MAINE COASTAL PROGRAM

Town of Machias, Maine

Waterfront Resilience Study

BAKER DESIGN CONSULTANTS
Civil, Marine, & Structural Engineering

In Partnership With:

RANSOM
Consulting Engineers and Scientists

West Falls Surveying
Machias, Maine

Completed - February 2019

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Leaders

Judy East – Washington County Council of Governments

Christine Therrien – Machias Town Manager

Tora Johnson – University of Maine at Machias GIS Service Center

Key Stakeholders and Advisors

Anne Ball – Maine Development Foundation, Maine Downtown Center

Angela Fochesato – Chair, Machias Downtown Revitalization Committee

Ann Fuchs- State Hazard Mitigation Officer, Maine Emergency Management Agency

Charles Rudelitch – Sunrise County Economic Council

Pete Slovinsky – Maine Geological Survey

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1. *Executive Summary*

The Machias Downtown Resilience and Renewal Study was made possible by a Maine Coastal Program Community Grant awarded to the Town Machias. The grant enabled the Town to retain a consultant team led by Baker Design Consultants, Inc. (BDC) to investigate and define the risk of flood damage to downtown Machias and to develop a concept engineering design for a flood protection system. On the BDC Team were West Falls Surveying (WFS) and Ransom Consulting (Ransom) who provided topographic survey and flood analysis respectively.

This study has drawn from related work programs undertaken and in progress by the Town of Machias, the Washington County Council of Governments and the University of Maine at Machias GIS Service Center. Refer to the APPENDIX located on page 27.

1.a. Introduction

The catalyst for this study is the periodic flooding that occurs in the historic Machias Downtown Area. The section of the 2017 FEMA Flood Map provided in Figure 1 below shows areas mapped as Special Flood Hazard Areas ([1]SFHAs). One SFHA extends east from the Route 1 Dyke into the Machias Downtown Area. Another isolated SFHA is next to the Machias Waste Water Treatment Plant. These areas and adjacent properties define the area considered for this project.

A separate initiative, in progress by the Maine Department of Transportation, includes design development for rehabilitation or replacement of the Route 1 Dyke with consideration of the Dyke location within the SFHA and tidal flow on the Middle River.

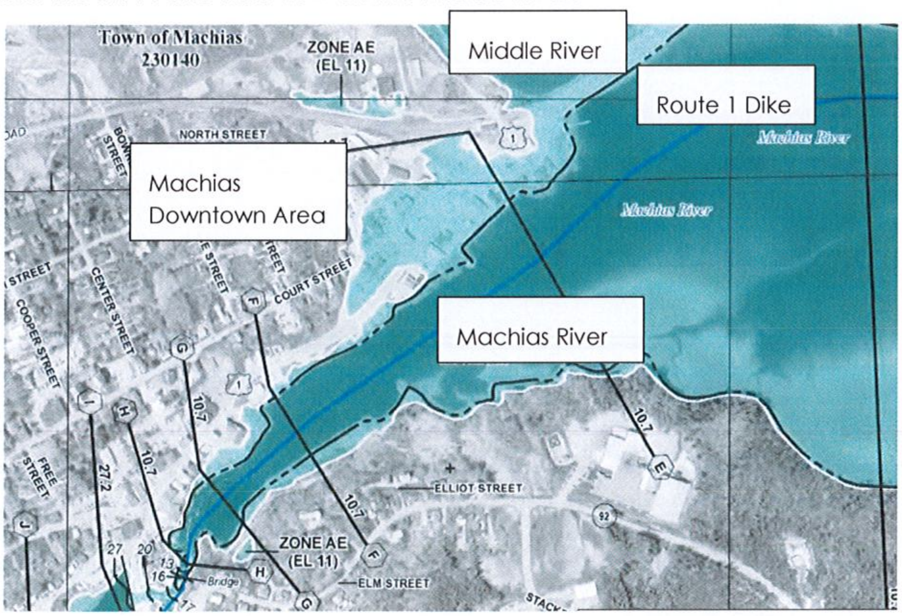

Figure 1 – Down town Machias on 2017 FEMA Flood Insurance Rate Map

[1] Special Flood Hazard Areas are where a flood that exceeds the Base Flood Elevation (BFE) is expected to occur with a probability of 1%. The BFE = 11 NAVD88 for the isolated Zone AE SFHA on the Town WWTP property. The BFE = 10.7 NAVD88 for those downtown area along the Machias River and across the Dyke.

1.b. Work undertaken for this Study

A summary of the concurrent activities that have been undertaken by the Baker Design Consultants Team and stakeholder are summarized below.

- West Falls Surveying (WFS) provided detailed mapping of the Machias downtown area using aerial survey drone technology rectified by and supplemented with detail ground measurements to determine building floor elevations.
- Ransom Consulting (Ransom) completed a flood hazard synopsis that considered current conditions, historical events and future sea level rise modeling to generate probability predictions for future flooding with sea level rise. This work is described in a report that is in *APPENDIX B-Present and Future Flood Risk.*
- The BDC team completed an inventory of buildings and properties in the downtown area in order to evaluate the impacts associated from a variety of flood inundation events that ranged from BFE+0-ft to BFE+6-ft.
- Staff and students from the University of Maine at Machias GIS Department completed a damage assessment modeling for the same series of flood inundation scenarios based on the building inventory, infrastructure and resources impacted by the flooding. This information provides an early cost-benefit indicator for the flood protection system concept design.
- The Washington County Council of Governments provided project management. Stakeholder selection and communication and collected oral history narratives referencing conditions in the Downtown area. Several Public Meetings were scheduled and well attended.
- BDC developed a concept design for a seawall system to protect the Downtown area based on the research, fieldwork and stakeholder input to date. The design is illustrated in drawings that are provided in Appendix E of this report.
- BDC prepared an estimate of construction cost based on the concept design presented in Appendix E. Refer to *Appendix D – Seawall System Program Costs*
- To move the project forward, BDC worked with the Town of Machias, Washington Council of Governments and the Maine Emergency Management Agency to define a Pre-Disaster Mitigation Advance Assistance Program for additional fieldwork and design necessary to move the project forward. Program tasks, costs and timeline are provided in *Section 6-Next Steps to move the Project forward.*

Figure 2 –Historical Development on Machias River looking downstream. Downtown Area is on left of River

Figure 3 –2018 picture looking upstream with remnants of cribwork that supported former docks.

1.c. The need for Flood Protection to the Downtown Area`

Based on the work completed for this study, a seawall system is needed to protect the Machias Downtown Area from flooding and associated property damage.

The Machias Downtown Area is primarily comprised of commercial development and includes the Waste Water Treatment Plant that is considered critical infrastructure. Highway Route 1 runs through this area and is considered the primary regional artery for north-south traffic.

The cost and property impact for single storm events at several flood inundation levels were estimated by staff and students from the University of Maine at Machias GIS Service Center. Inventory information for each property and plans that illustrate the extent of flooding for each inundation event are provided in *APPENDIX C- Flood Impacts to Machias Downtown Property*. It is not surprising that the number of properties impacted, and the cost associated with each storm event increases exponentially as the flood inundation level increases. What is also apparent is the acute reduction in primary road network access to the area that directly impacts fire, rescue and emergency response. Not only will a seawall protection system make the area safer by reducing the risk of flooding, but it will also reduce costs to property owners by effectively eliminating flood damage. With the installation of a Seawall System, the mapped SFHA areas are effectively removed from the FEMA FIRM with a Zone X designation.

Flood scenarios are summarized in the Table 1 below and illustrated in Figures 2 to 6 that follow.

<table>
<tr><th>Flood Event/Elevation</th><th>Total Economic Impact</th><th>No of Buildings Inundated</th><th>Route 1 Status</th><th>Notes</th></tr>
<tr><td>Base Flood</td><td>$ 713,297</td><td>1</td><td>Passable</td><td>Court Street Flooded</td></tr>
<tr><td>Base Flood Plus 2-ft</td><td>$ 7,918,338</td><td>12</td><td rowspan="3">Flooded for Length of Dyke</td><td>Many Buidings surrounded by water</td></tr>
<tr><td>Base Flood Plus 4-ft</td><td>$ 16,889,819</td><td>22 including WWTP</td><td rowspan="2">Significant Risk to Shellfish Habitat</td></tr>
<tr><td>Base Flood Plus 6-ft</td><td>$ 23,699,916</td><td>23 including WWTP</td></tr>
</table>

Table 1 – Building Inundation and Estimated Costs per Flood Event

The Downtown Area topography was mapped using drone technology that resulted in a very detailed survey that allowed for a more accurate determination of the Base Flood boundary and corresponding SFHA areas than currently shown on the 2017 FEMA FIRM (larger light blue area in . Figure 2 below.

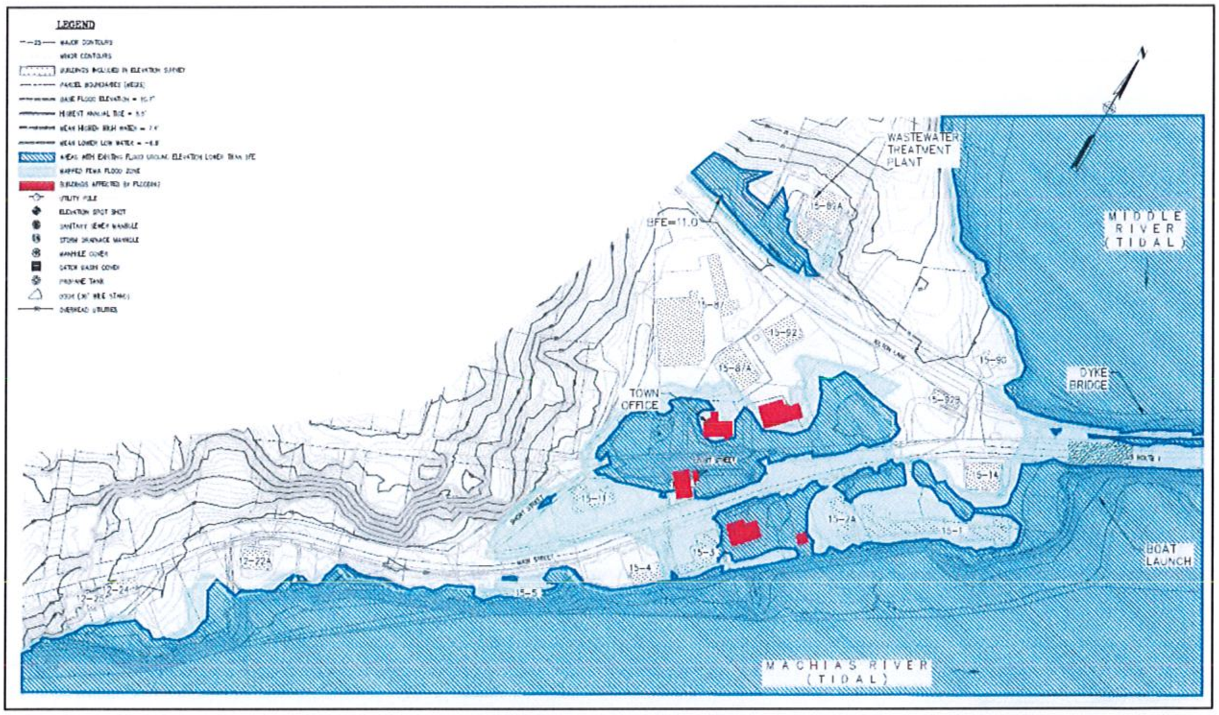

Figure 4 – Mapped SFHA's vs Surveyed Areas above BFE; Building Inundation shown in red.

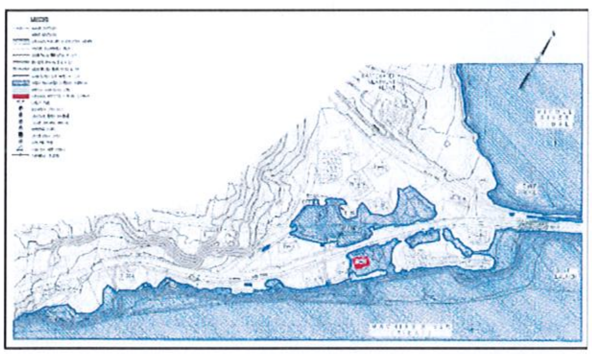

Figure 5 – Effective Base Flood Elevation;

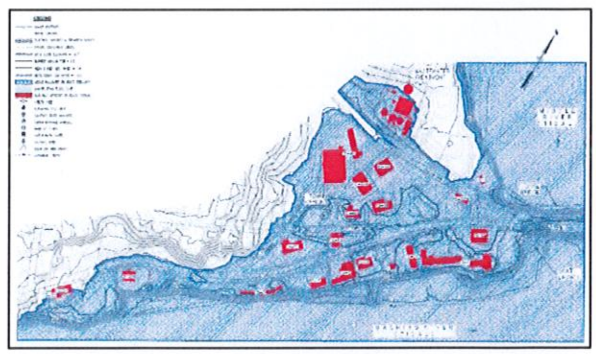

Figure 7 – Base Flood Elevation plus 4-FT

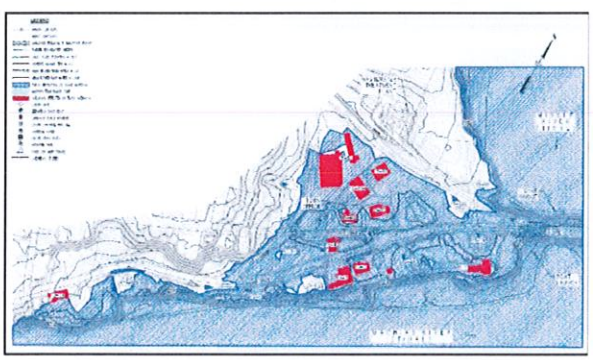

Figure 6 –Base Flood Elevation plus 2-FT

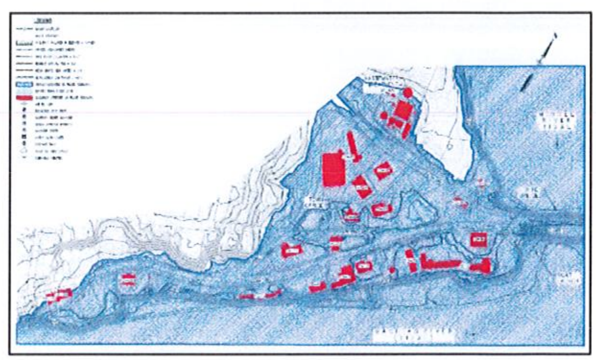

Figure 8 – Base Flood Elevation plus 6-FT

1.a. Recommended Design Height for the Seawall System

The primary goal of the seawall system is to protect property for the life of the structure. The basis for design height selection is discussed in detail in12 *Section 3 Predicting Future Flood Elevations* that starts on page12.

Freeboard and Sea Level Rise (SLR) are used to determine the height of the seawall protection system for Machias. Freeboard is the clearance of the seawall crest above the design flood elevation and is easily determined using standards established by FEMA. However, SLR will affect the future design flood elevation, so it is paramount to include some provision for SLR in determination of the height of the seawall. While existing FEMA determination of Base Flood Elevation is based on historical data, SLR can only be predicted by probability models.

A summary of SLR predictions for Cutler, Maine is tabulated and shown graphically in Figure 2.

Flood Scenario	Flood Elevation (FT, NAVD88)	Description	Sea Level Rise Accommodated* At 2060 (40 yrs)	At 2100 (80 yrs)
1	10.7	BFE	---	---
2	12.7	BFE + 2'	Intermediate	Intermediate-Low
3	14.7	BFE + 4'	High	Intermediate
4	16.7	BFE + 6'	Extreme+	Intermediate-High

**SLR scenarios based on NOAA et al. 2017 model for Cutler, ME*

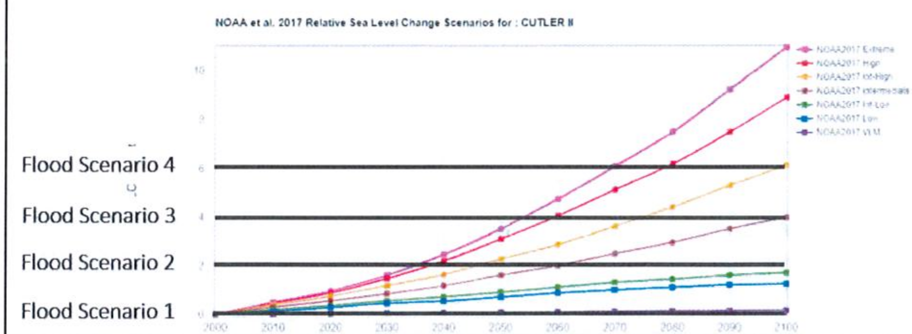

Figure 9 – SLR Predictions for Cutler Tidal Station based on NOAA 2017 Model

The basis for the recommended seawall system design height selected for this study is summarized in Table 2 on the next page with the primary factors being as follows.

- A minimum freeboard[2] of 2-ft is required to maintain a FEMA certification for a seawall shown on the FEMA FIRM maps.
- A minimum freeboard of 3-ft is required to protect the Machias Waste Water Treatment Plant which is considered critical infrastructure in compliance with the New

[2] The minimum 2-ft Freeboard above BFE was selected because the flooding in this area is more influenced by coastal storm surge than riverine conditions.

England Interstate Water Pollution Control Commission TR-16 Guides for the Design of Wastewater Treatment Works.

- If properly constructed, managed and maintained, a flood protection structures will effectively have an indefinite life span. Therefore, the Seawall System design must include provision for Sea Level Rise (SLR) over the life of the structure. A minimum of 2-ft SLR has been applied to the design with the understanding that this is an 'intermediate' model prediction over the next 80 years and with the understanding that the seawall system will include some provisions to increase height during this period if higher increases in SLR occur.
- It is recognized that the lowest cost opportunity to increase future seawall height is to incorporate adaptability features into the seawall system that would allow it to be modified in the future to increase flood protection in a cost-effective manner that did not require total reconstruction. Future height adaptability to accommodate a higher SLR should be considered in final design of the seawall system.

The Concept Design developed for this report was for a seawall system that provides protection in accordance with the Tabulated elevations in Table 2 below. Protection against overtopping is BFE + 4-ft for the entire downtown area with additional protection (BFE+ 5-ft for the WWTP which is considered critical infrastructure. The Seawall System concept design includes provisions to increase the height to maintain recommended freeboard.

Flood Protection	2017 BFE NAVD88	Min criteria for FEMA FIRM Designated Seawall (Levee)		NE Interstate Water Pollution Control Commission TR-16		SLR Allowance (FT)	2020 Design Seawall Ht (Nearest FT)	Future Ht Adaptability	
		BFE Freeboard (FT)	Min Seawall Ht NAVD88	BFE Freeboard (FT)	Min Seawall Ht NAVD88			Increased SLR	Seawall Ht NAVD88
Downtown Buildings	10.7	2	12.7			2	15	2	17
WWTP (Critical Infrastructure)	11			3	14	2	16	2	18

Table 2 – Determination of Seawall Design Height

1.b. Seawall System Design Summary and Cost

The concept design for the seawall system is illustrated in the Appendix E –Seawall System Concept Design Drawings. An overview plan is provided below. The design is discussed in detail in *Section 4 Design Development of the Seawall System.*

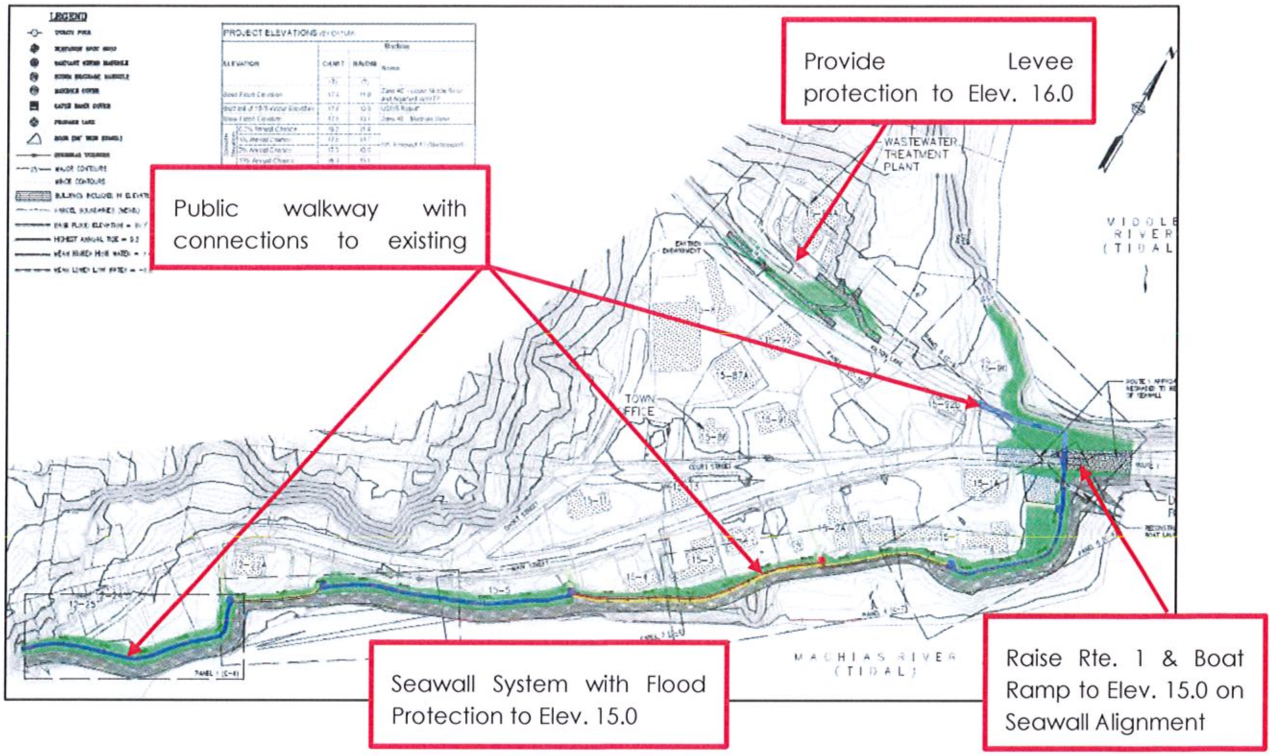

Figure 10 – Machias Downtown Seawall System Overview Plan

Three (3) distinct cross-sections combine to form contiguous elements of a perimeter flood protection system around the downtown area. One section is an earthen embankment, one incorporates a shorefront bulkhead and the third section includes an elevated timber walkway in combination with the bulkhead. In accordance with the Machias Comprehensive Plan, the seawall system is integrated with a pedestrian walkway with links to internal sidewalks within the downtown area and connections to an established and popular trail corridor that is used extensively by Town residents and visitors to the area.

The alignment for the seawall system was selected to minimize impacts to existing upland properties and to address coastal embankment erosion which extends into an intertidal area that has a history of marine development. Today, the remnants of former docks that lined the Machias River are deteriorating exposing the shorefront properties to coastal erosion. The proposed seawall system is intended to stabilize the shore. While stone armoring is used extensively as an effective measure against wave action and river scour, the seawall system is intended to include 'living shoreline' features such as plantings, vegetation and habitat restoration.

The cost for the Seawall system based on the Concept Design Drawings provided in APPENDIX E estimated to be in the range of $11 Million Dollars. Refer to the Construction Cost Estimate provided in *Appendix D – Seawall System Program Costs.*

2. *Background, Purpose, and Need*

The Town of Machias is in Washington County, Maine with a historic downtown waterfront along the Machias River.

The focus of this study is the Downtown Waterfront area which includes low-lying areas on the north/west side of the Machias River downstream of Bad Little Falls, and west of the Middle River, with the Dyke on the Downstream end.

The Downtown Waterfront area has a long and storied history dating back to the 1600's that includes shipbuilding, log driving, and other water-dependent commerce that has relied on connections to the Machias River and the Gulf of Maine downstream. In more recent history, marine traffic has been limited to smaller vessels due to the construction of a fixed bridge downstream in Machiasport in 1971 with limited vertical clearances.

As a transportation corridor, this area is important locally and regionally. US Route 1 (Main Street) passes through the Downtown Waterfront area before it crosses the Dyke and continues into East Machias.

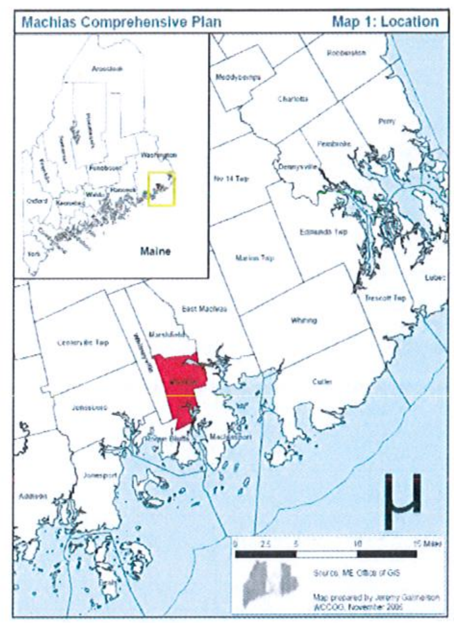

Figure 11 - Location Map of Machias, ME (Source: Town of Machias 2006 Comprehensive Plan)

Today, a range of upland uses are present in the Downtown Waterfront area that includes residential homes, commercial businesses, municipal buildings (the Town Office), and open space. The Town's Shoreland Zoning Map delineates downtown areas as General Development and Maritime, or Commercial Fisheries/ Marine Activities. These zones generally allow dense development with support for water-dependent and traditional maritime uses of the waterfront.

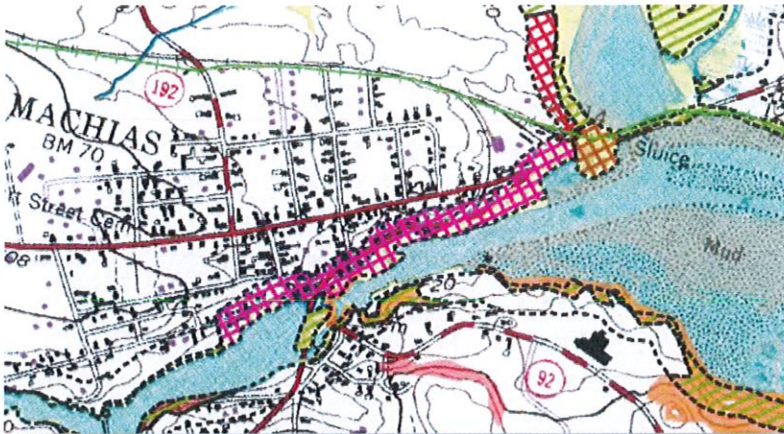

Figure 12 - Section of Machias Zoning Map

The geographical setting and development history of the Downtown Waterfront area each contribute to current flood exposure and an increasing vulnerability that will occur with sea level rise (SLR). **The purpose of this study has been to evaluate current flood stage conditions, model the impact of Sea Level Rise and to identify solutions to improve flood resiliency.** The report considers each of these items in detail and concludes that a **Disaster Mitigation Plan** that includes a flood protection seawall is needed to address flood resiliency for the Downtown Waterfront Area. The outline below provides a summary of the critical findings/components of this plan:

2.a. Flood Risk

Much of the Downtown Waterfront area is located below or only slightly above the Base Flood Elevation (BFE) as established by FEMA. The location of the BFE serves as a benchmark from which to compare historical and recent flooding and defines the regulatory standards for an evaluation of current building compliance within the Town's Floodplain Management Ordinance.

It is recognized that both buildings and non-building infrastructure (roads and utilities) are currently impacted by flooding in the Downtown Waterfront area. The report presents damage estimates for costs that have occurred in recent storm events that approach the BFE and makes projections for costs associated with flooding associated with an increase in Sea Level Rise (SLR).

2.b. Bank Erosion

The immediate shoreline along the Machias Waterfront has been heavily altered during a long history of waterfront development where fill, timber cribs and wharves were used to create upland above tidal wetlands and an armored shorefront along the river. Today, there are sections where structures are deteriorating, resulting in the exposure and erosion of fill material. Stabilization is primarily needed to protect upland property and to reduce migration of fines into the coastal wetland. A secondary goal that goes beyond the scope of this study is to incorporate 'living shoreline' concepts to restore sections of the intertidal resource.

2.c. Stormwater Management

Ineffective stormwater management contributes to flooding issues in Downtown Machias. For example, low area ponding on Court Street in front of the Town Office effectively close that road to access during flood stage conditions.

An inventory of storm drain grate inlets in the Downtown Waterfront area found many to be at elevations only 1'+/- above the highest annual tide which is significantly below the BFE. Clearly, the storm water system needs to be upgraded with improvements that include backflow prevention and storage and/or pumping infrastructure to address flood stage stormwater runoff.

2.d. Critical Infrastructure (WWTP) At Risk of Flooding

The Wastewater Treatment Plant is in the Downtown Waterfront Area and is partially within a FEMA mapped Special Flood Hazard Area. Currently, the facility outfall discharges by gravity when tidal elevations are low, but during normal high water (and flood stage conditions) the outfall must be pumped to prevent back-flow through the system. Clearly, any increase in the duration or height of flooding will put greater stress on the facility.

2.e. Revitalization

The Downtown Waterfront area is ripe for revitalization, and the completion of shoreline stabilization and installation of flood protection structures provides an opportunity to extend an existing coastal trail, to create public spaces on the shore, and to improve waterfront access for recreational and commercial boating. These enhancements would serve to increase public access and interest in a beautiful setting and contribute the transformation into a vibrant downtown.

In summary, this study provides a survey and an assessment of downtown infrastructure to support flood risk and damage projections and considers a new seawall system to protect downtown Machias, along with associated improvements to stormwater and transportation networks.

3. *Predicting Future Flood Elevations*

3.a. Historical Data Review

The Machias River experiences fluctuations in daily and seasonal water level that are influenced by semi-diurnal tides in the Atlantic Ocean, as well as riverine conditions in the 60-mile-long Machias River that originates at Fifth Lake in T36 MD BPP.

Several sources were referenced to establish the range of potential water levels in Downtown Machias, including normal tides, storms of record, and regulatory flood elevations. Additionally, a review of recent storm surge modeling completed by Ransom Consulting Engineers (included in Appendix B) provides a candid review of potential future water levels in consideration of sea level rise, storm surge, and uncertainty with future projections.

In 2011, Maine DOT completed tidal monitoring in the Machias River just downstream of the Dyke as part of a Hydrology and Hydraulic study associated with the replacement of the Dyke Bridge. For this study, the Maine DOT data was used to establish MLLW, MLW, MHW, and MHHW elevations. The total tidal range based on this data is 14.2'.

For comparison, tidal data in Eastport and Machiasport are provided in Table 3, along with predicted tidal elevations using NOAA's online vertical datum transformation tool. The data suggest that the tidal data established by Maine DOT are appropriate.

Table 3 – Tidal Elevations at Machias and Nearby Locations

Location	Eastport	Machiasport, Machias River	Machias River Downstream of Dyke	Machias River, Downstream of Dike
Source	**NOAA Tidal Station 8410140**	**NOAA Tidal Station 8411467***	**Maine DOT 2011 Tidal Monitoring**	**Predicted using NOAA VDATUM**
MHHW	9.34	6.44	7.40	6.88
MHW	8.86	6.11	6.50	6.46
NAVD88	0.00	0.00	0.00	0.00
MLW	-9.49	-6.55	-6.40	-6.62
MLLW	-9.93	-6.85	-6.80	-6.93
Tidal Range	19.27	13.29	14.2	13.81

**Subordinate Station of Eastport, Tidal elevations predicted by multiplying values at Eastport by a conversion factor of 0.69.*

The report "Coastal Flood of February 7, 1978 in Maine, Massachusetts, and New Hampshire" published by U.S. Geological Survey lists a water elevation of 10.8' (converted to NAVD88 from the published elevation of 11.51' in NGVD29) observed at the Sears store on Route 1.

FEMA has published a new Flood Insurance Study and corresponding Flood Insurance Rate Maps as of summer 2017. Based on the mapping for the Machias River, the Base Flood Elevation is 10.7'.

Additionally, some of the most severe coastal flooding in recent history occurred during Winter Storm Grayson on January 4, 2018. During this time, the following verified elevations were recorded or predicted at nearby tidal stations on the Maine Coast:

Table 4 – Winter Storm Grayson Water Elevations

Location	**Bar Harbor**	**Cutler**	**Eastport**	**Machiasport**
Winter Storm Grayson	**9.07**	**11.06**	**13.46**	*10.5 (Estimated from Photographs[3])*
Predicted	7.33	9.33	12.37	8.54
MHHW	5.40	7.01	9.34	6.44
Difference between recorded water elevation and:				
Predicted	1.74	1.73	1.09	1.66 to 1.96
MHHW	3.67	4.05	4.12	*3.76 to 4.06*

Photo evidence from the Machias Downtown area during the storm event, combined with survey data from this study, show the water level to be in the range of 10.5'+/-. Localized conditions may have caused the water level to exceed the Base Flood Elevation. Several photos are shown for reference on the following page.

[3] From the data that was recorded at Bar Harbor and Cutler, and the predictions for Machiasport during the corresponding tide cycle, it can be estimated that the water level in Machias likely reached an elevation in the range of 10.2' – 10.5'.

Typical Conditions | **Winter Storm Grayson, Jan. 4, 2018**

Machias Boat Ramp

Parking Lot Adjacent Machias River Inn

Machias River Redemption

Figure 13 – 1.4.18 Winter Storm Grayson Pictures- Flooding approaches BFE

3.b. Sea Level Rise

In addition to regular tidal fluctuations, storm surge, wave action, and riverine flooding, another potentially significant factor in the future water elevations experienced in Downtown Machias is Sea Level Rise.

The plot below shows projections for Sea Level Rise at the Cutler tidal station based on NOAA's 2017 model. The plot provides a range of scenarios that can be considered, however provides no basis for assessing how likely any of these scenarios is to occur.

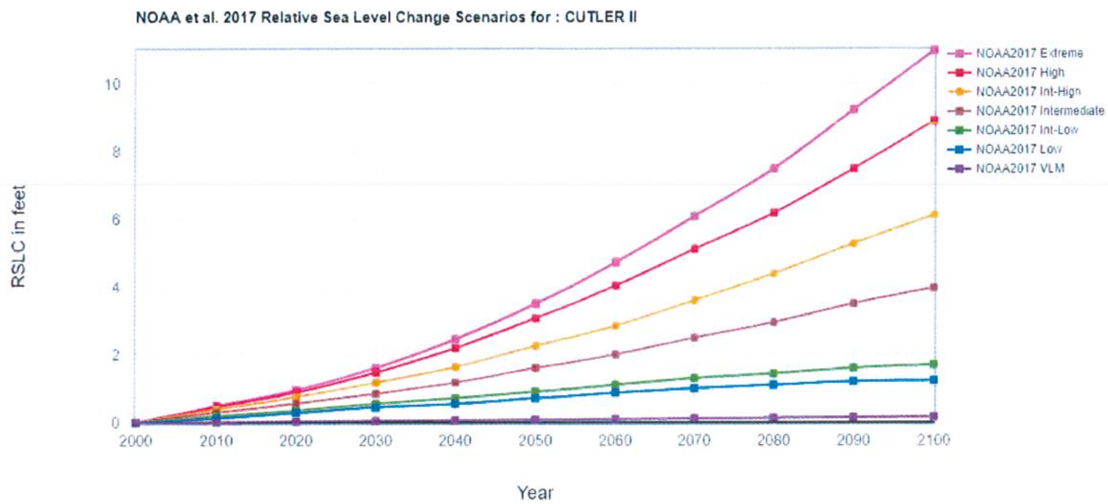

Figure 14 – SLR Predictions for Cutler Tidal Station based on NOAA 2017 Model (produced by BDC using Corps Climate Sea Level Change Curve Calculator)

In order to develop a more detailed understanding of potential future water levels that may be experienced by the Downtown Machias area, a review was completed by Ransom Consulting Engineers. This review considers the complex factors contributing to sea level rise, as well as statistical variability in mean sea level, potential storm surge events, and reasonable levels of uncertainty, to develop projected Total Water Levels at future times and at a range of recurrence intervals. This data is presented in <u>*APPENDIX B-Present and Future Flood Risk.*</u>

3.c. Determining Economic Losses from Future Flood Events

Flood damage assessments are traditionally tied to the BFE mapped by FEMA. The Ransom report provided in <u>*Appendix B – Present and Future Flood Risk Assessment Memo*</u> contains water surface elevations for various recurrence intervals that change by decade to incorporate long-term sea level rise and/or changing storm intensities (e.g., a 100-year recurrence interval has a BFE of 10.7 ft today but the 100-year recurrence interval has a BFE of 12.2 ft in 2050). Therefore, an assessment of future flood damages should consider and increase in BFE. Furthermore, an estimate of the cumulative economic losses that the proposed flood protection structures would protect against throughout their useful life would have two distinct components

- An estimate of the frequency and magnitude of flood events that may occur throughout the lifespan of the flood protection structures
- An estimate of economic losses resulting from these flood events.

TWL in Feet NAVD88		Average Recurrence Interval (years)							
		2	5	10	20	50	100 (BFE)	250	500
Future Year	2020	8.3	9.5	10.1	10.7	11.3	11.7	12.3	12.7
	2030	8.8	10.0	10.6	11.2	11.7	12.1	12.7	13.1
	2040	9.0	10.3	10.9	11.5	12.1	12.5	13.0	13.3
	2050	9.3	10.5	11.2	11.8	12.4	12.9	13.4	13.7
	2060	9.5	10.8	11.5	12.1	12.7	13.2	13.7	14.0
	2070	9.7	11.1	11.8	12.4	13.1	13.6	14.2	14.8
	2080	10.0	11.4	12.1	12.8	13.5	13.9	14.7	15.2
	2090	10.2	11.7	12.4	13.1	14.0	14.5	15.3	16.1
	2100	10.4	12.0	12.8	13.6	14.4	15.2	16.2	17.8
	2110	10.7	12.3	13.2	14.0	15.0	15.9	17.4	18.5
	2120	10.9	12.6	13.5	14.4	15.4	16.4	17.5	19.4

Scenario1: Flood Elevation = 10.7' (Current BFE)

Scenario 2: Flood Elevation = 12.7' (Current BFE + 2')

Scenario 3: Flood Elevation = 14.7' (Current BFE + 4')

Scenario 4: Flood Elevation = 16.7+A4:J23' (Current BFE + 6')

Table 5 – Future Year Flood Water Levels (Ransom Consulting)

In the Table above, the Ransom report (located in Appendix B) is shaded to coincide with the specific flood scenarios considered for the damage assessment by the University of Maine Machias GIS Service Center. The table provides predicted water levels and average recurrence interval over for future years.

For example: if you consider a Scenario 1 event, this would be a 20 to 50-year ARI in 2020, a 10-20-year ARI in 2030, a 5 to 10-year ARI in 2040-2050, and a 2 to 5 year ARI from 2060-2100. Altogether, this method would predict that you may see anywhere from approximately 12 to 30 Scenario 1 events between 2020 and 2100. A similar approach would result in a prediction of approximately 0 to 6 Scenario 3 events between 2020 and 2100.

The estimation of economic losses becomes more complicated, as you must consider not only the damages that could occur from a single flood event, but also what remedial actions may be taken after that flood event that would alter the potential for future flood damage and economic impact projections. For example, it may be that multiple severe (say, Scenario 3) flood events will occur in the next 100 years, however after the first event of this magnitude many buildings and roads that are substantially damaged would likely (hopefully) be rebuilt in a more resilient manner so the losses from future similar flood events would be lessened. On the other hand, multiple Scenario 1 storms may occur and due to the less severe nature of damages, owners may elect to repair in-kind or not at all, leaving the structures still susceptible to similar damages from future events.

There are several methods that could be used to come up with a cumulative damage estimate that could be used in a Benefit Cost analysis. These are considered beyond the scope of this study and they require more refinement in the construction cost estimate for the seawall system . That said, the comparison of damages for single storm events with the concept design construction estimate would indicate that the Benefit Cost ratio for a seawall protection system is significantly greater than 1.

3.d. Determining Economic Losses from Future Flood Events

Depth damage assessments were developed in collaboration with Dr. Tora Johnson and her students at the University of Maine at Machias GIS Service Center and Laboratory (UMM-GIS). To weigh costs of alternative designs against risks, UMM-GIS gathered best available data on flood impacts and applied best practices for mapping and science communication to estimate potential impacts for a variety of flood scenarios. The approach involved co-production of knowledge, focus on local priorities and vulnerabilities, and scaling maps and economic information to local needs.

UMM-GIS found inundation at the base flood elevation (BFE = 10.7 feet) could cause $700,000 in damage and take two months for recovery with relatively minor ecosystem impacts. The Town had experienced two floods near BFE in recent years. With floods two or more feet above BFE--increasingly likely due to climate change--potential impacts rise dramatically: BFE plus two feet could cost $8 million with six months recovery. BFE plus 4 feet could cost $17 million with 11 months recovery and major impacts on shellfisheries.

Map/Lot		Machias Downtown Building Invento	Property Value	Lowest Floor Elev	Within SFHA ?	Inundation Scenario (Flooding exceeds level indicated)				
						Scenario 1 BFE	BFE+1-ft	Scenario 2 BFE+2-ft	Scenario 3 BFE+4-ft	Scenario 4 BFE+6-ft
12	24	Machias Hardware	$ 95,200.00	11.9	---	No	No	Yes	Yes	Yes
12	25	Barber Shop	$ 24,300.00	16.0	---	No	No	No	No	Yes
15	1A	Helen's Restaurant	$ 727,200.00	13.3	AE 10.7	No	No	No	Yes	Yes
15	2A	Berry Vines	$ 75,800.00	14.0	AE 10.7	No	No	No	Yes	Yes
15	2A	Rivers Edge Drive-In/Shake Pit	$ 75,800.00	11.5	AE 10.7	No	Yes	Yes	Yes	Yes
15	11	Bluebird Restaurant	$ 283,600.00	13.3	AE 10.7	No	No	No	Yes	Yes
15	91	US Cellular, Subway, Etc.	$ 209,000.00	10.9	AE 10.7	No	Yes	Yes	Yes	Yes
15	92	Pellon Center	$ 216,700.00	11.9	---	No	No	Yes	Yes	Yes
15	92B	Machias Bay Chamber of Commerce	$ 15,000.00	13.0	---	No	No	No	Yes	Yes
15	1	Machias River Inn, East	$ 1,171,100.00	12.4	AE 10.7	No	No	Yes	Yes	Yes
15	1	Machias River Inn, West		13.6	AE 10.7	No	No	No	Yes	Yes
15	2	Living Innovations	$ 166,800.00	10.1	AE 10.7	Yes	Yes	Yes	Yes	Yes
12	22A	Bar Harbor Bank & Trust	$ 209,700.00	14.08	---	No	No	No	Yes	Yes
15	3	Wall's Appliance	$ 135,700.00	11.7	AE 10.7	No	No	Yes	Yes	Yes
15	4	Irving*	$ 530,000.00	13.7	---	No	No	No	Yes	Yes
15	13	Skywalker's Bar & Grille	$ 143,000.00	11.0	AE 10.7	No	Yes	Yes	Yes	Yes
15	86	Machias Town Office	$ 134,500.00	11.14	AE 10.7	No	Yes	Yes	Yes	Yes
15	87/87A	EBS Building Supplies, Back		12.0	---	No	No	Yes	Yes	Yes
15	87/87A	EBS Building Supplies, Side	$ 137,900.00	12.1	AE 10.7	No	No	Yes	Yes	Yes
15	87/87A	EBS Building Supplies, Main	$ 416,100.00	12.3	---	No	No	Yes	Yes	Yes
15	5	Machias River Redemption	$ 43,900.00	13.51	AE 10.7	No	No	No	Yes	Yes
15	89	Wastewater Treatment Plant	$ 1,024,800.00	16.0	AE 10.7	No	No	No	No	Yes
15	90	Private Residence	$ 45,000.00	13.4	---	No	No	No	Yes	Yes
15	85	Private Garage 13 Court St	$ 4,500.00	8.1		Yes	Yes	Yes	Yes	Yes
15	84	Private Abandoned 15 Court	$ 14,000.00	10.1		------	------	------	------	------
Notes:			$ 5,899,600.00		14	2	6	13	22	24

1 All elevations are to NAVD88 Vertical Datum
2 LAG - Lowest adjacent finished grade next to building; HAG - Highest adjacent finished grade adjacent to building
3 Properties identified as "Mapped within SFHA" based on 2017 FEMA FIRMs for Machias, ME
4 Based on Town of Machias Floodplain Management Ordinance, minimum FFE elevation is 1' above BFE for buildings in AE Zone
*US Army Corps of Engineers (Table 43) (http://www.mvn.usace.army.mil/Portals/56/docs/PD/Donaldsv-Gulf.pdf)

Table 6 –Machias Downtown Building Inventory impact by Flood Scenario

4. *Design Development of the Seawall System*

This section reviews options to provide flood protection to the Machias Downtown Area,

4.a. Flood Protection Options Considered

Coastal flood protection can be accomplished through a variety of techniques that can be summarized in the categories below. Notes on the practicality of incorporating these measures in the Machias Downtown area are provided.

- **Elevate – increase the elevation of flood prone properties and/or buildings in order to reduce their effective flood risk. This will generally involve setting building elevations or finish grades above a reference flood elevation, with some additional accommodation for freeboard.**

  Raising the entire downtown area would require a cost prohibitive full-scale reconstruction of the urban environment with the attendant loss in character and history of the downtown.

- **Floodproof – In-place floodproofing that does not reduce the risk of flooding but reduces the risk of damage associated with flooding.**

  Refer to the flood inundation scenarios depicted in the flood inundation scenarios on page 5, Currently, large sections of the Downtown are within a Special Flood Hazard Area (SFHA). These areas will increase significantly with sea level rise. The ability to flood proof existing buildings and infrastructure is at best, a short-term solution to flood protection.

- **Permanent Flood Protection – Installation of levees or floodwalls that protect from flooding by providing perimeter protection for low-lying areas at risk of flooding.**

  This is the most practical long-term solution. The geographical setting of the downtown favors a perimeter seawall running along the shore to protect landward properties . The seawall will provide flood protection, stabilize an eroding shore and will support a public walkway. Providing flood protection will serve to revitalize the downtown and ensure safe passage along the major Route 1 corridor that runs through the area.

- **Temporary Flood Protection – Installation of temporary flood wall panels and/or dams that can be installed in advance of a severe storm event and removed after the event is complete.**

  It is recommended that a permanent seawall system for Machias include some provisions for increasing the height of protection in the future. The practicality of installing temporary panels needs to be weighed against the manpower requirements, the timing required to put these measures in place and the feasibility of doing the work in winter/freezing conditions.

- **Retreat – abandon a facility or location and relocate to higher ground with less flood risk.**

  Retreat will be necessary if a seawall system is not put into place. Relocation of the history and character of the area would not be possible.

4.b. Design Elevations (for the Project Area

A summary for key elevations that define the project area are included in the Table below. These elevations guide the design of a seawall system by providing flood and tidal parameters and are also used to establish the regulatory limits of the coastal wetland.

ELEVATION		Machias CHART (ft)	Machias NAVD88 (ft)	Notes
Base Flood Elevation		17.8	11.0	Zone AE - Upper Middle River and Adjacent WWTP
Blizzard of 1978 Water Elevation		17.6	10.8	USGS Report
Base Flood Elevation		17.5	10.7	Zone AE - Machias River
Stillwater Elevations	0.2% Annual Chance	18.2	11.4	FIS Transect 41 (Machiasport)
	1% Annual Chance	17.5	10.7	
	2% Annual Chance	17.3	10.5	
	10% Annual Chance	16.9	10.1	
Highest Annual Tide		15.30	8.50	Maine DEP 2018 HAT (Machiasport, Machias River)
MHHW		14.20	7.40	Maine DOT 2011 Tidal Monitoring Data
MHW		13.30	6.50	
NAVD88		6.80	0.00	
MLW		0.40	-6.40	
MLLW		0.00	-6.80	

1. BASE FLOOD INFORMATION TAKEN FROM FEMA FLOOD INSURANCE RATE MAP
2. HIGHEST ANNUAL TIDE TAKEN FROM MAINE DEP PUBLISHED PREDICTIONS
3. TIDAL INFORMATION TAKEN FROM MDOT PUBLISHED DATA

Table 7 – Machias Downtown Elevation Table

4.c. Levee (Seawall System) Design and Accreditation Criteria

The regulations governing the certification of a levee or floodwall by FEMA are contained in 44 CFR 65.10 which includes standards for riverine and coastal conditions. The FEMA mapping for Machias presents flood elevations to the nearest decimal suggesting riverine conditions. However, the features and exposure of the Downtown Waterfront area are more representative of a coastal environment and throughout this study, it is assumed that conditions in Machias are Coastal, and the appropriate conditions apply.

Requirements for certification (for both riverine and coastal) are summarized below:

1. Design Requirements for levees to be recognized by FEMA include the following:
    - Freeboard
        - Riverine conditions

          A minimum of 3-ft above the water surface of the base flood with an additional 1-ft within 100-ft of structures or wherever the flow is restricted.

        - Coastal Conditions

          No less than the greater of:

            - 1-ft above the 1% wave height
            - 1-ft above the 1% annual chance wave runup
            - 2-ft above the Stillwater surge elevation

    - Closures
        - All openings must be provided with closure devices. This includes any penetrations in the seawall system that includes:
            - Drainage, Outfalls, vents.
            - Openings in the seawall system for use during non-flood stage conditions for access or maintenance.
    - Embankment Protection
        - Embankment must be designed so that no appreciable erosion of the embankment can be expected during the Base Flood.
    - Embankment and Foundation Stability
        - Engineering analysis of embankment and foundation stability must be submitted
    - Settlement analysis
        - An engineering assessment is required that assess the potential magnitude of future losses of freeboard as a result of levee settlement.
    - Interior drainage
        - An engineering analysis must be completed to size stormwater infrastructure (e.g. drainage lines and pumps) needed to address secondary and cumulative interior flooding that would occur during the design storm event.

2. Operations plans and criteria
    - For a levee system to be accredited by FEMA, a comprehensive Operations Plan is required that includes:
        - flood warning system protocol
        - provisions for levee maintenance, monitoring and management. Current and Future Water Levels
    - The plan must be officially adopted by the operator under the jurisdiction of a federal or state agency (likely to be the Maine Emergency Management Agency).

4.d. Regulatory Review/Permit Requirements

Town, State and Federal regulatory permits will be required for a flood protection system. The lead agencies are listed below together with permit considerations that have been discussed for this project. Moving forward into design development, it will be necessary to continue to engage lead and sub agencies in design development.

Town of Machias

The seawall system, stormwater improvements and public walkway will have a significant impact on downtown property within the General Development and Maritime, or Commercial Fisheries/ Marine Activities Districts and the Shoreland Overlay Districts. As a minimum, the proposed work will require Planning Board approval, a Flood Hazard Development permit and a Shoreland permit. It is anticipated that property owner and stakeholder communication and participation will be a key component of the public and municipal project review process.

Maine Department of Environmental Protection (MeDEP)

MeDEP is the clearing house for all state agencies that are concerned with the impact of the proposed seawall system on the coastal wetland and intertidal area. The work will require a Natural Resource Protection Act (NRPA) permit. A coastal wetland and wildlife assessment will be required. Wetland impacts greater than 500 SF may need to be mitigated at the discretion of the MeDEP. The seawall system outlined in the concept design drawings located in Appendix E does exceed the 500 SF threshold but stays within the area of shoreline that has been previously altered by development.

Separate permits will need to be obtained for new or modified outfalls for the Municipal Stormwater System and the Waste Water Treatment Plant.

Maine Department of Transportation

It is anticipated that the design associated with the Dyke/Route 1 improvements that are currently being considered by the Department will overlap with the Seawall System design to address the need to elevate Route I at the intersection with the seawall system so that flood protection is maintained for the Downtown Area.

US Army Corps of Engineers

A Department of the Army permit will be required for the construction program that develops. The Army Corps of Engineers has federal jurisdiction for any work that extends seaward of the highwater line. All federal agencies (Environmental Protection Agency (EPA), US Fish &Wildlife (USF&W), National Marine Fisheries and the US Coast Guard) will review the proposed development for compliance with federal Standards. Historic Preservation and Tribal Nations will have input.

It is likely that the coastal Wetland impacts will require a Public Hearing to be orchestrated by the Maine Project Office of the Army Corps of Engineers.

A joint review of the proposed seawall system design will likely be undertaken by the Army Corps and FEMA as part of the levee (seawall) certification process to make sure the design follows Federal standards

Federal Emergency Management Agency and Maine Emergency Management Agency

FEMA and MEMA will coordinate the certification review of the seawall system and the Map changes that develop.

4.e. Concept Design Development

Refer to Drawings provided in Appendix E which illustrate the proposed Seawall System, Public walkway, Boat Ramp, Route 1 Corridor Improvements, Stormwater and Outfall provisions and associated impacts to the Downtown area.

The mitigation strategy recommended by the conclusions reached in the assessments listed in #2 is a flood protection structure that will protect the downtown and the wastewater treatment plant from a Base Flood Elevation (BFE)+4 flood event. Advance Assistance is requested to complete additional fieldwork and design development to optimize the project footprint as highlighted at the start of this section. This information will be the basis for discussions with local properties on the need for Right of Way acquisition and will establish the parameters needed to develop a fully engineered design.

The Downtown area that will be protected by the proposed seawall system will benefit from a seawall system that protects current businesses and critical infrastructure (Waste Water Treatment Plant) from current and future flood events. The seawall construction will also address existing coastal erosion associated with sections of unstable shore and will incorporate a public waterfront walkway that will connect with an existing trail network for the enjoyment of the public. The sum of the improvements will serve to increase the economic vitality and interest in the downtown area.

5. *Next Steps to Move the Project Forward*

The next steps needed to move the flood protection project beyond concept design for the Machias Downtown is discussed in this section.

The tasks, timeline and estimated cost for this work is summarized in the Table below and has been used as the basis for a **Pre-Disaster Advance Assistance** grant application to FEMA. Getting the grant maintain the project momentum. With a successful grant award, A Request for Proposals will be issued to obtain the services of a qualified engineering consultant team.

Pre-Disaster Mitigation	Town Contribution			Consultant Services	Program Cost		Timeline (months)
Cost Breakdown & Timeline by Task	Staff/UMM	Materials	SHIP		Task	Summary	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Project Management						$ 16,300	
Consultant RFP; Grant Monitoring;	$ 1,500				$ 1,500		
Program Coordination/Management	$ 4,800			$ 10,000	$ 14,800		
Field Investigation						$ 60,000	
Coastal Wetland Survey				$ 15,000	$ 15,000		
Geotechnical Investigation				$ 30,000	$ 30,000		
Survey Support				$ 15,000	$ 15,000		
Coastal Protection System Design Development						$138,962	
Concept Design & Alignment Review				$ 10,000	$ 10,000		
Seawall Footprint Assessment/Optimization				$ 10,000	$ 10,000		
Public Walkway Parameters				$ 2,500	$ 2,500		
MDOT Route 1 Coordination				$ 5,000	$ 5,000		
Boat Ramp Design (SHIP Program)	$ 2,160	$ 9,503	$ 66,800	$ 14,000	$ 92,462		
Living Shoreline Opportunities	$ 1,000			$ 3,000	$ 4,000		
Value Engineering and Cost Benefit Analysis				$ 15,000	$ 15,000		
Stormwater/Waste Water Treatment Plant Assessment						$ 15,000	
Existing Network Infrastructure				$ 5,000	$ 5,000		
Pump System & Outfall Location				$ 10,000	$ 10,000		
ROW Acquisition						$ 15,000	
Landowner Outreach/Education				$ 5,000	$ 5,000		
Easement Negotiation				$ 10,000	$ 10,000		
Regulatory Permitting						$ 13,000	
Town of Machias	Permit Fees Waived			$ 3,000	$ 3,000		
Maine DEP				$ 5,000	$ 5,000		
Army Corps of Engineers				$ 5,000	$ 5,000		
Construction Phase Preparation						$ 34,200	
Design Build Documents				$ 31,200	$ 31,200		
2020 FEMA Grant Application				$ 3,000	$ 3,000		
Total	$ 9,460	$ 9,503	$ 66,800	$ 206,700	$ 292,462	$292,462	
	$ 85,762	29%				$ 292,462	

PROJECT FUNDING		
FEMA Pre-Disaster Mitigation Grant	$200,000	
25% Town Match (SHIP Funds)	$ 73,116	$92,462
SHIP Balance	$ 19,347	
Total	$292,462	

NOTES

1. Project Funding dependent on pending Small Harbor Improvement Program (SHIP) grant consideration with MaineDOT.
2. SHIP funding program is 100% funded by the State of Maine with no federal fund support.
3. The Schedule may need to be adjusted once the grant is awarded as it is not practical to complete some elements of field survey work in Maine during snow cover or freezing conditions..
4. Timeline extensions to Task Items indicate built in flexibility to accommodate time delays.
5. Task item costs are based on best available information. Rebalancing with new information is anticipated.

Table 8 – Next Steps Summary- Tasks, Timeline, And Cost

5.a. Field Investigation

Undertake an assessment of environmental impacts associated with the concept design footprint by wetland scientists and wildlife biologists to provide the basis of an environmental assessment. Include an assessment of site opportunities and habitat potential for coastal stabilization using living shoreline techniques.

Complete an investigation of subsurface conditions to obtain the parameters necessary to analyze the quality and depth of native soils, the presence and quality of fill material, subsurface permeability, groundwater infiltration, bearing capacity and settlement to mitigate seawall structure behavior and performance.

Review the presence and extent of historical cribwork structures that were constructed to define the waterfront.

5.b. Coastal Protection System Design Development

Complete seawall and walkway alignment optimization to achieve regulatory requirements for 'avoidance' and 'minimization' of resource impacts and to support stable embankment construction that addresses existing coastal erosion.

The concept design is based on providing a FEMA certified flood protection structure with an elevation of BFE +4-ft (BFE + 5-ft for the Waste Water Treatment Plant). While fully reasoned and based on detailed topographic survey, predictions for sea level rise and thorough analysis of damage assessments for several flood scenarios, the concept design has been based on limited fieldwork. It is important to take a step back once the fieldwork has been completed to confirm the optimum seawall/levee crest elevations together with a review of the cost benefit analysis that develops with further design.

Prepare Maintenance Plan and Operation Criteria for seawall certification.

5.c. Stormwater/Wastewater System Assessment

Evaluate the existing Stormwater and Waste Water Treatment Facility piping network to determine requirements to upgrade collection, storage and outfall infrastructure with consideration of a perimeter seawall.

Determine the design basis for a pump system to operate in conjunction with the seawall in periods of flooding.

5.d. ROW Acquisition

Review the impact of new construction with local property owners to convey an understanding of the benefits of seawall (flood protection, coastal erosion control, shorefront walkway) .

Continue one-on-one contact with affected landowners,

Identity impacts to property frontage and Right of Way acquisition.

5.e. Regulatory Permitting

Meet with Local, State and Federal regulatory representatives to discuss regulatory permit requirements for the project.

File applications with property owner and stakeholder support.

5.f. Construction Phase Preparation

Prepare Design-Build bid documents and support grant applications for a future construction phase. These documents, together with project permits provide the parameters needed for final design and construction of the seawall system. The Design-Build method of project delivery will allow the successful team to tailor the project to respective equipment and personnel expertise to achieve a certified seawall system.

Appendix A – References

1. Project Documentation
    a. Public Forum Notices/Presentations/Meeting Minutes- APRIL 9, 2018; June 11, 2018; JUNE 27, 2018; September 17, 2018; October 15, 2018
2. Beginning with Habitat Mapping (BWH) -https://www.beginningwithhabitat.org/the_maps/.
    a. Data Sets for Machias Maine
        i. Map2 -Rare, Threatened and Endangered Wildlife, Rare or Exemplary Plants and Natural Communities; Essential Wildlife Habitats; Significant Wildlife Habitats; Atlantic Salmon Spawning/Rearing Habitat: 2018.
        ii. Shape Files- Tidal Marshes.
3. Federal Emergency Management Agency (FEMA).
    a. Code of Federal Regulations
        i. Title 44, Chapter 1, Section 65.10 (44 CFR 65.10); "Mapping of areas protected by levee systems."
    b. Flood Insurance Studies (FIS)
        i. Washington County Maine; Vol 1 of 1; Effective 18Juy 2017.
        ii. Machias Maine- Community Number 230140; 11.18.1988.
    c. Flood Insurance Rate Maps- (FIRMS)
        i. Washington County Maine; PANELS 1627 & 1629 of 2075; Machias Town of- 230140; Version No. 2.2.2.1 Map Nos. 23029C1627E/23029C1629E; Effective 18Juy 2017.
        ii. Town of Machias Maine; Washington County; Community Number 230140; 11.18.1988.
    d. Guidelines, Memorandums and Fact Sheets
        i. Meeting the Criteria for Accrediting Levee Systems on NFIP Flood Maps; How to guide for Floodplain Managers and Engineers; Nov 2008.
        ii. LEVEE MAPPING- COMPLYING WITH 44 CFR 65.10; Oct 2012.
        iii. FEMA Coastal Flood Hazard- ANALYSIS AND MAPPING GUIDELINES; Feb 2005.
4. GROWashington-Aroostook
    a. Climate Vulnerability Assessment for Washington County; University of Maine at Machias GIS Service Center; Washington County Council of Governments; June 2014.
5. Maine Department of Transportation
    a. WIN 16714 Machias Dyke Bridge #2226- Replacement Alternatives
        i. Bridge Inspection Reports.
        ii. Existing Bridge Plans
        iii. Alternatives Matrix

iv. Geotechnical Logs and Grain Size Distribution Curve; BB-MMR-101; BB-MMR-101A; 11.4.2014.

v. Historic Bridge Inventory and Management Plan.

vi. HYDROLOGIC ANALYSES AND ALTERNATIVES EVALUATIONS, DYKE BRIDGE AND STRIDE BRIDGE, MIDDLE RIVER, MACHIAS, MAINE; Stantec; 6.30.2015.

vii. Preliminary Public Meeting; Machias Dyke Bridge #2246 (Route 1 over Middle River).

6. Maine Flood Management Program.
    a. UPDATES TO COASTAL FLOOD INSURANCE RATE MAPS: WHAT A LOCAL OFFICIAL SHOULD KNOW; Presentation by Jennifer Curtis; Sept 2016
7. Maine Geological Survey
    a. A SUMMARY OF CLIMATE CHANGE TRENDS, SEA LEVEL RISE, AND SOME HIGHLIGHTED LOCAL EFFORTS TO ADDRESS VULNERABILITY OF TRANSPORTATION INFRASTRUCTURE; Presentation to Maine DOT; 1.28.2014.
    b. Maine Sea Level Rise Storm Surge Scenarios 2018 -Spatial Datasets; https://mgs-maine.opendata.arcgis.com/datasets/maine-sea-level-rise-storm-surge-scenarios
8. Maine Interagency Climate Adaptation Work Group (MICA)
    a. MAINE PREPARES FOR CLIMATE CHANGE; MICA; Jan2018 Update
9. National Society of Professional Engineers (NSPE)
    a. NSPE Position Statement (No. 07-1771- FEMA Levee Certification; July 2018.
10. New England Interstate Water Pollution Control Commission
    a. TR-16 GUIDES FOR THE DESIGN OF WASTEWATER TREATMENT WORKS; May 2016.
11. NOAA CHART 13326- Machias Bay to Tibbett Narrows.
12. Ransom Consulting
    a. PRELIMINARY FLOOD RATE INSURANCE MAPS INITIAL REVIEW; 24Feb2017; Memo to Town of Machias 24Feb 2017.
    b. MACHIAS FLOOD RESILIENCE STUDY, PRESENT AND FUTURE FLOOD RISK; 24Feb2017; Memo to Baker Design Consultants; 24Sept 2018. Refer to Appendix B.
13. Town of Machias
    a. Machias Downtown and Riverfront Master Plan; Copion Associates; 7.15.2009.
    b. Town of Machias Shoreland Zoning Map.
    c. Ordinances
        i. Flood Hazard Development Ordinance
        ii. Floodplain Ordinance
        iii. Shoreland Zoning Ordinance.
    d. Olver Associates Inc. Environmental Engineers; Winterport, Maine.
        i. Machias Pollution Control Facility; Town of Machias; Peak Flow Upgrade Project; Oct 2013

1. Sheet C-2 Proposed Site Plan
2. Sheet C-4 Proposed Outfall Sewer Plan
3. Sheet C-7 Sewer Plan and Profile
4. Sheet C-8A Main St (US Route 1) Services & Court St Sanitary Sewer Plan & Profile
5. Sheet C-9 Main St (US Route 1) Sanitary Sewer Abandonment Plan & Profile

ii. East Side Sewer Extension- Phase I; Oct 2013

1. Sheet C-1 Sanitary Sewer Plan & Profile.
2. Sheet C-2 Sanitary Sewer Plan & Profile.

14. US Army Corps of Engineers (ACOE)

a. Machias River Federal Navigation Project

i. Map; MACHIAS RIVER ME; 9.30.1976; Showing limits of FNP.

ii. Narrative Description of Machias River Federal Navigation Project- Author Unknown.

b. Design Manuals

i. EM 1110-2-1913; DESIGN AND CONSTRUCTION OF LEVEES; Engineering and Design; 4.30.2000.

ii. EM 1110-2-2502; RETAINING AND FLOOD WALLS; Engineering and Design; 9.29.1989.

iii. EC 1110-2-6067; USACE PROCESS FOR THE NATIONAL FLOOD INSURANCE PROGRAM (NFIP) LEVEE SSTEM EVALUATION; Engineering and Design; 8.31.2010.

c. Technical Reports

i. CERC-89-15; CRITERIA FOR EVALUATING COASTAL FLOOD PROTECTION STRUCTURES; Dec 1989.

d. Presentations

i. Levee Accreditation for the NFIP; 11.2.2015 15; Presentation with FEMA.

ii. Upcoming Changes for EM 1110-2-1913 Design Construction and Evaluation of Levees; 11.3.2015.

e. Condition Surveys

i. MEMO; RESULTS OF MACHIAS RIVER SURVEY; CENAE-EP-DS(11-2-240a); 5.12.2005.

ii. SHEETS V-1/V-2; MACHIAS RIVER CONDION SURVEY 4-FT CHANNEL; 5.7.2005.

15. US Environ mental Protection Agency (EPA)

a. EPA 817-B-14-006; FLOOD RESLILIENCE- A Basics Guide for Water and Wastewater Utilities; Sept 2014.

16. U.S. Geological Survey

a. COASTAL FLOOD OF FEBRUARY 7, 1978 IN MAINE, MASSACHUSETTS, AND NEW HAMPSHIRE".

Appendix B – Present and Future Flood Risk Assessment Memo

a. MACHIAS FLOOD RESILIENCE STUDY, PRESENT AND FUTURE FLOOD RISK; 24Feb2017; Memo to Baker Design Consultants; 24Sept 2018

RANSOM
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Memo

Date:	September 18, 2018
To:	Daniel Bannon, P.E, Baker Design Consultants, Inc.
From:	Nathan Dill, P.E.
Subject:	Machias Flood Resilience Study, Present and Future Flood Risk

Ransom Consulting, Inc. (Ransom) understands the Town of Machias, Maine (Town) is taking a proactive approach to mitigating coastal flood risks as they seek to revitalize the historic waterfront area in downtown Machias. As part of this effort the Town has obtained a grant through the Maine Coastal Communities Program to assist in a planning study that will identify conceptual design plans for flood protection structures along the downtown waterfront, assess the feasibility of such flood protection, perform an economic analysis of the protection afforded by proposed flood protection, and incorporate structural flood protection measures into existing downtown revitalization planning. The Town has engaged Baker Design Consultants, Inc. (Baker) to identify conceptual designs and establish a plan to build flood protection along the existing seawall in downtown Machias. In turn, Baker has engaged Ransom to identify and synthesize existing available information on the present and future flood hazard to aid in seawall design efforts. This memorandum describes our effort to identify appropriate flood hazard information and provides a synthesis of flood hazard information with future sea level rise projections that will be helpful for flood protection design and flood risk assessment.

An assessment of flood risk requires an understanding of two components that make up the risk. First it is necessary to understand the flood hazard, which can be characterized by estimated site-specific flood elevations and the likelihood that a given flood may occur. The second component is an assessment of the possible damages or cost that would be incurred if/when a flood occurs. When this information is known across the entire range of possible flood conditions it can be aggregated to estimate the total risk in terms of an expected cost of damages, which in turn can be used to support planning efforts and cost-benefit analyses for proposed projects that would mitigate risks. This memorandum provides flood hazard information suitable for such an analysis. Possible damage assessment information and subsequent risk analyses are expected to be performed by others.

PRESENT DAY COASTAL FLOOD HAZARD DATA

Ransom has gathered and reviewed sources of available information regarding coastal flood risk in Machias. These include Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRM) and Flood Insurance Studies (FIS), GROWashington-Aroostook Storm Surge Scenarios, and information from the U.S. Army Corps of Engineers (USACE) North Atlantic Coast Comprehensive Study (NACCS). From this review it was determined that information from the NACCS was most suitable because it provides coastal flood hazard probability information over a range of possible flood conditions, considering exposure to storm surge from possible tropical storm events (e.g. hurricanes) as well as extra-tropical cyclone events (e.g. northeasters). FEMA's information was determined to be less suitable because it only considers flooding from a single extra-tropical event that represents only the single hazard level that has a 1% annual chance of occurrence. The GROWashingtion-Aroostook information does provides flood levels for a range of tropical storm scenarios, which is beneficial for evaluating flooding vulnerability. However, it does not identify the likelihood associated with flooding, and therefore is of limited use in risk analysis.

<u>The North Atlantic Coast Comprehensive Study</u>

Following the wide-spread destruction caused by Hurricane Sandy in October 2012, Congress appropriated funding for the USACE to conduct an extensive study of the impacts of Hurricane Sandy, as well as a comprehensive study of coastal flood hazards from Maine to Virginia. The primary objective of the NACCS was to address the flood risks of vulnerable coastal populations throughout the North Atlantic Coastal Region. Although the impacts of Hurricane Sandy were minimal in Maine, Maine was included in the study so that state interests and local communities would have a consistent approach to identify local flood risk throughout the entire North Atlantic region.

The NACCS used state-of-the-practice statistical methods to determine the magnitude and likelihood of the coastal flood hazard associated with coastal storms, including tropical cyclones (e.g. hurricanes) and extra-tropical cyclones (e.g. nor'easters). These statistical methods, known as the Joint Probability with Optimal Sampling (JPM-OS) method for tropical storms, and the Composite Storm Set (CSS) method for extra-tropical storms, represent the culmination of advances in coastal storm climatology, after more than a decade of effort from the USACE, FEMA, and others, to modernize coastal flood hazard assessments for Atlantic and Gulf of Mexico coasts of the United States.

The NACCS also used leading edge advancements in high-fidelity numerical modeling to simulate the spatially variable physics of the tides, storm surge, and wave responses from extreme coastal storms. The NACCS employed the USACE's Coastal Storm Modeling System (CSTORM-MS), which couples together a sequence of numerical models including the Planetary Boundary Layer model (PBL) to simulate wind and barometric pressure fields, the WAM wave model to simulate deep ocean wave generation and propagation, and the ADvanced CIRCulation hydrodynamic model tightly coupled with the Steady-state WAVE spectral model (ADCIRC+STWAVE) to simulate the combined physics of tides, storm surge, wave transformation, and wave setup. CSTORM-MS was used to simulate the coastal ocean's response to 1,050 synthetic tropical cyclones and 100 historic extra-tropical cyclones utilizing High Performance Computing (HPC) on the massive supercomputers housed at the USACE's Engineer Research Development Center (ERDC) in Vicksburg, Mississippi. The storms were simulated with and without the dynamic interaction of tides to estimate the non-linear interactions between tides and storm surge; and the storms were also simulated for a scenario with 1 meter of sea level rise to quantify non-linear effects that may occur with sea level rise.

Basic Hazard Statistics

When we discuss flood hazards within a probabilistic framework, we often talk about the likelihood of experiencing a flood of a given magnitude in terms of the Annual Exceedance Probability (AEP). The AEP expresses the probability that the water will exceed a given elevation within any given year. For example, an event with an AEP of 10% has a 1 out of 10 chance of happening within a given year.

Another common way of expressing the likelihood of a hazard is the Average Recurrence Interval (ARI), which is also commonly called the "Return Period". For example, FEMA flood maps are commonly understood to illustrate the extent and elevation of the "100-year flood". The ARI expresses how often, on average, the hazardous conditions is expected to occur given a sufficiently long period of time. For example, an event with an ARI of 10 years would be expected to happen once every ten years on average, which is approximately equivalent to an AEP of 10%.

It is important to understand that an ARI of 10-years does not mean that the event will reoccur precisely every 10 years, but rather, in the long run it will reoccur about every 10 years on average. For example, a 10-year event would be expected to occur about 10 times every 100 years, but within a century you may have multiple decades without a 10-year event and other decades that have multiple 10-year events. The concept of the ARI becomes more challenging and conceptually limited when we consider that sea level rise tends to increase the likelihood of flooding in the future (e.g. the 10-year event of today is not the same as the 10-year event of tomorrow). For this reason, it is helpful to think about the coastal flood hazard in terms of an AEP that changes year to year with changes in the sea level, even when the hazard is commonly expressed in terms of ARI.

For coastal flooding we are concerned with the peak water level that may occur during a coastal storm resulting from a combination of high tide, storm surge, and wave processes. This water level is known as the Total Water level (TWL). Assets that are at elevations lower than the TWL are generally at risk of flooding. The NACCS provides estimates of TWL for a range of flood magnitudes that could occur from either a tropical cyclone event or an extra-tropical event. Figure 1 shows the TWL hazard curve for the NACCS save point nearest to Machias. The curves shown in Figure 1 express the likelihood the TWL would exceed a given elevation in terms of the ARI. Because it is located close to the downtown Machias waterfront, the data from this NACCS save point are appropriate to characterize the coastal flood hazard in Machias.

Table 1 shows TWL hazard data in tabular form, it also lists the AEP that is equivalent to the ARI values. For events rarer than the 10-year event, the AEP is practically equal to the reciprocal of the ARI expressed as a percentage (i.e. AEP=100*1/ARI), while more frequent events have AEP that is less than that. This makes sense if you consider that an event which occurs on average once a year, may happen twice or more in some years and not at all in others.

The NACCS also provides estimates of the uncertainty in the hazard curve. These are shown in Figure 1 and listed in Table 1. Uncertainty arises in the hazard curve estimates due to imperfect knowledge about climatic conditions, model error, observed data limitations, and limitations of the statistical methods employed. NACCS has provided these uncertainty estimates in terms of upper confidence limits on the hazard curve to aid in certain design procedures that require such confidence limits. Alternatively, the uncertainty can be incorporated into the hazard curves by assuming a specific distribution for possible errors. When considered this way, uncertainty increases the hazard somewhat to account for limited accuracy of the precise flood levels. Incorporation of the uncertainty into the hazard curves is performed using the Monte Carlo techniques described later in this memo. For our purposes we take the upper 68% percent confidence limit to represent the standard deviation of the uncertainty and assume that error is normally distributed.

The information presented in Figure 1 and Table 1 provide representation of the present-day hazard. This information may be useful for risk assessments that do not need to consider increasing risk due to sea level rise. It also forms the basis for the future flood hazard analyses that incorporates sea level rise projections and are described later in this memorandum.

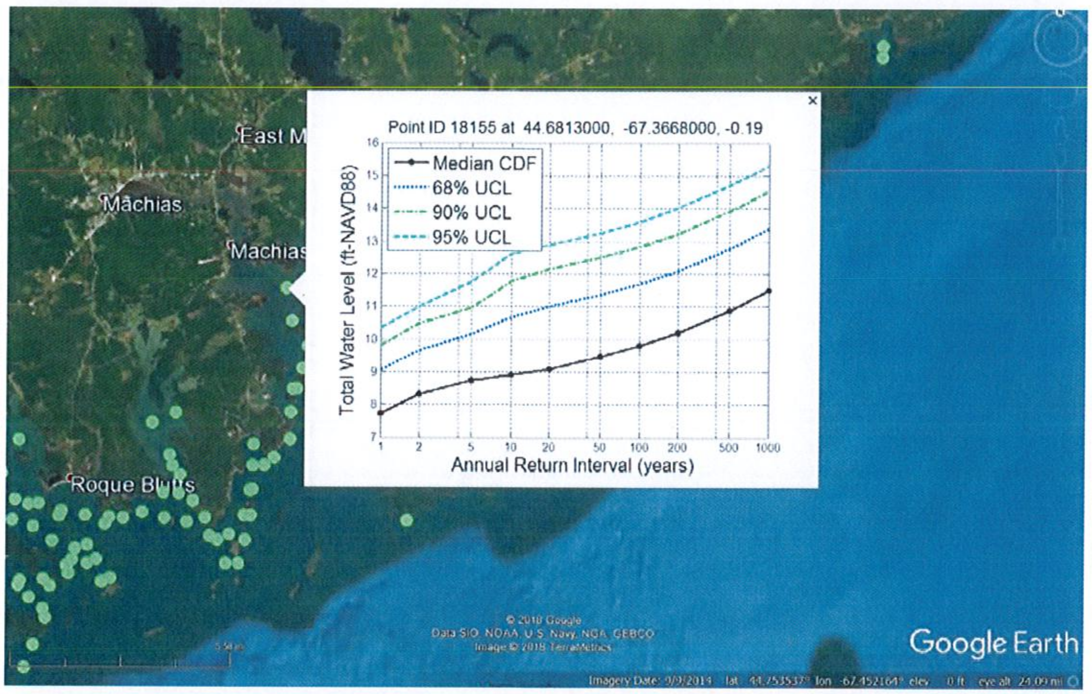

Figure 1. NACCS save points and nearest flood hazard information for Machias.

Table 1. Total Water Level Average Recurrence Interval, Equivalent Annual Exceedance Probability, and 68% Upper Confidence Level for Machias.

Average Recurrence Interval	Annual Exceedance Probability	Median Total Water Level (Ft-NAVD88)	Std. Deviation of Uncertainty (ft)
1-year	63%	7.7	1.35
2-year	39%	8.3	1.35
5-year	18%	8.7	1.41
10-year	9.5%	8.9	1.77
20-year	4.9%	9.1	1.90
50-year	2.0%	9.5	1.90
100-year	1.0%	9.8	1.90
200-year	0.5%	10.2	1.90
500-year	0.2%	10.9	1.90
1000-year	0.1%	11.5	1.90

SEA LEVEL RISE SCENARIO BASED GUIDANCE

Much of the current guidance for sea level rise planning recommends evaluating discrete sea level rise scenarios that cover a range of possible futures in order to encourage decision makers to consider multiple future conditions and identify robust solutions that will be functional in a highly uncertain future[1,2]. Figure 2 shows a set of sea level rise scenarios for Eastport, Maine based on recommendations from the USACE and NOAA and obtained from the USACE's online Sea-Level Change Curve Calculator[3]. The sea level rise scenarios are also tabulated in Table 2. This is the closest location where local sea level rise curves are available from the Sea-Level Change Curve Calculator and should be reasonable for Machias. Following this guidance, Machias should consider the possibility that, by 2050 mean sea level could rise as little as 0.38 feet to as much as 2.10 feet higher than it was in 1992; and that by 2100 sea level could be anywhere from 0.71 feet to 6.67 feet higher than it was in 1992.

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[1] Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K, Knuuti, R. Moss, J. Obeysekera, A. Sallenger, J. Weiss, 2012. Global Sea Level Rise Scenarios for the United States National Climate Assessment. National Oceanic and Atmospheric Administration Technical Report OAR CPO-1, Climate Program Office (Silver Spring, MD.

[2] USACE, 2014. Global Changes Procedures to Evaluate Sea Level Change Impacts, Responses, and Adaptation, Engineer Technical Letter No. 1100-2-1. Department of the Army, U.S. Army Corps of Engineers Washington, DC

[3] http://www.corpsclimate.us/ccaceslcurves.cfm

Curves like those presented in Figure 2 may intuitively suggest that sea level will follow a particular scenario into the future, but that is actually very unlikely. The scenarios should not be thought of as individual predictions of future sea level, but rather as limits that bound the range of possible future sea levels. This caveat is explained in the federal guidance, but many stakeholders may not be familiar with this detail, resulting in a tendency to focus on a particular scenario in the decision-making process rather than considering a full set of scenarios as recommended.

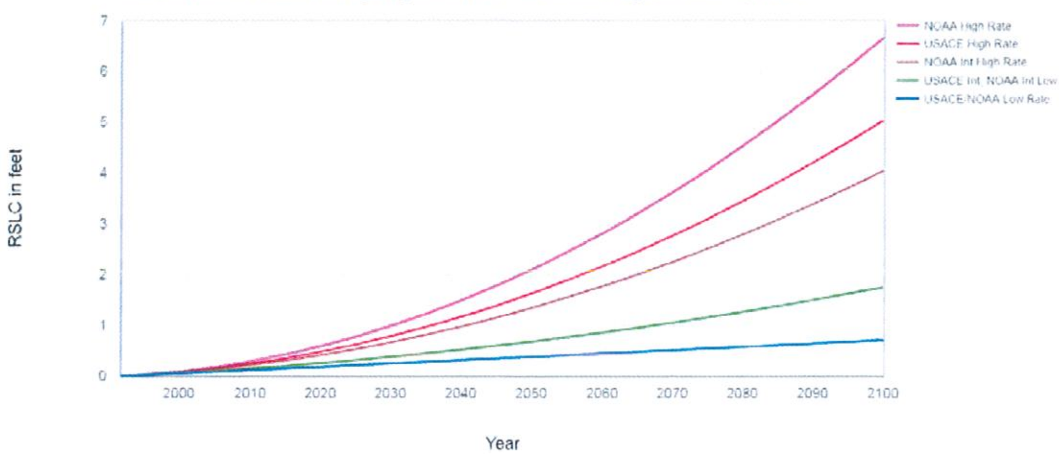

Figure 2. USACE/NOAA Local Sea Level Rise Scenarios for Bar Harbor, Maine

We know from observations that the mean sea level does not follow a smooth curve. In fact, it can vary quite a bit from day to day, month to month, and year to year. The shorter the time scale, the greater the variance. To put this in perspective, Figure 3 adds the observed mean sea level from the historic record at Cutler, Maine to the sea level change scenario curves from Figure 2 showing the transition from what we know about mean sea level to what is projected. The observed mean sea level has been calculated at a range of time scales including the annual mean shown in yellow, the monthly mean shown in cyan, and the daily mean shown in black. The vertical datum for the mean sea levels is the mean level determined by averaging all hourly records during the National Tidal Datum Epoch[4] (NTDE) of 1983-2001. When observations and projections are compared side by side, it becomes apparent that projected sea level rise scenarios ignore the real observed variability in the local mean sea level. Figure 4 shows the same data as Figure 3 but with focus on the present decade, where there is some overlap in the observed data and the sea level change scenarios that are projected from 1992. In Figure 4 we can see the projected scenarios do not even bracket the range of observations. For example, the annual mean

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[4] The NTDE is a specific 19-year period over which tide observations are averaged to determine tidal datums, such as Local Mean Sea Level (LMSL), Mean Higher High Water (MHHW), Mean Lower Low Water (MLLW) etc. The NOAA National Ocean Service (NOS) considers a revised NDTE every 20-25 years in order to take into account long-term relative sea level changes caused by global sea level change, and the effects of land movement due to subsidence and/or glacial rebound. When the NDTE is updated, older data which refer to the past NDTE are adjusted to the new NDTE.

sea level (yellow line) was actually higher than the NOAA High Rate in 2010, and then decreased over the following 5 years to a value lower than the Low Rate. The variability in the monthly mean is greater than the full range of scenario guidance out to about 2030, and the variability in the daily mean is greater than full range of scenarios out to about 2050. For this reason, the sea level change scenarios are not really indicative of the possible change in mean sea level that we should expect in the next few decades.

Table 2. USACE/NOAA Local Sea Level Rise Scenarios for Eastport, Maine (feet)

Year	USACE/NOAA Low	USACE Low NOAA Int. Low	NOAA Int. High	USACE High	NOAA High
1992	0.00	0.00	0.00	0.00	0.00
1995	0.02	0.02	0.02	0.02	0.02
2000	0.05	0.06	0.07	0.08	0.09
2005	0.09	0.10	0.13	0.15	0.17
2010	0.12	0.15	0.21	0.24	0.28
2015	0.15	0.20	0.30	0.35	0.42
2020	0.18	0.25	0.41	0.47	0.58
2025	0.22	0.31	0.53	0.62	0.77
2030	0.25	0.38	0.66	0.79	0.99
2035	0.28	0.45	0.81	0.97	1.23
2040	0.32	0.52	0.97	1.17	1.49
2045	0.35	0.60	1.15	1.39	1.78
2050	0.38	0.68	1.34	1.63	2.10
2055	0.41	0.77	1.55	1.89	2.44
2060	0.45	0.86	1.77	2.16	2.81
2065	0.48	0.95	2.00	2.46	3.20
2070	0.51	1.05	2.25	2.77	3.62
2075	0.55	1.16	2.51	3.10	4.06
2080	0.58	1.27	2.79	3.45	4.53
2085	0.61	1.38	3.08	3.82	5.03
2090	0.64	1.50	3.39	4.20	5.55
2095	0.68	1.62	3.71	4.61	6.10
2100	0.71	1.75	4.04	5.03	6.67

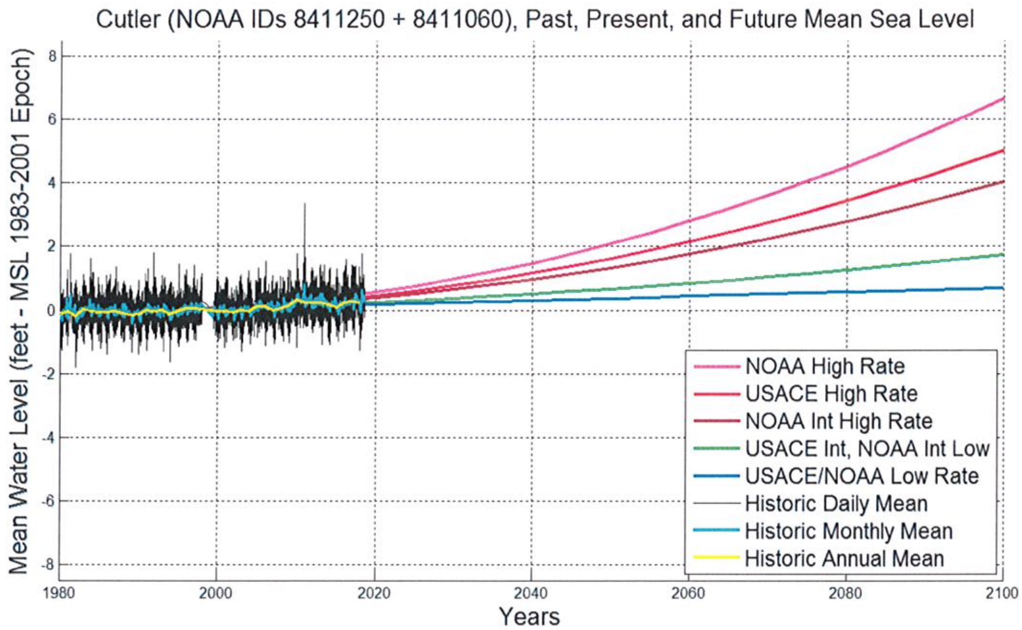

Figure 3. USACE/NOAA Local Sea Level Rise Scenarios and Historic Mean Sea Level for Cutler, Maine – 1980 to 2100

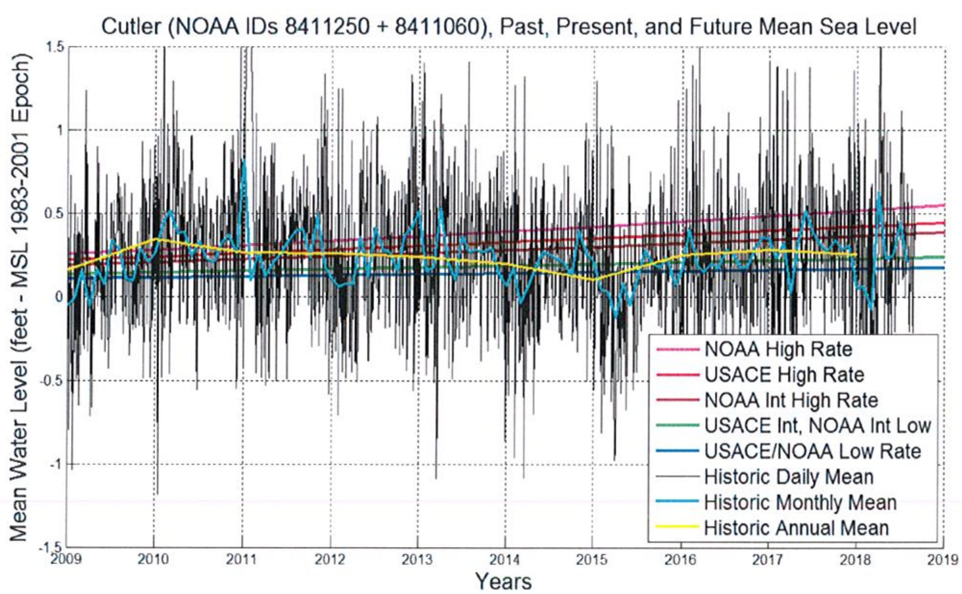

Figure 4. USACE/NOAA Local Sea Level Rise Scenarios and Historic Mean Sea Level for Cutler, Maine - 2010 to 2019

PROBABILISTIC SEA LEVEL CHANGE

The scenario based approach to sea level change suffers from two inter-related problems. The first, mentioned in the previous section, is that it inadvertently inspires focus on individual scenarios, which are subject to prejudices of decision makers. The second problem is that it provides no information about how likely the various scenarios may be. So even when decision makers correctly consider a range of scenarios, they are at a loss when it comes to weighing the different scenarios against one another. They may inadvertently place too much weight on an unlikely outcome and/or too little weight on the more likely outcomes.

These problems can be alleviated by considering the mean sea level as a non-stationary random process. A random (or stochastic) process describes a variable that evolves through time in a non-deterministic way. This means that, even though values of the variable that are close in time may be close to one another, there is no way to precisely determine a future value based on the history of past values. Instead, a future value is characterized by a probability distribution that expresses how likely it is within a range of possible values. In other words, we can expect the mean sea level for next year to be close to the mean sea level this year, but history cannot tell us if it will go up or down, or precisely how much it will change. History only tells us how likely the change will be within a range of possible values. A random process is considered non-stationary if the parameters that describe its probability distribution (e.g. mean and variance) change with time. In the case of sea level, current climate science tells us that the mean is expected to change, and the variance will increase in the future because more distant projections are less certain. When we consider that the future mean sea level is a non-stationary random process we are able to apply a statistical model to offer guidance on the likelihood of future scenarios. With this type of probabilistic information we are able to apply Risk Informed Decision Making (RIDM) to planning for sea level rise adaptation, and mitigation of future coastal flood risk. This approach is also conceptually appealing because it does not preclude the possibility that sea level may actually decrease at times in the future; a circumstance that is clearly possible given observations presented in Figure 4 and sometimes used by climate change skeptics to discount scenario based guidance that increases sea levels into the future without any limits.

Probabilistic sea level change guidance should not be thought of as a replacement for the scenario based guidance recommended by NOAA and the USACE. Instead it should be considered as a supplement to scenario based guidance that quantifies the likelihood of individual scenarios and allows application of RIDM. Probabilistic guidance for sea level change is not a new idea. For example, the U.S. Environmental Protection Agency (USEPA) saw the need for probability-based guidance on sea level rise over 20 years ago, and provided probability-based projections of global sea level rise for planning use[5]. Paris et al (2012)[1] mention probabilistic projections as another form of scenario guidance, but they do not pursue it, citing no accepted widely available method for producing probabilistic guidance at regional or local scales. The USACE also mentions probabilistic guidance, but then echo the same lack of accepted methods and large degree of uncertainty cited by NOAA.

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[5] Titus, J.G., V. K. Narayanan. 1995. The Probability of Sea Level Rise. United States Environmental Protection Agency, Office of Policy, Planning, and Evaluation, EPA 230-R-95-008, September 1995.

More recently, Kopp et al. (2014)[6] provide localized actionable probabilistic information. For our study, we adopt their data to characterize probabilistic future sea level change at Cutler. Their data provide cumulative probability distributions for local mean sea level at years 2030, 2050, 2100, and 2150 for three of the Representative Concentration Pathways (RCP) adopted by the Intergovernmental Panel on Climate Change (IPCC) in their fifth assessment report[7]; these are shown in Figure 5 thru Figure 8, respectively. The cumulative probability distributions show the probability that the future sea level will be less than the corresponding sea level rise value. For example, in Figure 5, for RCP 2.6, we see that there is a 60% probability that sea level rise by 2030 will be less than 20 centimeters (0.7 feet), or complementarily a 40% probability that local mean sea level will rise more than 20 centimeters (0.7 feet) before 2030. Using this information, we can evaluate the probability that future sea levels will be greater or less than the USACE and NOAA scenarios. Table 3 lists the probability sea level will be greater than the USACE and NOAA sea level rise scenarios at 2030, 2050, and 2100 based on the probabilistic guidance.

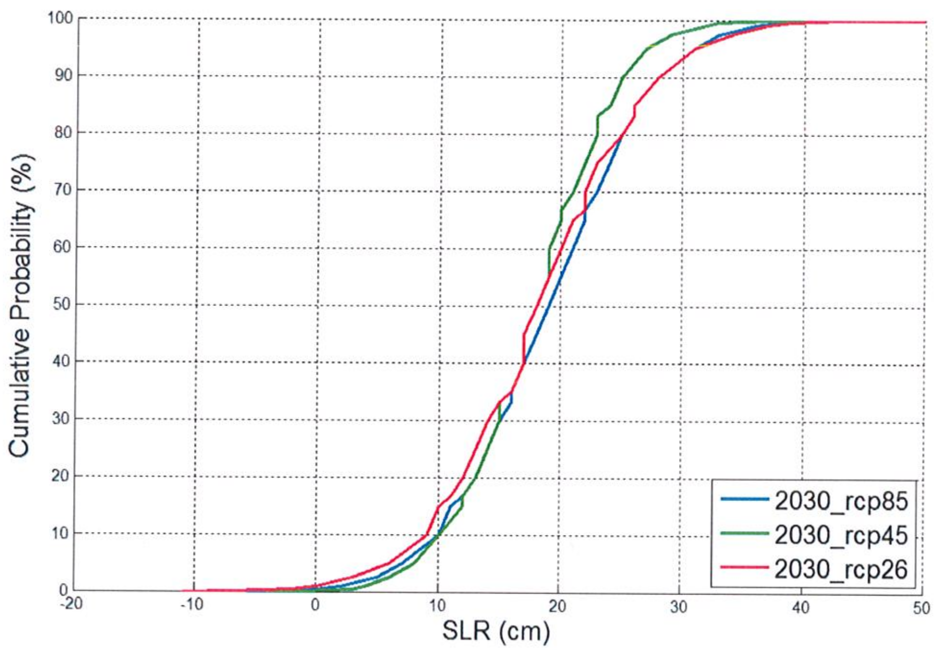

Figure 5. Sea Level Rise Cumulative Probability Distributions for 2030, Cutler, ME

[6] Kopp, R. E., R. M. Horton, C. M. Little, J. X. Mitrovica, M. Oppenheimer, D. J. Rasmussen, B. H. Strauss, and C. Tebaldi (2014), Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites, *Earth's Future*, *2*, 383–406, doi:10.1002/2014EF000239.

[7] Intergovernmental Panel on Climate Change (2013), Summary for policy makers, in *Climate Change 2013: The Physical Science Basis*, edited by T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. Midgley, pp. 3–29, Cambridge Univ. Press, Cambridge, U. K.

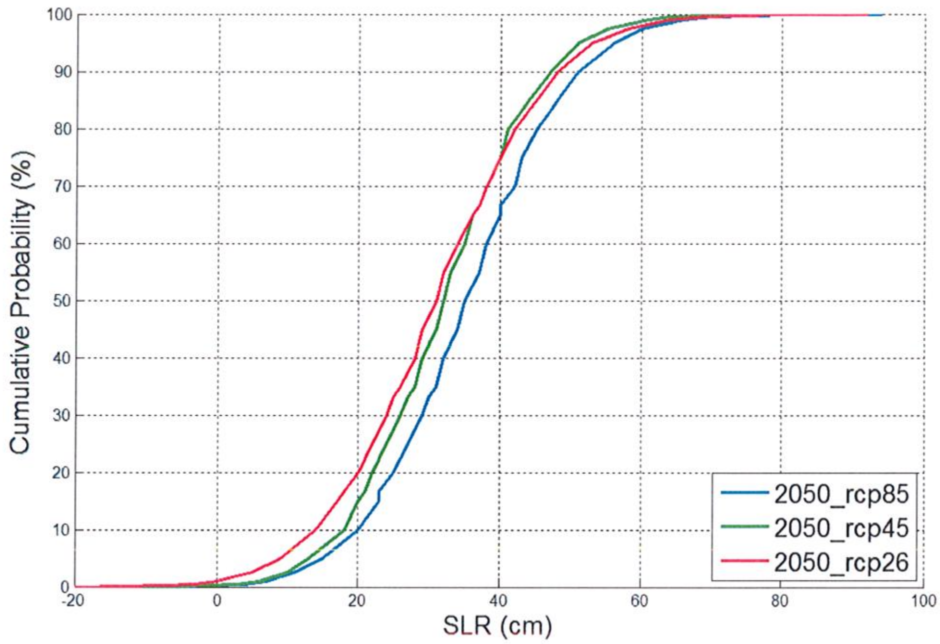

Figure 6. Sea Level Rise Cumulative Probability Distributions for 2050, Cutler, ME

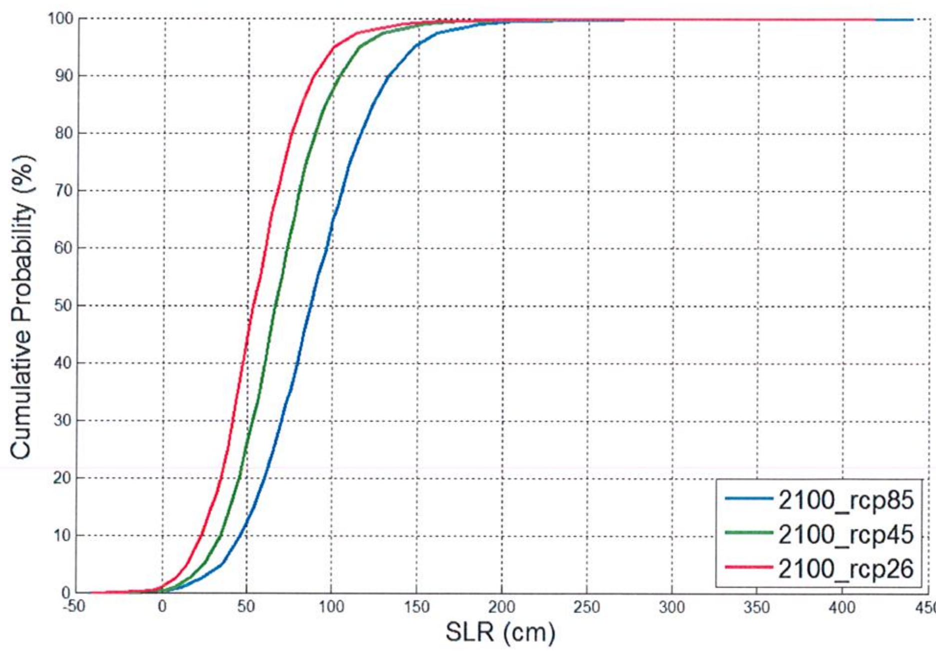

Figure 7. Sea Level Rise Cumulative Probability Distributions for 2100, Cutler, ME

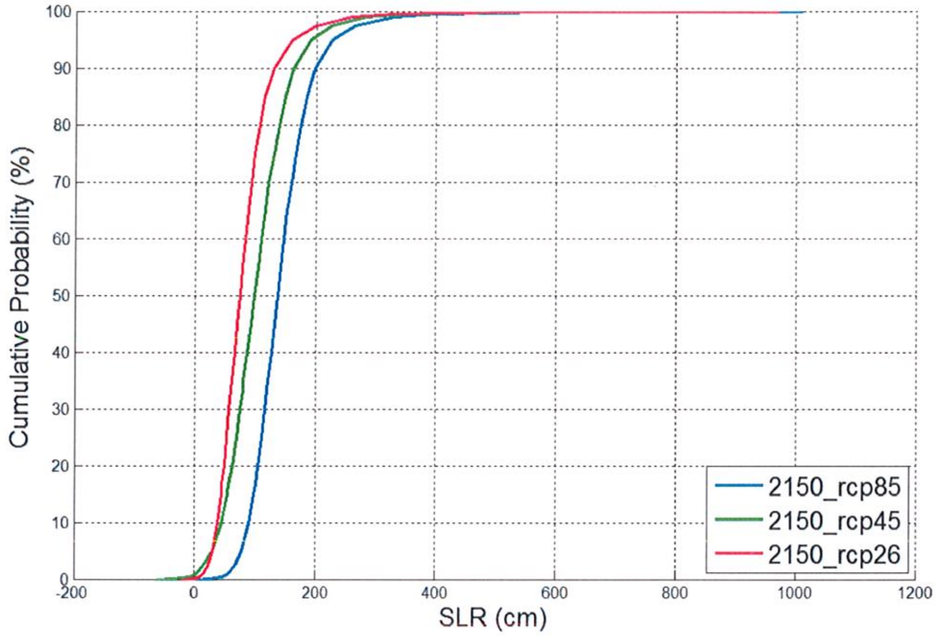

Figure 8. Sea Level Rise Cumulative Probability Distributions for 2150, Cutler, ME

Table 3. Probability Sea Level Rise will exceed the USACE/NOAA Scenarios

Year	Low Rate	USACE Low NOAA Int. Low	NOAA Int. High	USACE High	NOAA High
2030	96%	79%	61%	16%	6%
2050	99%	91%	75%	17%	4%
2100	100%	99%	95%	28%	4%

We can visualize the future sea level probability with greater detail by generating a large number of possible future sea levels and plotting the probability density (i.e. the relative probability that mean sea level will fall within a given time and height range. Samples of future sea levels can be generated randomly following the technique illustrated in Figure 9. This technique uses the sea level rise cumulative probability distribution curves to find a set of future sea levels that are consistent with the probabilistic guidance. Uniform values of probability (green squares) are used to find corresponding sea level rise values (red squares). In practice, we use a random number generating algorithm that applies this technique to generate a large set of possible future sea levels. A new set of possible sea levels is generated for each year by linearly interpolating between the curves given by Kopp et al. (2014), while the three RCP scenarios are each given equal weight. Then the set of random possible sea levels is sorted into elevation bins, and the number of samples within each bin is counted to estimate the probability that sea level will fall within that bin in that future year.

Figure 10 shows the future sea level probability density overlaid by the NOAA and USACE sea level change scenario curves. Inspection of Figure 10 and the data in Table 3 suggest that for the near future (to about 2050) sea level chance will most likely coincide with the intermediate to high scenarios, and that it is reasonably possible that sea level will rise more than the highest scenario. However, as we get toward the end of the 21st century the higher scenarios become much less likely and the range of possible future sea levels spreads out significantly.

It may be tempting to use this probabilistic guidance to identify a most probable scenario for planning purposes; for example, by projecting a scenario that follows the maximum probability density. However, the identification and use of a most probable scenario is ill-advised because, given large degree of uncertainty in future projections, even the most probable scenario is very unlikely. Instead of using the probabilistic guidance to identify a most probable scenario, we recommend an approach to coastal hazard analysis that considers the full range of possible future sea level scenarios that is informed by the probabilistic information so that the results can be applied within a RIDM framework. This may be accomplished through the Monte Carlo analysis methods that combine the probabilistic sea level change information with probabilistic flood hazard information.

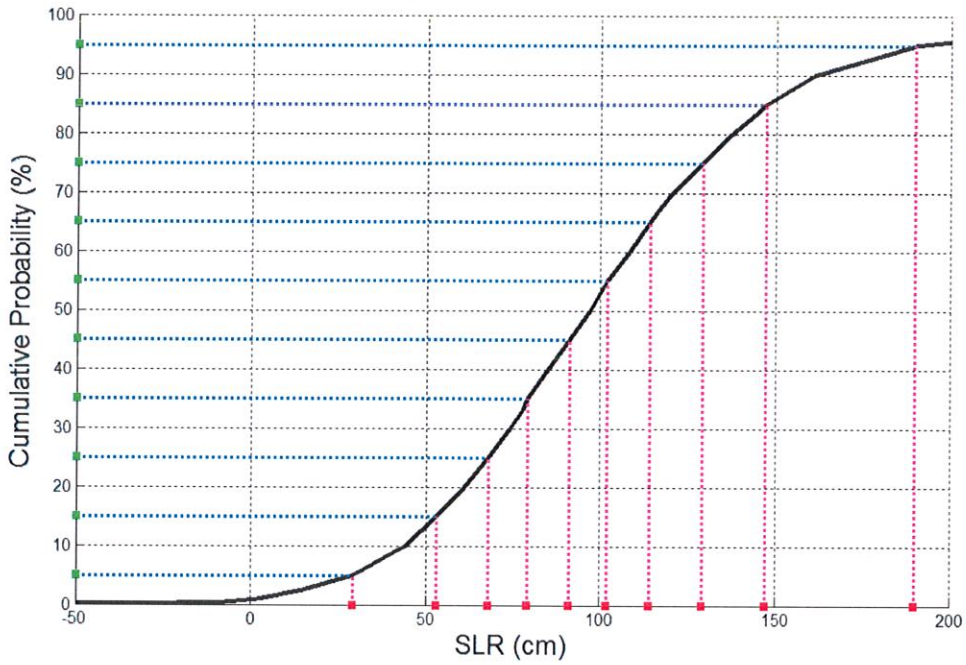

Figure 9. Random Sampling from a Sea Level Rise Cumulative Probability Distribution

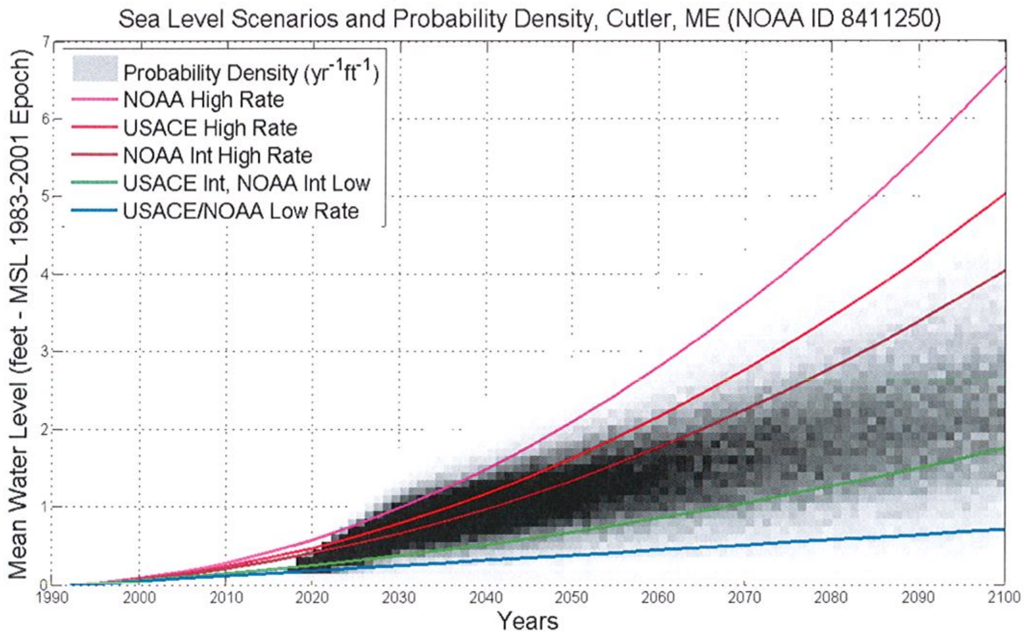

Figure 10. Comparison of NOAA/USACE Sea Level Rise Scenarios and Future Sea Level Probability Density, Cutler, Maine

MONTE CARLO SIMULATION - COMBINED SEA LEVEL RISE AND FLOOD HAZARD

Monte Carlo simulation, named after the well-known gambling establishment in Monaco, is a technique that uses randomness to solve numerical problems. In this case, we combine a large number of random samples of flood levels with a large number of random samples of future sea level rise values to generate a large sample of possible future flood levels. We also add an additional term to the simulation to account for uncertainty. To account for uncertainty, we draw random samples from a normal (Gaussian) distribution with a mean and standard deviation specified to approximate the model error. In this case a standard deviation of 1.9 feet is used based on the NACCS 68% percent Upper Confidence Interval.

The Monte Carlo simulation is executed with the following steps to determine the ARI curves for future storm tide water levels. For a future year that we would like to know the coastal storm hazard:

1. Randomly select a maximum storm tide from the storm tide ARI/AEP curve;

2. Randomly select a sea level change value from the sea level rise cumulative probability distribution for the future year. If necessary, find values from a year before the year of interest and a year after the year of interest and linearly interpolate to get the value for the year of interest;

3. Randomly select an error value from the uncertainty cumulative probability distribution curve;

4. Sum the values from steps 1 thru 3 and record one possible future annual maximum storm tide level for the year of interest;

5. Repeat steps 1 thru 4 20,000 times to generate 20,000 possible annual maximum storm tide values for the future year; and

6. Sort the values from step 5 into elevation bins, count the number in each bin and empirically determine the ARI curve for the future flood hazard.

To illustrate the Monte Carlo procedure, and in keeping with the gambling analogy, we have developed the Storm Surge Slot Machine (S3M). S3M is an educational game of chance designed to give the players a sense of the range possibilities and the degree of uncertainty with future coastal flood hazards. S3M can be played with any number of players. The game play is simple, requiring only a pair of dice and a set of playing cards, which are analogous to the cylinders in a slot machine. The playing cards are based on the cumulative probability distributions used in the Monte Carlo analysis and may be developed for a specific site. A ruler and notepad are also recommended to aid in play. Playing instructions and playing cards based on the hazard analysis at Machias are provided in Attachment A.

PRESENT AND FUTURE FLOOD HAZARDS

When probabilistic projections of sea level rise are mathematically combined with the flood hazard data through Monte Carlo Simulation, the resulting future hazard curves express the hazard considering all possibilities for sea level rise. In this case it becomes meaningless to discuss any particular sea level rise scenario because the hazard curve probabilistically considers all possible scenarios. In other words, where the results show a flood level associated with a particular ARI for a particular future year (e.g. the 100-year flood level for the year 2070), the level shown represents the future hazard considering all possibilities of sea level rise up to that future year. Because the sea level rise probability information used in this analysis has been developed by experts in the area of climate science and sea level rise processes[8], this approach places the choice of what sea level rise scenarios and how likely each of those scenarios are into the hands of those experts, allowing the community stakeholders to focus on identifying the vulnerabilities within their community and the adaptation measures that may reduce their risk. In contrast, current scenario-based guidance may ask stakeholders to consider very unlikely scenarios in their decision-making process (e.g. a 100-year flood plus the NOAA high projection for 2100) without providing any understanding of how unlikely the scenario may actually be.

RISK ASSESSMENT

The Monte Carlo simulation described above was carried out for each decade between 2020 and 2120. The resulting future flood hazard curves are shown in Figure 11 and tabulated in Table 4. It is noteworthy that future sea level rise is expected to cause the hazard associated with rarer events to increase faster than the hazard associated with more frequent events. For example, the

[8] Kopp, R. E., R. M. Horton, C. M. Little, J. X. Mitrovica, M. Oppenheimer, D. J. Rasmussen, B. H. Strauss, and C. Tebaldi (2014), Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites, *Earth's Future*, *2*, 383–406, doi:10.1002/2014EF000239.

10-year TWL is expected to increase about 3.4 feet from 2020 to 2120 while the 500-year TWL is expected to increase 6.7 feet feet during the same period. The greater increase in the more extreme hazards reflects the fact that increasing uncertainty in future sea level rise leads to greater risk in the future. This fact may not be apparent with scenario-based sea level rise guidance and is often ignored in planning studies that apply uniform sea level rise values to a present-day hazard curve to estimate future risks. In contrast, the Monte Carlo approach allows us to quantify how much the risk will increase due to increasing uncertainty in the future.

When the elevation of a specific asset is known, this hazard information can be used to evaluate Changes in the flood hazard. For example, Figure 12 presents the probability of flooding in two ways. The blue line on the figure shows the probability that an elevation of 11 feet will be exceeded within each future year. The red line shows the compounded probability that 11 feet will be exceeded at least once prior to the future year. From the annual probability plot (blue line) we can see that there is about a 4% chance the TWL exceeded 11 feet once during 2020, this chance will increase to about 12% by 2050, and be nearly 40 % by 2120. The compounded probability plot (red line) shows us that there is about a 72% chance that the TWL will exceed 11 feet at least once by 2040, and it is nearly certain (greater than 95% chance) that the TWL will exceed 11 feet at least once before 2060.

This information can also be used to assess the risk of particular assets that are exposed to this flood hazard. In addition to the hazard information, a risk assessment requires information that describes the cost of damage associated with the hazard. This may be done using depth-damage functions like the example shown in Figure 13. Better yet, asset specific damage functions may be developed for specific infrastructure. Once the damage associated with a certain depth of flooding is established the hazard information presented here may be used to determine the likelihood of experiencing that damage. The expected cost of damage in a given year can then be determined by multiplying the cost of damage by the probability of flooding at that level. Summing costs over the full range of possible flood levels results in the expected cost of risk for that year. This cost can then be aggregated over a range of future years to determine the lifetime cost associated with flood risk. An example for a $500,000 asset at 11 feet elevation is shown in Figure 14. In this example the present day risk accounts to less than $5000 per year (about 1% of the asset value) however when future risk is considered we see the risk increases dramatically over the next few decades to nearly $10,000 per year by 2060, and more than $25,000 per year by 2100. The aggregate cost over the next century is about $670,000, which is significantly more than present value of the asset. This simplified analysis is just an example of how the cost of future flood risk may be evaluated. It is recommended that asset specific depth damage functions and elevations be used to determine risk for specific assets in downtown Machias. Additional economic factors such as inflation and projected changes in real estate value may also be considered.

RECOMMENDATIONS AND NEXT STEPS

At this time Ransom is not providing any specific recommendations regarding the elevation of proposed flood protection structures for downtown Machias. Instead we recommend that the information in this memorandum be considered along with the economic analyses that are being undertaken as part of this project to weight the costs and benefits of flood protection alternatives. Benefits may include cost savings from reduced flood risk afforded by flood protection alternatives. However, it is important to consider the role of flood insurance in managing flood risk in this case. Specifically, National Flood Insurance Program (NFIP) requirements for flood protection structures must be met in order to realize the benefit of risk reduction in terms of reduced flood insurance costs. These requirements include designing and building a structure that can be certified to provide protection against the 1% annual chance flood as defined by FEMA, and FEMA flood maps must be revised to reflect this protection. If the structure does not meet this requirement or the flood maps are not adequately revised, property owners may still be required to purchase flood insurance which might negate reduced risk benefits provided by the flood protection structure.

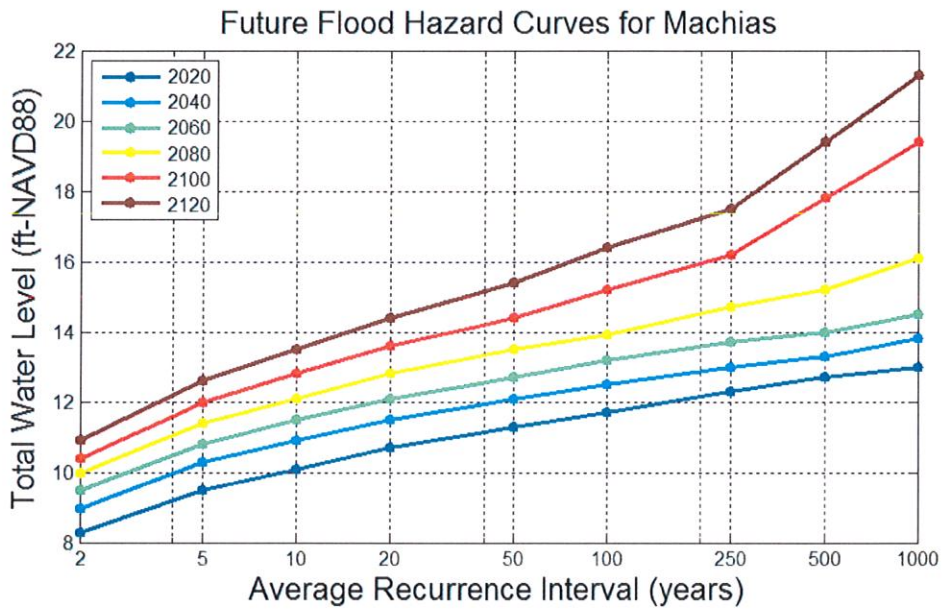

Figure 11. Total Water Level Flood Hazard for Future Sea Levels at Machias.

Table 4. Total Water Level Average Recurrence Interval for Future Years Including Uncertainty and Probabilistic Sea Level Rise Guidance for All Sea Level Rise Scenarios.

TWL in Feet NAVD88		Average Recurrence Interval (years)							
		2	5	10	20	50	100	250	500
Future Year	2020	8.3	9.5	10.1	10.7	11.3	11.7	12.3	12.7
	2030	8.8	10	10.6	11.2	11.7	12.1	12.7	13.1
	2040	9	10.3	10.9	11.5	12.1	12.5	13	13.3
	2050	9.3	10.5	11.2	11.8	12.4	12.9	13.4	13.7
	2060	9.5	10.8	11.5	12.1	12.7	13.2	13.7	14
	2070	9.7	11.1	11.8	12.4	13.1	13.6	14.2	14.8
	2080	10	11.4	12.1	12.8	13.5	13.9	14.7	15.2
	2090	10.2	11.7	12.4	13.1	14	14.5	15.3	16.1
	2100	10.4	12	12.8	13.6	14.4	15.2	16.2	17.8
	2110	10.7	12.3	13.2	14	15	15.9	17.4	18.5
	2120	10.9	12.6	13.5	14.4	15.4	16.4	17.5	19.4

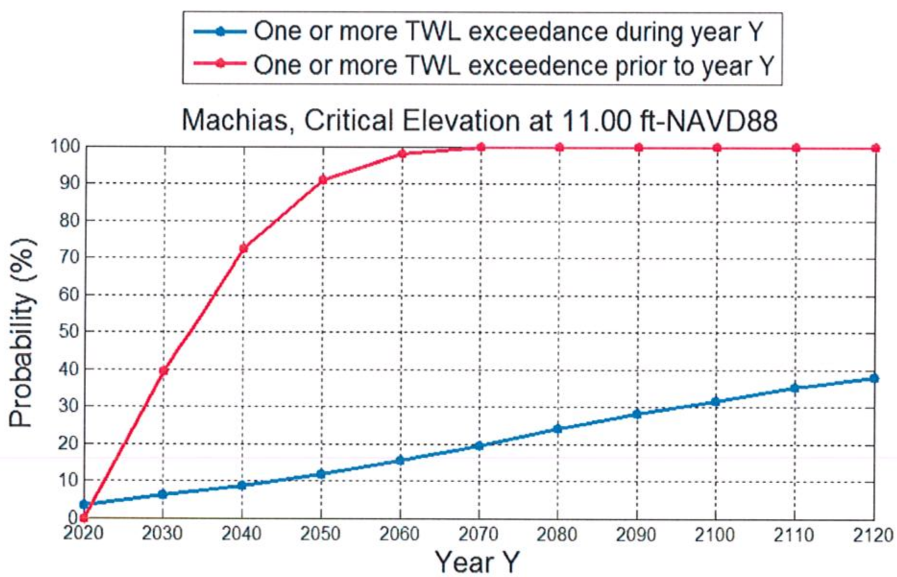

Figure 12. Present and Future Probability of TWL Exceeding 11 feet at Machias Waterfront

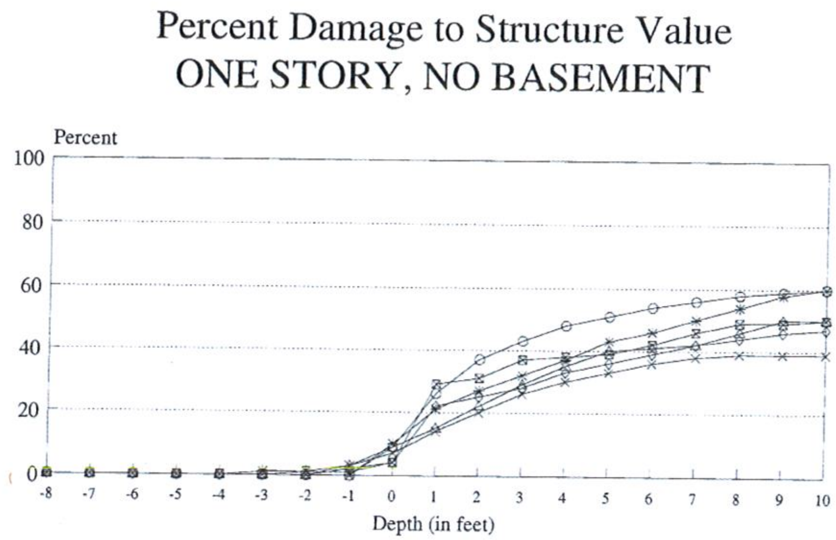

Figure 13. Example Depth Damage Functions[9]

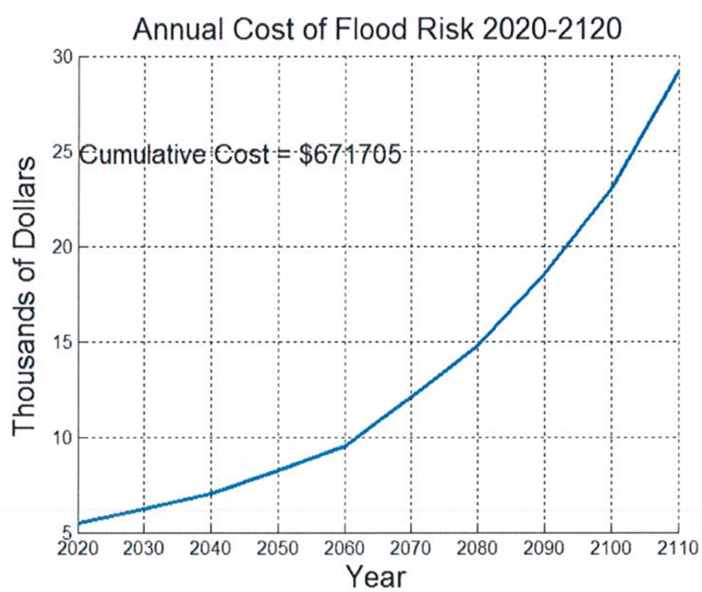

Figure 14. Example Risk Assessment for a $500,000 asset at 11 feet elevation in Downtown Machias considering future flood risk.

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[9] USACE, 1992. Catalog of Residential Depth-Damage Functions Used by the Army Corps of Engineers in Flood Damage Estimation. IWR Report 92-R-3, May 1992

Appendix C – Flood Impacts to Machias Downtown Property

a. BUILDING INVENTORY SPREADHEET; Baker Design Consultants; Data Collected in 2018.

b. Flood Hazard Inundation Plans; Baker Design Consultants

   a. Sheet FH-0 Mapped Hazard Areas and Surveyed Topography

   b. Sheet FH-1 Flood Scenario 1- Flooding to Base Flood Elevation (BFE) = 10.7 NAVD88.

   c. Sheet FH-2 Flood Scenario 2- BFE + 2-ft = 12.7 NAVD88.

   d. Sheet FH-3 Flood Scenario 3- BFE + 4-ft = 14.7 NAVD88

   e. Sheet FH-4 Flood Scenario 4- BFE + 6-ft = 16.7 NAVD88

Downtown Building Inventory
1/30/2019

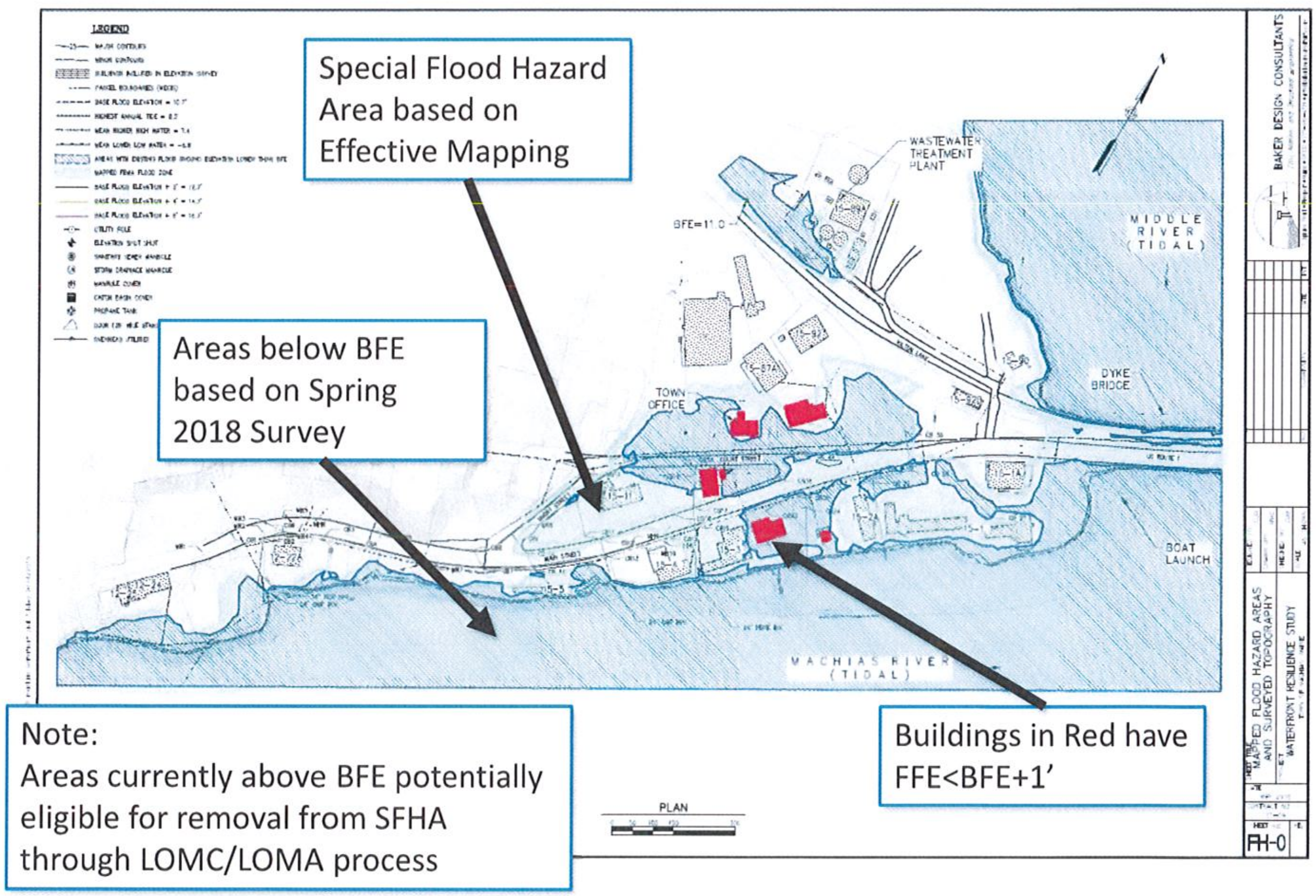
Baker Design Consultants

Map/Lot		Machias Downtown Building Inventory	Property Value	Lowest Floor Elev	HAG	LAG	Within SFHA ?	Freeboard Above BFE			Inundation Scenario (Flooding exceeds level indicated)				Floor At Grade	Base-ment ?	Garage?	Ext Propane Tank Elev
								FFE	HAG	LAG	Scenario 1 BFE	Scenario 2 BFE+2-ft	Scenario 3 BFE+4-ft	Scenario 4 BFE+6-ft				
12	24	Machias Hardware	$ 95,200.00	11.9	18.8	11.8	---	1.2	8.1	1.1	No	Yes	Yes	Yes	Slab	No	No	13.1
12	25	Barber Shop	$ 24,300.00	16.0	22.0	12.1	---	5.3	11.3	1.4	No	No	No	Yes	On Posts	?	No	---
15	1A	Helen's Restaurant	$ 727,200.00	13.3	12.4	11.2	AE 10.7	2.6	1.7	0.5	No	Yes	Yes	Yes	Slab	No	No	Undergrnd
15	2A	Berry Vines	$ 75,800.00	14.0	12.7	10.8	AE 10.7	3.3	2.0	0.1	No	No	Yes	Yes	Slab	No	No	11.5
15	2A	Rivers Edge Drive-In/Shake Pit	$ 75,800.00	11.5	10.5	10.2	AE 10.7	0.8	-0.2	-0.5	Yes	Yes	Yes	Yes	Slab	No	No	10.2
15	11	Bluebird Restaurant	$ 283,600.00	13.3	13.5	11.0	AE 10.7	2.6	2.8	0.3	No	Yes	Yes	Yes	Slab	No	No	12.1
15	91	US Cellular, Subway, Etc.	$ 209,000.00	10.9	11.5	10.6	AE 10.7	0.2	0.8	-0.1	Yes	Yes	Yes	Yes	Slab	No	No	---
15	92	Pellon Center	$ 216,700.00	11.9	11.9	11.6	---	1.2	1.2	0.9	No	Yes	Yes	Yes	Slab	No	No	---
15	92B	Machias Bay Chamber of Commerce	$ 15,000.00	13.0	13.2	12.8	---		2.5	2.1	No	Yes	Yes	Yes	On Posts	No	No	12.8
15	1	Machias River Inn, East	$ 1,171,100.00	12.4	12.4	9.7	AE 10.7	1.7	1.7	-1.0	No	Yes	Yes	Yes	Slab	No	No	11.9
15	1	Machias River Inn, West		13.6	13.7	11.4	AE 10.7	2.9	3.0	0.7	No	No	Yes	Yes	Slab	No	No	12.4
15	2	Living Innovations	$ 166,800.00	10.1	10.8	9.8	AE 10.7	-0.6	0.1	-0.9	Yes	Yes	Yes	Yes	Slab	No	No	10.3
12	22A	Bar Harbor Bank & Trust	$ 209,700.00	14.08	13.97	13.4	---	3.38	3.27	2.7	No	No	Yes	Yes	Slab	No	No	---
15	3	Wall's Appliance	$ 135,700.00	11.7	11.7	10.8	AE 10.7	1.0	1.0	0.1	Yes	Yes	Yes	Yes	Slab	No	Yes	---
15	4	Irving*	$ 530,000.00	13.7	14.1	12.0	---	3.0	3.4	1.3	No	No	Yes	Yes	Slab	No	No	11.9
15	13	Skywalker's Bar & Grille	$ 143,000.00	11.0	11.0	9.6	AE 10.7	0.3	0.3	-1.1	Yes	Yes	Yes	Yes	Slab	No	No	10.4
15	86	Machias Town Office	$ 134,500.00	11.14	11.23	10.57	AE 10.7	0.44	0.53	-0.13	Yes	Yes	Yes	Yes	Slab	No	No	---
15	87/87A	EBS Building Supplies, Back		12.0	12.5	12.0	---		1.8	1.3	No	No	No	No				---
15	87/87A	EBS Building Supplies, Side	$ 137,900.00	12.1	11.8	10.8	AE 10.7	1.4	1.1	0.1	No	Yes	Yes	Yes				---
15	87/87A	EBS Building Supplies, Main	$ 416,100.00	12.3	12.6	11.4	---	1.6	1.9	0.7	No	Yes	Yes	Yes				---
15	5	Machias River Redemption	$ 43,900.00	13.51	11.99	8.69	AE 10.7	2.81	1.29	-2.01	No	No	Yes	Yes	On Posts	No	Yes	8.58
15	89	Wastewater Treatment Plant	$ 1,024,800.00	16.0	14.0	11.7	AE 11.0	5.0	3.0	0.7	No	No	No	Yes	Slab	No	No	---
15	90	Private Residence	$ 45,000.00	13.4	13.4	12.6	---	2.4	2.7	1.9	No	Yes	Yes	Yes				13.5
15	85	Private Garage 13 Court St	$ 4,500.00	8.1	8.1	8.1				-2.6	Yes	Yes	Yes	Yes				
15	84	Private Abandoned 15 Court	$ 14,000.00	10.1		9.1				-1.6	Yes	Yes	Yes	Yes				
Notes:			$ 5,899,600.00			Total	14				8	17	21	23				

1 All elevations are to NAVD88 Vertical Datum
2 LAG - Lowest adjacent finished grade next to building; HAG - Highest adjacent finished grade adjacent to building
3 Properties identified as "Mapped within SFHA" based on 2017 FEMA FIRMs for Machias, ME
4 Based on Town of Machias Floodplain Management Ordinance, minimum FFE elevation is 1' above BFE for buildings in AE Zone
*US Army Corps of Engineers (Table 43) (http://www.mvn.usace.army.mil/Portals/56/docs/PD/Donaldsv-Gulf.pdf)

Yes — Below Floor damage

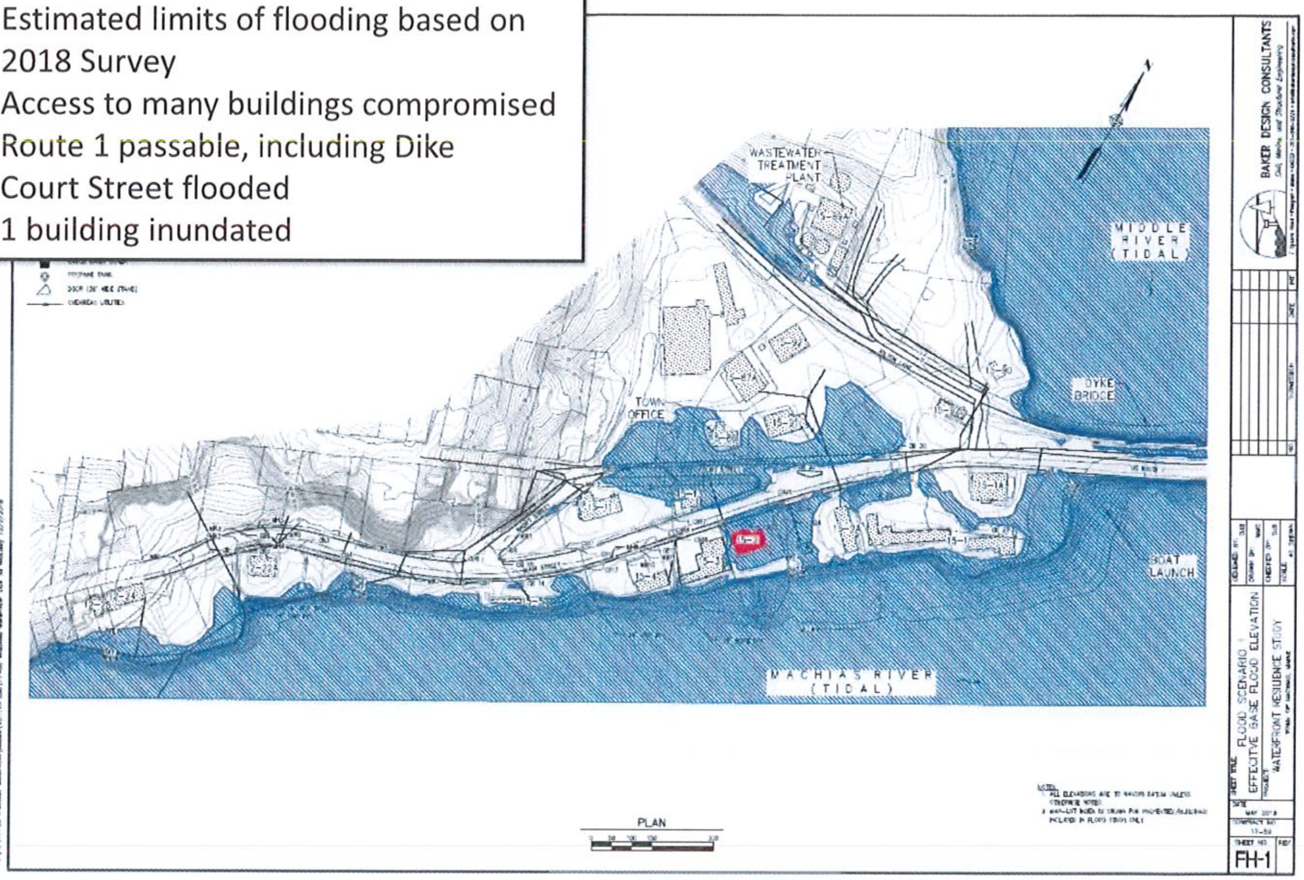
Flood Risk


Special Flood Hazard Area based on Effective Mapping
Areas below BFE based on Spring 2018 Survey
Buildings in Red have FFE<BFE+1'
Note:
Areas currently above BFE potentially eligible for removal from SFHA through LOMC/LOMA process
LEGEND
WASTEWATER TREATMENT PLANT
BFE=11.0
MIDDLE RIVER (TIDAL)
TOWN OFFICE
DYKE BRIDGE
BOAT LAUNCH
MACHIAS RIVER (TIDAL)
PLAN
BAKER DESIGN CONSULTANTS
MAPPED FLOOD HAZARD AREAS AND SURVEYED TOPOGRAPHY
WATERFRONT RESILIENCE STUDY
FH-0

Flood Scenario 1: Effective BFE = 10.7' NAVD88

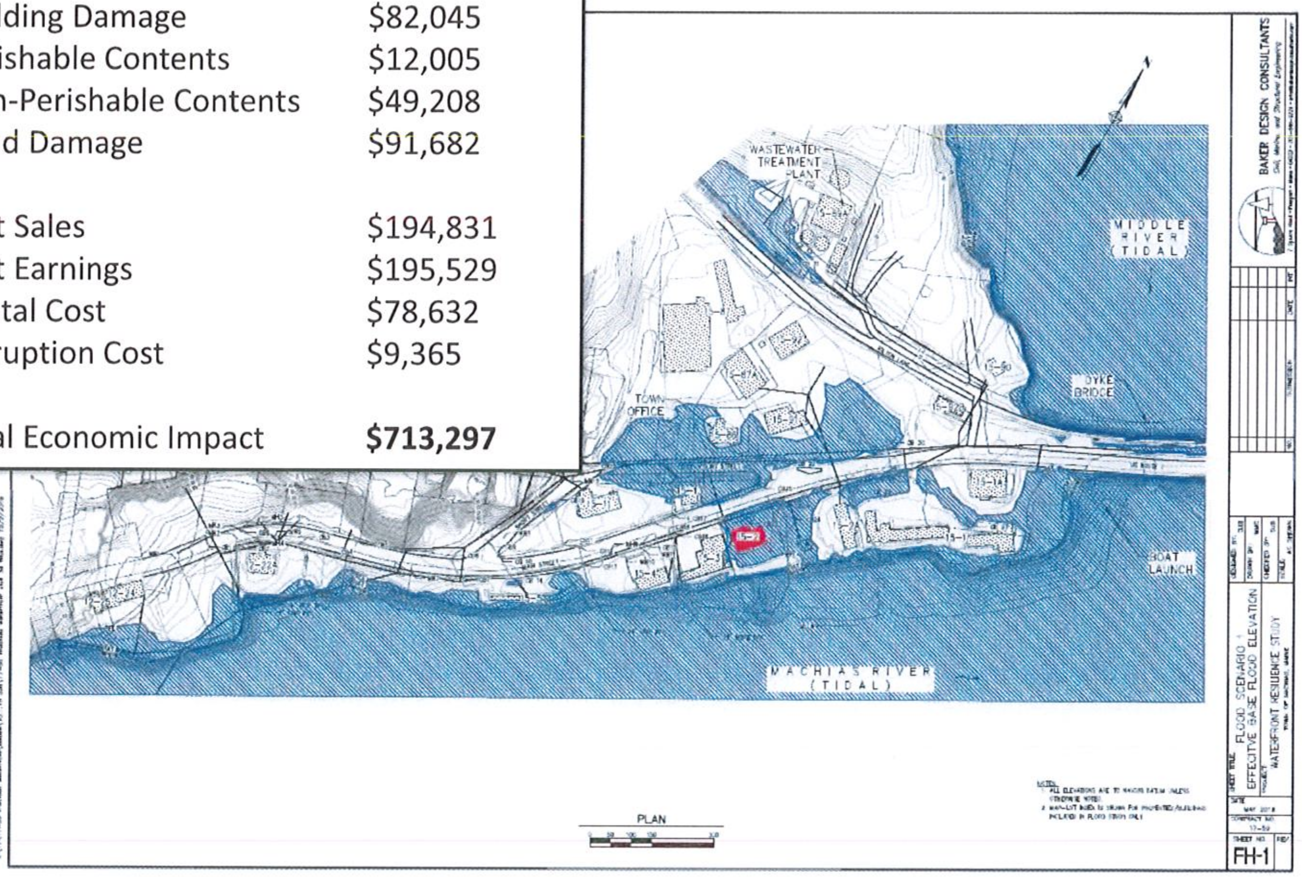
Summary of Impacts

1. Estimated limits of flooding based on 2018 Survey
2. Access to many buildings compromised
3. Route 1 passable, including Dike
4. Court Street flooded
5. 1 building inundated



Flood Scenario 1: Effective BFE = 10.7’ NAVD88

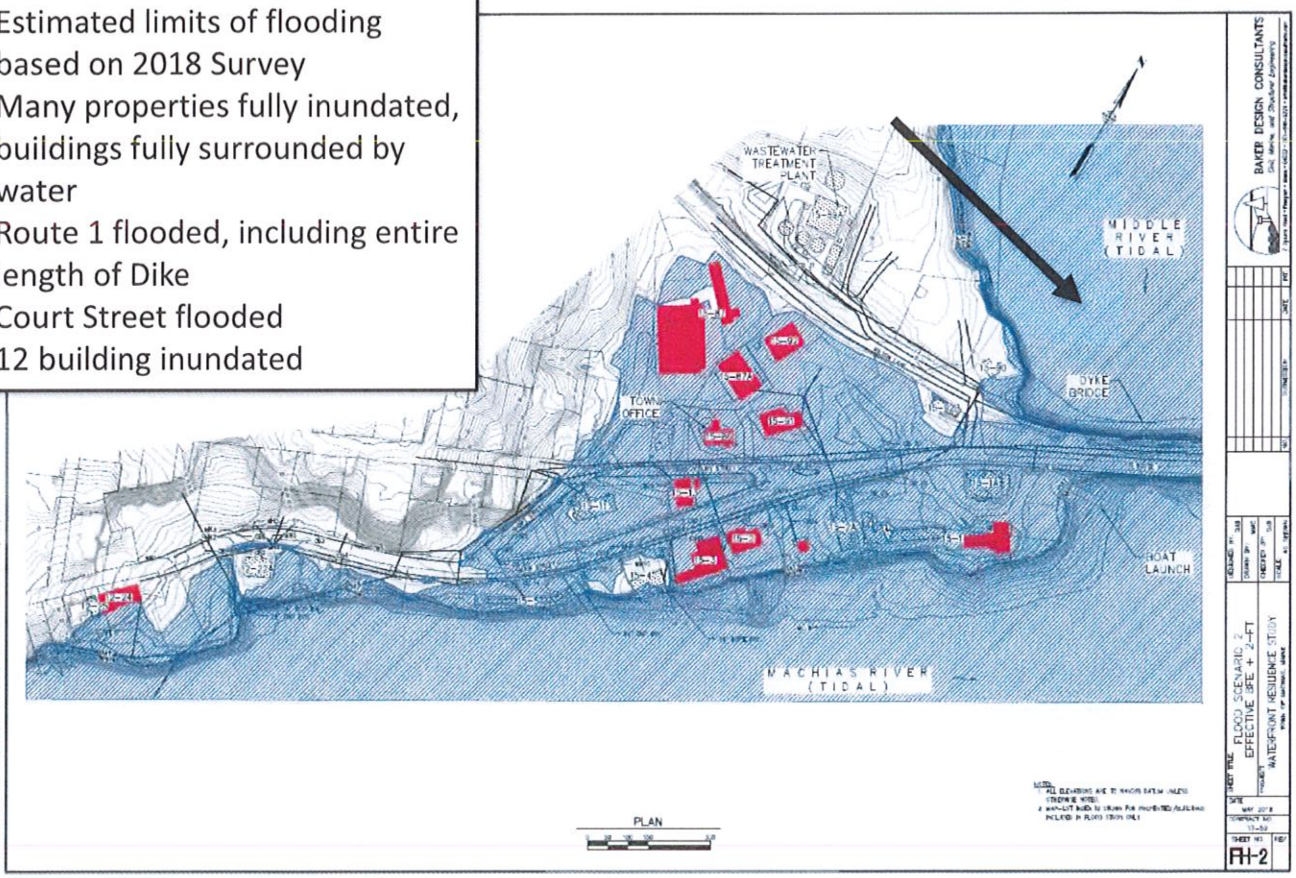
Estimated Losses	
Building Damage	$82,045
Perishable Contents	$12,005
Non-Perishable Contents	$49,208
Road Damage	$91,682
Lost Sales	$194,831
Lost Earnings	$195,529
Rental Cost	$78,632
Disruption Cost	$9,365
Total Economic Impact	**$713,297**



Flood Scenario 2: Effective BFE+2’ = 12.7’ NAVD88

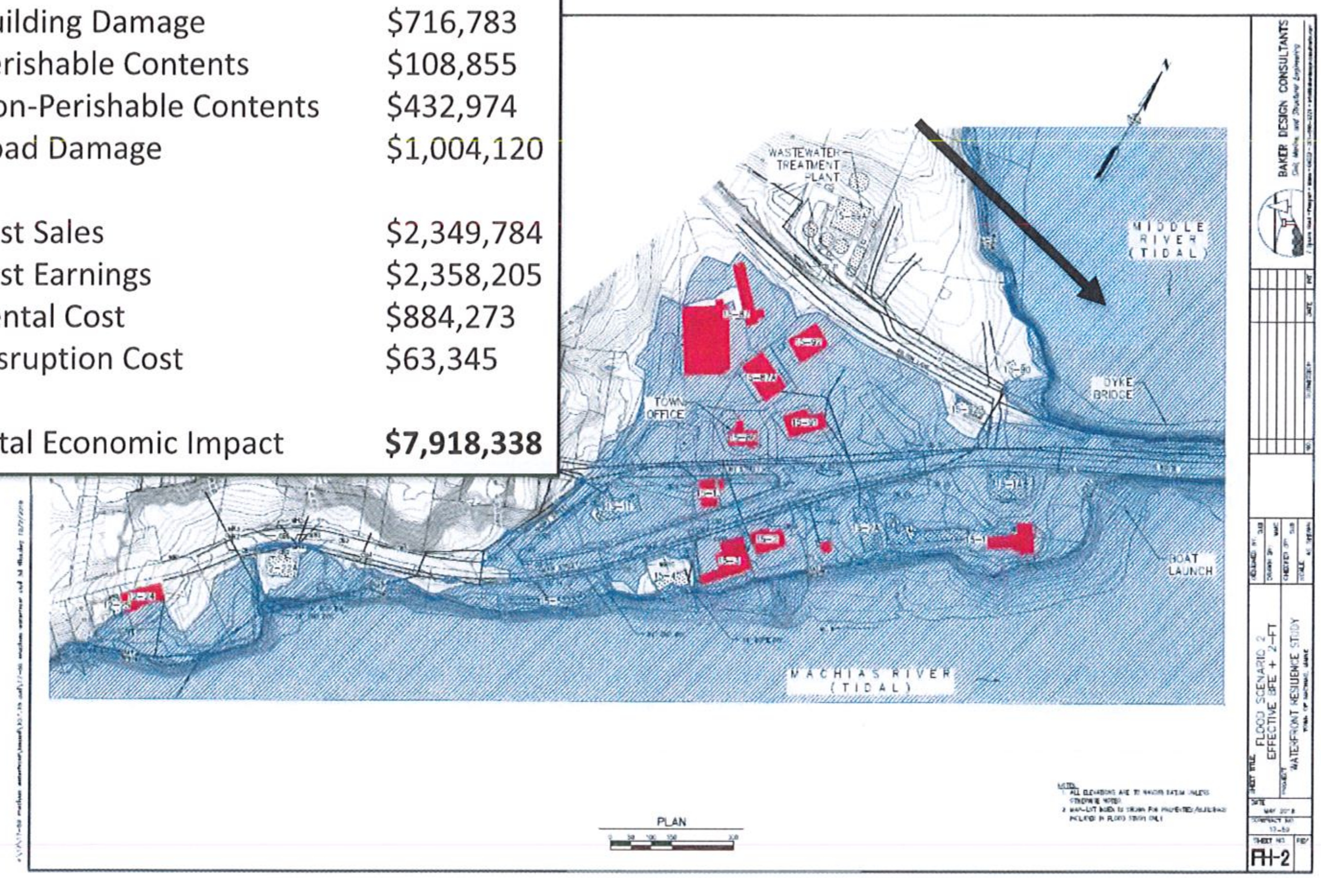
Summary of Impacts

1. Estimated limits of flooding based on 2018 Survey
2. Many properties fully inundated, buildings fully surrounded by water
3. Route 1 flooded, including entire length of Dike
4. Court Street flooded
5. 12 building inundated



Flood Scenario 2: Effective BFE+2' = 12.7' NAVD88

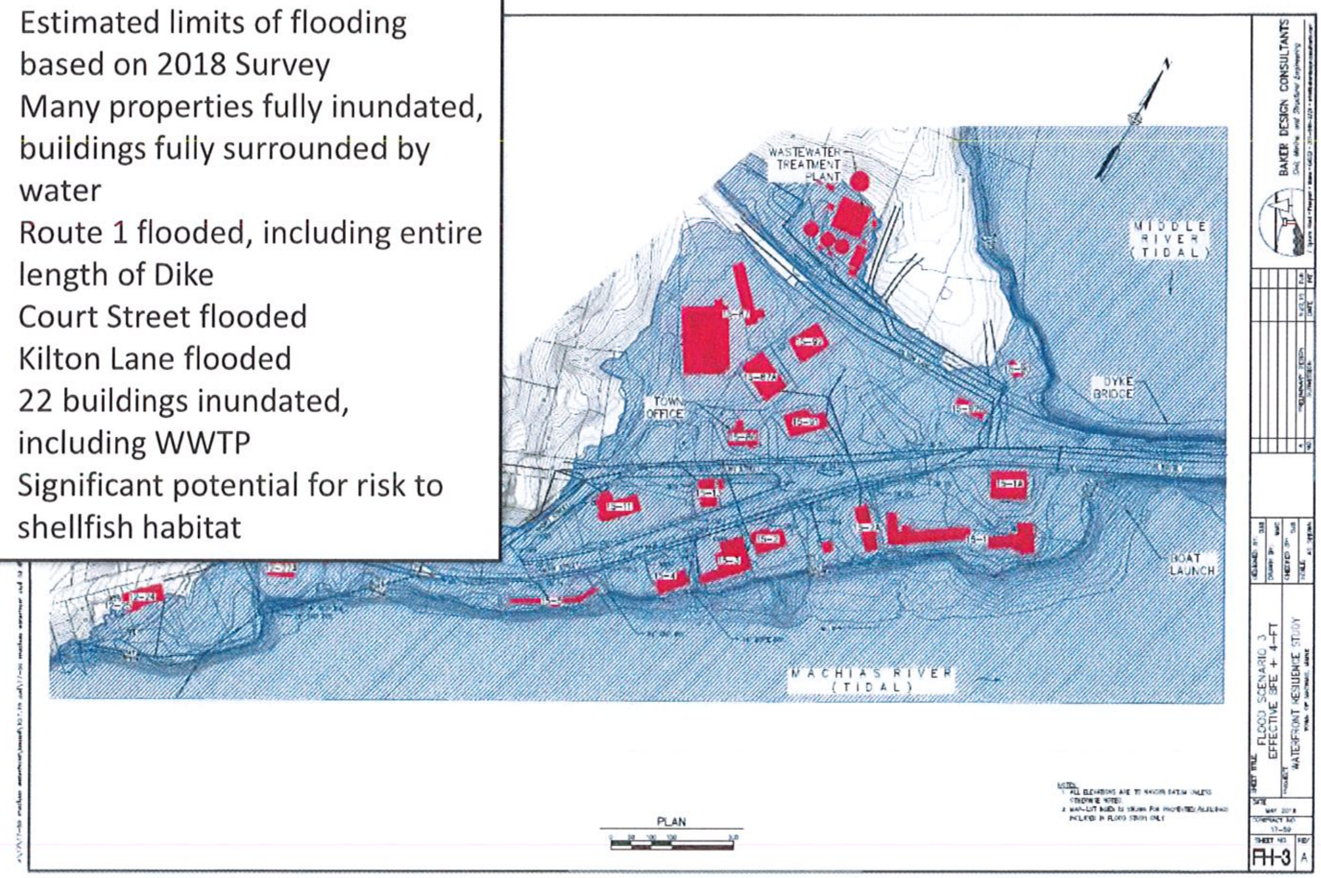
Estimated Losses	
Building Damage	$716,783
Perishable Contents	$108,855
Non-Perishable Contents	$432,974
Road Damage	$1,004,120
Lost Sales	$2,349,784
Lost Earnings	$2,358,205
Rental Cost	$884,273
Disruption Cost	$63,345
Total Economic Impact	**$7,918,338**



Flood Scenario 3: Effective BFE+4' = 14.7' NAVD88

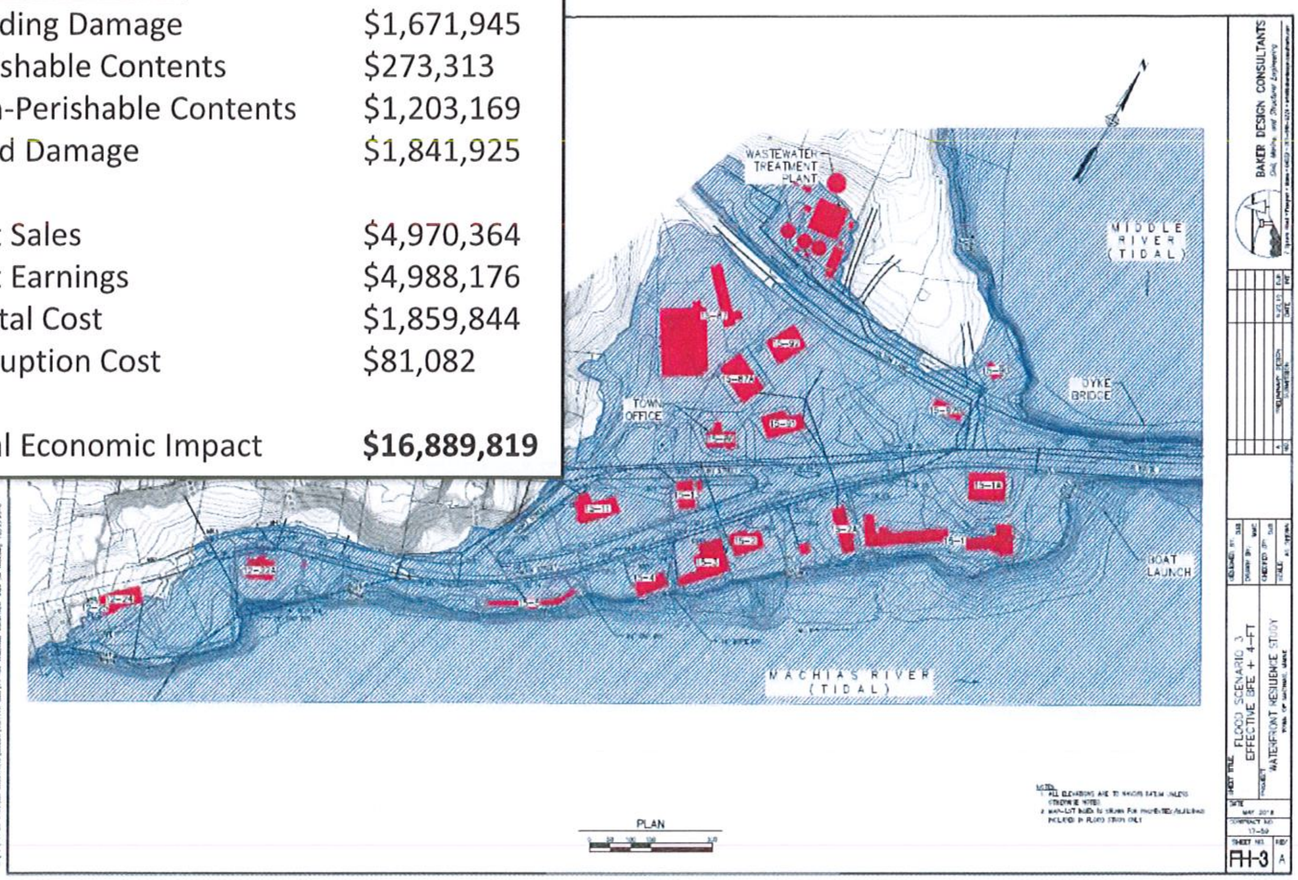
Summary of Impacts

1. Estimated limits of flooding based on 2018 Survey
2. Many properties fully inundated, buildings fully surrounded by water
3. Route 1 flooded, including entire length of Dike
4. Court Street flooded
5. Kilton Lane flooded
6. 22 buildings inundated, including WWTP
7. Significant potential for risk to shellfish habitat



Flood Scenario 3: Effective BFE+4' = 14.7' NAVD88

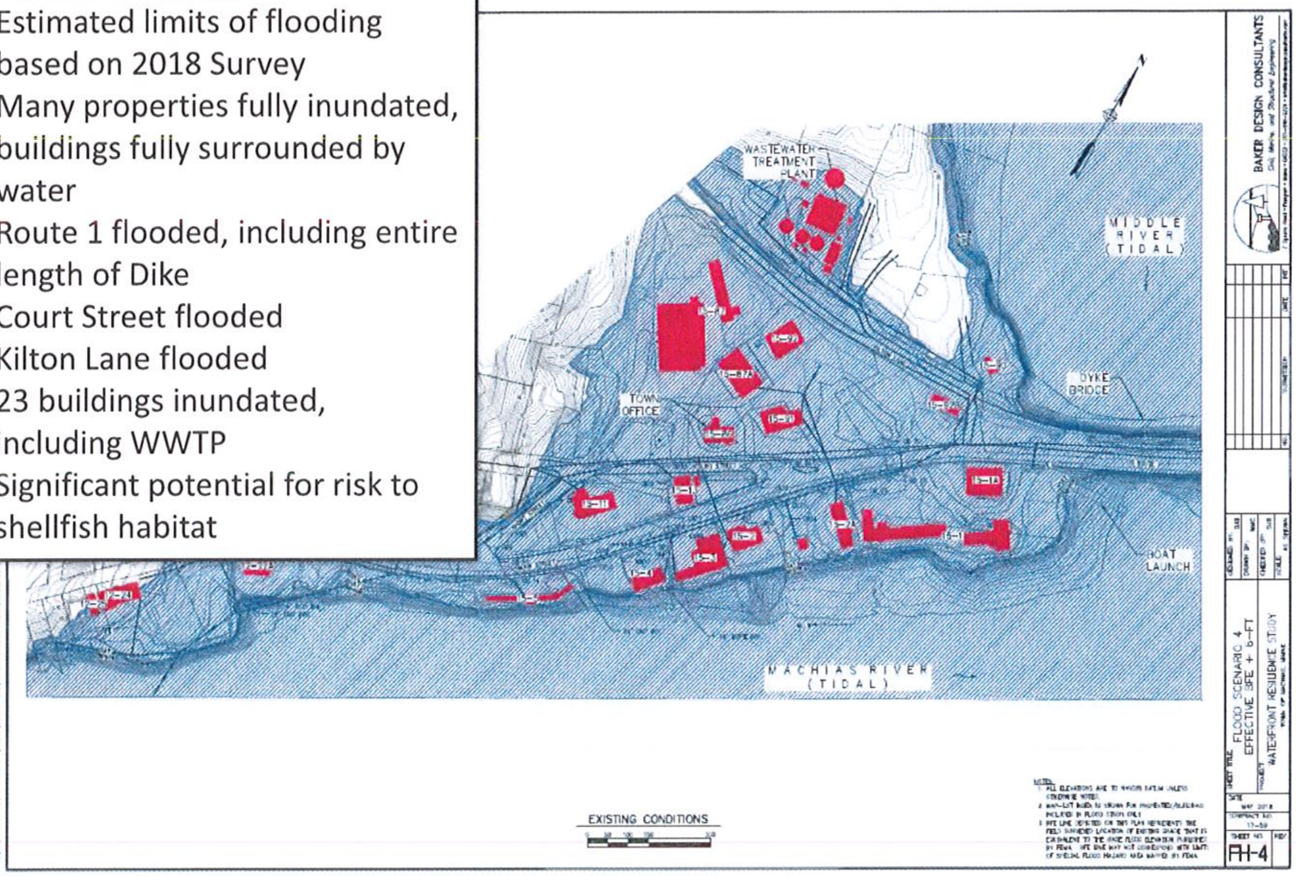
Estimated Losses	
Building Damage	$1,671,945
Perishable Contents	$273,313
Non-Perishable Contents	$1,203,169
Road Damage	$1,841,925
Lost Sales	$4,970,364
Lost Earnings	$4,988,176
Rental Cost	$1,859,844
Disruption Cost	$81,082
Total Economic Impact	**$16,889,819**



Flood Scenario 4: Effective BFE+6’ = 16.7’ NAVD88

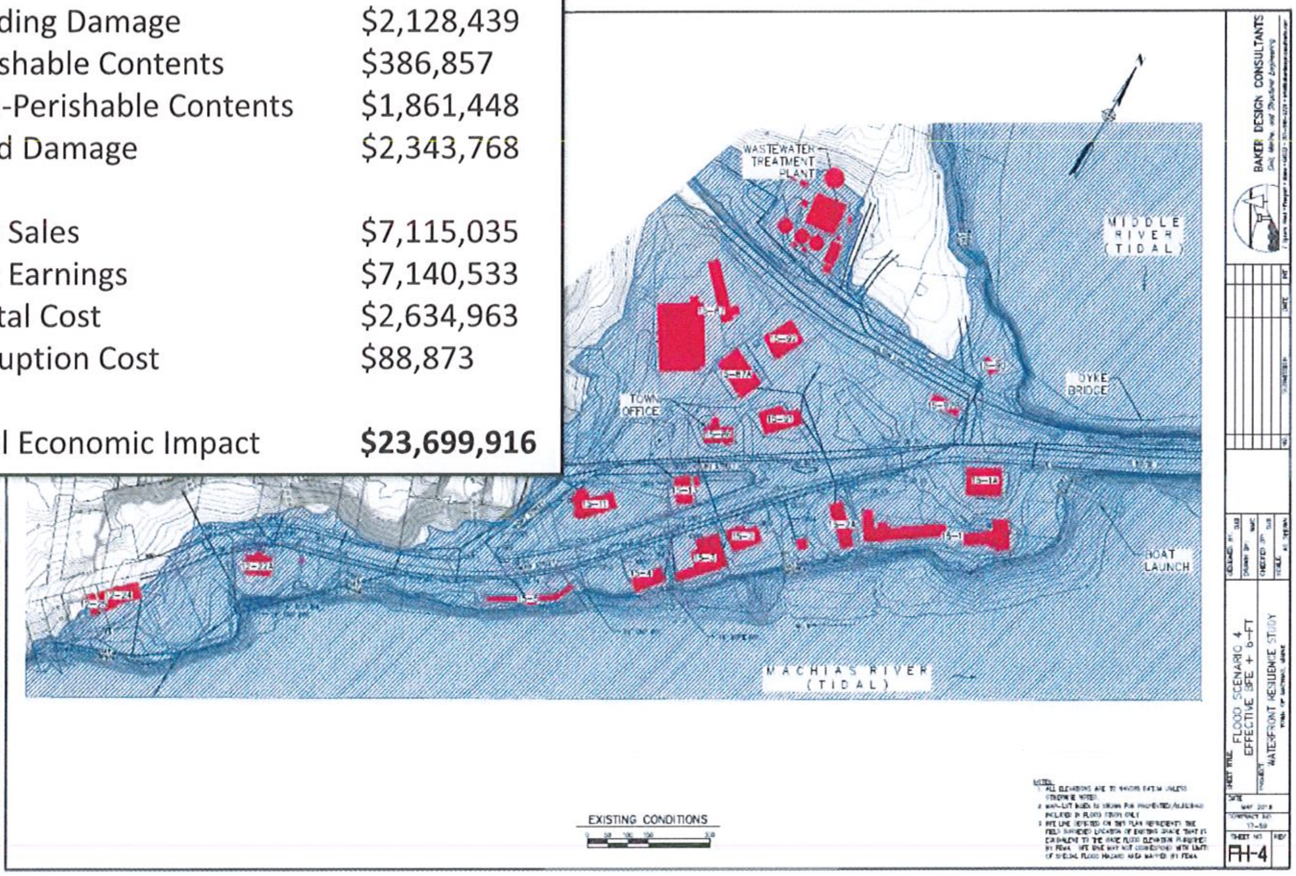
Summary of Impacts

1. Estimated limits of flooding based on 2018 Survey
2. Many properties fully inundated, buildings fully surrounded by water
3. Route 1 flooded, including entire length of Dike
4. Court Street flooded
5. Kilton Lane flooded
6. 23 buildings inundated, including WWTP
7. Significant potential for risk to shellfish habitat



Flood Scenario 4: Effective BFE+6’ = 16.7’ NAVD88

Estimated Losses	
Building Damage	$2,128,439
Perishable Contents	$386,857
Non-Perishable Contents	$1,861,448
Road Damage	$2,343,768
Lost Sales	$7,115,035
Lost Earnings	$7,140,533
Rental Cost	$2,634,963
Disruption Cost	$88,873
Total Economic Impact	**$23,699,916**



Appendix D – Seawall System Program Costs

a. CONCEPT DESIGN CONSTRUCTION COST ESTIMATE; Baker Design Consultants

Seawall System Concept Design
1/30/2019

Baker Design Consultants

Seawall System Refer to Sheet C-2 Typical Sections	Station			Appendix D Sheet Reference	Cost to Address Effective BFE+4 for Entire Downtown (Flood Scenario 3)								
	Start	End	Length		Walkway Paved	Walkway Elevated	Embankment	Bulkhead	Drainage	MDOT	Boatramp	TOTAL	Per LF
Perimeter Seawall				G-2									
Option 1-Embankment	0	575	575	C-4	$ 48,683		$ 949,602	NA	$ 86,250			$ 1,084,535	$ 1,886.15
Option 3- Elevated Walkway	575	800	225	C-5		$ 95,850	$ 227,750	$ 441,250	$ 33,750			$ 798,600	$ 3,549.33
Option 1-Embankment	800	1425	625	C-5, C-6	$ 52,917		$ 1,032,176	NA	$ 93,750			$ 1,178,843	$ 1,886.15
Option 2- Bulkhead	1425	2045	620	C-6, C-7, C-8	$ 52,493		$ 640,322	$ 1,215,889	$ 93,000			$ 2,001,704	$ 3,228.56
Option 3- Elevated Walkway	2045	2360	315	C-8, C-9		$ 134,190	$ 318,850	$ 617,750	$ 47,250			$ 1,118,040	$ 3,549.33
Option 1-Embankment	2360	2750	390	C-9	$ 33,020		$ 644,078	NA	$ 58,500			$ 735,598	$ 1,886.15
WWTP North Embankment	0	750	750	C-10	$ -		$ 366,944					$ 366,944	$ 489.26
BoatRamp Reconstruction	2750	2800	50	C-11							$ 78,379	$ 78,379	$ 1,567.57
Route 1 MDOT Approaches Assumes Road reconstruction part of Dyke recinstruction Project	2800	2900	100	C-12						$ 94,950		$ 94,950	$ 949.50
		TOTAL	3650	$ -	$ 187,113	$ 230,040	$ 4,179,722	$ 2,274,889	$ 412,500	$ 94,950	$ 78,379	$ 7,457,593	$ 2,043.18
with 50% Engineering, Permitting and Contingency												$ 11,186,389	$ 3,064.76

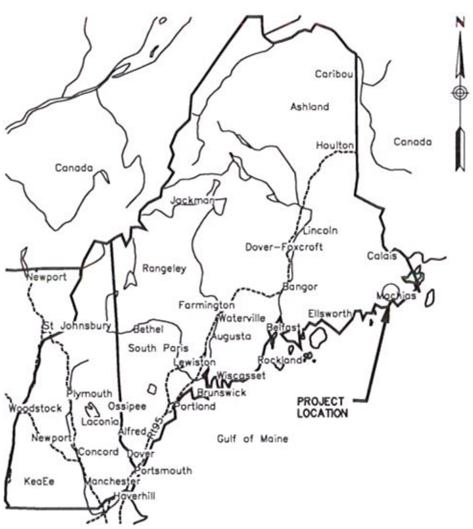
Appendix E -Seawall System Concept Design Drawings

Seawall System Concept Design Solution

WATERFRONT RESILIENCE STUDY

SEAWALL SYSTEM CONCEPT DESIGN; PROTECTION TO BFE + 4FT

TOWN OF MACHIAS, MAINE
PROJECT NO. 17-59



LOCATION MAP

INDEX OF SHEETS

SHEET NO.	DESCRIPTION
G-1	COVERSHEET
G-2	OVERVIEW PLAN
C-1	EXISTING CONDITIONS
C-2	FLOOD HAZARD AREAS
C-3	TYPICAL SEAWALL SECTIONS
C-4	PLAN & PROFILE: PANEL 1
C-5	PLAN & PROFILE: PANEL 2
C-6	PLAN & PROFILE: PANEL 3
C-7	PLAN & PROFILE: PANEL 4
C-8	PLAN & PROFILE: PANEL 5
C-9	PLAN & PROFILE: PANEL 6
C-10	PLAN & PROFILE: PANEL 7
C-11	PLAN & PROFILE: BOAT RAMP
C-12	PLAN & PROFILE: ROUTE 1

MACHIAS TAX MAP COMPOSITE

BAKER DESIGN CONSULTANTS
Civil, Marine, and Structural Engineering
7 Spruce Road • Freeport • Maine • 04032 • 207-846-9724 • info@bakerdesignconsultants.com

NO.	SUBMISSION	DATE	INT.
A	FINAL REPORT	1.23.19	DJB

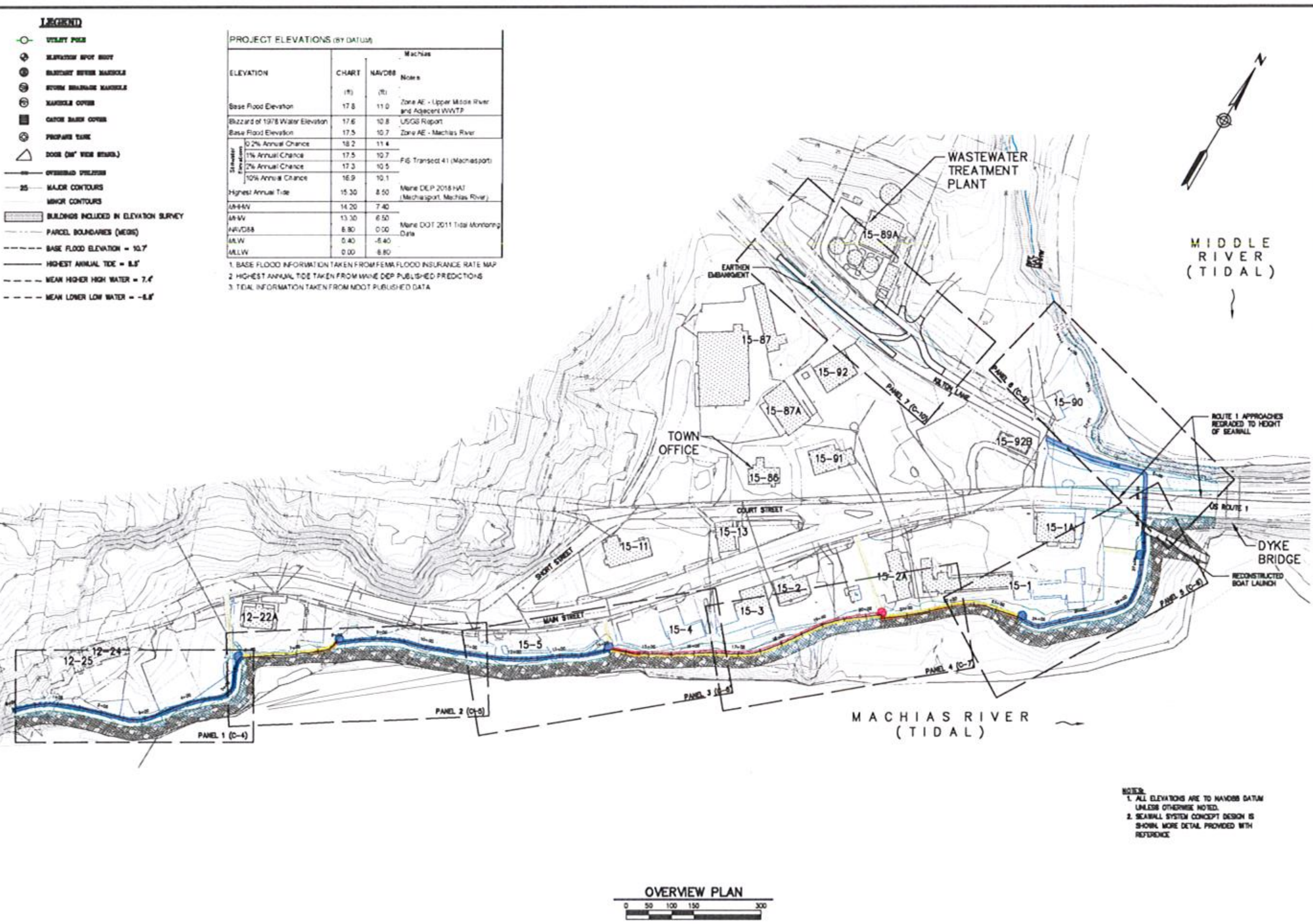
STATE OF MAINE — BARNEY J. BAKER No. 5737 — LICENSED — PROFESSIONAL ENGINEER

DESIGNED BY: DJB
DRAWN BY: MMC
CHECKED BY: DJB
SCALE: AS SHOWN

SHEET TITLE: COVERSHEET

PROJECT: SEAWALL SYSTEM CONCEPT DESIGN
WATERFRONT RESILIENCE STUDY
TOWN OF MACHIAS, MAINE

DATE: MAY 2018
CONTRACT NO. 17-59
SHEET NO. G-1
REV. A



PROJECT ELEVATIONS (BY DATUM)

ELEVATION		CHART (ft)	NAVD88 (ft)	Machias Notes
Base Flood Elevation		17.8	11.0	Zone AE - Upper Middle River and Adjacent WWTP
Blizzard of 1978 Water Elevation		17.6	10.8	USGS Report
Base Flood Elevation		17.5	10.7	Zone AE - Machias River
Stillwater Elevations	0.2% Annual Chance	18.2	11.4	FIS Transect 41 (Machiasport)
	1% Annual Chance	17.5	10.7	
	2% Annual Chance	17.3	10.5	
	10% Annual Chance	16.9	10.1	
Highest Annual Tide		15.30	8.50	Maine DEP 2018 HAT (Machiasport, Machias River)
MHHW		14.20	7.40	Maine DOT 2011 Tidal Monitoring Data
MHW		13.30	6.50	
NAVD88		6.80	0.00	
MLW		0.40	-6.40	
MLLW		0.00	-6.80	

1. BASE FLOOD INFORMATION TAKEN FROM FEMA FLOOD INSURANCE RATE MAP
2. HIGHEST ANNUAL TIDE TAKEN FROM MAINE DEP PUBLISHED PREDICTIONS
3. TIDAL INFORMATION TAKEN FROM MDOT PUBLISHED DATA

NOTES:
1. ALL ELEVATIONS ARE TO NAVD88 DATUM UNLESS OTHERWISE NOTED.
2. SEAWALL SYSTEM CONCEPT DESIGN IS SHOWN, MORE DETAIL PROVIDED WITH REFERENCE

BAKER DESIGN CONSULTANTS
Civil, Marine, and Structural Engineering
7 Spruce Road • Freeport • Maine • 04032 • 207-846-9724 • info@bakerdesignconsultants.com

NO.	SUBMISSION	DATE	INT.
B	FINAL REPORT	1.23.19	BJB
A	10.15.18 MEETING	10.15.18	BJB

STATE OF MAINE — BARNEY J. BAKER No. 5737 — LICENSED — PROFESSIONAL ENGINEER

DESIGNED BY: BJB
DRAWN BY: MMC
CHECKED BY: BJB
SCALE: AS SHOWN

SHEET TITLE: OVERVIEW PLAN PROTECTION TO BFE+4 FT

PROJECT: SEAWALL SYSTEM CONCEPT DESIGN WATERFRONT RESILIENCE STUDY
TOWN OF MACHIAS, MAINE

DATE: MAY 2018
CONTRACT NO. 17-59
SHEET NO. G-2
REV. B

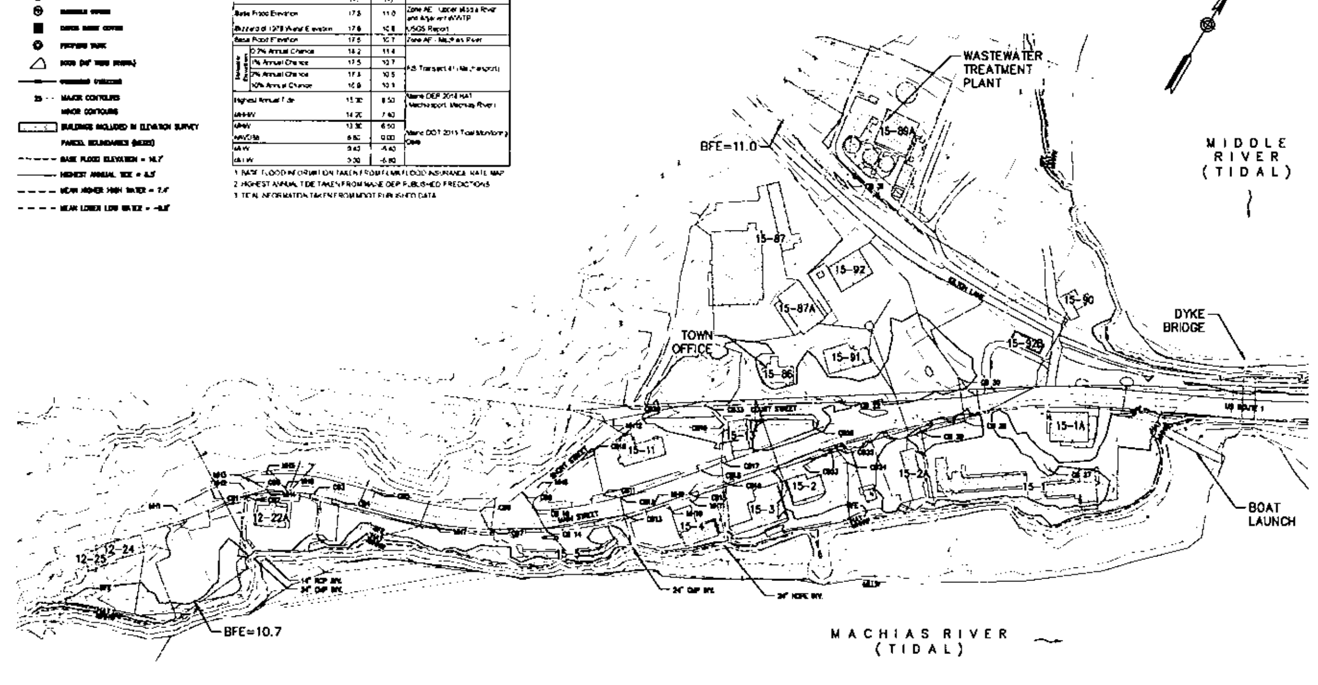
LEGEND

- MAJOR CONTOURS
- MINOR CONTOURS
- BUILDINGS INCLUDED IN ELEVATION SURVEY
- PARCEL BOUNDARIES (MEGIS)
- BASE FLOOD ELEVATION = 10.7'
- HIGHEST ANNUAL TIDE = 8.5'
- MEAN HIGHER HIGH WATER = 7.4'
- MEAN LOWER LOW WATER = -6.8'

PROJECT ELEVATIONS (BY DATUM)

ELEVATION		CHART (ft)	NAVD88 (ft)	Machias Notes
Base Flood Elevation		17.8	11.0	Zone AE - Upper Middle River and Adjacent WWTP
Blizzard of 1978 Water Elevation		17.6	10.8	USGS Report
Base Flood Elevation		17.5	10.7	Zone AE - Machias River
Selected Elevations	0.2% Annual Chance	18.2	11.4	FIS Transect 41 (Machiasport)
	1% Annual Chance	17.5	10.7	
	2% Annual Chance	17.3	10.5	
	10% Annual Chance	16.9	10.1	
Highest Annual Tide		15.30	8.50	Maine DEP 2018 HAT (Machiasport, Machias River)
MHHW		14.20	7.40	
MHW		13.30	6.50	Maine DOT 2015 Tidal Monitoring Data
NAVD88		6.80	0.00	
MLW		0.40	-6.40	
MLLW		0.00	-6.80	

1. BASE FLOOD INFORMATION TAKEN FROM FEMA FLOOD INSURANCE RATE MAP
2. HIGHEST ANNUAL TIDE TAKEN FROM MAINE DEP PUBLISHED PREDICTIONS
3. TIDAL INFORMATION TAKEN FROM MDOT PUBLISHED DATA



EXISTING CONDITIONS

0 50 100 150 300

NOTES:

1. ALL ELEVATIONS ARE TO NAVD88 DATUM UNLESS OTHERWISE NOTED.
2. MAP-LOT INDEX IS SHOWN FOR PROPERTIES/BUILDINGS INCLUDED IN FLOOD STUDY ONLY.
3. BFE LINE DEPICTED ON THIS PLAN REPRESENTS THE FIELD SURVEYED LOCATION OF EXISTING GRADE THAT IS EQUIVALENT TO THE BASE FLOOD ELEVATION PUBLISHED BY FEMA. BFE LINE MAY NOT CORRESPOND WITH LIMITS OF SPECIAL FLOOD HAZARD AREA MAPPED BY FEMA.

BAKER DESIGN CONSULTANTS
Civil, Marine, and Structural Engineering

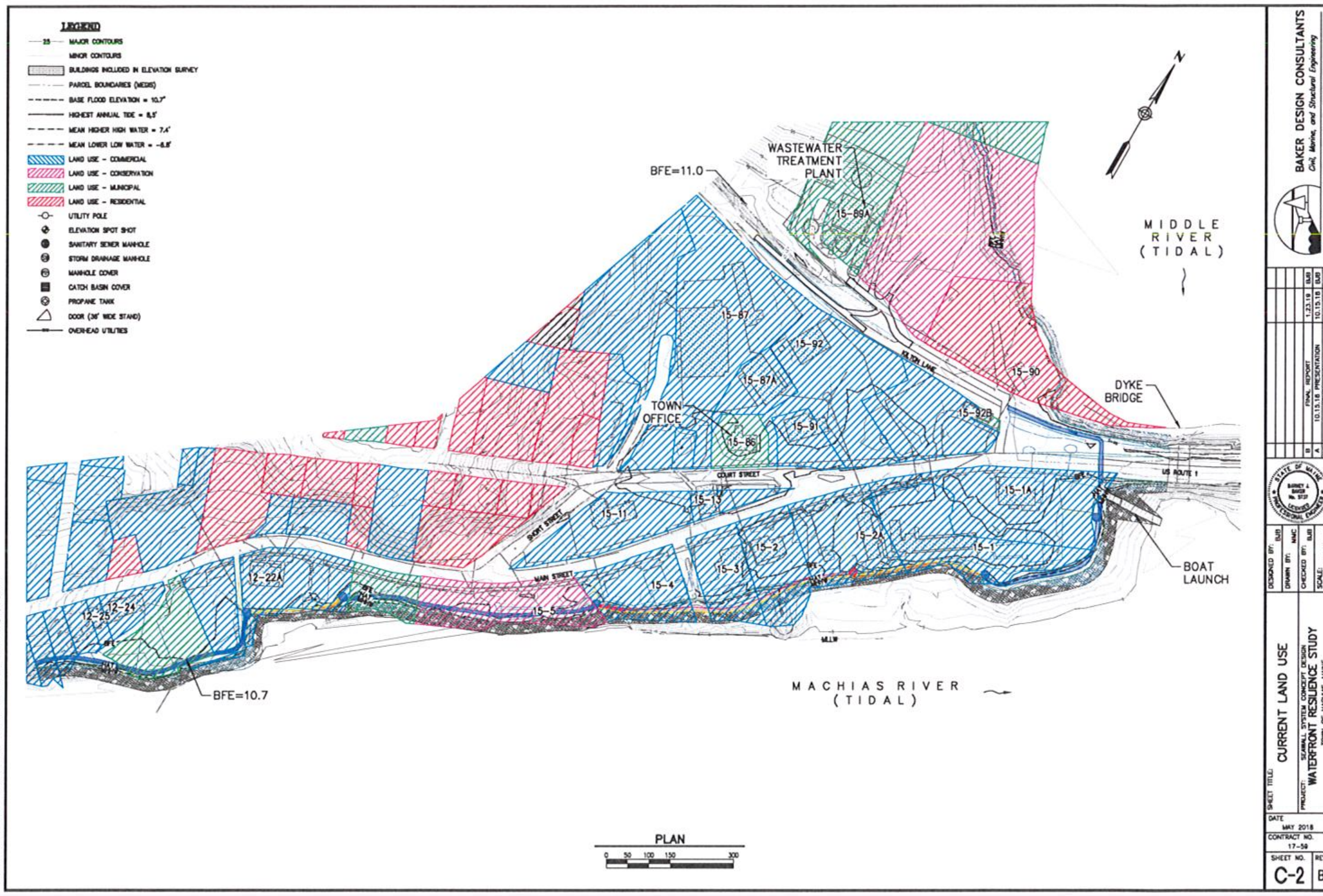
NO.		DATE	BY
B	FINAL REPORT	1.23.19	BJB
A	PRELIMINARY DESIGN SUBMISSION	6.27.18	BJB

DESIGNED BY: BJB
DRAWN BY: MAC
CHECKED BY: BJB
SCALE: AS SHOWN

SHEET TITLE: EXISTING CONDITIONS

PROJECT: SEAWALL SYSTEM CONCEPT DESIGN
WATERFRONT RESILIENCE STUDY
TOWN OF MACHIAS, MAINE

DATE: MAY 2018
CONTRACT NO: 17-38
SHEET NO.: C-1
REV.: B



LEGEND
MAJOR CONTOURS
MINOR CONTOURS
BUILDINGS INCLUDED IN ELEVATION SURVEY
PARCEL BOUNDARIES (MEGIS)
BASE FLOOD ELEVATION = 10.7'
HIGHEST ANNUAL TIDE = 8.5'
MEAN HIGHER HIGH WATER = 7.4'
MEAN LOWER LOW WATER = -6.8'
LAND USE - COMMERCIAL
LAND USE - CONSERVATION
LAND USE - MUNICIPAL
LAND USE - RESIDENTIAL
UTILITY POLE
ELEVATION SPOT SHOT
SANITARY SEWER MANHOLE
STORM DRAINAGE MANHOLE
MANHOLE COVER
CATCH BASIN COVER
PROPANE TANK
DOOR (36" WIDE STAND)
OVERHEAD UTILITIES
BFE=11.0
WASTEWATER TREATMENT PLANT
15-89A
MIDDLE RIVER (TIDAL)
15-87
15-92
15-87A
15-90
TOWN OFFICE
15-86
15-91
15-92B
DYKE BRIDGE
COURT STREET
US ROUTE 1
SHORT STREET
15-11
15-13
15-1A
15-2A
15-1
15-2
15-3
MAIN STREET
15-4
BOAT LAUNCH
12-22A
12-25
12-24
15-5
BFE=10.7
MACHIAS RIVER (TIDAL)
PLAN
0 50 100 150 300
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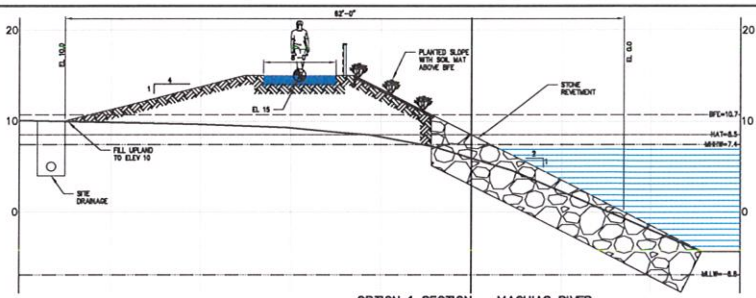
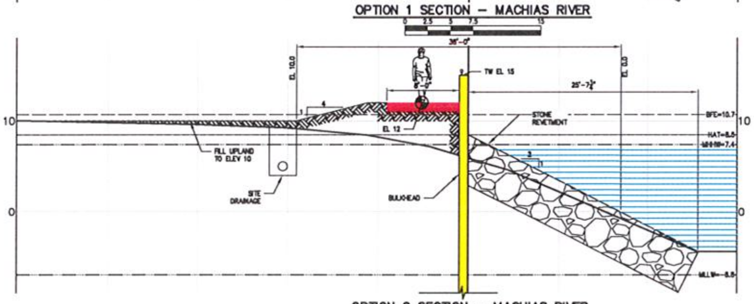
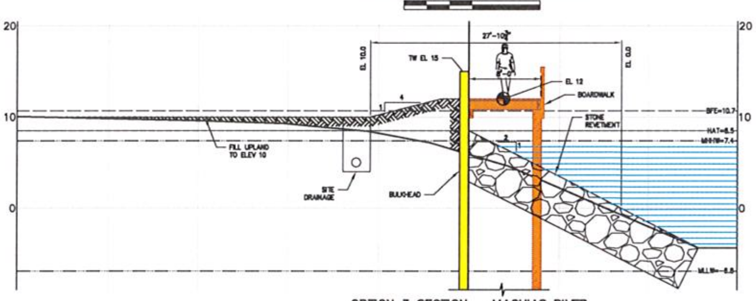
Civil, Marine, and Structural Engineering
7 Spruce Road • Freeport • Maine • 04032 • 207-846-9724
B FINAL REPORT 1.23.19 BJB
A 10.15.18 PRESENTATION 10.15.18 BJB
NO. SUBMISSION DATE INT.
DESIGNED BY: BJB
DRAWN BY: MMC
CHECKED BY: BJB
SCALE: AS SHOWN
SHEET TITLE: CURRENT LAND USE
PROJECT: SEAWALL SYSTEM CONCEPT DESIGN
WATERFRONT RESILIENCE STUDY
TOWN OF MACHIAS, MAINE
DATE MAY 2018
CONTRACT NO. 17-59
SHEET NO. C-2
REV. B



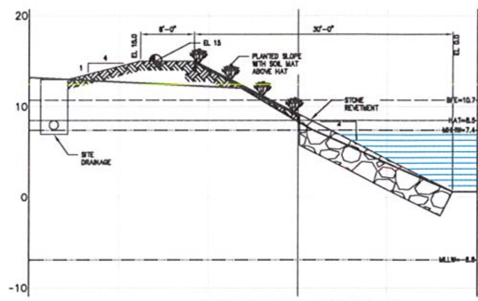
OPTION 1 SECTION – MACHIAS RIVER



OPTION 2 SECTION – MACHIAS RIVER



OPTION 3 SECTION – MACHIAS RIVER



NORTH SECTION – MIDDLE RIVER

NOTES:
1. SECTIONS ARE COMBINED FOR A CONTIGUOUS SEAWALL SYSTEM.
2. REFER TO SHEETS C-4 TO C-12 FOR SECTION LOCATION.

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NO.	SUBMISSION	DATE	INT.
A	FINAL REPORT	1.23.19	BJB

STATE OF MAINE — BARNEY J. BAKER No. 9737 — LICENSED PROFESSIONAL ENGINEER

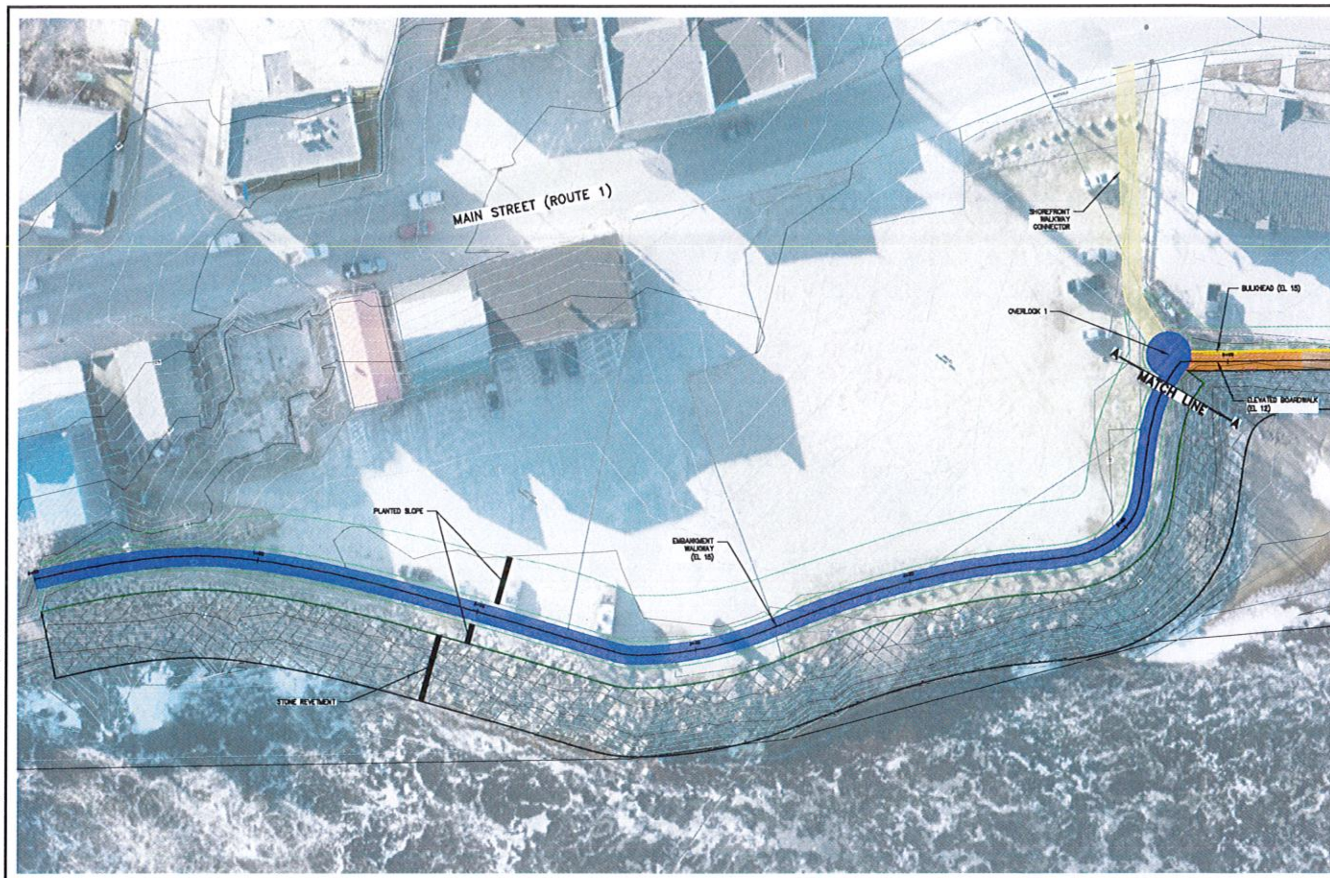
DESIGNED BY: BJB
DRAWN BY: MMC
CHECKED BY: BJB
SCALE: AS SHOWN

SHEET TITLE: TYPICAL SEAWALL SECTIONS

PROJECT: SEAWALL SYSTEM CONCEPT DESIGN
WATERFRONT RESILIENCE STUDY
TOWN OF MACHIAS, MAINE

DATE: MAY 2018
CONTRACT NO. 17-59
SHEET NO. C-3
REV. A

x:\17\17-59 machias waterfront\civil\17-59 machias waterfront civil 3d c-3.dwg 1/23/2019



PANEL 1 PLAN

0 10 20 30 60

NOTES:
1. REFER TO TYPICAL SEAWALL SECTIONS ON SHEET C-3.

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NO.	SUBMISSION	DATE	INT.
B	FINAL REPORT	1.23.19	BJB
A	10.15.18 MEETING	10.15.18	BJB

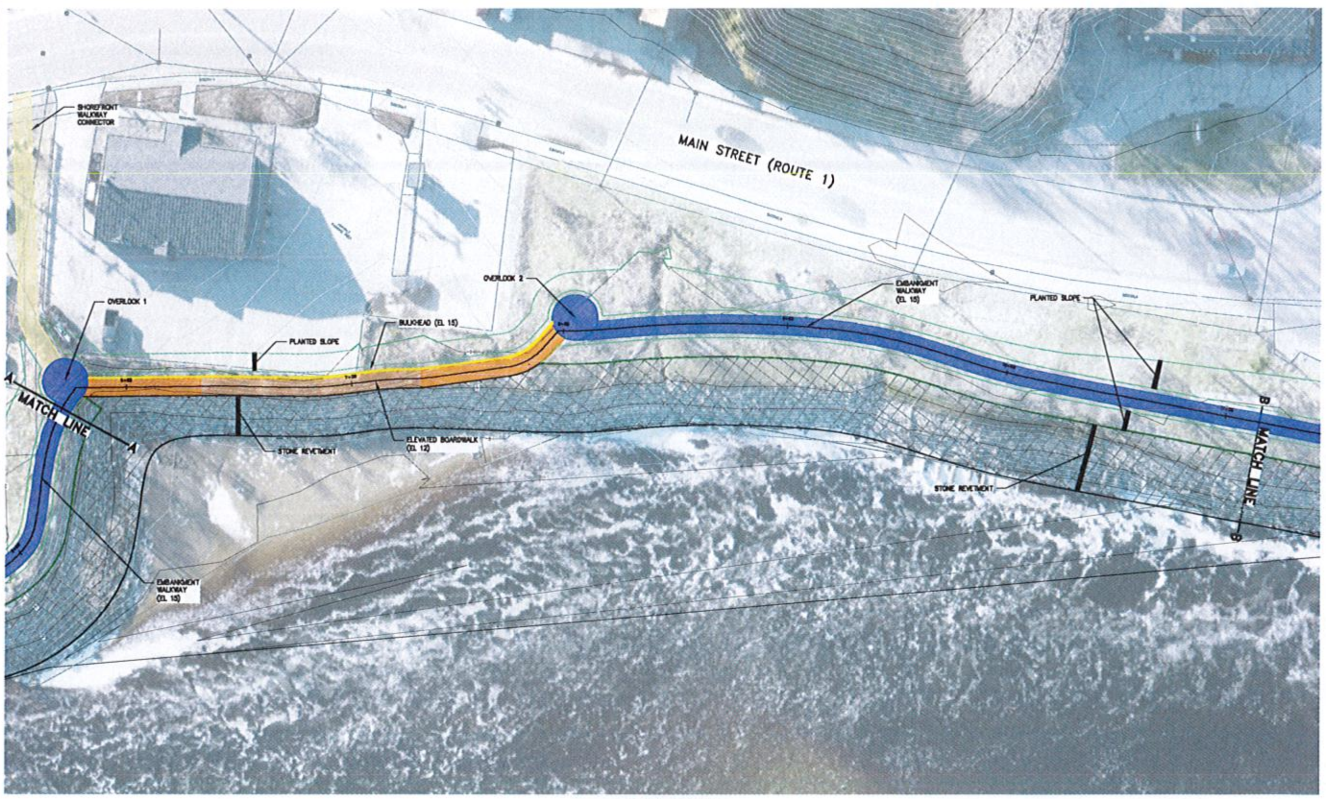
STATE OF MAINE — BARNEY A. BAKER — No. 5737 — LICENSED — PROFESSIONAL ENGINEER

DESIGNED BY: BJB
DRAWN BY: MMC
CHECKED BY: BJB
SCALE: AS SHOWN

SHEET TITLE: PANEL 1 PLAN
PROJECT: WATERFRONT RESILIENCE STUDY
TOWN OF MACHIAS, MAINE

DATE: MAY 2018
CONTRACT NO.: 17-59
SHEET NO.: C-4
REV.: B

x:\17\17-59 machias waterfront\civil\17-59 machias waterfront civil 3d.dwg 1/28/2019



PANEL 2 PLAN

0 10 20 30 80

NOTES:
1. REFER TO TYPICAL SEAWALL SECTIONS ON SHEET C-3.

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NO.	SUBMISSION	DATE	INT.
B	FINAL REPORT	1.23.19	BJB
A	10.15.18 MEETING	10.15.18	BJB

STATE OF MAINE — BARNEY J. BAKER No. 5737 — LICENSED PROFESSIONAL ENGINEER

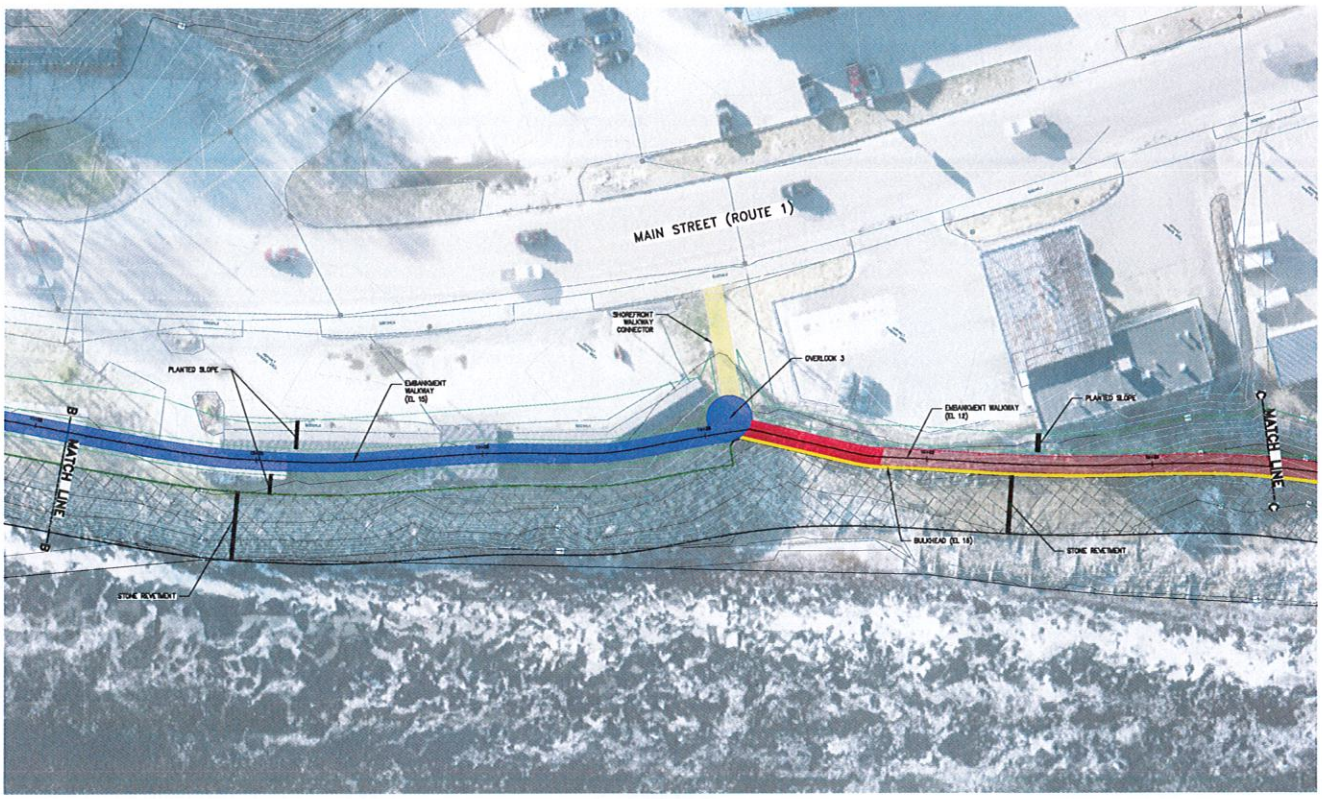
DESIGNED BY: BJB
DRAWN BY: NMC
CHECKED BY: BJB
SCALE: AS SHOWN

SHEET TITLE: PANEL 2 PLAN

PROJECT: SEAWALL SYSTEM CONCEPT DESIGN
WATERFRONT RESILIENCE STUDY
TOWN OF MACHIAS, MAINE

DATE: MAY 2018
CONTRACT NO. 17-59
SHEET NO. C-5
REV. B

z:\17\17-59 machias waterfront\cad\17-59 machias waterfront civil 3d.dwg 1/28/2019



PANEL 3 PLAN

0 10 20 30 60

NOTES:
1. REFER TO TYPICAL SEAWALL SECTIONS ON SHEET C-3.

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NO.	SUBMISSION	DATE	INT.
A	10.15.18 MEETING	10.15.18	BJB
B	FINAL REPORT	1.23.19	BJB

STATE OF MAINE — BARNEY J. BAKER No. 5737 LICENSED PROFESSIONAL ENGINEER

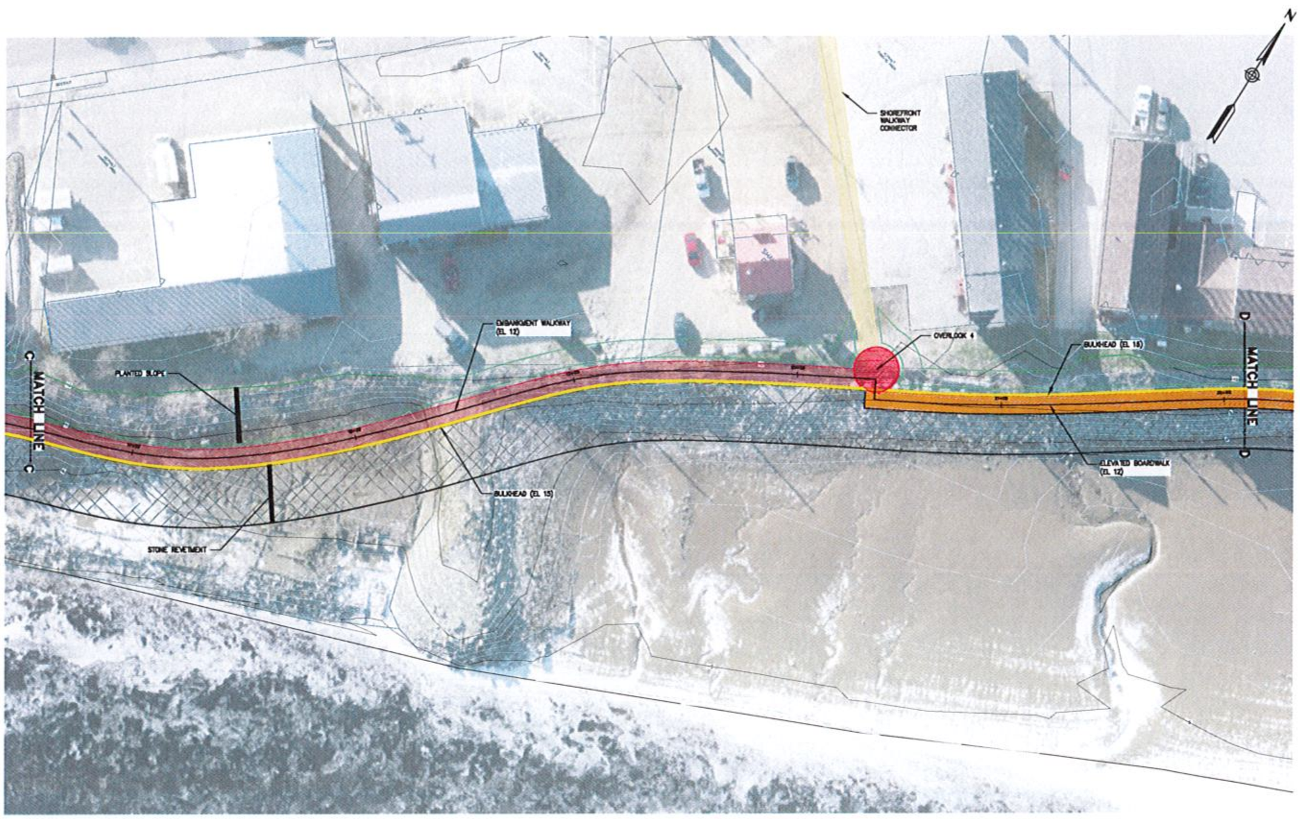
DESIGNED BY: BJB
DRAWN BY: MMC
CHECKED BY: BJB
SCALE: AS SHOWN

SHEET TITLE: PANEL 3 PLAN

PROJECT: SEAWALL SYSTEM CONCEPT DESIGN
WATERFRONT RESILIENCE STUDY
TOWN OF MACHIAS, MAINE

DATE: MAY 2018
CONTRACT NO. 17-59
SHEET NO. C-6
REV. B

s:\17\17-59 machias waterfront\cad\17-59 machias waterfront civil 3d.dwg 1/28/2019



PANEL 4 PLAN

0 10 20 30 60

NOTES:
1. REFER TO TYPICAL SEAWALL SECTIONS ON SHEET C-3.

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NO.	SUBMISSION	DATE	INT.
B	FINAL REPORT	10.19.18	BJB
A	10.15.18 MEETING	10.15.18	BJB

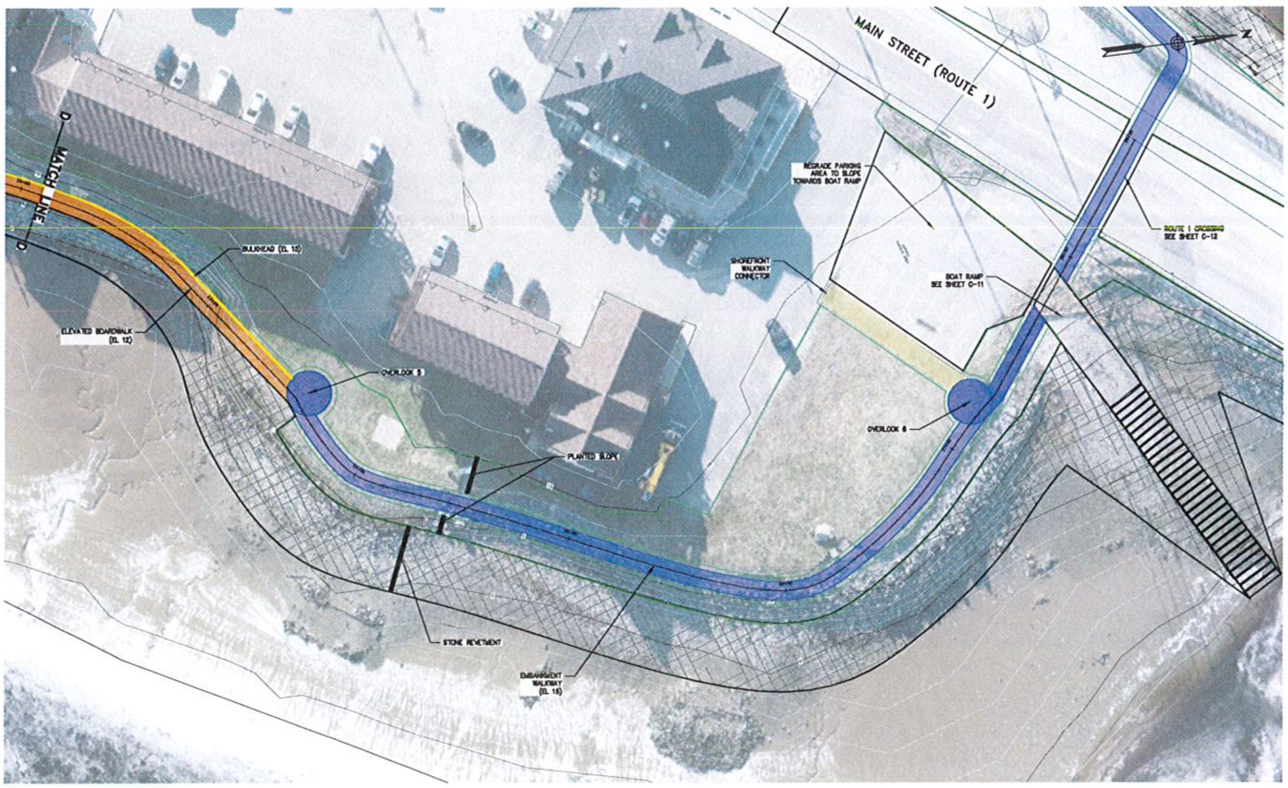
STATE OF MAINE — BARNEY L. BAKER No. 5737 — LICENSED — PROFESSIONAL ENGINEER

DESIGNED BY: BJB
DRAWN BY: MMC
CHECKED BY: BJB
SCALE: AS SHOWN

SHEET TITLE: PANEL 4 PLAN

PROJECT: WATERFRONT RESILIENCE STUDY
TOWN OF MACHIAS, MAINE

DATE: MAY 2018
CONTRACT NO. 17-59
SHEET NO. C-7
REV. B



PANEL 5 PLAN

0 10 20 30 60

NOTES:
1. REFER TO TYPICAL SEAWALL SECTIONS ON SHEET C-3.

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NO.	SUBMISSION	DATE	INT.
B	FINAL REPORT	1.23.19	BJB
A	10.15.18 MEETING	10.15.18	BJB

DESIGNED BY: BJB
DRAWN BY: MMC
CHECKED BY: BJB
SCALE: AS SHOWN

SHEET TITLE: PANEL 5 PLAN

PROJECT: SEAWALL SYSTEM CONCEPT DESIGN
WATERFRONT RESILIENCE STUDY
TOWN OF MACHIAS, MAINE

DATE: MAY 2018
CONTRACT NO. 17-59
SHEET NO. C-8
REV. B

PANEL 6 PLAN

0 10 20 30 60

NOTES:
1. REFER TO TYPICAL SEAWALL SECTIONS ON SHEET C-3.

B	FINAL REPORT	1.23.19	BJB
A	10.15.18 MEETING	10.15.18	BJB
NO.	SUBMISSION	DATE	INT.

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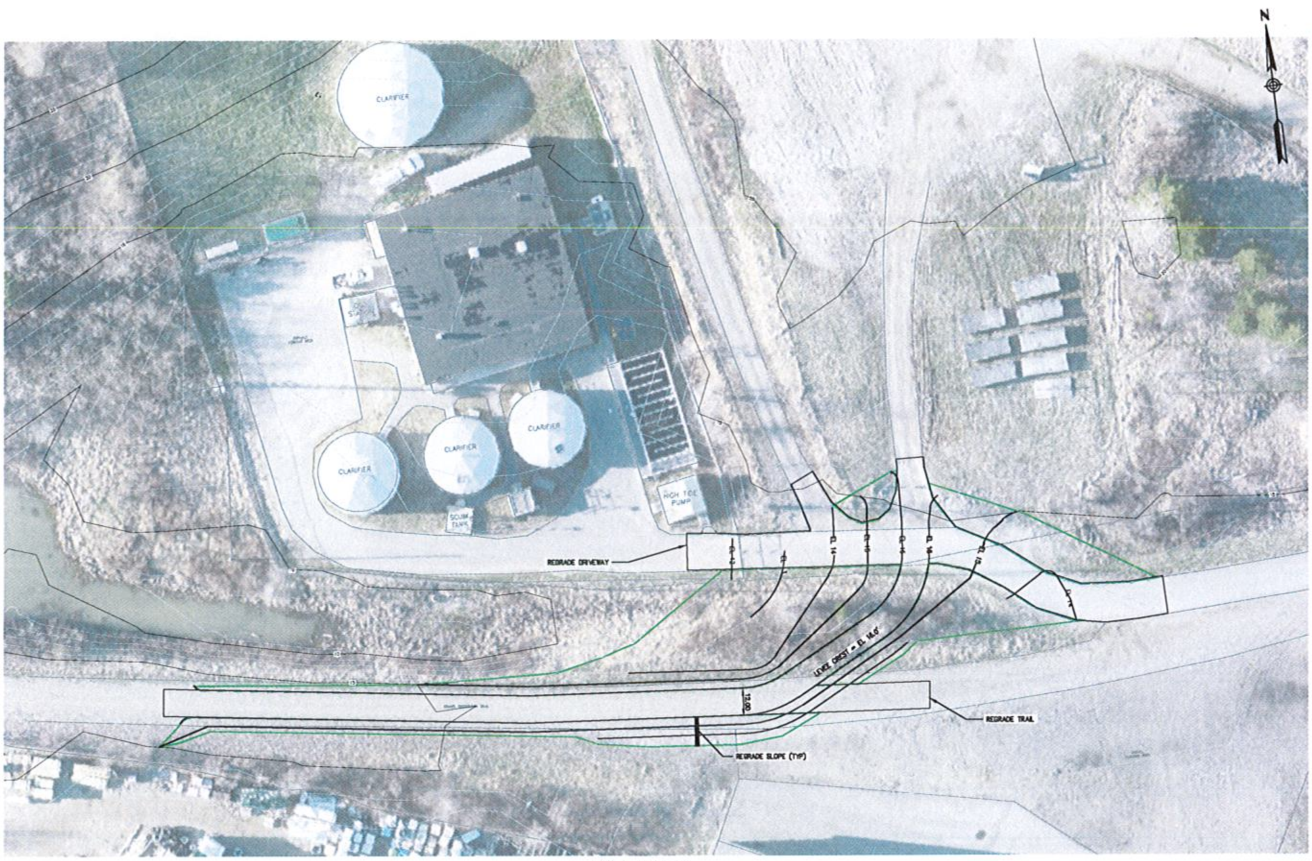
STATE OF MAINE — BARNEY A. BAKER No. 9737 — LICENSED PROFESSIONAL ENGINEER

DESIGNED BY: BJB
DRAWN BY: NMC
CHECKED BY: BJB
SCALE: AS SHOWN

SHEET TITLE: PANEL 6 PLAN

PROJECT: SEAWALL SYSTEM CONCEPT DESIGN
WATERFRONT RESILIENCE STUDY
TOWN OF MACHIAS, MAINE

DATE: MAY 2018
CONTRACT NO. 17-59
SHEET NO. C-9
REV. B



PANEL 7 PLAN

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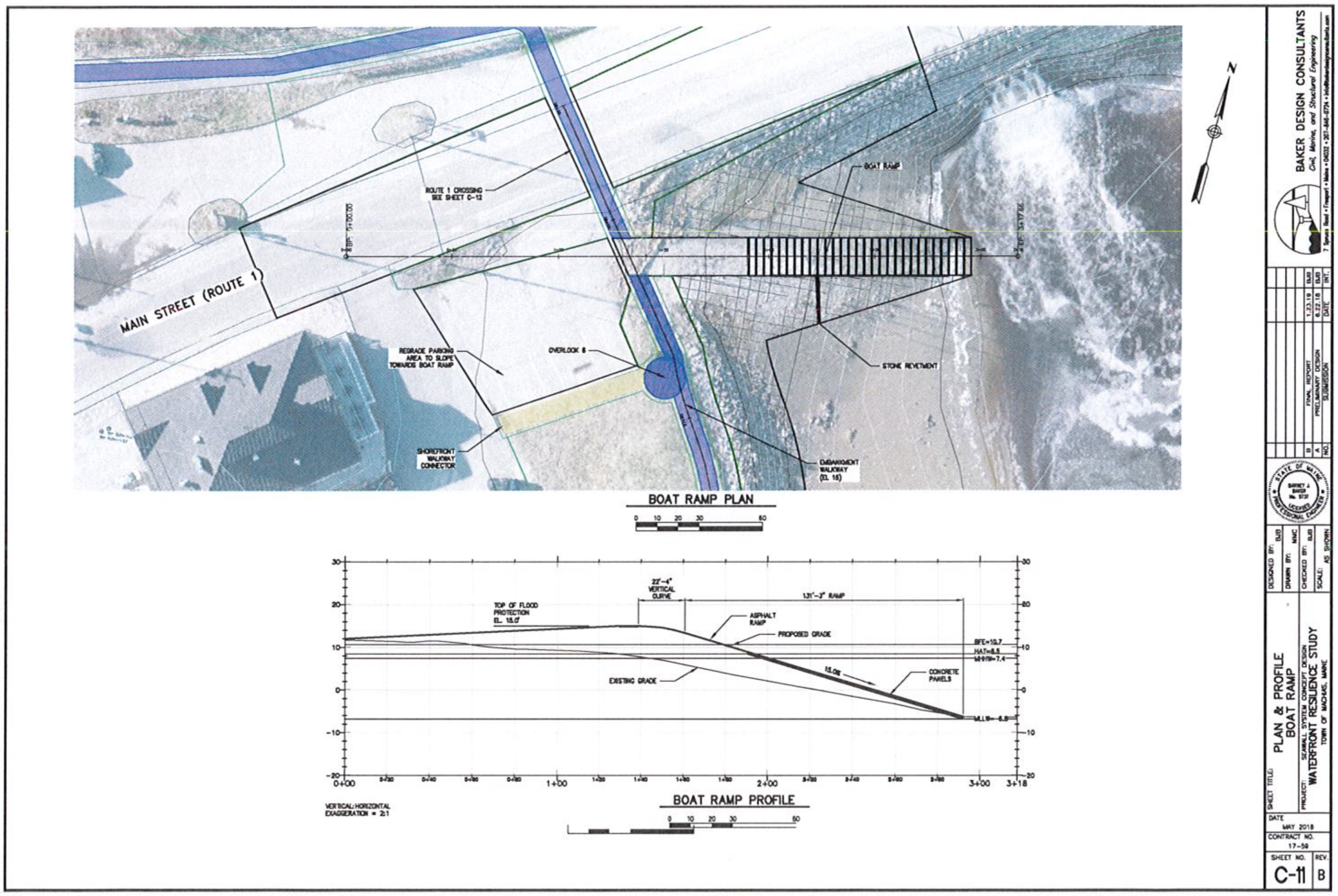
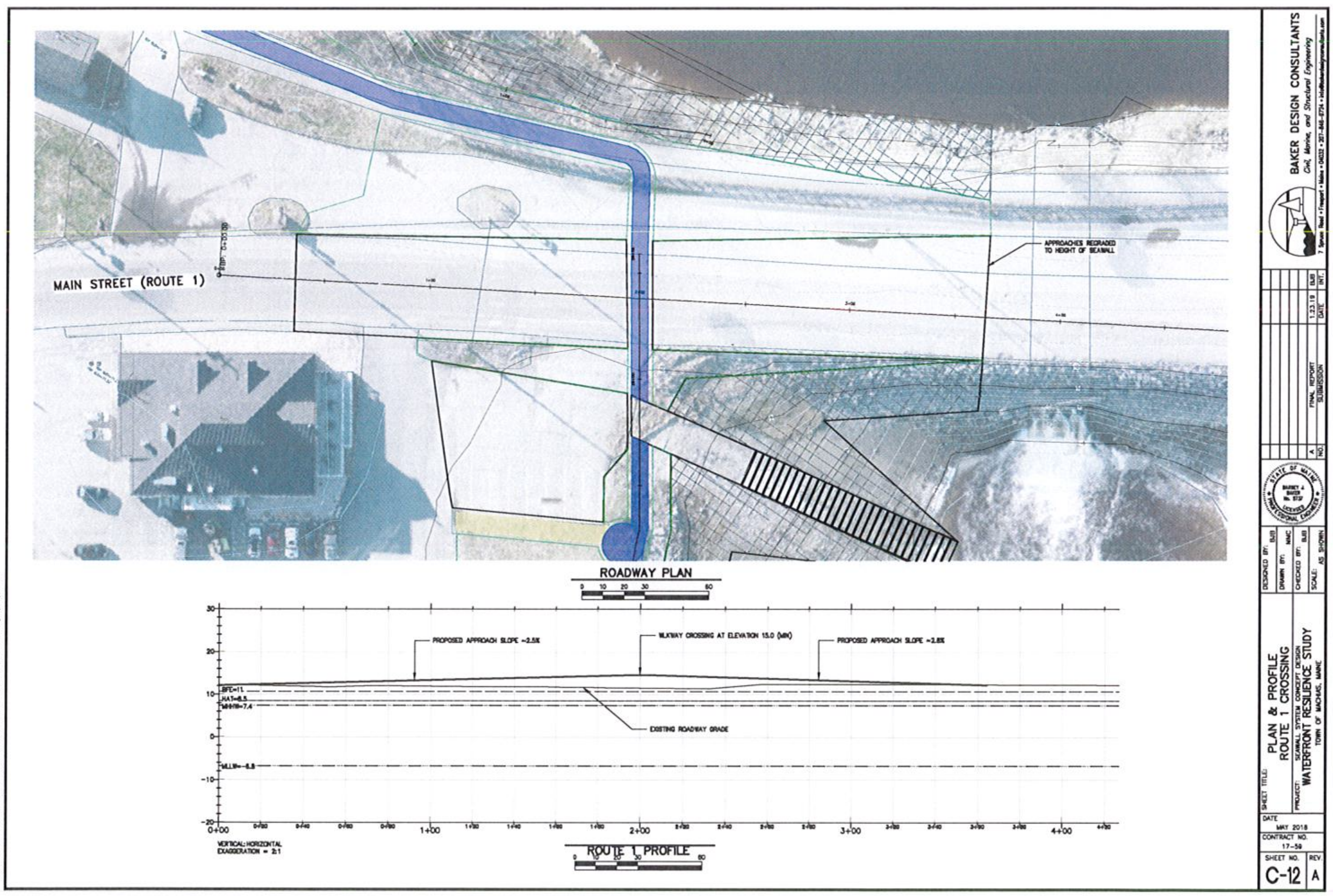
NO.		DATE	INT.
B	FINAL REPORT	1.23.19	BJB
A	10.15.18 MEETING SUBMISSION	10.15.18	BJB

DESIGNED BY: BJB
DRAWN BY: MMC
CHECKED BY: BJB
SCALE: AS SHOWN

SHEET TITLE: PANEL 7 PLAN
PROJECT: SEAWALL SYSTEM CONCEPT DESIGN
WATERFRONT RESILIENCE STUDY
TOWN OF MACHIAS, MAINE

DATE: MAY 2018
CONTRACT NO. 17-39
SHEET NO. C-10
REV. B


MAIN STREET (ROUTE 1)
ROUTE 1 CROSSING SEE SHEET C-12
BOAT RAMP
REGRADE PARKING AREA TO SLOPE TOWARDS BOAT RAMP
OVERLOOK 8
STONE REVETMENT
SHOREFRONT WALKWAY CONNECTOR
EMBANKMENT WALKWAY (EL 15)
BOAT RAMP PLAN
TOP OF FLOOD PROTECTION EL. 15.0'
22'-4" VERTICAL CURVE
131'-3" RAMP
ASPHALT RAMP
PROPOSED GRADE
EXISTING GRADE
CONCRETE PANELS
BFE=10.7
HAT=8.5
MHHW=7.4
MLLW=-6.8
BOAT RAMP PROFILE
VERTICAL:HORIZONTAL EXAGGERATION = 2:1
BAKER DESIGN CONSULTANTS
Civil, Marine, and Structural Engineering
SHEET TITLE: PLAN & PROFILE BOAT RAMP
PROJECT: SEAWALL SYSTEM CONCEPT DESIGN
WATERFRONT RESILIENCE STUDY
TOWN OF MACHIAS, MAINE
DESIGNED BY: BJB
DRAWN BY: MAC
CHECKED BY: BJB
SCALE: AS SHOWN
B FINAL REPORT 1.23.19 BJB
A PRELIMINARY DESIGN 6.22.18 BJB
NO. SUBMISSION DATE INT.
DATE MAY 2018
CONTRACT NO. 17-59
SHEET NO. C-11
REV. B


MAIN STREET (ROUTE 1)
APPROACHES REGRADED TO HEIGHT OF SEAWALL
ROADWAY PLAN
PROPOSED APPROACH SLOPE =2.5%
WLKWAY CROSSING AT ELEVATION 15.0 (MIN)
PROPOSED APPROACH SLOPE =2.8%
BFE=11
HAT=8.5
MHHW=7.4
EXISTING ROADWAY GRADE
MLLW=-6.8
VERTICAL:HORIZONTAL EXAGGERATION = 2:1
ROUTE 1 PROFILE
BAKER DESIGN CONSULTANTS
Civil, Marine, and Structural Engineering
A FINAL REPORT SUBMISSION 1.23.19 BJB
NO. DATE INT.
DESIGNED BY: BJB
DRAWN BY: NMC
CHECKED BY: BJB
SCALE: AS SHOWN
SHEET TITLE: PLAN & PROFILE ROUTE 1 CROSSING
PROJECT: SEAWALL SYSTEM CONCEPT DESIGN
WATERFRONT RESILIENCE STUDY
TOWN OF MACHIAS, MAINE
DATE MAY 2018
CONTRACT NO. 17-59
SHEET NO. C-12
REV. A