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Subject: Vulnerability Assessment and Resilience Planning, Public Landing, Belfast, Maine
Penobscot Bay Working Waterfront Resiliency Analysis
State of Maine, Department of Marine Resources

Wood Environment & Infrastructure Solutions, Inc. (Wood) is pleased to provide the Maine Department of Marine Resources (DMR) this report on the baseline characterization, vulnerability assessment and resilience planning for the Public Landing, Belfast, Maine. This report provides findings for one of ten sites included in DMR's Penobscot Bay Working Waterfront Resiliency Analysis project. Reports on the other nine sites are provided under separate cover. 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

As proposed for DMR's Penobscot Bay Working Waterfront Resilience project, Wood conducted an assessment of the Public Landing in Belfast, Maine which included:

- Facility 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;
- Facility vulnerability analyses based on the baseline survey data, condition of structures, and modelling of potential storm surge and wave affects under three sea-level rise (SLR) scenarios; and
- Development of resilience measures, including strategies for incremental adaptation under the modelled storm and SLR scenarios.

This report contains a summary of our document review, personnel interviews, structural observations, photographs documenting our observations (**Appendix A**), and the approximate location of potential structural deficiencies. Following our analysis of the site and as part of the vulnerability analysis, we were able to identify the risks for the affected site features (see **Table 5**) from inundation data. Inundation maps developed for the site by Wood's consulting partner, Woods Hole Group (WHG) are provided in **Appendix B**. The vulnerability analysis establishes the future risk framework for the site and its structural features. Wood has evaluated the degree of impact of these site-specific vulnerabilities, and we have provided recommendations for improved resilience (e.g., repair, reinforcement) in relation to the feature's immediate performance and/or expected performance per the vulnerability analysis.

As part of the subsequent discussion, the following terms are defined below:

Base Flood Elevation (BFE) -	Elevation of flooding, including wave height, having a 1% chance of being equaled or exceeded in any given year.
Checks	A separation of the wood occurring across or through the rings of annual growth and usually as a result of seasoning.
Coastal High hazard Area (CHHA) -	Area within a special flood hazard area extending from off-shore to the inland limit of a primary frontal dune along an open coast and any other area that is subject to high velocity wave action.
Design Flood Elevation (DFE)	Based on the design flood, the DFE is the higher of the base flood elevation (BFE) shown on FIRMs prepared by FEMA or the flood elevations shown on the map adopted by a community.
FIRM -	Flood Insurance Rate Map. Official map of a community on which FEMA has delineated both special flood hazard areas and the risk premium zones applicable to the community.
Highest Annual Tide (HAT) –	The elevation of the highest predicted astronomical tide expected to occur at a specific tide station over the National Tidal Datum Epoch.
Mean Higher High Water (MHHW) –	The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch. The highest high tide or water height is referred to as the Highest Astronomical Tide (HAT) and is defined as the highest level which can be predicted to occur under average meteorological conditions and any combination of astronomical conditions.
National Tidal Datum Epoch –	The specific 19-year period (Currently 1983 to 2001) adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (Mean Lower Low Water, etc.) for tidal datums.
Pre-FIRM	Construction or substantial improvement occurred on or before December 31, 1974.
Shakes	Lengthwise separations of the wood along the grain, usually occurring between or through the rings of annual growth.
Splits	A separation of the wood through the piece to the opposite surface or to an adjoining surface due to tearing apart of the wood cells.
Still Water Elevation –	Elevation that the surface of the water would assume in the absence of waves referenced to a specified vertical datum at the defined recurrence interval.
Wave Height –	Vertical distance between the crest and the trough of a wave.

2.0 DOCUMENT REVIEW AND PERSONNEL INTERVIEWS

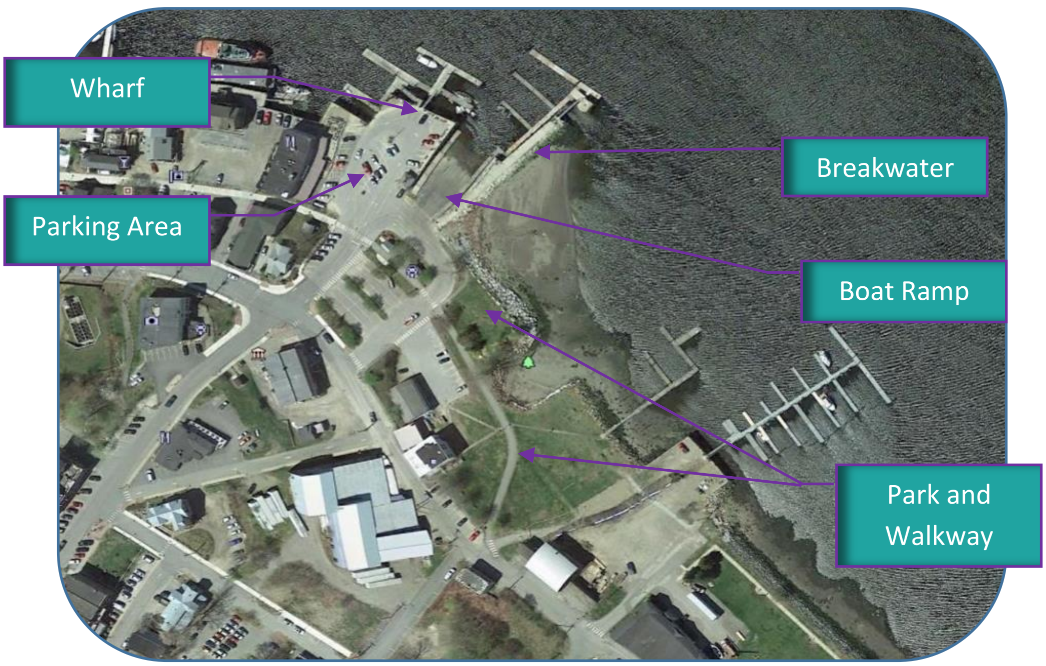
Wood was escorted by Harbor Master Katherine Pickering during a site visit on 21 June 2019. We discussed the site features and historical development of the site. Ms. Pickering mentioned that the primary use of the harbor is for tourism. She advised that the breakwater was previously remediated due to erosion on the south side and that voids had developed in the breakwater which are visible from the north side of the structure. Further, she disclosed that previous plans for a breakwater would place it further southeast of the site, from which the worst wave action originates. The following is a summary of key site features identified during the site visit:

- The site consists of the wharf, breakwater, floating docks, parking area, and a boat ramp (See **Figure 1** below).
- Harbor Master's office was reportedly built in 1997.
- The breakwater is constructed on loose fill backfill; material loss was reported on the north side.
- Gas and diesel fuel are provided on site via above ground storage tanks.
- Storm drainage is located at west side of property (see **Photograph No. 38, Appendix A**).
- There is no formal ongoing maintenance plan in place; maintenance is addressed, as needed, when a deficiency is identified.

No structural plans or as-built drawings were available for our review. Our assessment is based on information provided onsite by our contact and the following document(s) provided while on site:

- *Breakwater Protection for Four Maine Harbors*, sponsored by the Maine State Planning Office in cooperation with the Department of Marine Resources, the Department of Transportation and the Maine Sea Grant Program, dated July 10, 1980

Figure 1: Site Overview



3.0 OBSERVATIONS AND FINDINGS

Tirrell Day and Lane Gray of Wood performed a site assessment and gathered geospatial data for key site features during the 21 June 2019 visit. This assessment included documenting the general condition and recording elevations of key features and structures. At the request of the City, the limits of our investigation include the wharf, Breakwater, attached floating docks, a boat ramp, site drainage, a park and walkway, and shoreline protection. Photos of the site and Wood's noteworthy observations are included in the Photolog (**Appendix A**). Elevations discussed in this report are with respect to North American Vertical Datum of 1988 (NAVD88). The site facilities and their associated elevations are included in **Table 1** for reference. During our site visit the approximate tidal levels where between -4.73 ft and 5.08 ft (predicted min. of -5.66 ft, max. of 5.27 ft).

3.1 Property Overview

This site is an approximate 3.75-acre property consisting of a timber wharf with floating docks, a breakwater, a hoist, boat ramp and multiple buildings (**Photograph 1**). The wharf is located at the northeast portion of the property and is equipped with a hoist, water, power and fuelling capabilities via onsite tanks. There are four (4) floating docks with access provided either by gangways or directly to grade (**Photograph 2**). Pontoons are secured by guide piles attached to the wharf or pier, isolated mooring piles formed as dolphins. Attachment to piles in either case is by means of mooring chains or clamps. In addition, we noted a mooring structure constructed of steel framing, sheet piling and concrete fill. The structure is a dolphin used as a mooring point for the floating dock 2 (**Photographs 24 – 27**). Wood observed the function of the gangway and floats during tidal action and the system appeared to function as intended (**Photographs 12, 16, 17, 19, 20, 24 – 31**).

The boat ramp is located between the wharf and the breakwater (**Photographs 18 – 20**). The ramp is paved, and the surface appears to be in good condition. The adjacent breakwater provides local protection to harbor assets which include the floating docks and the wharf/pier. Per the above mentioned document, provided by our site contact, the breakwater is 235 feet long, with a width ranging from 9 to 22 feet. Construction of the breakwater is granite block at the exterior and an interior of loose fill. A small beach area begins at the south side of the breakwater, extends south along the coastline and terminates at the next pier. Bordering to the east of the beach is a greenway, both being part of Heritage Park. Included in this park is a walking path, Belfast Harbor Walk, which extends beyond the property limits to the north and south (**Photographs 21 – 23 & 35 – 40**). Various shops, restaurants and tourism venders occupy or border the property (**Photographs 3 – 5, & 14**).

Table 1: Site Elevations

Location	***Lowest Horizontal Member***	***Lowest Deck or Adjacent Grade***	***First Finished Floor / Mid Mark***	***Lowest Opening/ Critical Elevation***
Source	***Estimate***	***Survey***	***Survey***	***Survey***
Facility	***[ft]***	***[ft]***	***[ft]***	***[ft]***
Wharf / Pier	6.44	8.19	n/a	n/a
Floating Dock 1	n/a	n/a	n/a	8.03
Floating Dock 2	n/a	n/a	n/a	8.65
Floating Dock 3	n/a	n/a	n/a	8.35
Floating Dock 4	n/a	10.01	10.03	10.3
Harbor Master's Office	n/a	n/a	n/a	7.73
Vender Offices	n/a	10.82	11.32	11.32
Fuel Storage Building	n/a	12	12	14
Breakwater	n/a	8.65	n/a	13.65
Shoreline Protection	n/a	7	n/a	12
Boat Ramp	n/a	-1	3.5	7

**Estimates indicate measurements referenced or derived from the actual site survey data.*

The wharf is constructed with stacked heavy timbers at the exterior face (**Photographs 6 – 13**) and asphalt paving above. Fill material could not be verified; however, structures of this type are typically constructed with a gravel or rock base. A portion of the pier protrudes from the wharf and provides a boardwalk along the waterfront (**Photographs 7 – 9, & 15**). Details on timber pile embedment were not provided. The Subsurface conditions of the site were not probed or verified by testing as part of Wood's scope of work. We were only able to view exterior and exposed sections of the structures. Timber framing appears to be attached using a combination of what appears to be galvanized steel through bolts, nails, and/or screws.

Site utilities include electrical and water lines provided at select locations at the wharf and/or floating docks (**Photographs 30 & 31**). Lighting is provided throughout the site and more frequently at the wharf **(Photograph 14 & 15**). In addition, diesel and regular unleaded fuel is stored on site in above ground tanks in a small building located at the west end of the property, off Main Street (**Photograph 33**).

In addition to the fuel storage building, other site facilities include the Harbor Master's office and two vender-occupied buildings which support local tourism (**Photographs 32 & 34**). The Harbor Master's office appears to be a slab-on-grade, wood-framed building, with asphalt shingle roof and wood siding. A copula is located in the center of the roof and appears to be for ventilation only. The building appears in good condition with no apparent notable defects. The first floor elevation of the structure is roughly 1.5 feet above the adjacent pavement elevation. The buildings which house the venders are of similar construction from our visual inspection. These buildings are smaller, and do not have a pronounced elevated first floor elevation such as the Harbor Master's office.

3.2 Noted Deficiencies

The wharf was viewed from above, the shoreline below, or from the floating docks. Timber members stacked at the face of wharf appear to be in serviceable condition. We noted weathered timber members throughout which exhibited signs of checking, splitting and shakes. Severity of these observed conditions ranged from minor to moderate in nature. Timber piles and pile caps appear to be in serviceable condition; however, connecting elements for these members could not be assessed due to limited access. Connecting elements such as fasteners appear to experience minor to moderate condition of corrosion. Similar conditions were noted at the pier, with the exception of the cross bracing which are, for the most part, within the tidal zone.

The floating docks appear to be in good condition with some decking exhibiting minor weathering. The pontoons appear to function as intended. Mooring chains and clamps show signs of corrosion (**Photographs 17 & 26**). Mooring structures exhibit signs of moderate to major corrosion at many locations throughout, such as delamination and cracking (**Photograph 27**).

Historical site information indicates that previous repairs to the breakwater in the form of pressure grouting were performed to reduce erosion of the interior loose fill material and undermining of the structure. A later remediation to re-secure the south face by means of stone and grouting was also performed (**Photograph 35**). Some voids were noted at the north side of the structure with loose material deposited on the adjacent pavement (**Photographs 41 & 42**). Given the type of construction and the conditions observed, conclusive signs of settlement would be expected but could not be confirmed. This may be due to the frequency of construction joints on the slab above. In addition, small rock material appears to be washing out (**Photograph 35**) at the south side of breakwater where no large riprap is present as shoreline protection.

As previously mentioned, the site is equipped with water and electrical services. Electrical fixtures do not appear to have moisture resistant covers and connections. Waterline fixtures show signs of corrosion (**Photograph 31**).

We noted a drainage pipe which discharged to the beach area to the south of the breakwater. Signs of channel erosions were noted along the path of discharge to the bay. There was minimal riprap to protect surrounding soils from water discharge and associated erosion (**Photographs 38 & 39**).

3.3 Risk Framework

As a basis for the vulnerability analysis, water surface elevation (WSE) exposure profiles were developed by WHG which summarize current and potential future tidal and storm surge inundation/wave impacts. The key flood elevation profiles provided include the Mean Higher High Water (MHHW), the Highest Astronomical Tide (HAT), the 1% Still Water Level, and the Base Flood Elevation (BFE). Values for these scenarios are site specific and take into consideration the topographic survey data obtained by Wood.

The MHHW and HAT tidal datums (present day) were sourced from the nearest long-term NOAA tide station and from spatial files developed by Maine Geological Survey[1]. The 1%-annual-chance still water level (present day) was obtained from the 2016 FEMA Flood Insurance Study for Knox County.

Table 2: Flood Modelling Data Summary – Transect 1

Scenario	*MHHW*	*HAT*	*1% Still Water Level*	*1% Wave Crest Elevation (BFE)*
Present day	5.2	7.5	9.7	10-11
Short Term (+1 ft)	6.2	8.5	10.7	11-13
Mid Term (+2 ft)	7.2	9.5	11.7	12-14
Long Term (+4 ft)	9.2	11.5	13.7	14-17

Table 3: Flood Modelling Data Summary – Transect 2

Scenario	*MHHW*	*HAT*	*1% Still Water Level*	*1% Wave Crest Elevation (BFE)*
Present day	5.2	7.5	9.7	10-14
Short Term (+1 ft)	6.2	8.5	10.7	11-15
Mid Term (+2 ft)	7.2	9.5	11.7	12-15
Long Term (+4 ft)	9.2	11.5	13.7	14-17.5

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.

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 discussion with the project team, the preferred SLR scenarios defined for evaluating short-term, mid-term, and long-term impacts were selected as 1 ft, 2 ft, and 4 ft, respectively. These projected increases in sea level roughly correspond with NOAA's Intermediate scenario for the years 2030, 2050, and 2085 with a rather low exceedance probability (17%) and are within the range of the SLR scenarios recommended by Maine DOT for 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

3.4 Site Vulnerabilities

The flood modelling data provided above in **Tables 2 and 3** includes scenarios for the Short Term, Mid Term, and Long Term SLR scenarios. NOAA's Intermediate scenario mentioned above compared with these timeframes should be taken into consideration for the identified return periods as illustrated in **Table 4**.

Table 4: Flood Return Period

Event Return Period	Percent Chance of Occurrence per Period			
	5 Years	10 Years	25 Years	50 Years
100 Year Flood (1%)	4.9%	9.6%	22.2%	39.5%
500 Year Flood (0.2%)	1%	2%	4.9%	9.5%

The various site features have been summarized in **Table 5** for each facility, indicating the associated risk and flood scenarios which result in inundation. Those elevations noted as 0 ft indicate an elevation equal to the identified feature of the facility. No elevations are noted in Table 5 where no inundation of the feature was identified (i.e., flood elevation is lower than that of the site feature). Below are the site-specific vulnerabilities based on our review of the property.

3.4.1 Wharf & Pier

From our preliminary non-destructive investigation, most areas of the wharf appear to be of sound condition, securely fastened and restrained against movement with fasteners or other mechanical means. The behaviour of the wharf for all scenarios, given the associated wave height, is dependent on these elements being properly attached to resist lateral and uplift loads. For the Short Term scenario, HAT levels are indicated above the grade elevation; however, it is not until the Mid Term scenario that the HAT creates a condition of over 1 foot of inundation. The Long Term scenario data indicates that MHHW levels will inundate the deck by at least 1 foot. Frequency of this event can be expected at least once a day.

Site utilities at the wharf, which include water and electricity, are exposed to wave action under the Present Day BFE. Already for the Short Term scenario, electrical boxes at the deck surface will be impacted by the BFE. For the Long Term scenario, these same items will be threatened from inundation from the HAT.

3.4.2 Floating Docks

The floating dock assembly consists of the gangway and pontoons. The critical elevation for proper function of the floating docks is the MHHW. This is based on the relatively frequent occurrence and the forces the gangway will exert on the attached wharf header from rising water level and functionality of the system for these levels. As is indicated in **Table 5** for the Present Day Scenario, minimal risk is foreseen for damage to the wharf from tidal action forces exerted from the gangway, but the 1% Stillwater for this same scenario may incur loading on this attachment. The risk of damage increases for all future scenarios where, for example, the Long Term MHHW is roughly 1 ft above the top of deck elevation for floating dock 1. For floating dock 2, the Stillwater elevation is also of concern as the steel clamp elevation overtops the attaching beam. Although there is no gangway attachment for floating docks 3 and 4, the buoy chain connection is of concern for the Long Term scenario.

3.4.3 Facilities

Given the elevation of the base flood, the Harbor Master's office could be impacted for the Present Day scenario. Several inches to over a foot of inundation are of likelihood for the Short Term and Mid Term scenarios, respectively, whereas the Long Term scenario indicated major flooding (3.4 ft) of the structure for the design Stillwater. Both vender offices, being constructed at grade, will experience the same flooding under the 1% Stillwater flood elevation for the Midterm scenario. The elevation and inland position of the vendor buildings allow a condition of minimal risk for the Present Day, Short Term and Mid Term scenarios, however, data provided for the Long Term scenario indicates that the HAT will produce occasional flooding. It is apparent that the fuel storage building will also be affected during the Long Term Scenario with 1% Stillwater flooding.

Table 5: Site Elevations and Risks

Facility			*Inundation above Elevation of Facility*															
Description		*Elevation (ft) to NAVD88*	*Present Day*				*Short Term Scenario*				*Mid Term Scenario*				*Long Term Scenario*			
			MHHW [ft]	*HAT [ft]*	*1% Stillwater [ft]*	*BFE [ft]*	*MHHW [ft]*	*HAT [ft]*	*1% Stillwater [ft]*	*BFE [ft]*	*MHHW [ft]*	*HAT [ft]*	*1% Stillwater [ft]*	*BFE [ft]*	*MHHW [ft]*	*HAT [ft]*	*1% Stillwater [ft]*	*BFE [ft]*
Wharf / Pier	Lowest Horizontal	6.44 ft		1.06	3.26	4.6		2.06	4.26	6.56	0.76	3.06	5.26	7.56	2.76	5.06	7.26	11.1
	Lowest Deck or Adjacent Grade	8.19 ft			1.51	2.8		0.31	2.51	4.81		1.31	3.51	5.81	1.01	3.31	5.51	9.31
Floating Dock 1	Buoy Chain max elevation	9.17 ft			0.53	1.8			1.53	3.83		0.33	2.53	4.83	0.03	2.33	4.53	8.33
	Gangway support	8.03 ft			1.67	3		0.47	2.67	4.97		1.47	3.67	5.97	1.17	3.47	5.67	9.47
Floating Dock 2	Buoy Chain max elevation	10.75 ft				0.3				2.25			0.95	3.25		0.75	2.95	6.75
	Gangway support	8.65 ft			1.05	2.4			2.05	4.35		0.85	3.05	5.35	0.55	2.85	5.05	8.85
Floating Dock 3	Buoy Chain max elevation	8.35 ft			1.35	2.7		0.15	2.35	4.65		1.15	3.35	5.65	0.85	3.15	5.35	9.15
	Gangway support																	
Floating Dock 4	Buoy Chain max elevation	9.98 ft				1			0.72	3.02			1.72	4.02		1.52	3.72	7.52
	Gangway support																	
Harbor Master's Office	Adjacent Grade	8.97 ft			0.73	2			1.73	4.03		0.53	2.73	5.03	0.23	2.53	4.73	8.53
	Lowest Horizontal	10.01 ft				1			0.69	2.99			1.69	3.99		1.49	3.69	7.49
	Lowest Opening	10.3 ft				0.7			0.4	2.7			1.4	3.7		1.2	3.4	7.2
Vender Offices	Adjacent Grade	10.82 ft				0.2				2.18			0.88	3.18		0.68	2.88	6.68
	Lowest Horizontal	11.32 ft								1.68			0.38	2.68		0.18	2.38	6.18
	Lowest Opening	11.32 ft								1.68			0.38	2.68		0.18	2.38	6.18
Fuel Storage Building	Adjacent Grade	12 ft								1				2			1.7	5.5
	Lowest Horizontal	12 ft								1				2			1.7	5.5
	Lowest Opening	14 ft												0				3.5
Breakwater	Top Elevation	8.65 ft			1.05	4.4			2.05	7.35		0.85	3.05	6.35	0.55	2.85	5.05	8.85
	Critical Elevation	13.65 ft								2.35				1.35			0.05	3.85
Shoreline Protection	Adjacent Grade	7 ft		0.5	2.7	4		1.5	3.7	6	0.2	2.5	4.7	7	2.2	4.5	6.7	10.5
	Critical Elevation	12 ft								1				2			1.7	5.5
Boat Ramp	Lowest Take off	-1 ft	6.2	8.5	10.7	12	7.2	9.5	11.7	14	8.2	10.5	12.7	15	10.2	12.5	14.7	18.5
	Midmark	3.5 ft	1.7	4	6.2	7.5	2.7	5	7.2	9.5	3.7	6	8.2	10.5	5.7	8	10.2	14
	Top/Slope	7 ft		0.5	2.7	4		1.5	3.7	6	0.2	2.5	4.7	7	2.2	4.5	6.7	10.5

Note: Facility elevations presented in this Table are referenced to NAVD88.

3.4.4 Breakwater

Results indicate that the 1% Stillwater elevation will overtop the breakwater elevation under the Present Day scenario, with the wave height roughly a foot above the Stillwater elevation. This condition increases for future scenarios with the 1% Stillwater elevation 5 feet over the top of the breakwater for the Long Term scenario. Although the south side has been grouted for protection against material migration and dislodgement during an event, the north side remains unprotected during inundation for Present Day design Stillwater.

3.4.5 Shoreline Protection

As previously mentioned, there are areas south of the breakwater needing attention and placement of shoreline protection to prevent erosion. All scenarios indicate that the current protection is inundated by the 1% Stillwater elevation. Wave heights increase from over a foot for the Present Day to almost 4 feet for the Long Term scenario. These wave heights are not anticipated to be a concern for this type of construction. However, the 1% Stillwater elevation exceeds the current height, which is not a preferred condition. Optimal design condition is for a Stillwater elevation between the upper and lower bounds of the structure.

3.4.6 Boat Ramp

Based on the position of the ramp relative to the road and rising water level for the MHHW, the boat ramp may not be usable, or difficult to use during the Mid Term and later scenarios. Regrading may be a viable option based on accessibility of adjacent land. We expect the frequency of downtime to increase based on the Long Term MHHW and HAT, during which the ramp will be often rendered unusable, unless improved.

4.0 RECOMMENDATIONS

4.1 General Recommendations

In accordance with American Society of Civil Engineers / Structural Engineering Institute Standard 24 – Flood Resistant Design and Construction (ASCE 24), existing structures that sustain substantial damage, or that are substantially improved, are treated as new construction. This standard considers damage beyond routine maintenance or otherwise minimal damage following an event, which nonetheless requires major improvements and even applies to structures classified as pre-FIRM. **For new construction we recommend, 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.** It is understood that local requirements coupled with available resources will dictate the ability for the communities to incorporate proactive designs. The following recommendations are provided with regard to areas of the site which fall within a special flood hazard area:

- All new construction, substantially improved, and substantially damaged buildings must be elevated on pilings, posts, wharfs, or columns so that the bottom of the lowest horizontal structural member of the lowest floor is at or above the BFE with any applicable freeboard (or DFE), per ASCE 24.
- The foundation system must be anchored to resist flotation, collapse, lateral movement due to wind and water loads acting simultaneously on all components of the building.
- Use of flood damage-resistant materials above the BFE per ASCE 24 and the local Building Code.
- Electrical equipment should be located on the landward side of any building and/or behind structural elements. They must be elevated and designed to prevent flood waters from entering and accumulating in components during flooding. Watertight conduits and fixtures should be used, and all metal should be stainless steel type 316 minimum.
- Install shutoff and isolation valves on water lines that extend into the flood-prone areas.

This list is not comprehensive but rather applies to site features observed during our site visit. There may exist other relevant items addressed in any of the above-mentioned design standards which are applicable for the site at a future date. We recommend a detailed site assessment be performed during the design stage to ensure implementation of all applicable items.

4.2 Site Specific Recommendations

Although the risks, vulnerabilities, and associated recommendations addressed herein are in reference to features located within the property limits of the Public Landing, there may be features of similar construction in close proximity and exposed to similar risks as described in this report but fall outside the property limits. We recommend that these sites and features undergo a similar assessment with the assumption that similar or greater risks may apply. The following are recommendations for the features identified at risk within the Public Landing, Belfast.

4.2.1 Wharf

The following recommendations are provided in reference to the **Present Day** scenario for flood values provided in Table 2 above:

- Confirm positive attachment of all structural members to their substrate or load-bearing elements. We recommend a detailed analysis to verify the structures are designed according to current standards and design loading. Incorporate redundancies in design as needed based on a detailed structural analysis.
- Utilities 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 enclosures should be incorporated for electrical equipment and conduits. Fuel supply fixtures should be confirmed for watertight and corrosion resistant fixtures and appurtenances or otherwise raise exposed elements above the DFE per design specifications when not unpractical for use.

The following recommendations are provided in reference to the **Short Term and all future scenarios** for inundation values provided in Table 2 above:

- Consider raising the wharf and pier in response to rising water levels and into flood zone of less impact (increase in elevation of 3.5-4 feet), and reconstruction incorporating a sustainable design at the current location.

While raising the wharf 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.

4.2.2 Floating Docks

The following recommendation is provided in reference to the **Present Day and Short Term scenarios** with regard to construction of the floating dock assemblies:

- Clean and coat all corroded steel framing members and replace severely corroded hardware. Confirm that all members are positively connected, and the substrate is reasonable condition to resist the intended design loading.
- Confirm the gangway attachments are sufficient to resist the design loading and repair or replace as needed.

The following recommendation is provided in reference to the **Mid Term and Long Term scenarios** with regard to construction of the floating dock assembly:

- Assuming the wharf elevation is not scheduled to be raised, consider raising the gangway and gangway platform to accommodate the rising water level. This alternative will provide an elevated gangway platform above the deck elevation, and greater resilience during future extreme high tide and storm events. Although raising the wharf should be considered for subsequent scenarios, this option may not be economically-viable.

4.2.3 Facilities

The following recommendation is provided in reference to the **Present Day, Short Term and Mid Term scenarios** with regard to the site facilities:

- Consider either flood proof construction at lower portion of building such as a minimum 5-foot stem wall, sealed openings, or relocation at or above Mid Term DFE. Confirm waterproof conduits and fixture/receptacles for electrical, water and sewer or other utilities/equipment to prevent intrusion and/or backflow.
- In addition, we recommend weatherproof openings against wind-driven rain. For the vender offices to accommodate the Mid Term scenario, we recommend raising or relocation of the structures due to a rising 1% Stillwater flood elevation.

The following recommendation is provided in reference to the **Long Term scenarios** with regard to the site facilities:

- The Harbor Master's Office, due to its close proximity to the shoreline, should be raised above the DFE and/or relocated to accommodate the impact of the BFE. The Vender Offices and fuel storage building should also be either raised or relocated to accommodate the DFE for those locations in response to the rising 1% Stillwater flood elevation.

4.2.4 Breakwater

The following recommendation is provided in reference to the **Present Day and all future scenarios** with regard to the current breakwater:

- The breakwater appears to experience continued erosion of interior material. A detailed analysis for the current breakwater should be performed given the level of inundation already expected at the Present Day scenario. In addition to repair, recommendations for raising or retrofitting the breakwater will be based on this analysis and performance of the breakwater in protecting harbor assets.

4.2.5 Shoreline Protection

The following recommendation is provided in reference to the **Present Day and all future scenarios** with regard to the current revetment:

- Design and provide additional shoreline protection at the south side of the existing breakwater where protection is missing. Consider continuing shoreline protection up the slope if allowed by local and federal regulations/authorities.

The following recommendation is provided in reference to the **Long Term scenario** with regard to the current revetment:

- An analysis should be performed to model the behaviour of the structure for the Mid Term scenario at a minimum; any reconstruction or retrofit design should be based on this analysis.
- Consider localized re-grading and raising area to accommodate rising water levels and increased wave height above the top of riprap. Design and apply correctly sized stone at the shoreline based on this analysis.

4.2.6 Boat Ramp

The following recommendation is provided in reference to the **Mid Term scenario** with regard to existing boat ramp:

- We recommend raising the ramp commensurate with rising tidal elevations and providing the recommended slope 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.

The following recommendation is provided in reference to the **Long Term scenario** with regard to existing boat ramp:

- In addition to considering regrading of the ramp, we recommend reviewing options for relocation of the ramp further inland to accommodate rising water levels as indicated from the MHHW level of inundation.

5.0 OPINION OF PROBABLE CONSTRUCTION COSTS

The costing information below is based on our recommendations for remedial action considering the flood modelling and observation of structures reported herein. These estimated costs include the associated design and engineering services where applicable. **Table 6** provides a summary of the estimated cost for repair or replacement of the identified vulnerabilities. A cost savings may also be expected for combined efforts for items similar in nature, for example, replacing an electrical cabinet while updating and/or securing electrical conduits. We have not considered this variable in our values. Where a complete replacement option is provided, this option and associated costs may be implemented sooner depending on the priorities and funding available to the Town.

Costing for the referenced scenario represents summation of all non-complementary improvements. That is, where other repairs or intermediate retrofitting are performed during preceding scenarios the associated costs become additive. All costs are based on present value without inflation. Provided below is a more detailed description of the items included for the associated risk scenario. Two conditions are provided in Table 6 below for costing which depends on whether or not the wharf and pier are raised. For example, certain costs are included in the scenario where the wharf/pier is raised and are therefore not itemized separately.

Table 6: Repair / Replacement / Retrofitting Costs

Facility	Present Day	Short Term	Mid Term	Long Term
Pier / Wharf	$200,000	$4,500,000	$4,500,000	$4,500,000
Floating Docks	$75,000			
Facilities	$150,000	$150,000	$250,000	$500,000
Breakwater	$150,000	$250,000	$250,000	$450,000
Shoreline Protection	$225,000	$225,000	$225,000	$300,000
Boat Ramp			$180,000	$250,000
TOTAL:	**$800,000**	**$5,125,000**	**$5,405,000**	**$6,000,000**
Improved Breakwater	**$6,000,000 - $12,000,000**	**$6,000,000 - $12,000,000**	**$6,000,000 - $12,000,000**	**$6,000,000 - $12,000,000**

As previously mentioned, we were informed that the City has considered the option of installing a more expansive breakwater to the southwest of the site, from which the majority of noteworthy threat originates. Although our assessment does not address any design related implications for the site based on reconstruction of the breakwater, we have considered costing for an option which excludes costs associated with acquiring private land or likely regulatory requirements, such as permitting. The proposed location is based on the transition between Passagassawakeag River and Belfast Bay. The costing for the improved breakwater is provided as a separate item in the table above, given it was not included as part of our analysis and no data exists indicating the degree of impact or any associated benefits from its construction. We recommend an analysis be performed which indicates the benefits achieved from installation of this structure to compare with these estimated costs. We also recommend a more fine-tuned costing effort following established options for the most cost effective locations for such a structure.

5.1 Present Day Scenario

The following costs should be expected to accommodate events associated with the Present Day scenario.

Wharf:

- 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. Repair or replace damaged section designated as Finger A herein. Design and Construction **$175,000**
- Utilities 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 enclosures should be incorporated for electrical equipment and conduits. **$10,000 - $25,000**

Floating Docks:

- Repair or replace deficient attachments and hardware as needed. Confirm systems are sufficient to resist design loading through analysis. Design and Construction **$75,000.**

Facilities:

- Raising, relocating or retrofitting Harbor Master's office. Design and Construction **$150,000**

Breakwater:

- Repair and raise breakwater based on results of current analysis. Design and Construction **$150,000**

Shoreline Protection:

- Design and install additional protection as needed on site. Design and Construction **$225,000**

5.2 Short Term Scenario

Items addressed for this section include any unaddressed items of the previous scenario (Present Day) and new risks related to the Short Term scenario. The following costs should be expected to accommodate events associated with the Short Term scenario:

Wharf:

- Consider raising the wharf and pier to accommodate rising water levels. Design and Construction **$4,500,000.**

Floating Docks:

- Repair or replace deficient attachments and hardware as needed. Confirm systems are sufficient to resist design loading through analysis. Design and Construction **$75,000.**

Facilities:

- Raising, relocating or retrofitting Harbor Master's office. Design and Construction **$150,000.**

Breakwater:

- Repair and raise breakwater based on results of current analysis. Design and Construction **$250,000.**

Shoreline Protection:

- Design and install additional protection as needed on site. Design and Construction **$225,000.**

5.3 Mid Term Scenario

Wharf:

- Consider raising the wharf and pier to accommodate rising water levels. Design and Construction **$4,500,000.**

Floating Docks:

- Raise the gangway and gangway platform to accommodate the rising water level. Design and Construction. **$275,000.**

Facilities:

- Raising, relocating or retrofitting Harbor Master's office. Design and Construction **$150,000.**
- Raise or relocate the vender offices. Design and Construction **$100,000.**

Breakwater:

- Repair and raise breakwater based on results of current analysis. Design and Construction **$250,000.**

Shoreline Protection:

- An analysis should be performed to model the behaviour of the structure for the Mid Term scenario at a minimum; any reconstruction or retrofit design should be based on this analysis. Design and Construction **$225,000.**

Boat Ramp:

- Recommend re-grading and raising. Design and Construction **$180,000.**

5.4 Long Term Scenario

This section includes costs which are expected due to the need for substantial site improvements, however some of these actions are recommended as early as the Present Day Term scenario. Items which are not addressed in earlier time periods are included here when not addressed during the course of other referenced improvements.

Wharf:

- Consider raising the wharf and pier to accommodate rising water levels. Design and Construction **$4,500,000.**

Floating Docks:

- Raise the gangway and gangway platform to accommodate the rising water level. Design and Construction **$275,000.**

Facilities:

- Raising, relocating or retrofitting Harbor Master's office. Design and Construction **$150,000.**
- Raise or relocate the vender offices. Design and Construction **$100,000.**
- Raise or relocate the fuel storage building and relocate appurtenances. Design and Construction **$250,000.**

Breakwater:

- Repair and raise breakwater based on results of current analysis. Design and Construction **$450,000.**

Shoreline Protection:

- Localized re-grading and raising area. Install riprap throughout. Design and Construction **$300,000.**

Boat Ramp:

- Re-grading and relocate as needed. Design and Construction **$250,000.**

6.0 QUALIFICATIONS OF THE REPORT

The DMR should understand that our observations may be inconclusive, or it may not be possible to identify a definitive cause of distress based on a structural inspection and visual observations alone/without further testing. The recommendations are made based on these limitations.

The "Opinion of Probable Construction Costs" is made on the basis of Wood's judgment, as experienced and qualified professionals generally familiar with the construction industry. However, since Wood has no control over the cost of labor, materials, equipment, or services furnished by others, or over the construction contractor's methods of determining prices, or over competitive bidding or market conditions, Wood cannot, and does not, guarantee that proposals, bids, or actual construction cost will not vary from the Opinion of Probable Construction Costs prepared by Wood. We have attempted to consider the general nature of the work and site conditions, based on information made available to us at this stage of the project. All costs are based on actual costs as provided by RS Means Costworks 2018, additional or other specified suppliers vendors and contractors.

7.0 CLOSING

Wood appreciate the opportunity to provide these services to DMR on this project. Please contact us with any questions or comments.

Sincerely,
Wood Environment & Infrastructure Solutions, Inc.

Tirrell Day, PE
Senior Structural Engineer

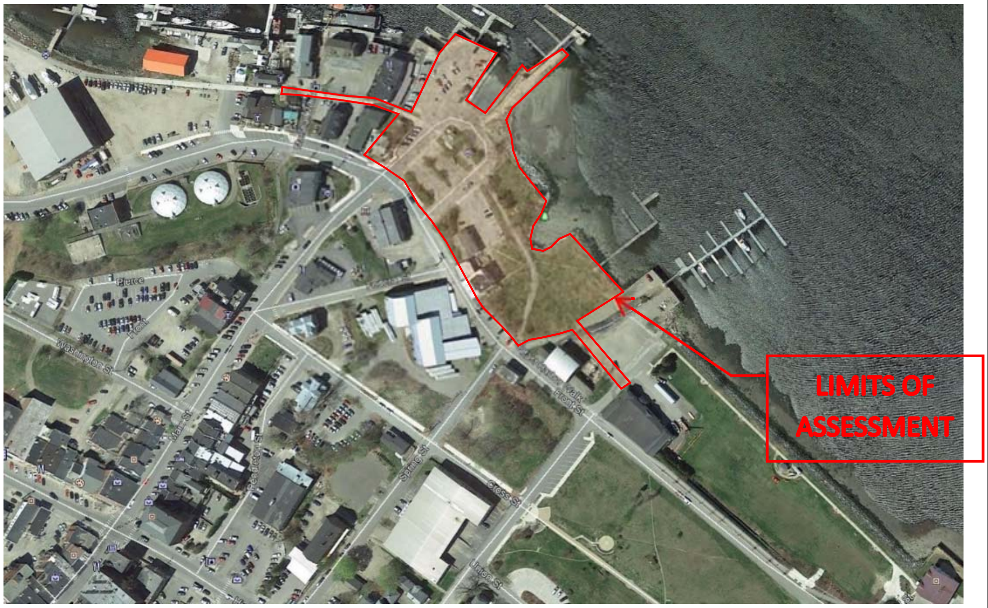
D. Todd Coffin
Associate Project Manager

Attachments: Appendix A - Photolog
Appendix B – Inundation Maps

Appendix A - Photolog for Public Landing
Belfast, ME

By: *T. Day* *Date:* *27OCT2019* *Reviewed:* *K. Sun* *Date:* *27OCT2019*

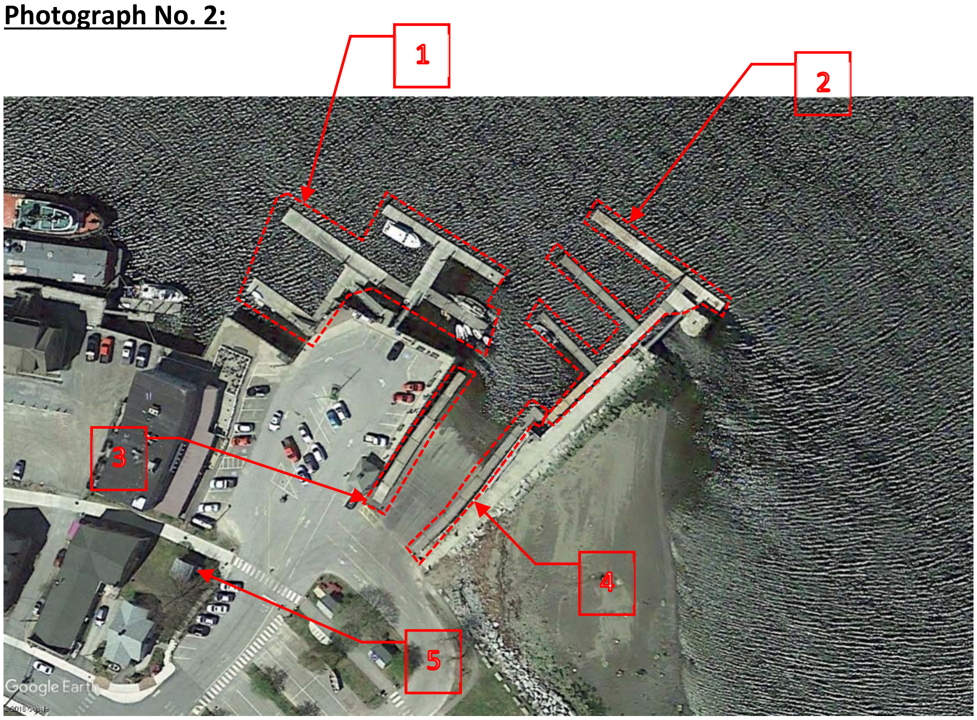
Photograph No. 1:



Comment:

Overview of Site

Photograph No. 2:



Comment:

Floating dock key

1. **Floating Dock 1**
2. **Floating Dock 2**
3. **Floating Dock 3**
4. **Floating Dock 4**

Location of Fuel Tank Storage (5).

By: *T. Day* *Date:* *27OCT2019* *Reviewed:* *K. Sun* *Date:* *27OCT2019*

Photograph No. 3: 	**Comment:** **View of wharf and parking of Public Landing Belfast**
Photograph No. 4: 	**Comment:** **View of site from east side of site looking west toward Front Street.**

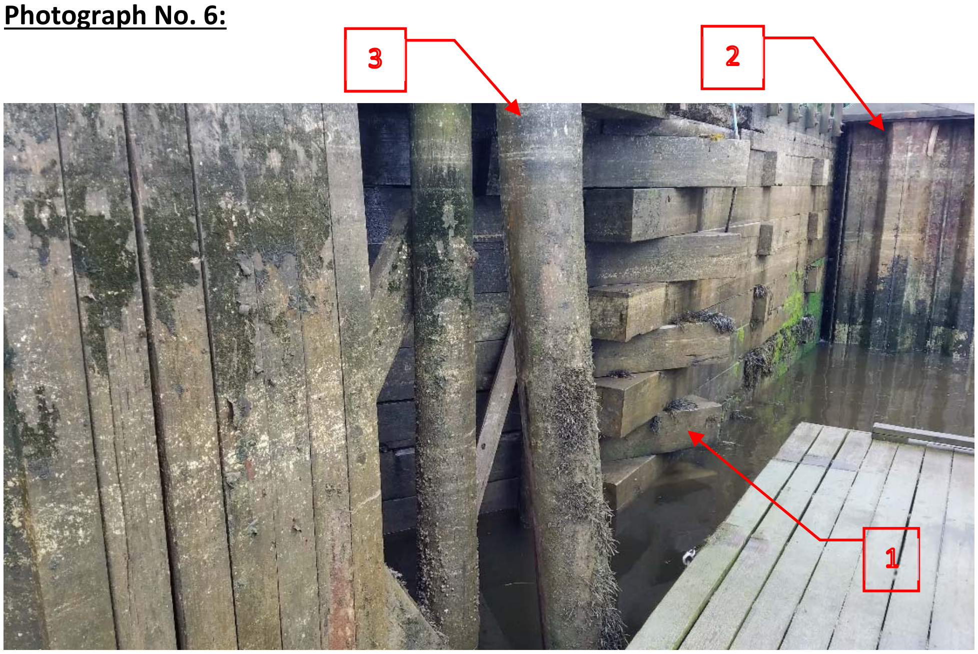
By: T. Day *Date:* 27OCT2019 *Reviewed:* K. Sun *Date:* 27OCT2019

Photograph No. 5:

Comment:

View of wharf and boat ramp.

Photograph No. 6:



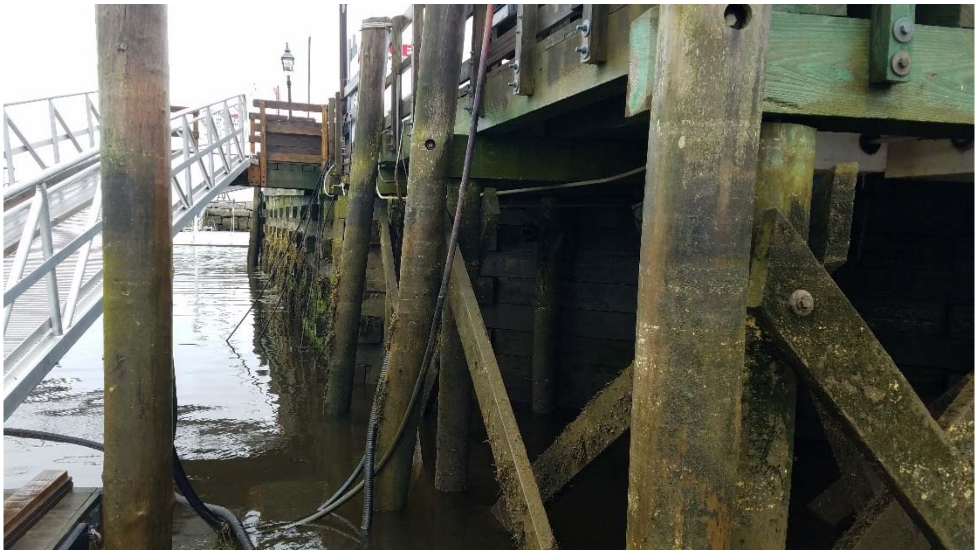
Comment:

Close up of wharf construction facing north.

1. **Stacked timbers**
2. **Sheet piles at adjacent property**
3. **Timber framing**

By: *T. Day* ***Date:*** *27OCT2019* ***Reviewed:*** *K. Sun* ***Date:*** *27OCT2019*

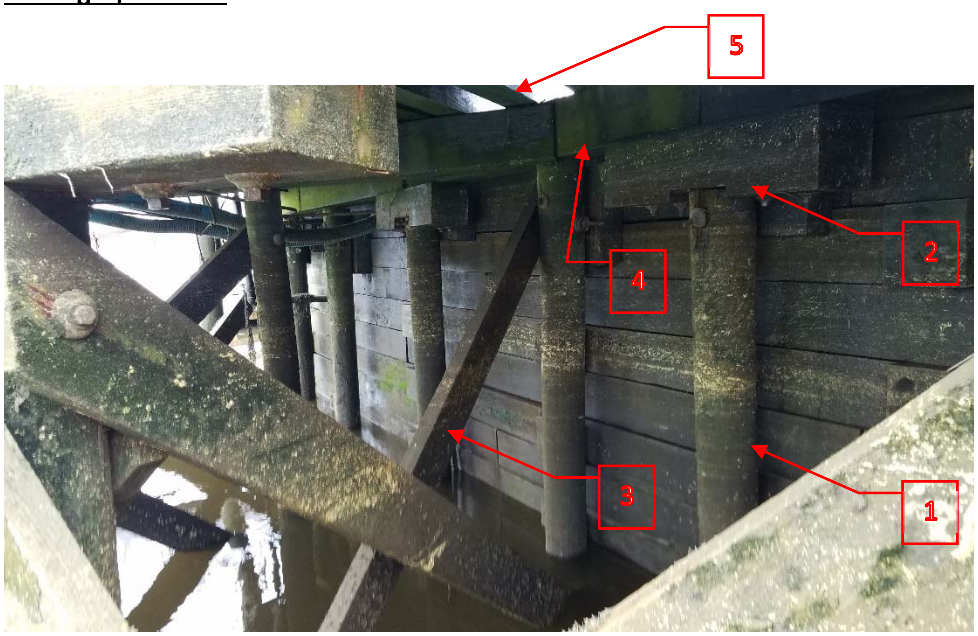
Photograph No. 7:



Comment:

Close up of wharf construction facing south.

Photograph No. 8:



Comment:

View of timber framing at underside of wharf.

1. **Timber piles**
2. **Pile cap**
3. **X-bracing**
4. **Cross beam**
5. **Stringer**

By: *T. Day* *Date:* *27OCT2019* *Reviewed:* *K. Sun* *Date:* *27OCT2019*

Photograph No. 9:

Comment:

Additional view of timber framing at underside of wharf.

1. **Deck stringer**
2. **Support for hoist**

Photograph No. 10:

Comment:

Small landing at wharf for access to floating dock.

***By:* T. Day *Date:* 27OCT2019 *Reviewed:* K. Sun *Date:* 27OCT2019**

Photograph No. 11:

Comment:

Splitting noted at timber pile supporting the small landing in previous photo.

1. **Splitting**

Photograph No. 12:

Comment:

Overview of wharf construction near boat ramp, and floating dock 3 and mooring piles.

By: *T. Day* *Date:* *27OCT2019* *Reviewed:* *K. Sun* *Date:* *27OCT2019*

Photograph No. 13:

Comment:

Closeup of wharf construction near boat ramp.

View of mooring piles for floating dock.

Photograph No. 14:

Comment:

View of wharf from above.

By: *T. Day* *Date:* *27OCT2019* *Reviewed:* *K. Sun* *Date:* *27OCT2019*

Photograph No. 15:	Comment:
	Closer view of north section of wharf.

Photograph No. 16:	Comment:
	View of Floating Dock No. 1 near second gangway access.

By: *T. Day* ***Date:*** *27OCT2019* ***Reviewed:*** *K. Sun* ***Date:*** *27OCT2019*

Photograph No. 17:

Comment:

Typical attachment of floating dock with buoy chains at mooring piles.

Photograph No. 18:

Comment:

View facing south of boat ramp and Harbor Master's office.

By: *T. Day* *Date:* *27OCT2019* *Reviewed:* *K. Sun* *Date:* *27OCT2019*

Photograph No. 19:

Comment:

1. **View of boat ramp**
2. **View of floating dock 4.**
3. **View of breakwater.**

Photograph No. 20:

Comment:

View of Floating Dock No. 4 at high tide.

By: *T. Day* *Date:* *27OCT2019* *Reviewed:* *K. Sun* *Date:* *27OCT2019*

Photograph No. 21:	Comment:
	Overview of breakwater. Remediated area visible from south side of structure.

Photograph No. 22:	Comment:
	View of Breakwater from south side.

By: T. Day Date: 27OCT2019 Reviewed: K. Sun Date: 27OCT2019

Photograph	Comment
Photograph No. 23: 	**Comment:** **View of breakwater from above.**
Photograph No. 24: 	**Comment:** **View at end of breakwater. Entrance to floating dock 2**

By: T. Day *Date:* 27OCT2019 *Reviewed:* K. Sun *Date:* 27OCT2019

Photograph No. 25:

Comment:

View of mooring structure for floating dock.

Photograph No. 26:

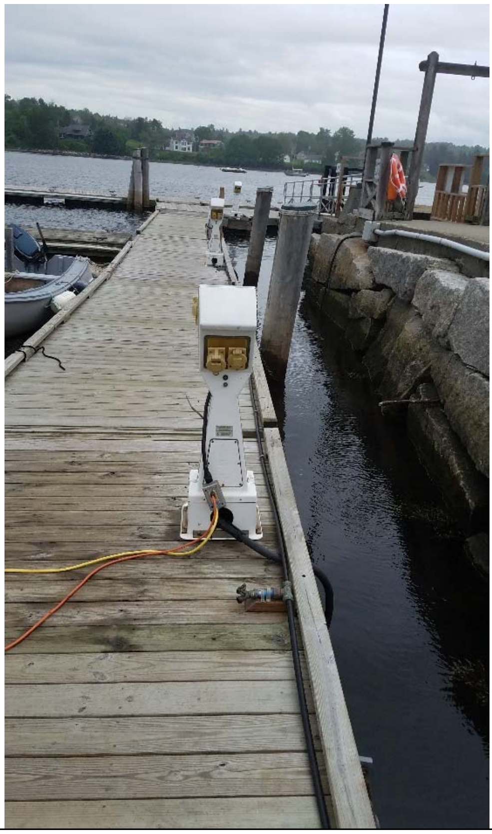
Comment:

View of attachment of floating dock to structure via mooring clamp.

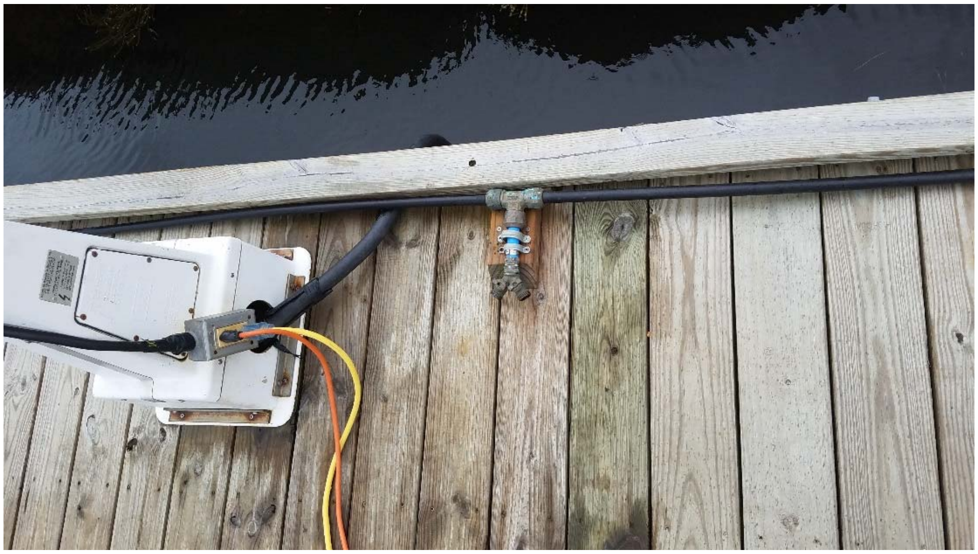
By: *T. Day* *Date:* *27OCT2019* *Reviewed:* *K. Sun* *Date:* *27OCT2019*

Photograph	Comments
Photograph No. 27: 	**Comments:** **Condition of steel at mooring structure noted. Moderate to major corrosion noted.**
Photograph No. 28: 	**Comments:** **View of floating dock 2 and gangway.**

By: T. Day *Date:* 27OCT2019 *Reviewed:* K. Sun *Date:* 27OCT2019

Photograph No. 29: 	**Comment:** 1. **View of support for gangway at end of breakwater.**
Photograph No. 30: 	**Comment:** **Floating dock 4.** **Utilities noted on dock to include water and power.**

By: *T. Day* ***Date:*** *27OCT2019* ***Reviewed:*** *K. Sun* ***Date:*** *27OCT2019*

Photograph No. 31:	**Comment:**
	**View of water and electrical conduits.** **Moisture proof electrical fixtures do not appear to be used.**
Photograph No. 32:	**Comment:**
	**View of Harbor Master's Office from wharf looking west.**

By: *T. Day* ***Date:*** *27OCT2019* ***Reviewed:*** *K. Sun* ***Date:*** *27OCT2019*

Photograph No. 33:

Comment:

View of Fuel storage building.

Photograph No. 34:

Comment:

View of vender building for boat tours.

By: T. Day Date: 27OCT2019 Reviewed: K. Sun Date: 27OCT2019

Photograph No. 35:

Comment:

View looking south at breakwater.

Shoreline Protection:

1. **Location of previous remedial work to stabilize breakwater deterioration.**
2. **Washed out smaller rock and bare area with no large riprap adjacent to breakwater as shoreline protection.**

Photograph No. 36:

Comment:

View of shoreline further south of the breakwater.

Greenway and trail visible.

By: T. Day Date: 27OCT2019 Reviewed: K. Sun Date: 27OCT2019

Photograph	Comment
Photograph No. 37: 	**Comment:** **View of shoreline protection near extents of property at south side.**
Photograph No. 38: 	**Comment:** **View of drain pipe which drains into shoreline.** **An unprotected channel is noted with signs of erosion.**

By: *T. Day* ***Date:*** *27OCT2019* ***Reviewed:*** *K. Sun* ***Date:*** *27OCT2019*

Photograph No. 39:

Comment:

Overview of location of storm pipe.

Photograph No. 40:

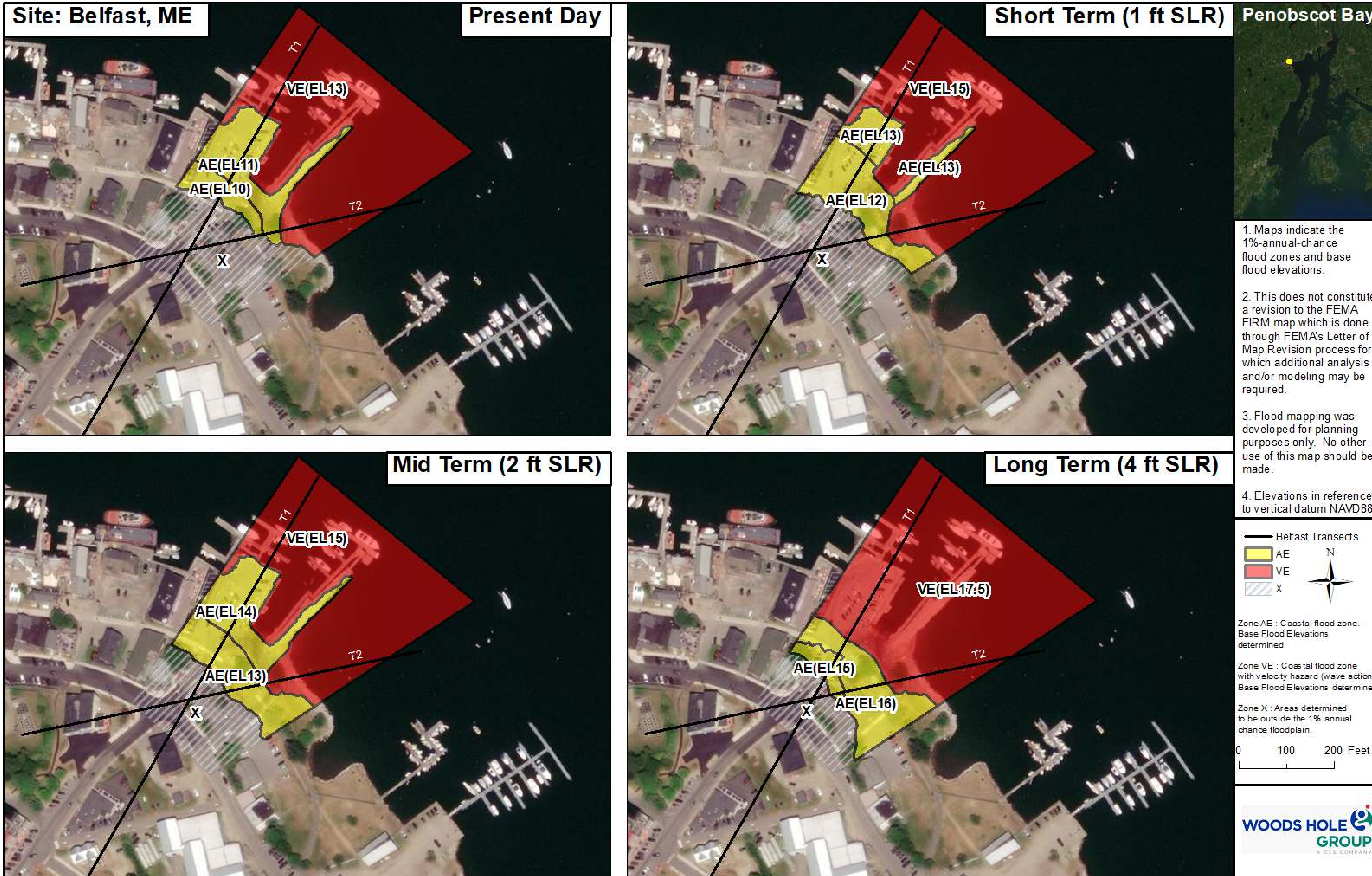
Comment:

View of Belfast Walkway

By: *T. Day* *Date:* *27OCT2019* *Reviewed:* *K. Sun* *Date:* *27OCT2019*

Photograph No. 41: 	**Comment:** **View at north side of breakwater.** **1. Material at north side which appears to have eroded from breakwater interior.**
Photograph No. 42: 	**Comment:** **Closer view at north side of breakwater.** **View of apparent void indicating loss of fill material.**

Appendix B – Inundation Maps


Site: Belfast, ME
Present Day
T1
T2
VE(EL13)
AE(EL11)
AE(EL10)
X
Short Term (1 ft SLR)
VE(EL15)
AE(EL13)
AE(EL13)
AE(EL12)
X
Mid Term (2 ft SLR)
VE(EL15)
AE(EL14)
AE(EL13)
X
Long Term (4 ft SLR)
VE(EL17.5)
AE(EL15)
AE(EL16)
X
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