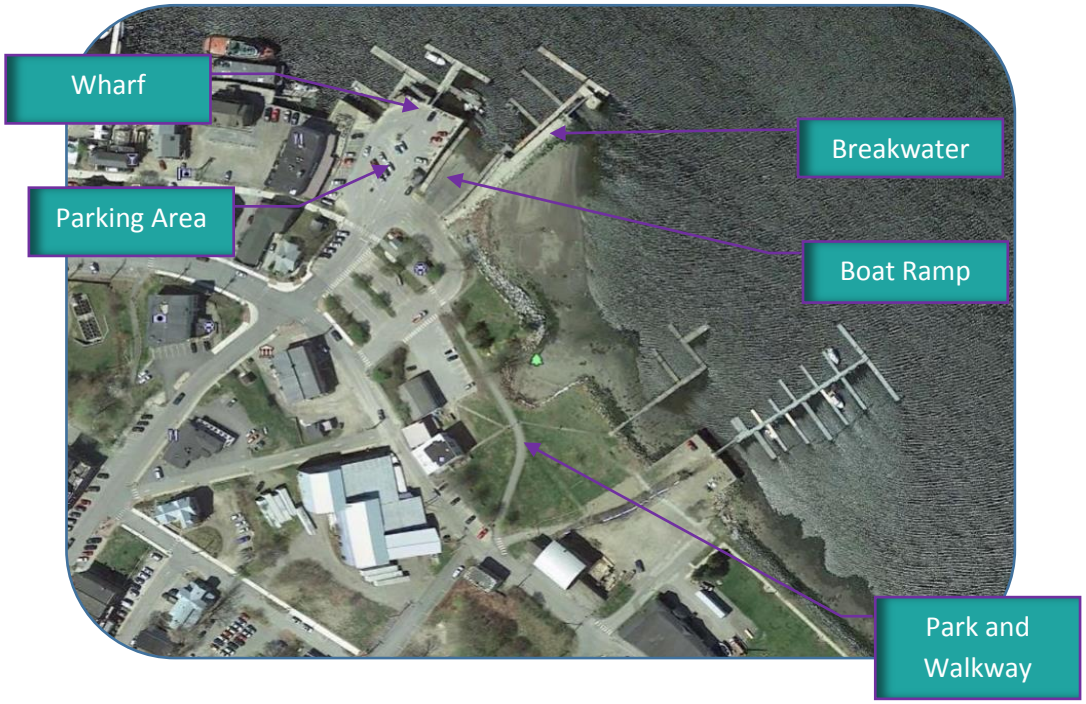


Public Landing, Camden



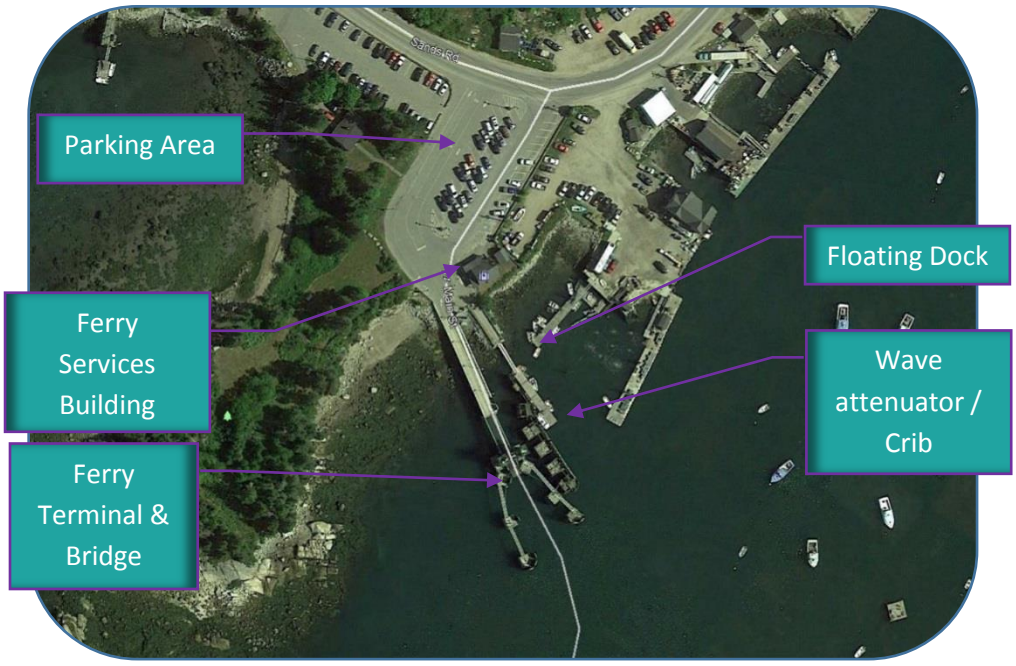
Municipal Fishing Pier, Lincolnville

Public Landing, Belfast

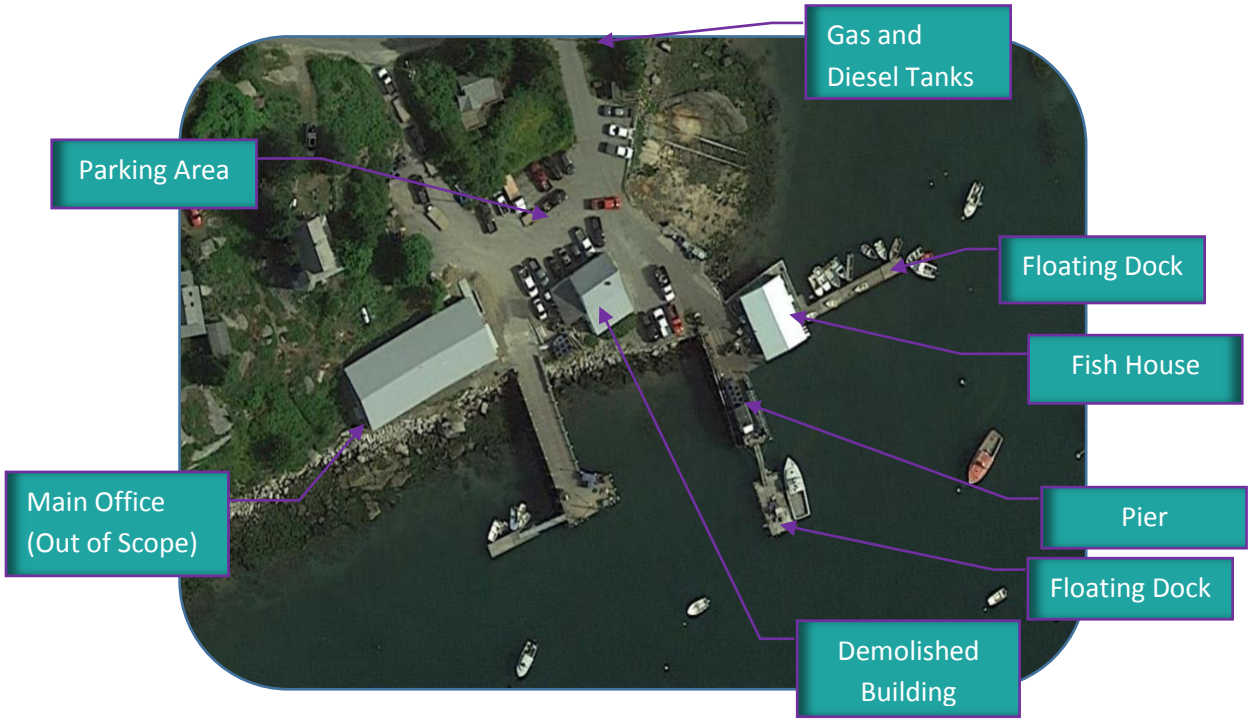


Hamilton Wharf, Searsport

Ferry Terminal, Vinalhaven



Lobster Co-op, Stonington



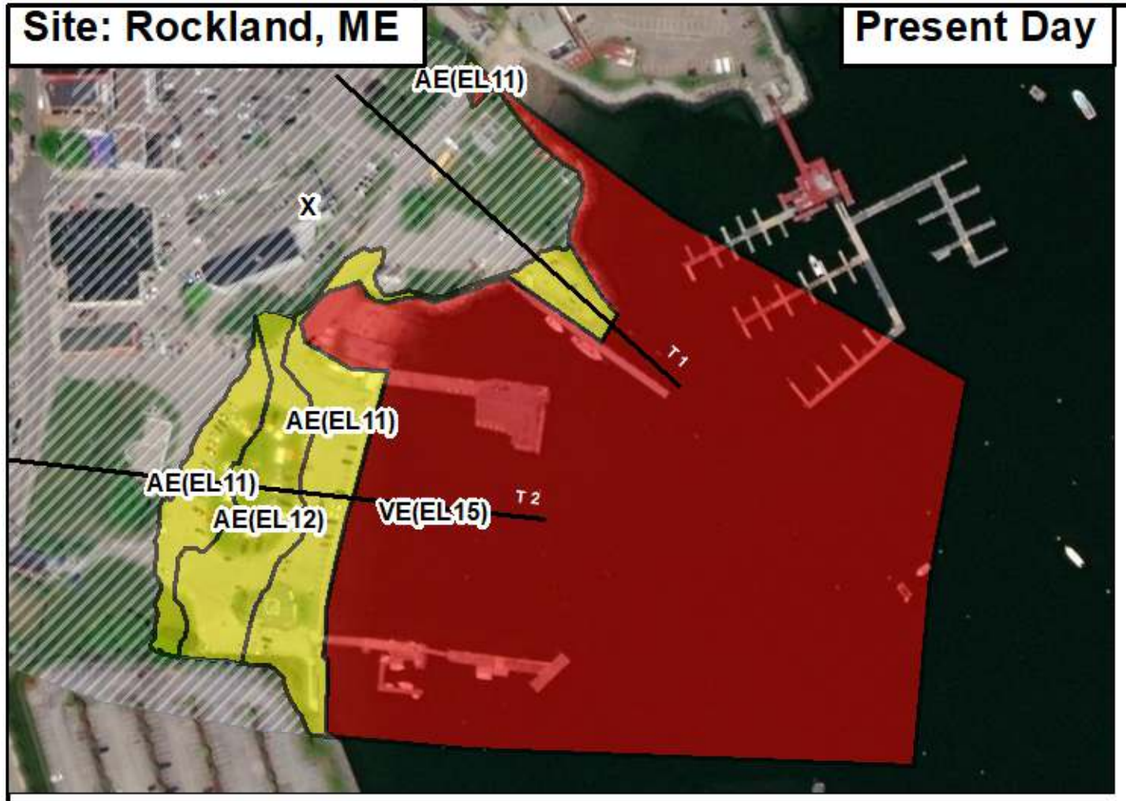
Town Dock, Castine

Appendix B

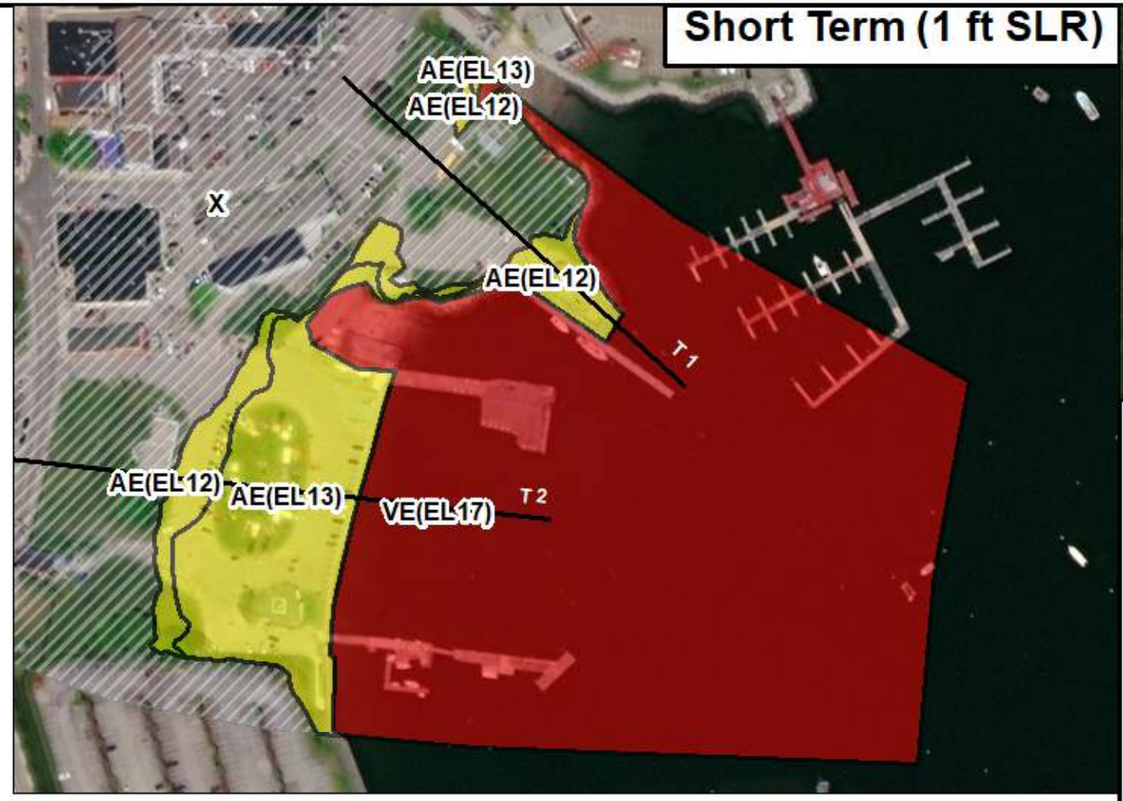
FLOOD MAPS

Site: Rockland, ME

Present Day

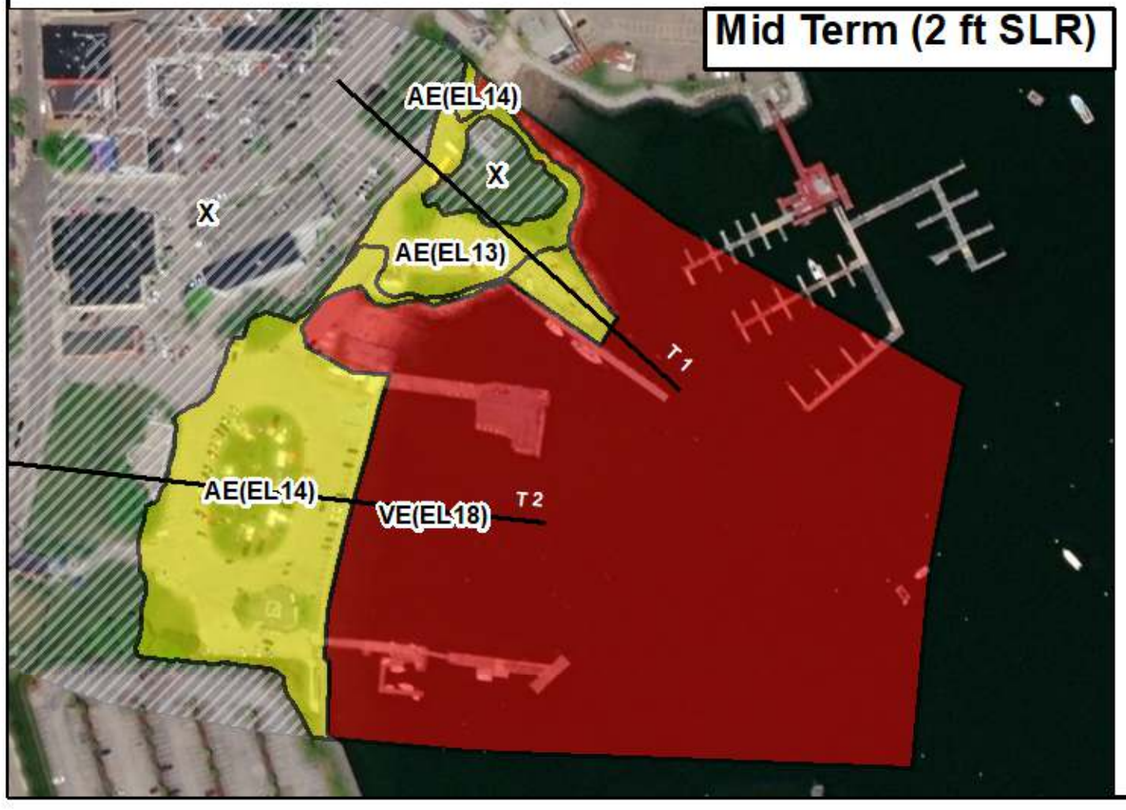


Short Term (1 ft SLR)

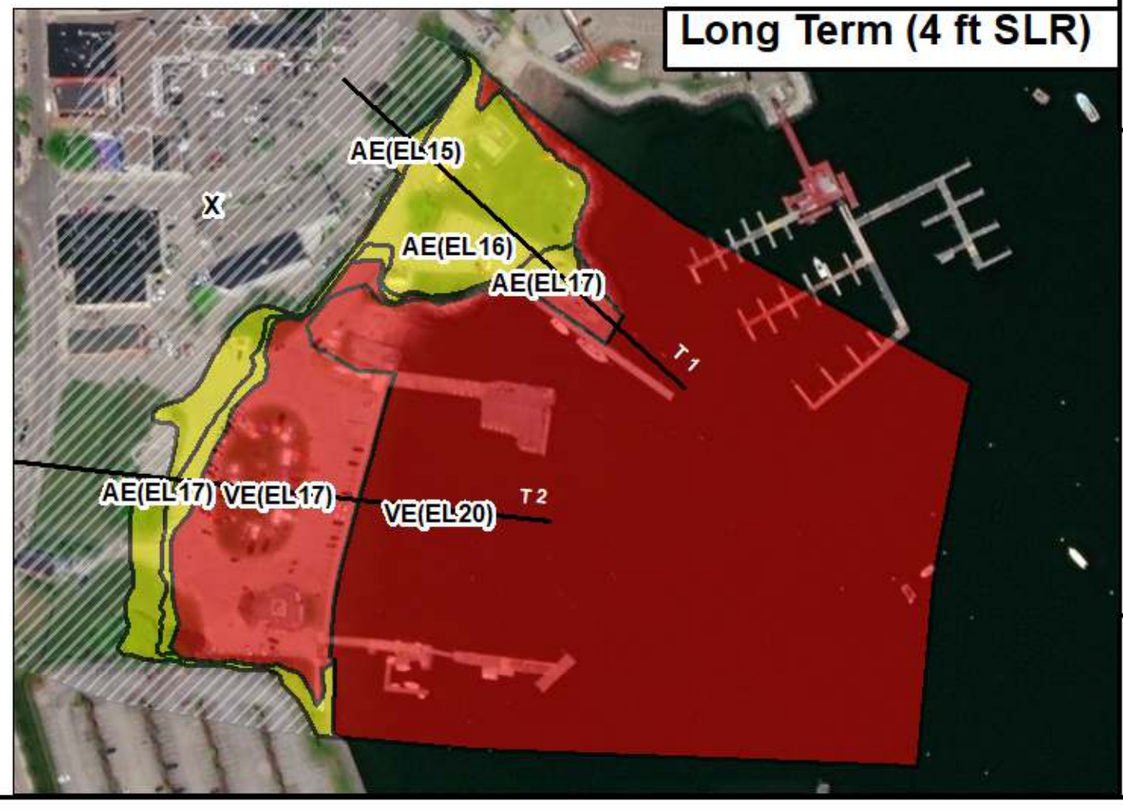


Penobscot Bay

Mid Term (2 ft SLR)



Long Term (4 ft SLR)



1. Maps indicate the 1%-annual-chance flood zones and base flood elevations.

2. This does not constitute a revision to the FEMA FIRM map which is done through FEMA's Letter of Map Revision process for which additional analysis and/or modeling may be required.

3. Flood mapping was developed for planning purposes only. No other use of this map should be made.

4. Elevations in reference to vertical datum NAVD88

Rockland Transects

AE

VE

X

N

Zone AE : Coastal flood zone. Base Flood Elevations determined.

Zone VE : Coastal flood zone with velocity hazard (wave action). Base Flood Elevations determined.

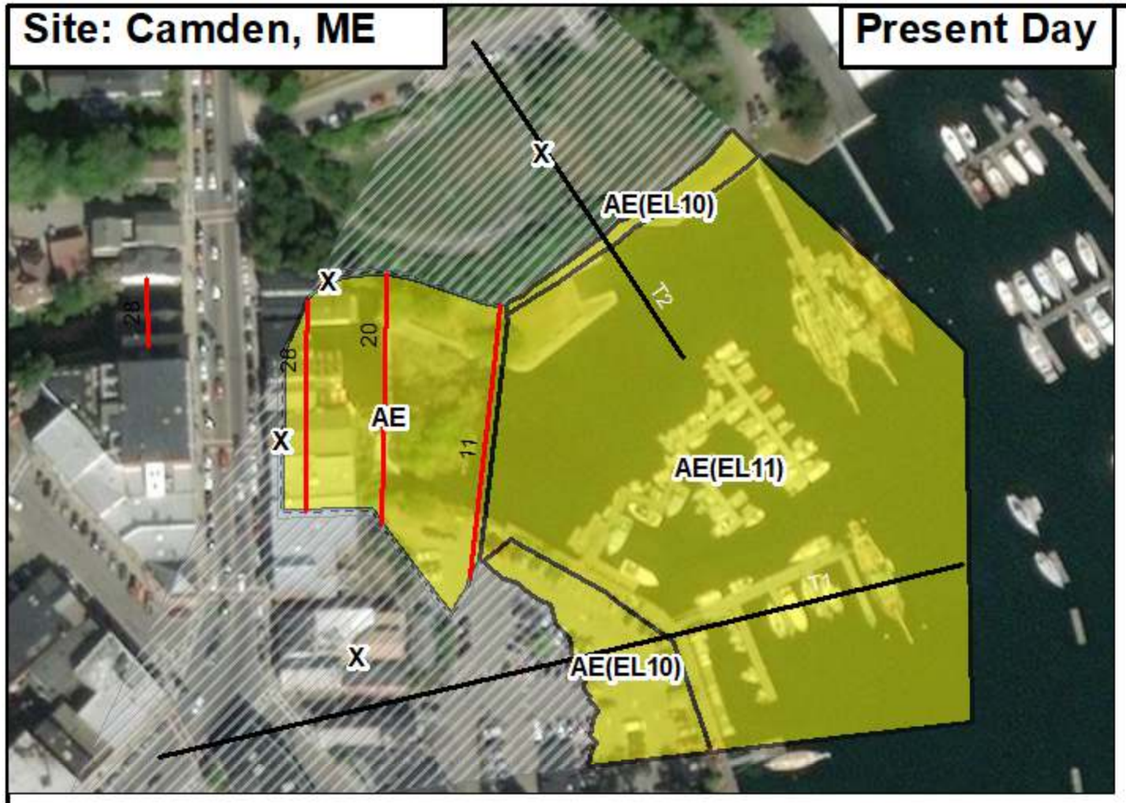
Zone X : Areas determined to be outside the 1% annual chance floodplain.

0 50 100 200 Feet

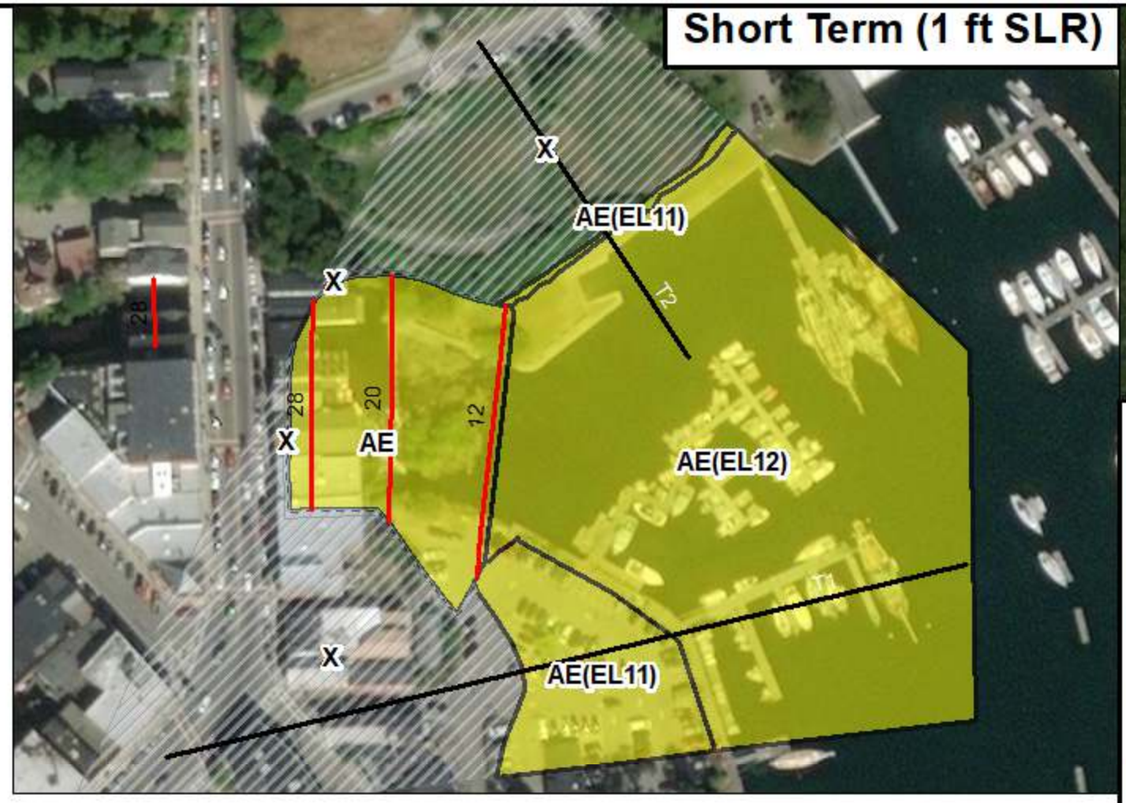
WOODS HOLE GROUP
A CLS COMPANY

Site: Camden, ME

Present Day



Short Term (1 ft SLR)



Penobscot Bay

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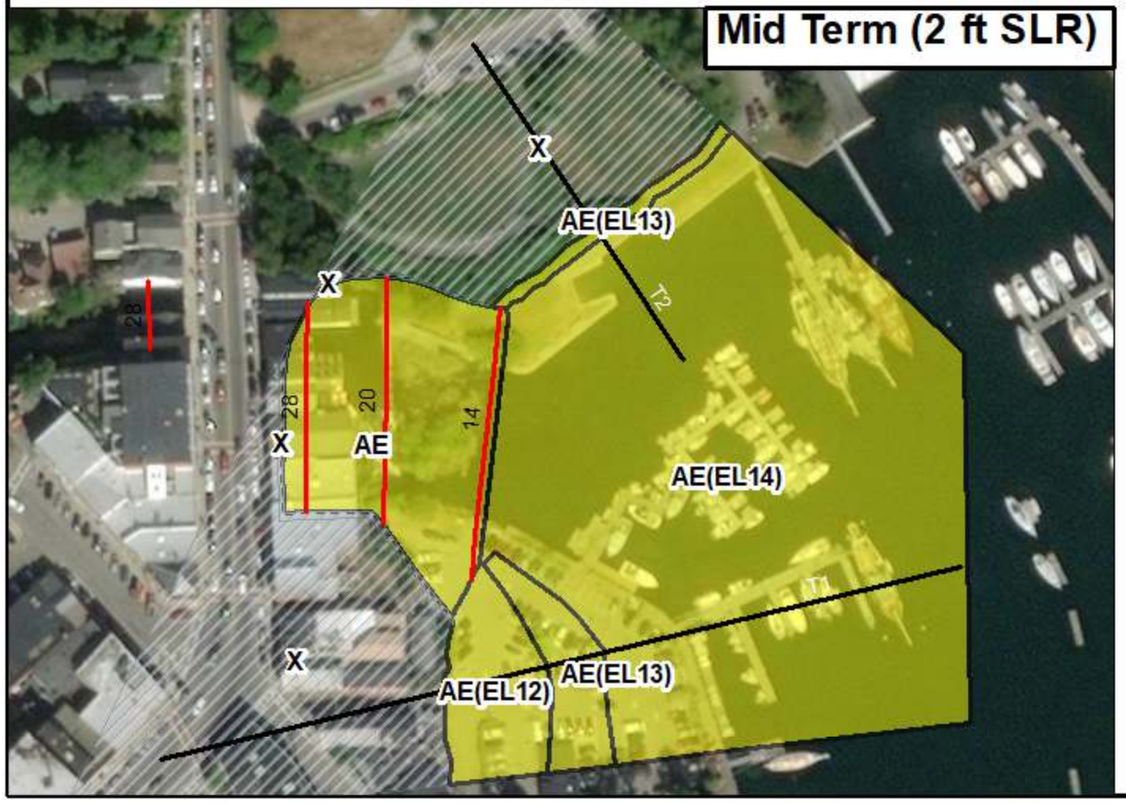
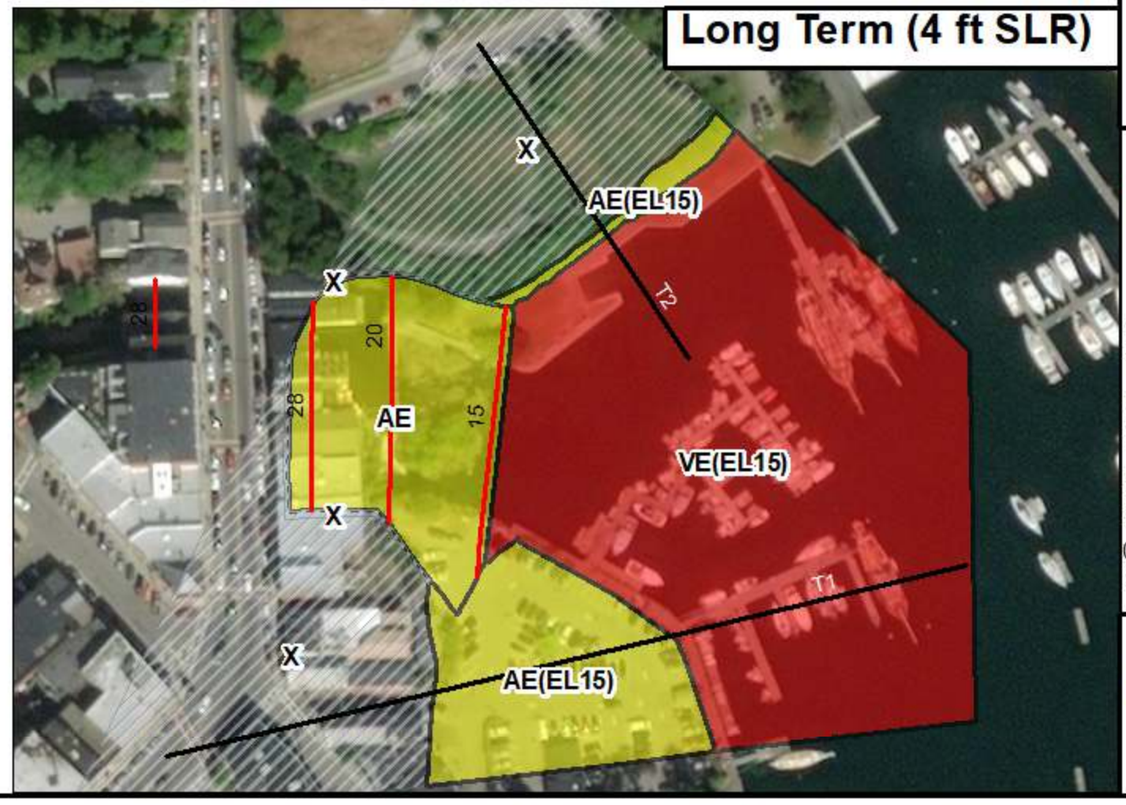
4. Elevations in reference to vertical datum NAVD88

Mid Term (2 ft SLR)



Long Term (4 ft SLR)



Camden Transects
BFE
AE
VE
X

N

Zone AE : Coastal flood zone. Base Flood Elevations determined.

Zone VE : Coastal flood zone with velocity hazard (wave action). Base Flood Elevations determined.

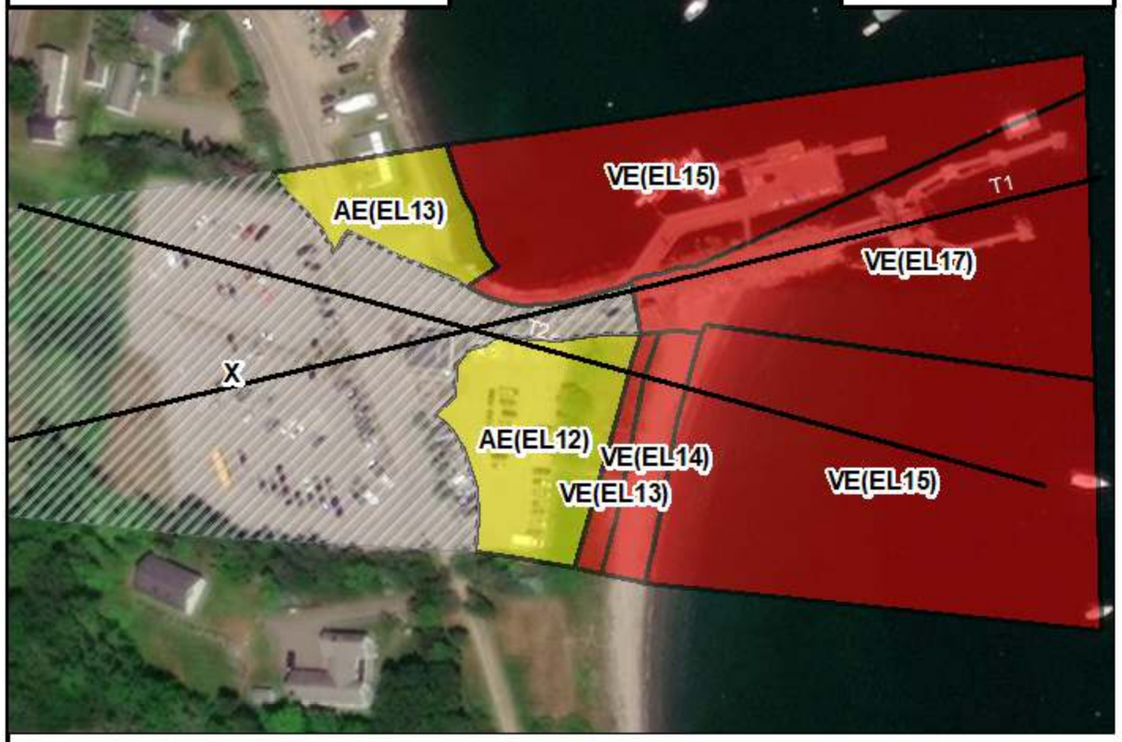
Zone X : Areas determined to be outside the 1% annual chance floodplain.

0 75 150 Feet

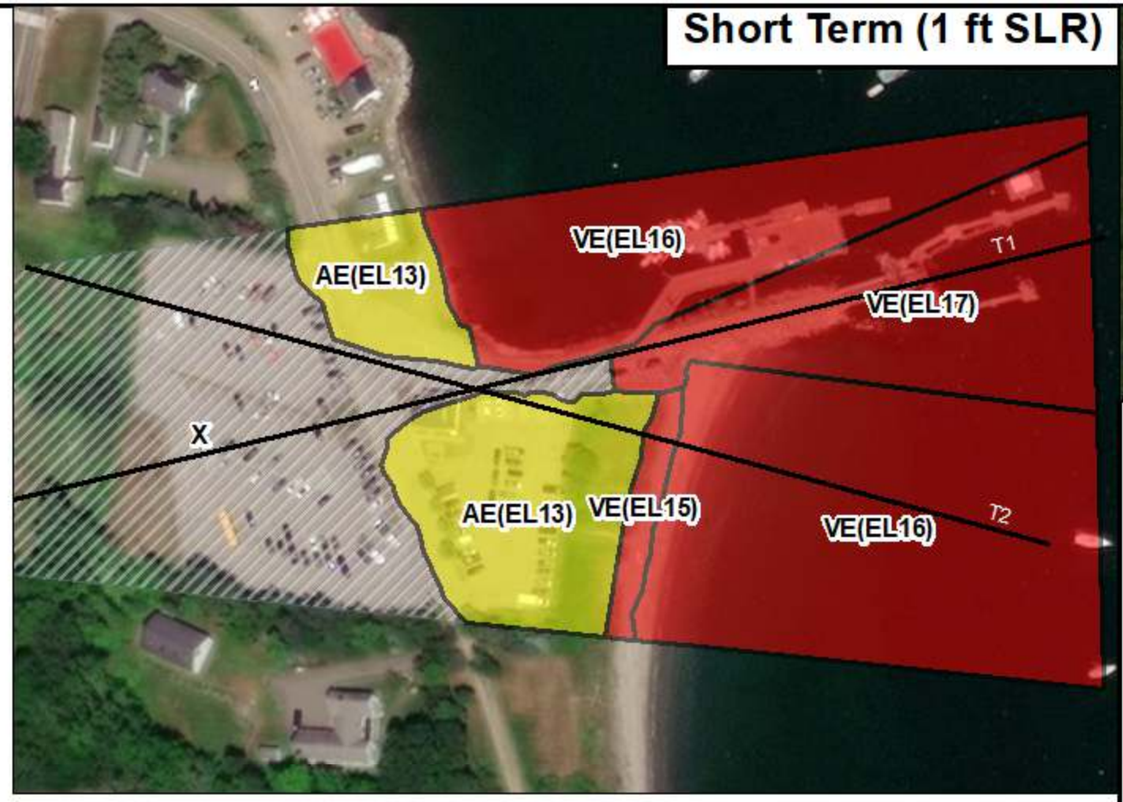
WOODS HOLE GROUP
A CLS COMPANY

Site: Lincolnville, ME

Present Day



Short Term (1 ft SLR)



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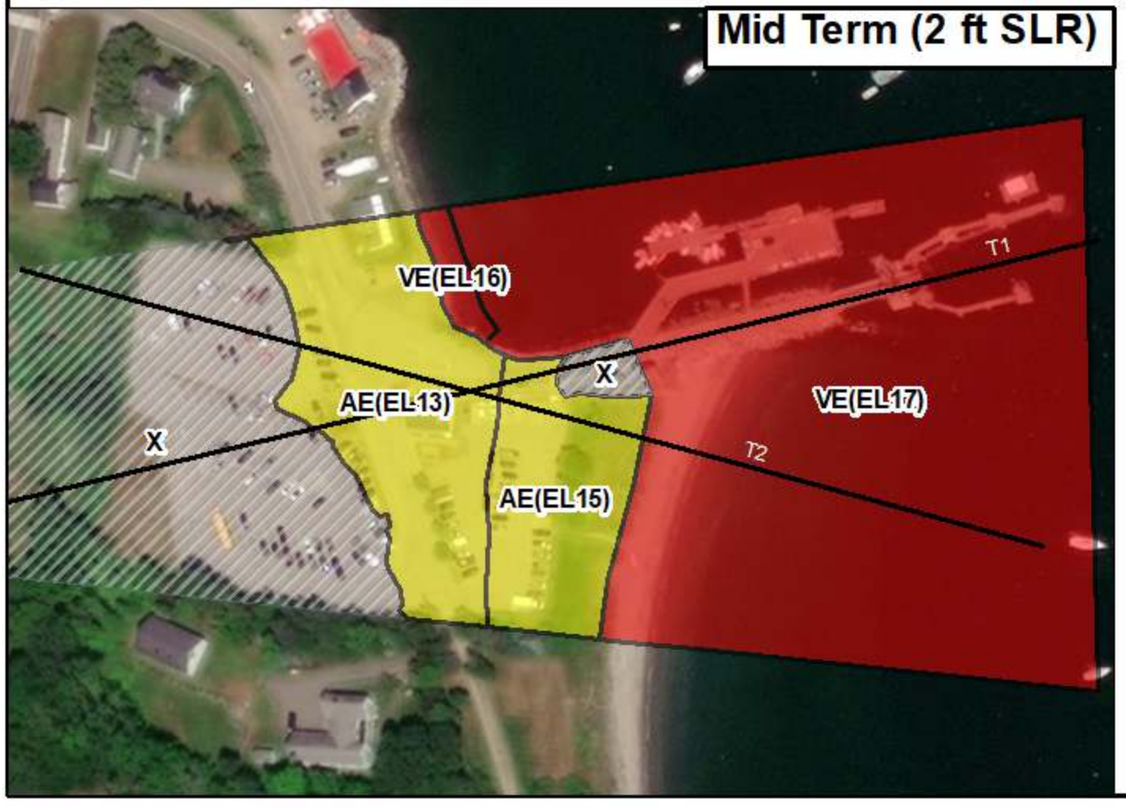
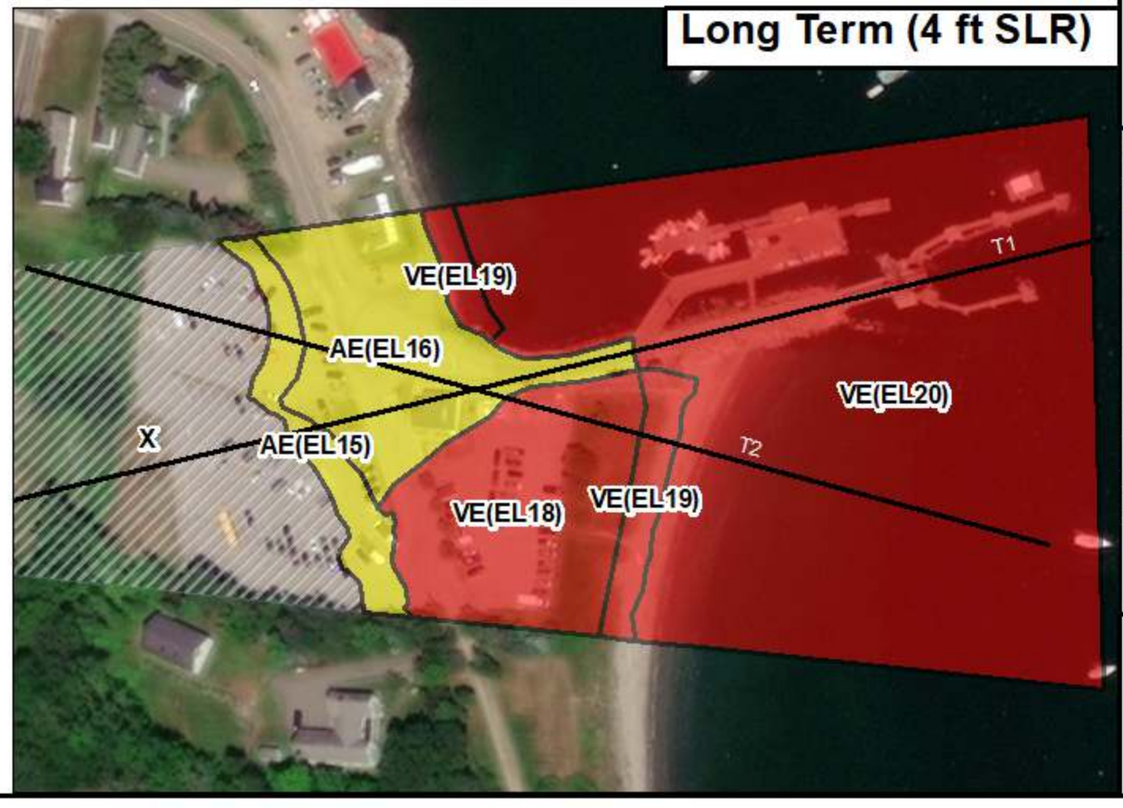
4. Elevations in reference to vertical datum NAVD88

Mid Term (2 ft SLR)



Long Term (4 ft SLR)



Legend

- Lincolnville Transects
- AE
- VE
- X

N

Zone AE : Coastal flood zone. Base Flood Elevations determined.

Zone VE : Coastal flood zone with velocity hazard (wave action). Base Flood Elevations determined.

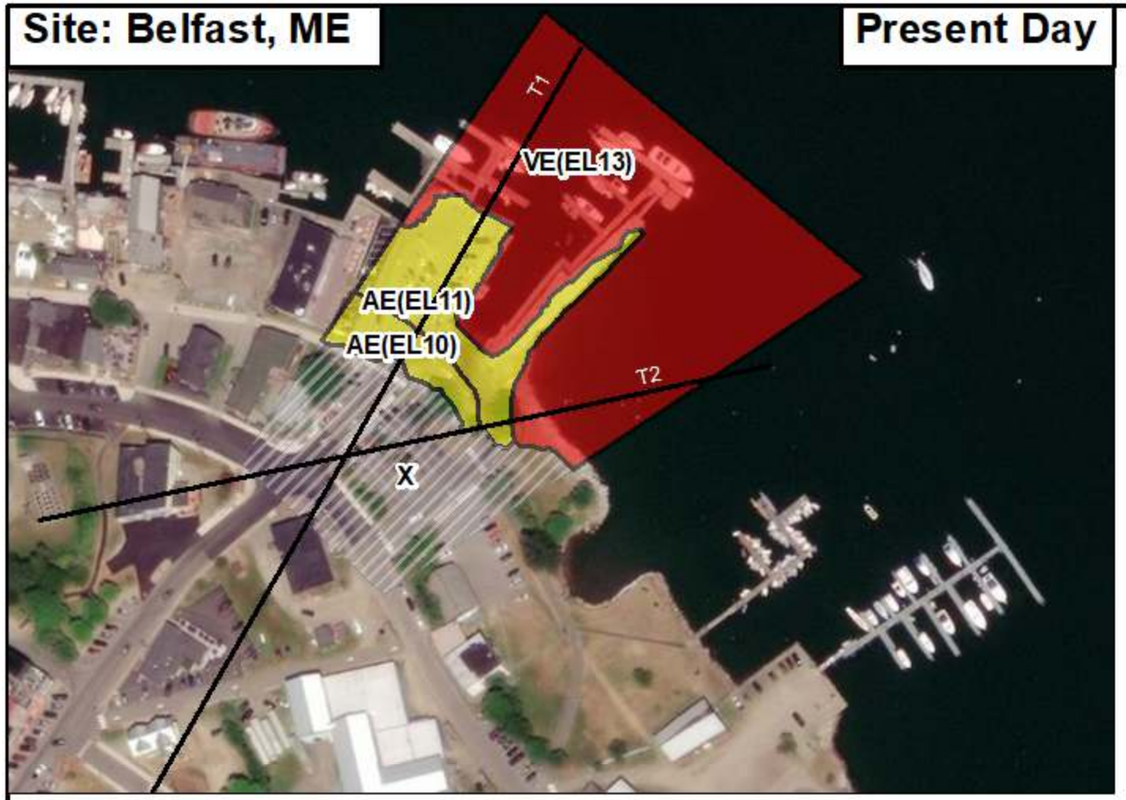
Zone X : Areas determined to be outside the 1% annual chance floodplain.

0 37.5 75 150 Feet

WOODS HOLE GROUP
A CLS COMPANY

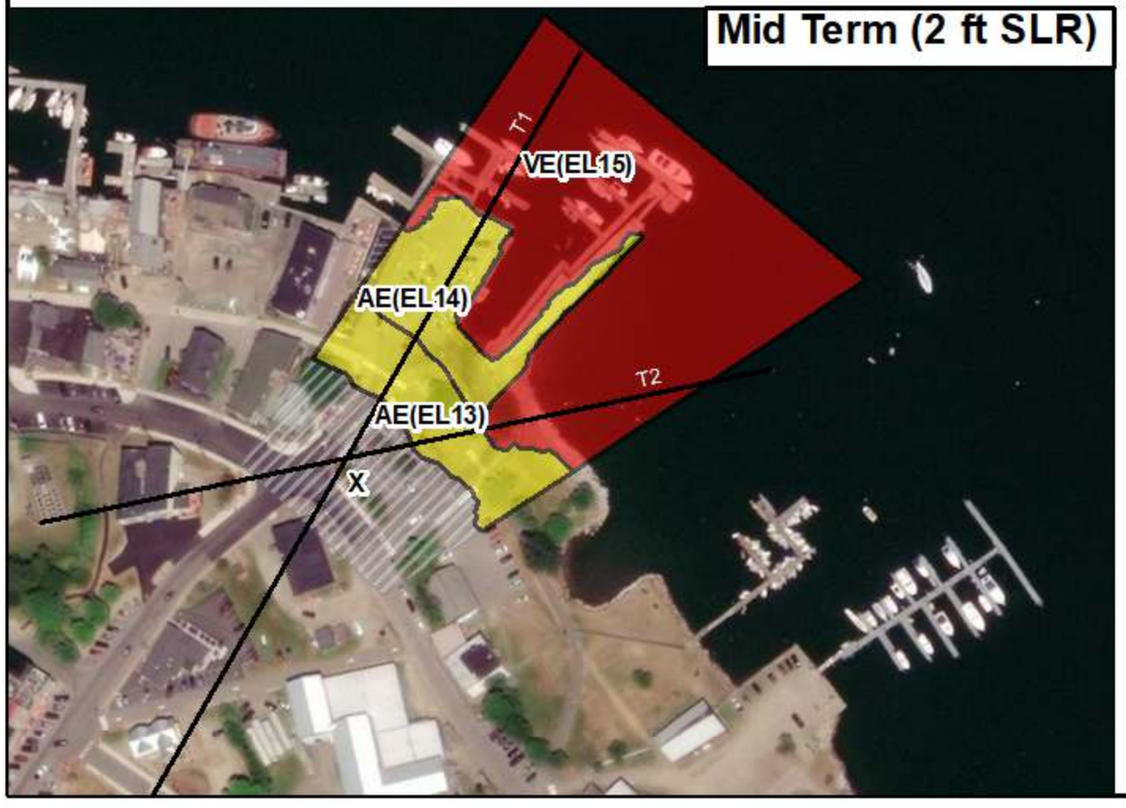
Site: Belfast, ME

Present Day

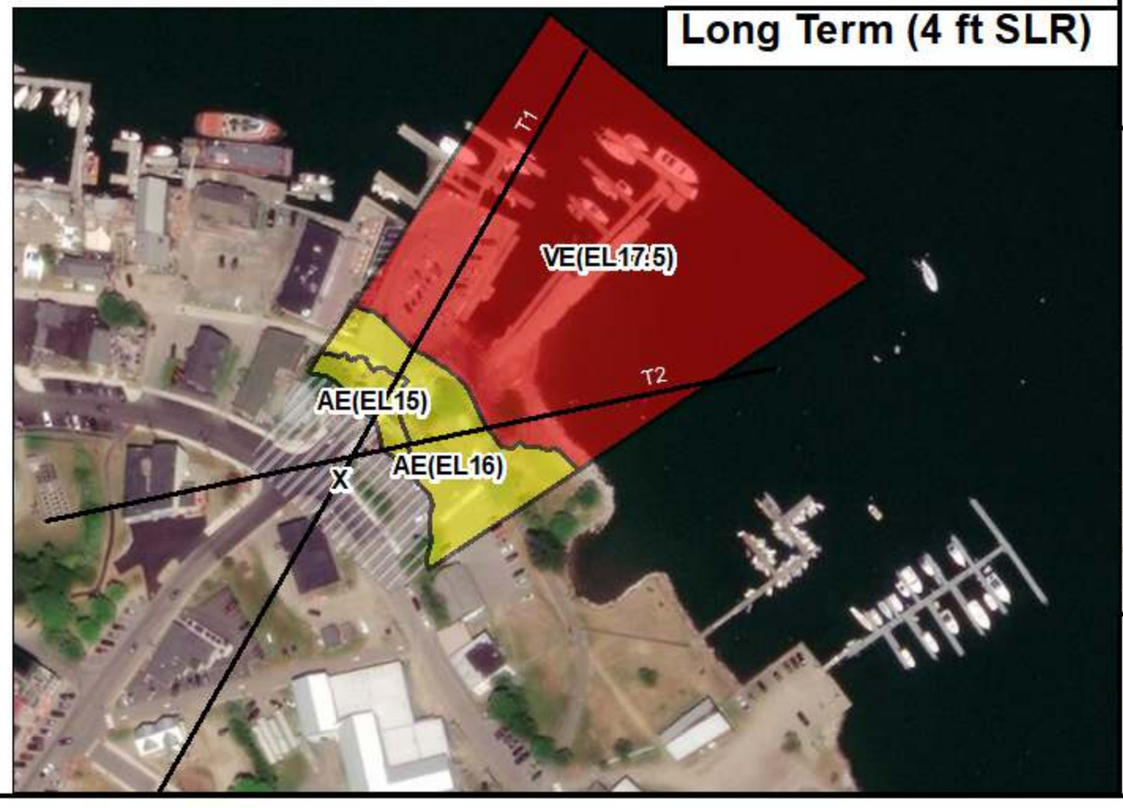


Short Term (1 ft SLR)

Mid Term (2 ft SLR)



Long Term (4 ft SLR)



Penobscot Bay

1. Maps indicate the 1%-annual-chance flood zones and base flood elevations.

2. This does not constitute a revision to the FEMA FIRM map which is done through FEMA's Letter of Map Revision process for which additional analysis and/or modeling may be required.

3. Flood mapping was developed for planning purposes only. No other use of this map should be made.

4. Elevations in reference to vertical datum NAVD88

Belfast Transects

AE

VE

X

N

Zone AE : Coastal flood zone. Base Flood Elevations determined.

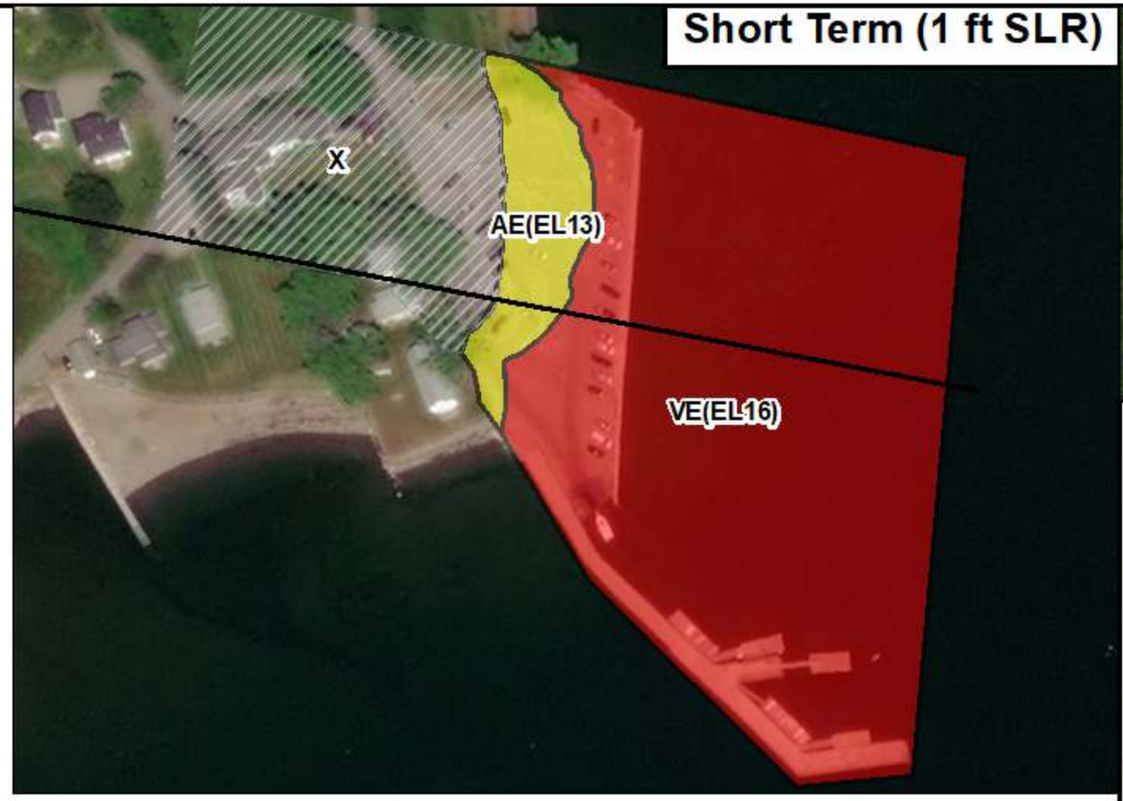
Zone VE : Coastal flood zone with velocity hazard (wave action). Base Flood Elevations determined.

Zone X : Areas determined to be outside the 1% annual chance floodplain.

0 100 200 Feet

WOODS HOLE GROUP
A GLS COMPANY

Site: Searsport, ME



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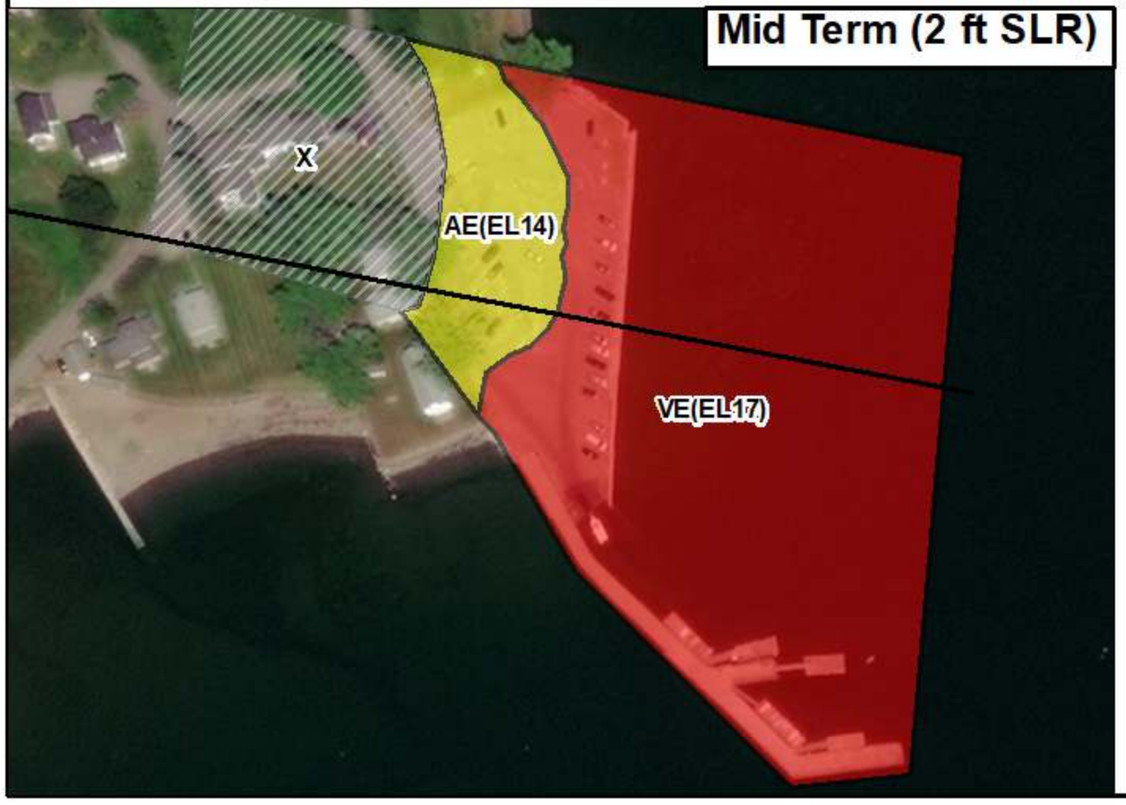
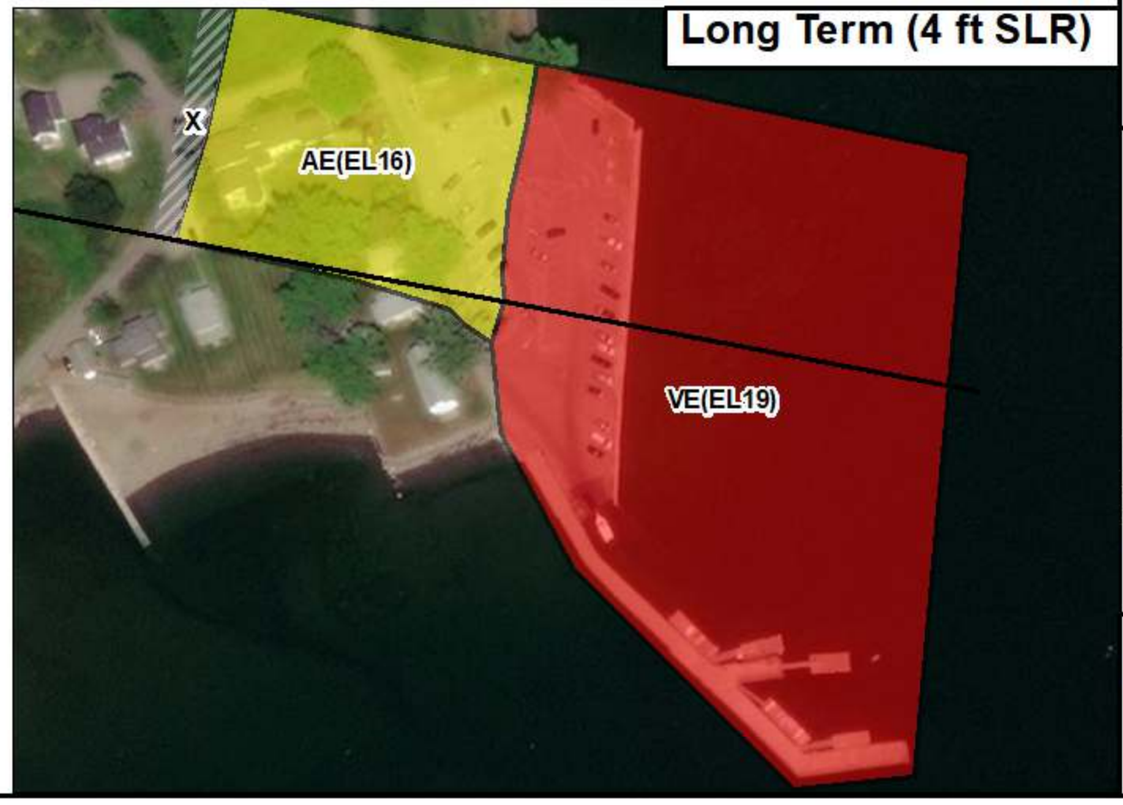




Searsport Transect

AE

VE

X

N

Zone AE : Coastal flood zone. Base Flood Elevations determined.

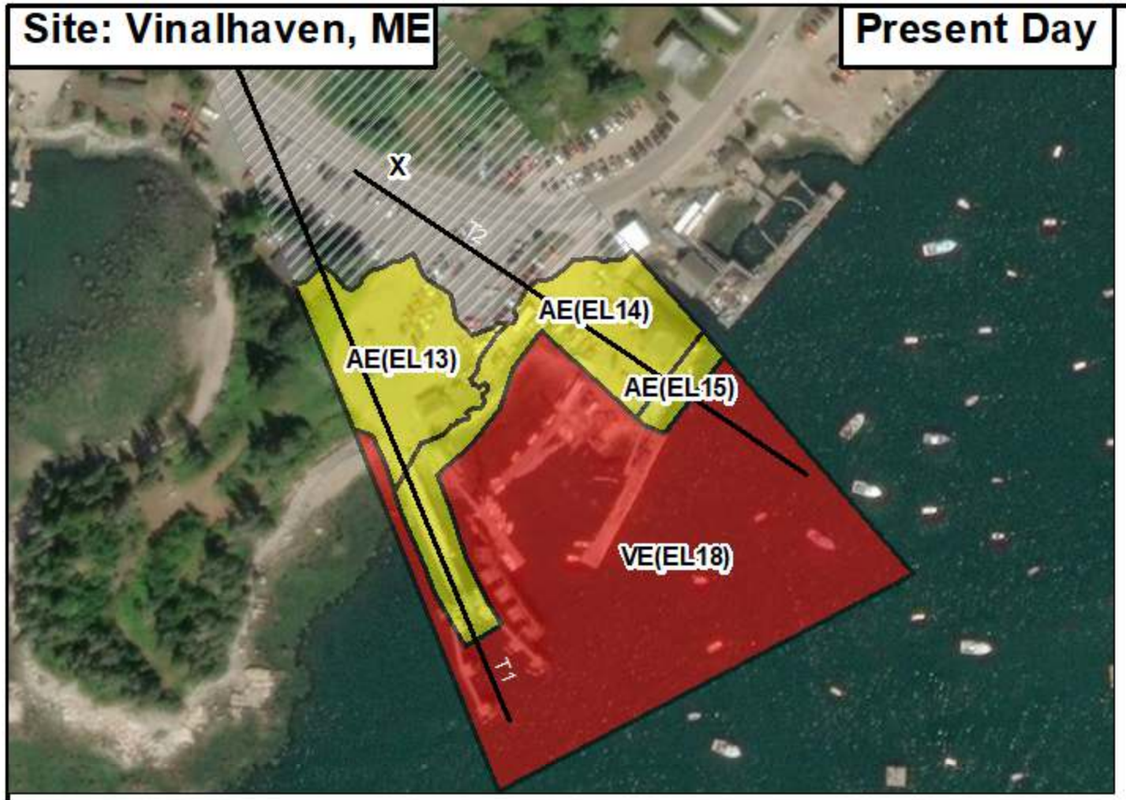
Zone VE : Coastal flood zone with velocity hazard (wave action). Base Flood Elevations determined.

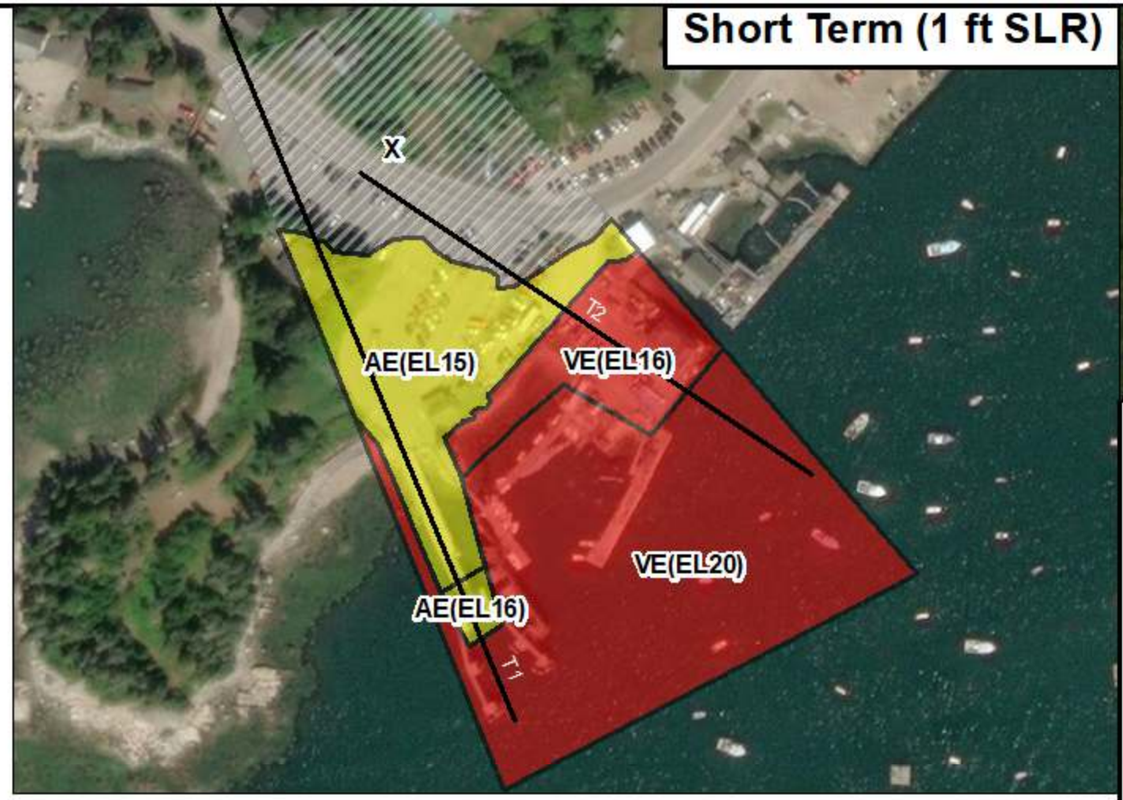
Zone X : Areas determined to be outside the 1% annual chance floodplain.

0 37.5 75 150 Feet

WOODS HOLE GROUP
A CLS COMPANY

Site: Vinalhaven, ME





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4. Elevations in reference to vertical datum NAVD88

Legend

Vinalhaven Transects

AE

VE

X

N

Zone AE : Coastal flood zone. Base Flood Elevations determined.

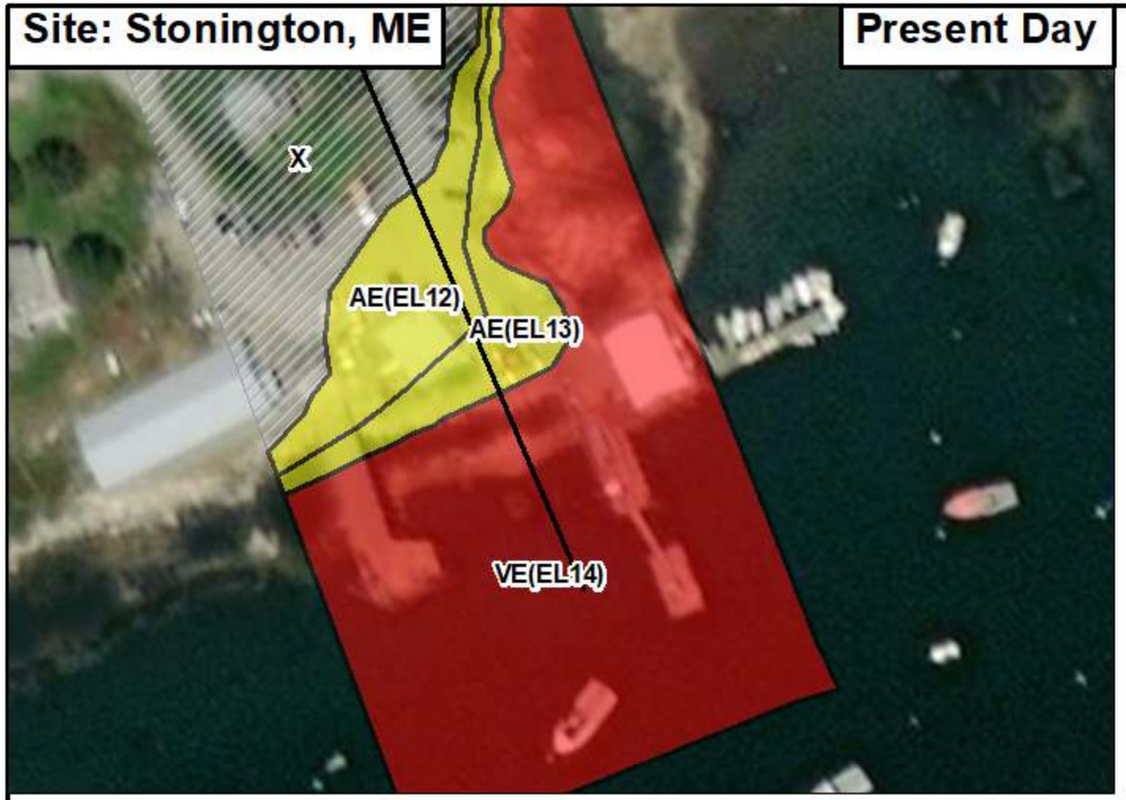
Zone VE : Coastal flood zone with velocity hazard (wave action). Base Flood Elevations determined.

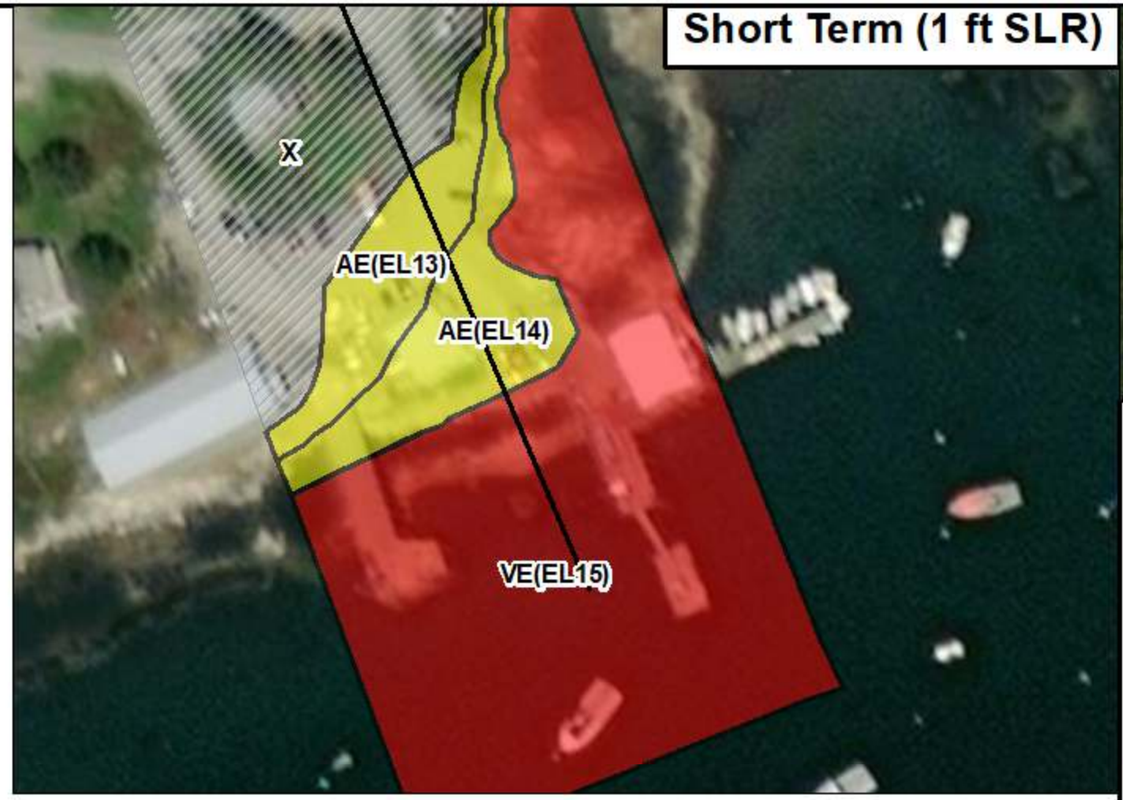
Zone X : Areas determined to be outside the 1% annual chance floodplain.

0 50 100 200 Feet

WOODS HOLE GROUP
A CLS COMPANY

Site: Stonington, ME





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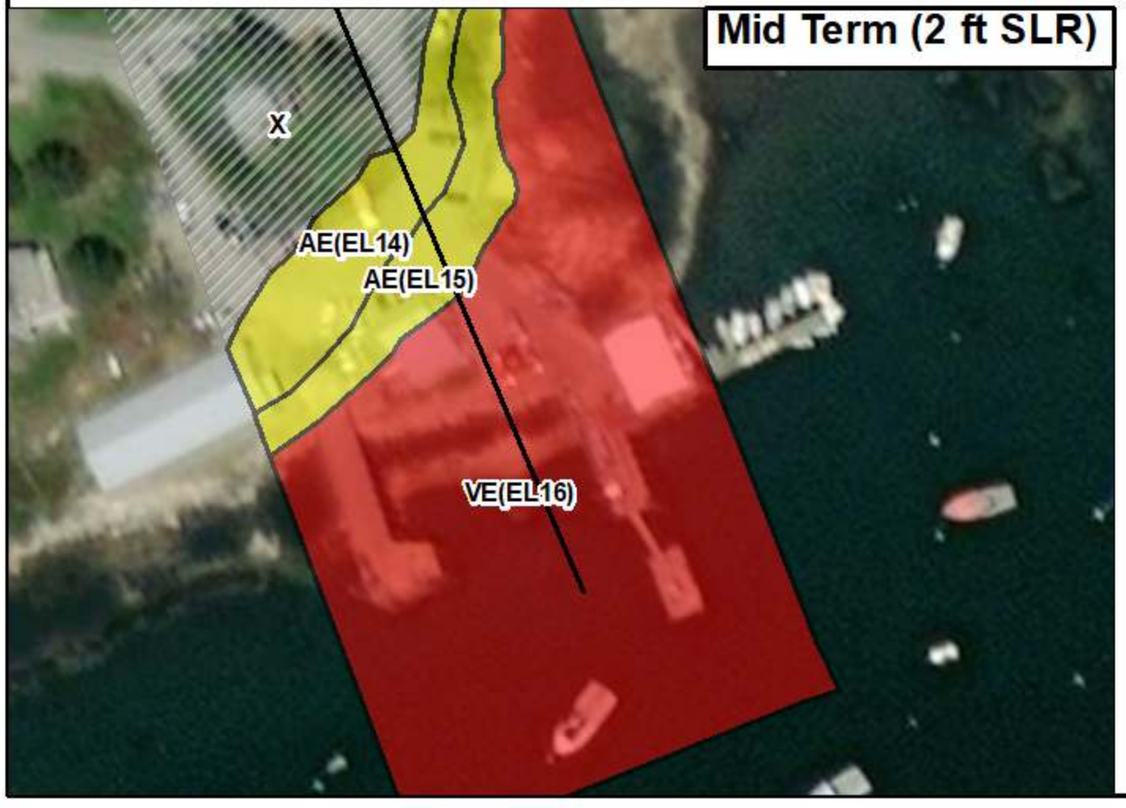
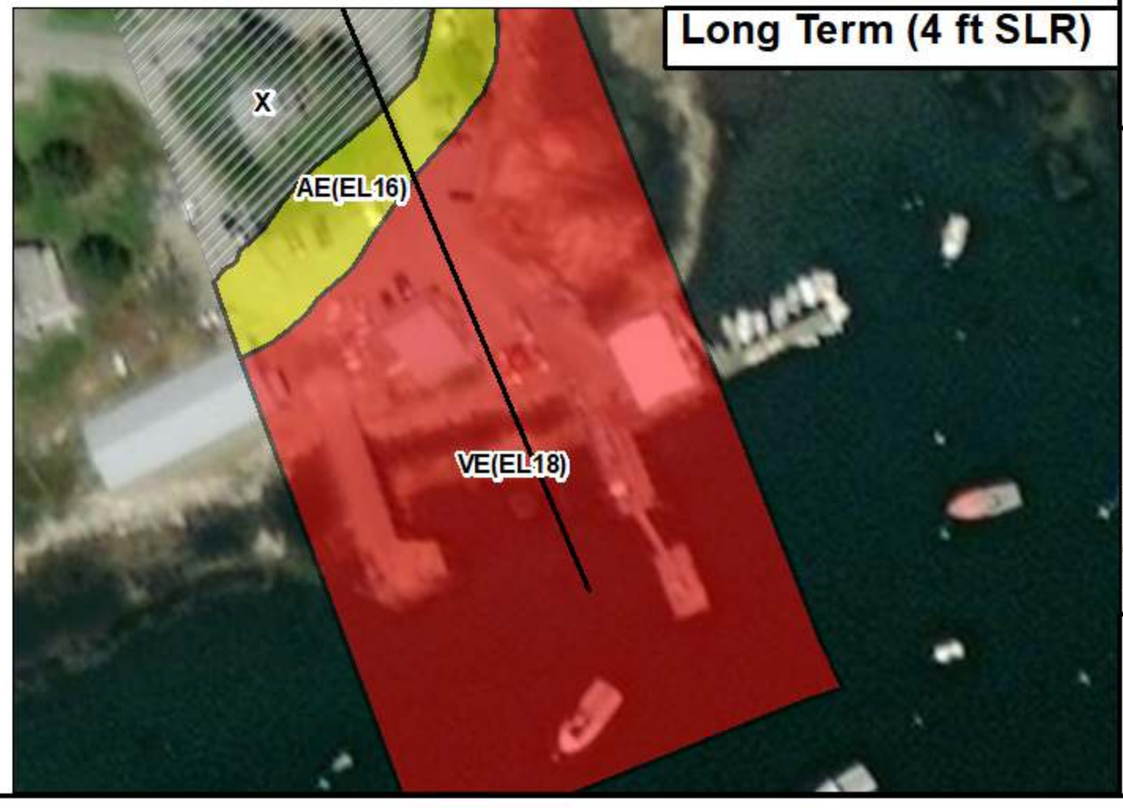
3. Flood mapping was developed for planning purposes only. No other use of this map should be made.

4. Elevations in reference to vertical datum NAVD88





Stonington Transects

AE

VE

X

N

Zone AE : Coastal flood zone. Base Flood Elevations determined.

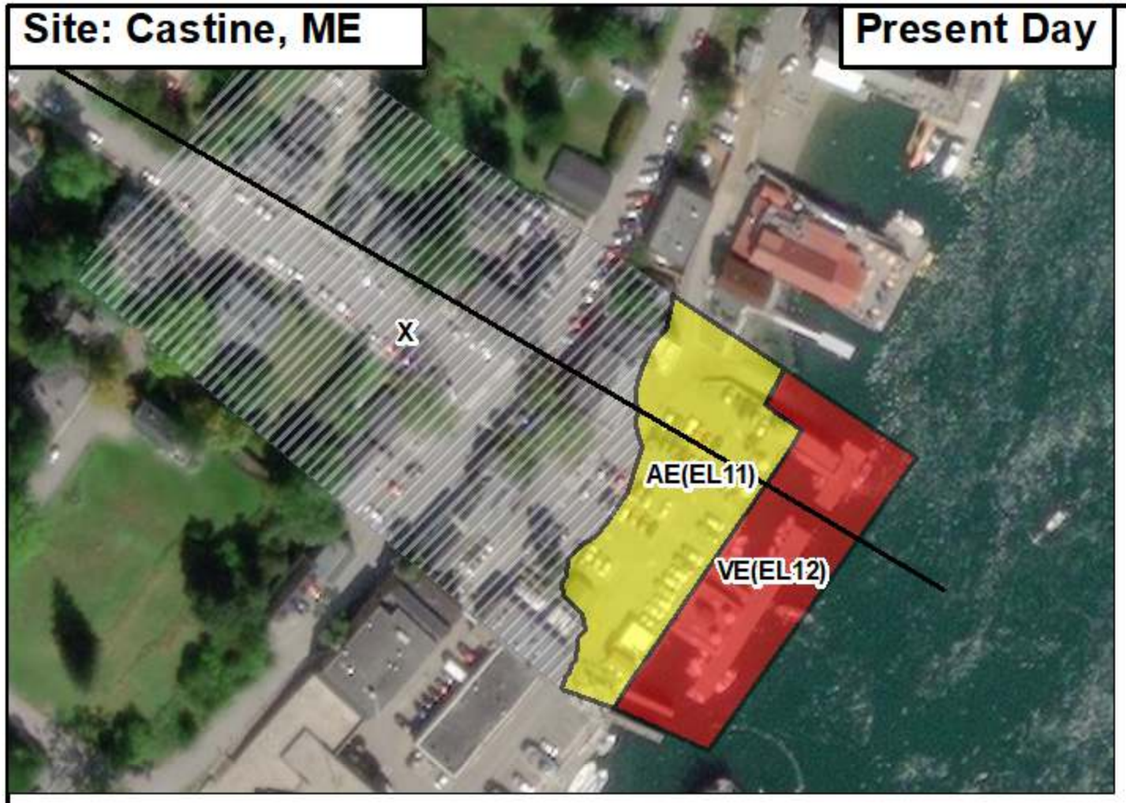
Zone VE : Coastal flood zone with velocity hazard (wave action). Base Flood Elevations determined.

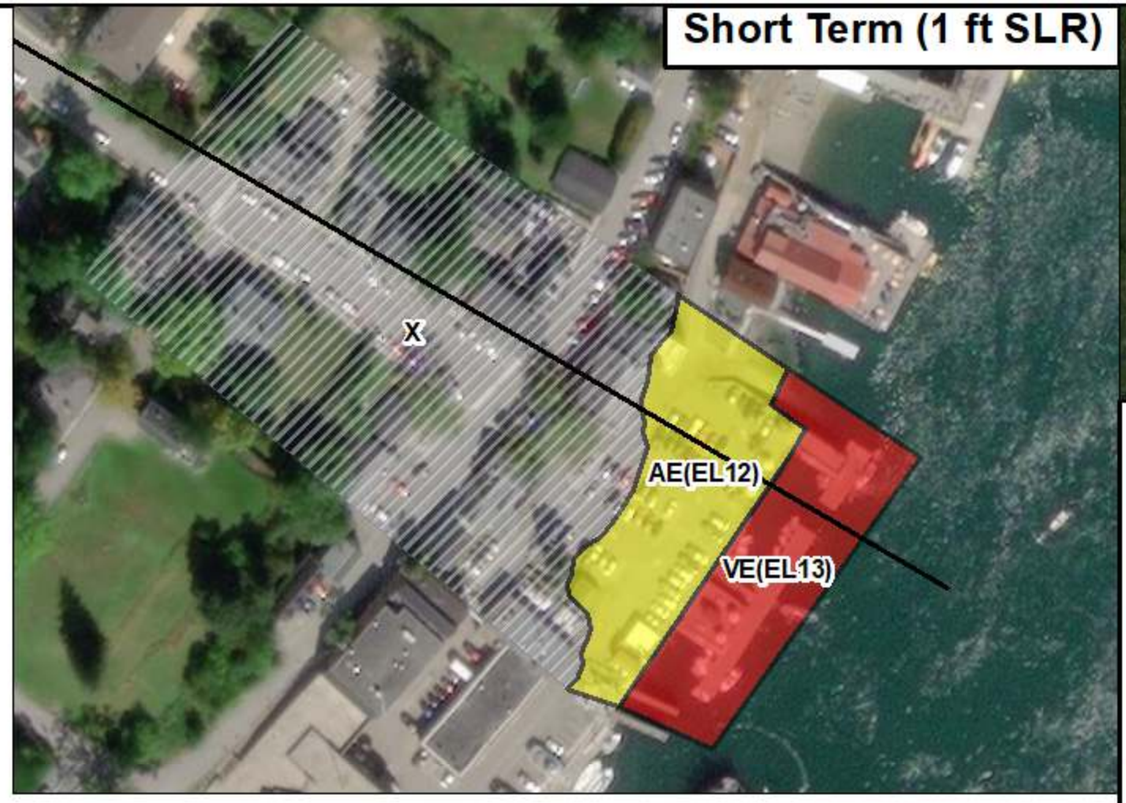
Zone X : Areas determined to be outside the 1% annual chance floodplain.

0 50 100 Feet

WOODS HOLE GROUP
A CLS COMPANY

Site: Castine, ME



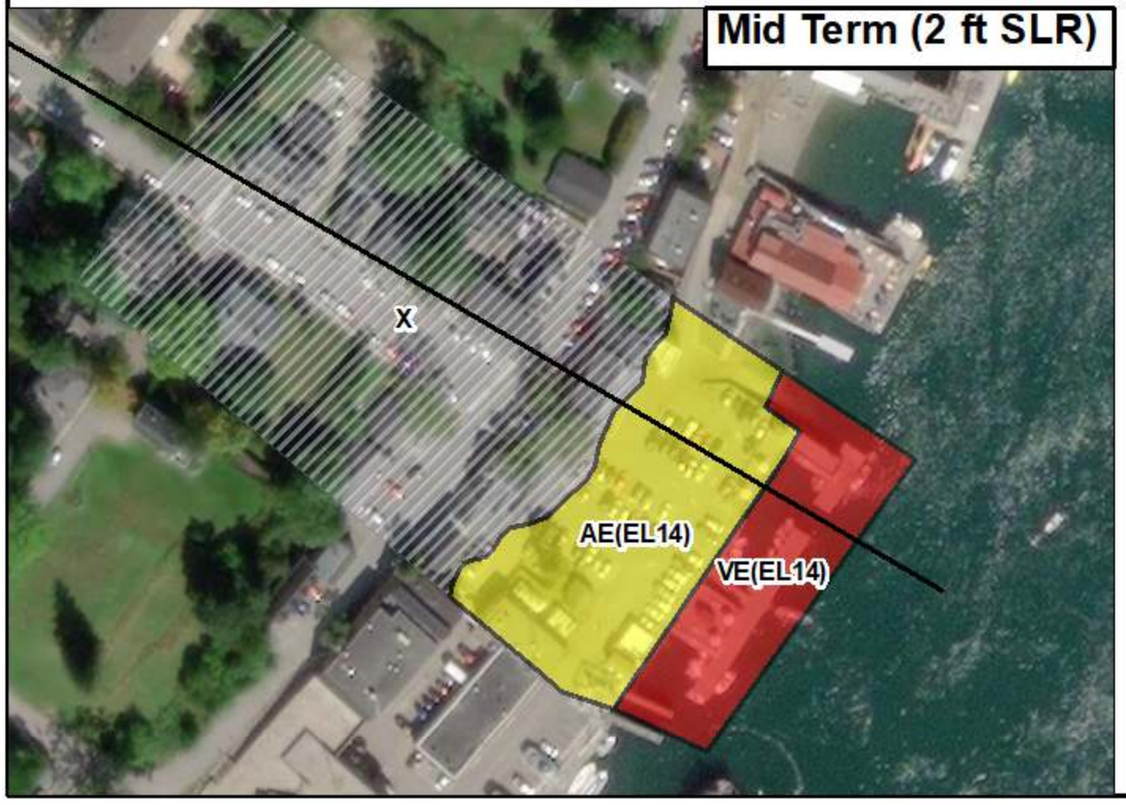


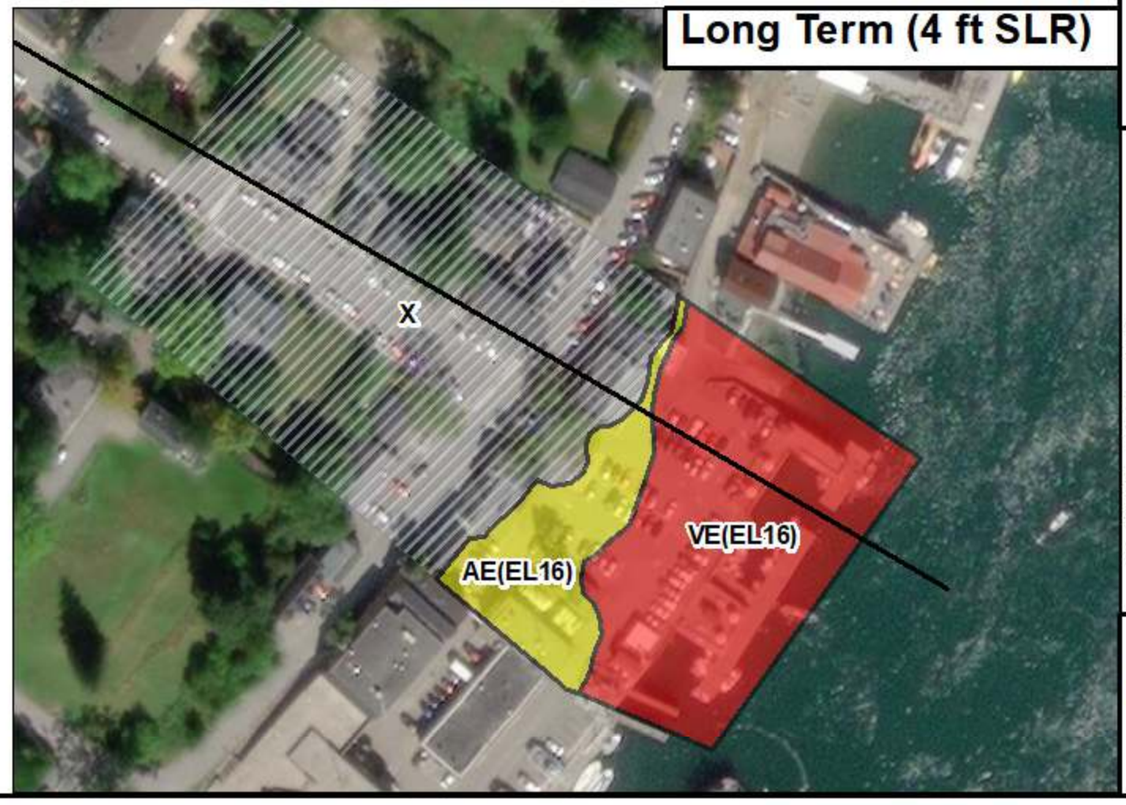
1. Maps indicate the 1%-annual-chance flood zones and base flood elevations.

2. This does not constitute a revision to the FEMA FIRM map which is done through FEMA's Letter of Map Revision process for which additional analysis and/or modeling may be required.

3. Flood mapping was developed for planning purposes only. No other use of this map should be made.

4. Elevations in reference to vertical datum NAVD88





Castine Transects

AE

VE

X

N

Zone AE : Coastal flood zone. Base Flood Elevations determined.

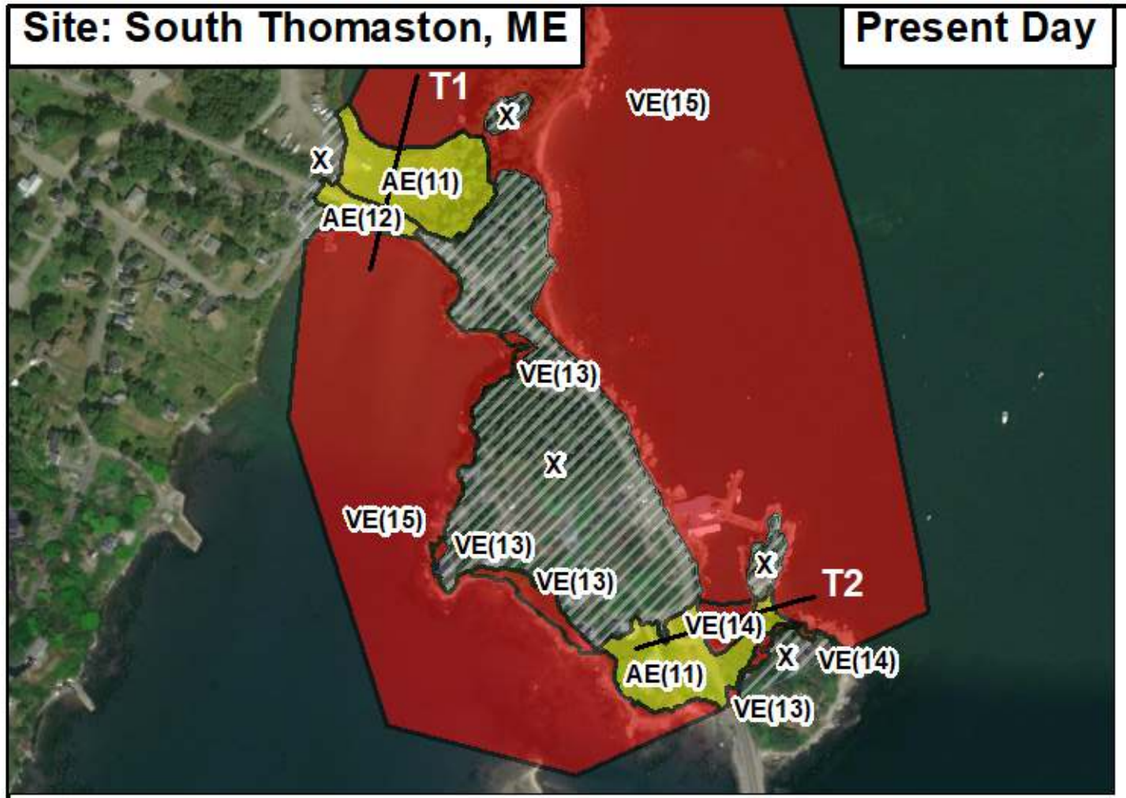
Zone VE : Coastal flood zone with velocity hazard (wave action). Base Flood Elevations determined.

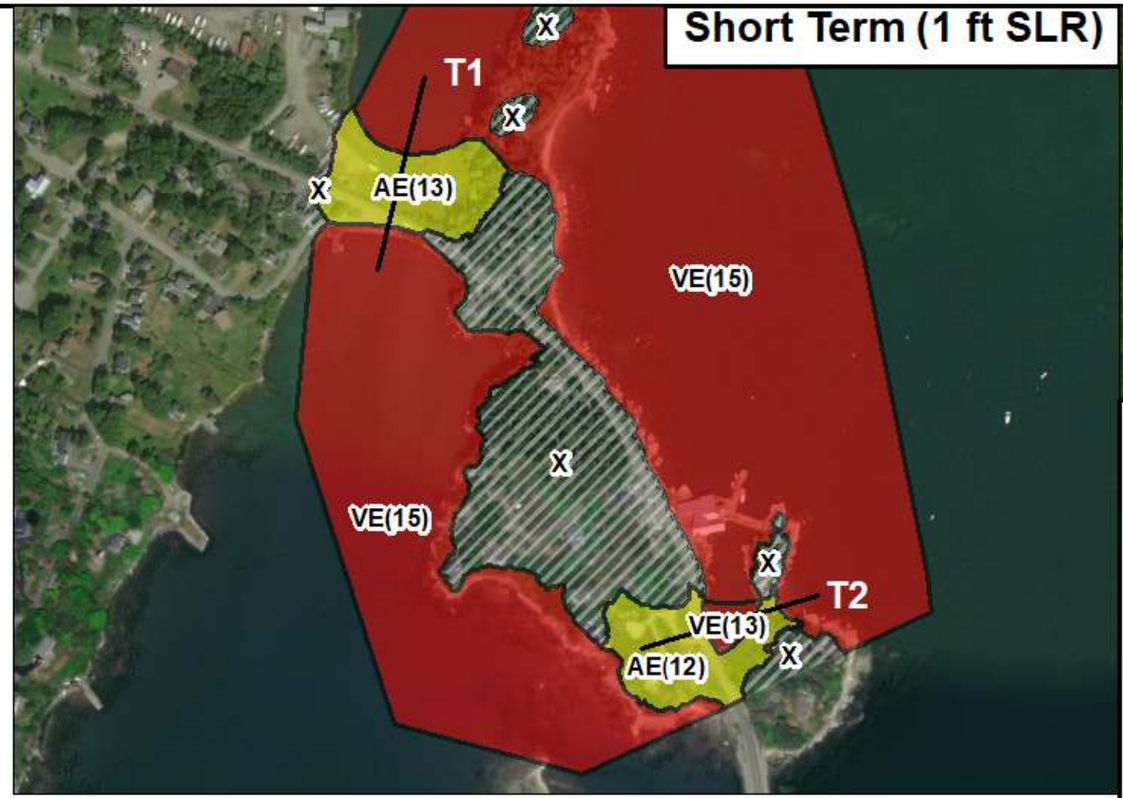
Zone X : Areas determined to be outside the 1% annual chance floodplain.

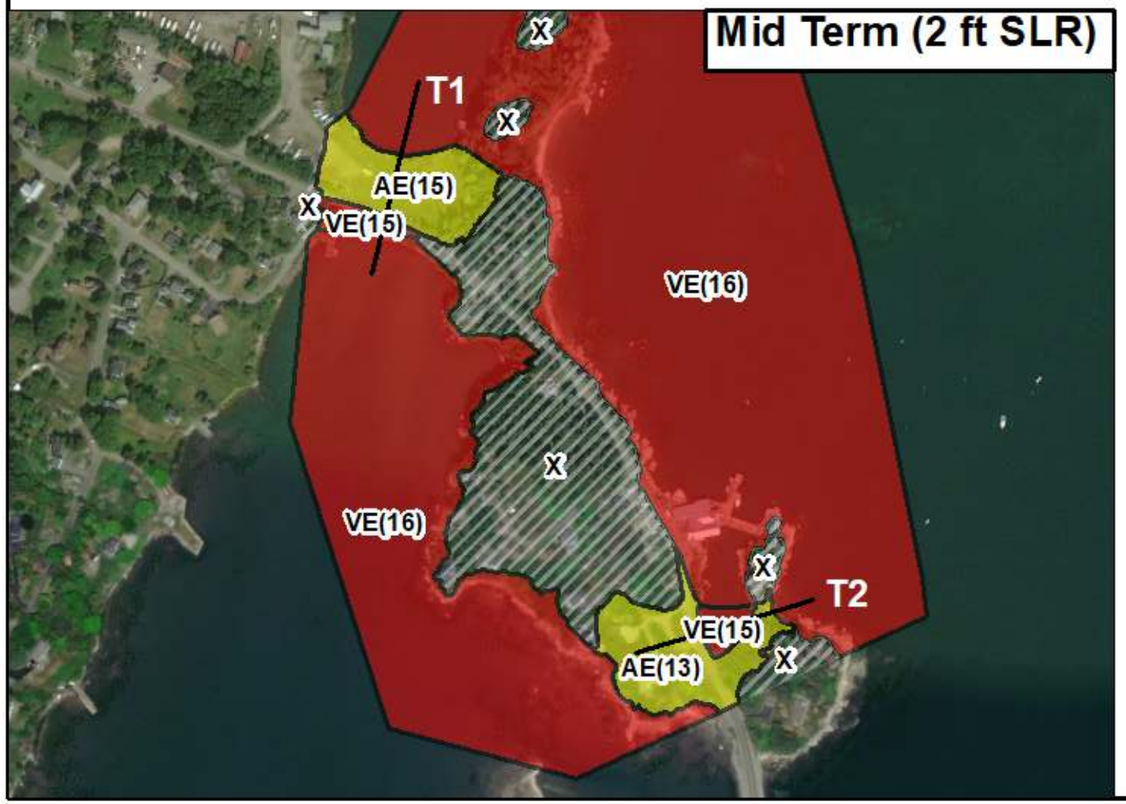
0 75 150 Feet

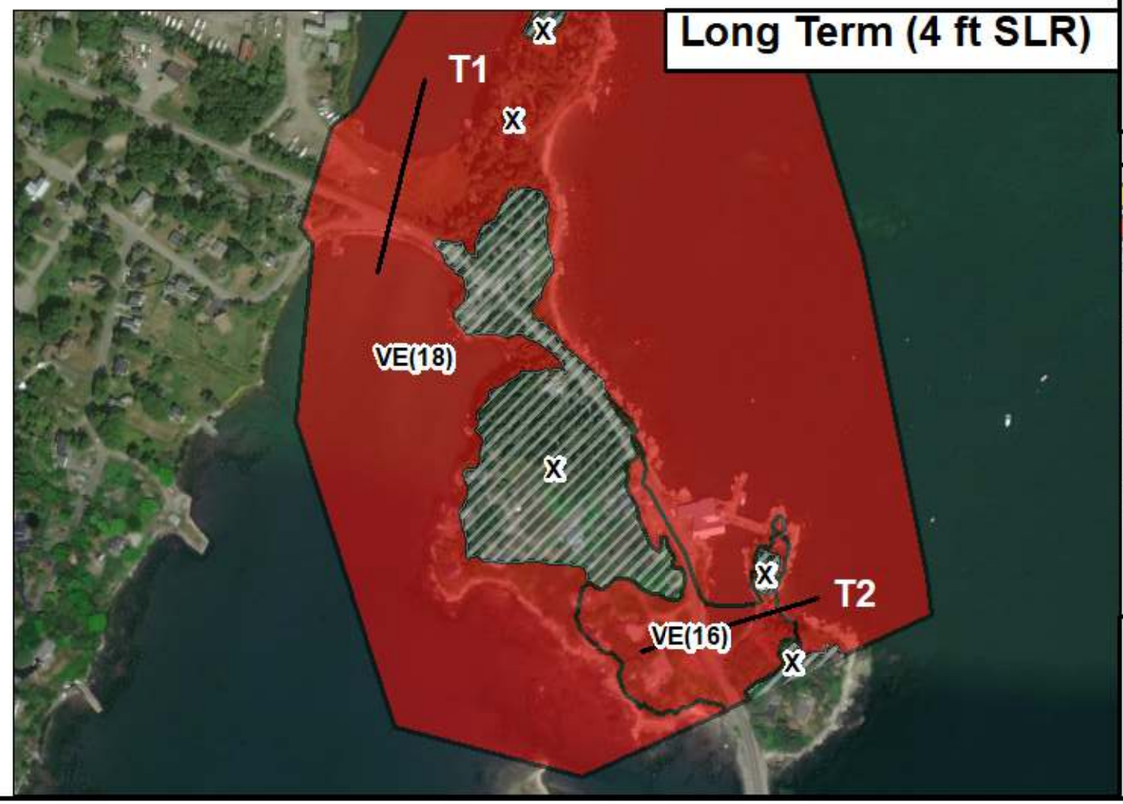
WOODS HOLE GROUP
A CLS COMPANY

Site: South Thomaston, ME









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4. Elevations in reference to vertical datum NAVD88

S. Thomaston Transects

AE

VE

X

N

Zone AE : Coastal flood zone. Base Flood Elevations determined.

Zone VE : Coastal flood zone with velocity hazard (wave action). Base Flood Elevations determined.

Zone X : Areas determined to be outside the 1% annual chance floodplain.

0 250 500 Feet

WOODS HOLE GROUP
A CLS COMPANY