MODELING THE
WEST BRANCH PLEASANT RIVER SYSTEM, ADDISON, MAINE
FOR RESTORED TIDAL FUNCTION

Ecosystem Restoration Feasibility Study

EXTENDED ABSTRACT

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New England District
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1.0 INTRODUCTION.

Ridge Road crosses the mouth of the West Branch of the Pleasant River in Addison Maine (Washington County). The town of Addison is located at the confluence of the Pleasant River and the West Branch of the Pleasant River, approximately 53 miles southeast of Bangor, Maine. The study area extends upstream from the mouth of the West Branch of the Pleasant River for approximately one mile until the river, and its tributaries, intersect Route 1. Up to approximately 470 acres of fresh water wetlands could be tidally restored in the towns of Addison and Columbia, Maine.

The purpose of the West Branch Pleasant River Ecosystem Restoration Feasibility Study is to develop and evaluate tidally restored salt marsh habitat alternatives for the West Branch of the Pleasant River (West Branch); with the goal of recommending a State and Federally preferred plan for development. The Federally preferred plan must also meet Maine Department of Environmental Protection (MEDOT) transportation needs.

The Maine Department of Transportation (MEDOT) requested the U.S. Army Corps of Engineers' (Corps) assistance in restoring the fresh water marsh upstream of Ridge Road to a salt marsh. MEDOT owns, and is responsible for, the tide gates and roadway embankment at Ridge Road that are currently in disrepair and need to be replaced. The tide gates consist of six culverts with one way flapper gates that open toward the sea when the tide is low. This allows the river waters to discharge from the West Branch while seawater is blocked from entering the West Branch marsh. As a consequence, there has been inconsequential tidal influence upstream of Ridge Road since 1940 when an old bridge was replaced with the current road works.

This hydrologic and hydraulic analysis evaluated several alternatives to replace the existing gated structure at Ridge Road as well as culverts located upstream along the West Branch and several tributaries to reintroduce tidal exchange and ultimately restore the salt marsh.

2.0 SITE HYDROLOGY

a. Climate and Principle Flood Sources.

The climate of Addison is coastal, with moderately warm summers and cold winters. The average annual temperature of Addison is 45 degrees Fahrenheit (F) ranging from an average minimum temperature of approximately 12 degrees F in January to an average maximum temperature of approximately 77 degrees F in July. Surrounding bodies of water tend to temper extreme climate conditions. The mean annual precipitation is approximately 41 inches and is fairly uniformly distributed throughout the year.

The town of Addison is subject to coastal flooding caused by nor'easters and hurricanes. Nor'easters are the more frequent type of storm in this area. They can occur any time of the year, but are more prevalent in the winter months. Hurricanes, which are relatively rare, occur in the later summer and early fall months; however, they historically have not produced significant flooding in this area.

b. Tidal Regime.

In the study area, tides are semi-diurnal, with two high and low waters occurring during each lunar day (approximately 24 hours and 50 minutes). The resulting astronomic tide range varies constantly in response to relative positions of the earth, moon, and sun; the moon having the primary tide producing effect. Maximum tide ranges occur when the orbital cycles of these bodies are in phase. A complete sequence of astronomic tide ranges is approximately repeated over an interval of 19 years, known as a tidal epoch. Coastal storms and hurricanes can cause tides to be much higher than astronomically predicted. Although exact information of tidal characteristics are presently lacking at the site, approximate characteristics were developed from historical tide data (1931 to present).

c. Tidal Analysis.

The West Branch Pleasant River confluence with the Pleasant River is approximately one mile upstream from Pleasant Bay, which extends approximately eight miles downstream before discharging into the Gulf of Maine at Dyer Island. Tide elevations, heights and ranges are most accurately recorded locally and at NOAA gage stations.

The nearest NOAA gage station to the West Branch study area is in Millbridge, Maine, on the Narraguagus Bay, which also discharges to Pleasant Bay, approximately 10 miles south of Addison, Maine. Tide elevations increase as the tide travels from the open ocean, through Pleasant Bay, and up the Pleasant River due to the narrowing of the river channel. Since tide elevations published in the USACE Tide Profiles often represent the open ocean, this is not considered an accurate reference for tide elevations at the West Branch.

In order to analyze the impact of tides along the West Branch, tide elevations were established for various tidal occurrences and datums, as shown in Table 1. Since a NOAA tide gage is not available at this study area, recorded tide data collected by David Burdick as part of the 2009 Evaluation of Pre-Restoration Conditions in the West Branch of the Pleasant River, Maine were correlated to the Millbridge, Maine NOAA tide. This allows various tide events, recorded in 6-minutes intervals to be evaluated at the West Branch study area.

During storm conditions, nor'easters and hurricanes cause the tides to increase. Due to the duration of nor'easters, they often last through one or more tide cycles. The combination of sustained onshore winds and high tide causes significant elevation increases. This is known as storm surge. In Addison, the greatest storm surge is caused by winds from the southeast quadrant. The FEMA FIS also includes the wave height analysis. The coastline along the Pleasant River, on the west side of the community has a limited fetch and thus a wave height of only 3-feet and a wave period of 2.8 seconds. The fetch includes the distance waves can be generated without intersecting a land mass. (Reference 1)

TABLE 1

Estimated Tide Elevations at West Branch Pleasant River, Addison, Maine
(Estimated from interpolating NOAA recorded tides at Milbridge, Maine
and tide data recorded at the Addison, Maine pier in 2005[4].)

	Elevation NAVD88 (ft)
FEMA Zone AE Elev	11.3
100-yr Frequency Flood Event	10.8
50-yr Frequency Flood Event	10.5
10-yr Frequency Flood Event	9.8
2-yr Frequency Flood Event	9.4
1-yr Frequency Flood Event	9.0
Maximum Predicted Astronomic High Water	8.5
Mean High Water Spring (MSHW)	7.5
Mean Higher High Water (MHHW)	6.6
Mean High Water (MHW)	6.2
National Atlantic Vertical Datum (NAVD88)	0
Mean Sea Level (MSL)	-0.2
Mean Tide Level (MTL)	-0.4
National Geodetic Vertical Datum (NGVD29)	-0.7
Mean Low Water (MLW)	-6.0
Mean Lower Low Water (MLLW)	-6.3

d. Freshwater Drainage Area.

The West Branch has a total drainage area of 11.0 square miles. The drainage area extends to the foothills of Columbia and Columbia Falls. The topography of Addison ranges from moderately sloped in some area to relatively flat in other areas. Soil cover of the area is generally shallow and rock outcroppings are common. Vegetation consists primarily of softwood forests and hay field meadows.

The West Branch drainage area does not include United States Geological Survey (USGS) continuously recorded streamflow monitoring to provide real-time flow data. Additionally, the 1991 Addison Maine FEMA FIS does not include a streamflow analysis of the West Branch (reference 2). Other USGS streamflow gages

located in Washington County with watershed characteristics similar to the West Branch were investigated for comparison purposes. Although USGS Gage 01021470 Libby Brook near Northfield, Maine (DA 7.79 square miles) and USGS Gage 01021480 Old Stream near Wesley, Maine (DA 29.1 square miles) have potentially similar watershed characteristics, both only include seven years of record which is not enough to develop of streamflow analysis. Additionally, neither of these towns have a flood insurance study with a streamflow analysis for reference. USGS Gage 01022500 Narraguagus River at Cherryfield, Maine (227 square miles) is considered too large for comparison with the West Branch Pleasant River; however, the Cherryfield, Maine flood insurance study does include a streamflow analysis of the West Branch Narraguagus River (79.6 square miles). Although still considerably larger than the West Branch Pleasant River, it was referenced for comparison with the hydrologic analysis conducted for this study.

e. Hydrologic Modeling.

The Corps of Engineers Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) was used to simulate the rainfall runoff in the West Branch. Since the West Branch does not have real-time streamflow data to compute 2-yr, 10-yr, and 100-yr flows from actual precipitation events, the U.S. Weather Bureau Technical Paper, No. 40 (TP-40) synthetic precipitation data was utilized to develop these relationships within the HEC-HMS model. The HEC-HMS model utilized similar methodology as the flow analysis conducted by the Natural Resources Conservation Service (NRCS) in their 2003 and 2007 report (reference 3).

The HEC-HMS model is comprised of two components, first the rainfall data necessary to calculate the storm event as provided by TP-40 as presented in Table 3. Secondly, the topography regime represented by the Soil Conservation Service (SCS) dimensionless unit hydrographs, based on the time of concentration, percent impervious, loss rates known as the curve number (CN) and initial abstraction (Ia) that includes all losses prior to runoff as presented in Table 4 (reference 1). Additionally, the West Branch watershed was delineated into three sub-watersheds representing Bells Brook (5.0 square miles), Branch Brook (4.4 square miles) and the unnamed tributary with Water and Point Streets (1.6 square miles).

This study also includes a flooding analysis of properties located adjacent to the West Branch, the peak flows were generated to represent wet, spring season soil conditions also referred to as a High Antecedent Moisture Condition (AMC). Therefore, these peak flows will simulate a worst case flooding analysis, see Section 3.0 Site Hydraulics. Comparison of the HEC-HMS model with the peak flows computed in the NRCS 2003/2007 reports concludes very similar results, which was expected since both analyses utilized similar computational methodologies. A comparison of these results is presented in Table 5.

Table 2
U.S. Weather Bureau Technical Paper, No. 40 (TP-40)
(Rainfall Depth in inches)

Time (hrs)	2yr/12 hr	10yr/12 hr	100yr/24 hr
1	.85	1.45	2.0
2	1.25	2.0	2.8
3	1.5	2.3	3.3
6	1.9	2.8	4.2
12	2.5	3.5	5.2
24	-	-	6.0

Table 3
Sub-Watershed Hydrologic Landuse Characteristics
Antecedent Moisture Condition (AMC) High

Watershed Area (Sq.Mi.)	Curve No. (CN)	Tc (min)	Initial Abstraction (Ia)	% Impervious
11.0	35-65	30-75	0.2-0.4	5

Table 4
Baseflow by Month (cfs)

Baseflow (cfs)												
Month	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Q (cfs)	28	28	61	63	22	16	11	9	10	16	24	34

Table 5
USACE New England District HEC-HMS Peak Flows
Compared with the NRCS 2003/2007 Report Peak Flows

Sub-Basin Location	Drainage Area (sq.miles)	Peak Flows (cfs)		
		2-Yr	10-Yr	100-Yr
Ridge Road HEC-HMS	11.0	420	945	2580
Ridge Road NRCS Report	11.0	350	1170	2650

3.0 SITE HYDRAULICS

a. General.

This section discusses the hydraulic methods and assumptions used to simulate tidal flow to study marsh restoration as well as estimates of flood elevations for selected recurrence intervals. It is noted that flood elevations shown on the Flood Insurance Rate Map (FIRM) represent rounded whole-foot elevations and may not exactly reflect the elevations computed for flood profiling, such as this. Flood elevations shown on the FIRM are primarily intended for flood insurance rating purposes. For construction and/or floodplain management purposes, users are encouraged to use the detailed flood elevation data computed in conjunction with elevations shown on the FIRM.

The existing river channel, culvert crossings and flood plain were hydraulically modeled for several different tide and storm recurrences. Alternatives consist of nine primary alternatives for Ridge Road each modeled with secondary alternatives for various flow conditions and upstream culvert modifications to determine corresponding water elevations, velocities, and acres restored. The results of each alternative were evaluated to compute the total restoration area, impacts of flooding to adjacent properties, flow velocities at roadway crossings, sedimentation and sea level rise (SLR).

The Ridge Road alternatives evaluated with the HEC-GeoRAS model are as follows:

A. No Action.
B. Six 5ft x 2.5ft Box Culverts at Ridge Rd.
C. Six 5ft x 5ft Box Culverts at Ridge Rd.
D. New Bridge at Ridge Road (150ft span/ existing upstream culverts)
E. New Bridge at Ridge Road (150ft span/enlarged culverts at Addison Road & flap gate at Water Street.)
F. New Bridge at Ridge Road (150ft span/enlarged culverts at Addison Road, Point Street and Water Street.)
G. New Culvert at Ridge Road (45ft x 12ft, or equivalent area, with existing upstream culverts.)
H. New Culvert at Ridge Road (45ft x 12ft, or equivalent area, and enlarged culverts at Addison Road, Point Street and Water Street.)
I. New Culvert at Ridge Road (45ft x 12ft, or equivalent area, and enlarged culverts at Addison Road and flap gates at Water Street.

b. Elevation Data and Datums.

Study area ground survey was obtained from Light Detection and Ranging (LIDAR) topography collected in 2012 and is available through NOAA Coastal Services Center. This data was processed, using the HEC-GeoRAS

geographical information system (GIS) arc-map processor, into cross-sections that follow the West Branch channel, tributaries and floodplain.

Photogrammetric topographic mapping was collected by James W. Sewall Company in 2004 with detailed 1-5 foot contour mapping at 1:40 scale. This topography included area at and below elevation 12.0 ft NGVD with elevations being converted to NAVD88. Additionally, this data included 201 spot elevations within the wetlands and limited ground field survey conducted on 20-21 August 2005 along Ridge Road, Water Street and Addison Road to validate the given elevations. (Reference 4). Culvert and bridge elevations were obtained from the NRCS report for culverts located at the following roadway crossings: Ridge Road, Addison Road, Water Street, Point Street, Ingersoll Brook and Route 1. (Reference 3).

All topographic and water elevations shown in this study are referenced to NAVD88 datum. It is important to note that prior studies/reports, including the Addison Maine FIS reference the NGVD29 datum. Ground, structure and water elevations may be compared and/or referenced to NGVD29 by applying a standard conversion factor. The conversion from NGVD29 to NAVD88 is -0.7 feet and from NAVD88 to NGVD29 is +0.7 feet.

c. HEC-RAS Development.

The Corp's one-dimensional Hydrologic Engineering Center's River Analysis System (HEC-RAS) computer model was used to conduct unsteady flow analyses. The HEC-RAS model calculates the water surface elevations (WSE) along a river channel using backwater analysis through a network of open channels. This model was used to simulate the WSE along the West Branch under conditions representing different culvert and bridge alternatives during the spring, 2-yr and 100-yr tide events. The model has the capability to accurately model culverts and bridges. Input for the model included boundary conditions, flow regimes, loss coefficients, structure characteristics, and LIDAR topography that was processed into cross-sections. Outputs from the model include computed water surface elevations, channel velocities, acres restored and floodplain mapping.

The Hydrologic Engineering Center's River Analysis System ArcGIS extension, HEC-GeoRAS, was used to layout cross sections and reaches based on topography (LiDAR). The existing marsh was divided into five reaches: Branch Brook, Bells Brook, Ingersoll Brook, Point Street marsh and West Branch. All reaches, cross sections, banks, and bridge/culvert alignments were georeferenced and their elevations extracted from the LiDAR data with HEC-GeoRAS for use in HEC-RAS. In HEC-RAS, water surface elevations were dynamically calculated to fluctuate with the tide and culverts were modeled both with their existing geometries (see Table 6) and proposed alternative configurations.

Table 6
Existing Culvert and Roadway Geometry
(Referenced from 2007 NRCS Culvert Survey)

Roadway	Existing Culvert Size (ft)	Top of Roadway Elev (ft NAVD88)	Downstream Culvert Inv. (ft NAVD88)	Upstream Culvert Inv. (ft NAVD88)
Ridge Road	(6) 5'x5'	13.0/11.3	-4.5	-4.0
Addison Road	(2) 6'Dia.	9.8	-4.7	-4.8
Water Street	4'Dia. & 2'Dia.	8.7	-4.5 & 2.2	-3.5 & 2.4
Point Street	4'Dia	6.1	0.4	0.6
Route 1 (Branch Bk)	10.5	NA	3.0	3.3
Route 1 (Bells Bk)	10.0	NA	7.0	7.5
Ingersoll Brook	6'Dia.	NA	13.5	14.0

d. Model Calibration.

Due to the West Branch Pleasant River being restricted to tidal flow by the roadway embankment and tide gates; calibration of the model relied on evaluation of historical documentation and photos of the tidal floodplain preceding the 1940 bridge construction. For calibration, the model was simulated with mean spring high water (MWHW) hydrographs through a channel opening representing the historic, pre-bridge conditions.

Roughness coefficients (Manning's "n") used in the hydraulic computations were determined by engineering judgment and were based on field conditions of the channel and floodplain areas. These values as well as minor modifications to the channel cross-sections were considered calibrated when the MSHW tide elevations reached the historic marsh floodplain footprint. The calibrated "n" values are presented in Table 7.

The hydraulic analysis was based on unobstructed flow. The flood elevations shown on the profiles are thus considered valid only if hydraulic structures remain unobstructed and do not fail.

Table 7

Calibrated Manning "n" values

Tributary Name	Main Channel "n" values	Right Overbank "n" values	Left Overbank "n" values
West Branch Reach 1	.035-0.05	.03-0.12	.03-0.12
West Branch Reach 2	.035-0.05	.05-0.12	.035-0.12
East Swamp Reach 1	0.035-0.05	0.03-0.05	0.03-0.12
East Swamp Reach 2	0.05-0.07	0.05-0.12	0.03-0.12
East Swamp Reach 3 – d/culvert	0.10-0.12	0.10-0.12	0.10-0.12
East Swamp Reach 3 – u/culvert	0.03-0.05	0.03-0.05	0.03-0.05
East Swamp Reach 4	0.10-0.12	0.10-0.12	0.10-0.12
East Swamp Trib.	0.05-0.12	0.05-0.12	0.05-0.12
Point Street Trib.	0.25-0.30	0.25-0.30	0.25-0.30
Water Street Trib.	0.05-0.12	0.03-0.12	0.05-0.12
Branch Brook	0.05-0.12	0.05-0.12	0.10-0.12
Bells Brook Reach 1	0.10	0.05-0.12	0.10-0.12
Bells Brook Reach 2	0.15-0.20	0.15-0.20	0.12-0.20
Bells Brook Reach 3	0.30	0.20-0.30	0.20-0.30
Bells Brook Reach 4	0.12-0.30	0.035-0.30	0.12-0.30
Bells Brook Reach 5	0.12-0.20	0.12-0.20	0.12-0.20
Bells Brook West Trib.	0.12-0.30	0.12-0.30	0.15-0.30
Bells Brook East Trib.	0.20-0.30	0.12-0.30	0.20-0.30
Bells Brook North Trib.	0.20-0.30	0.12-0.30	0.20-0.30
Ingersoll Brook	0.20-0.30	0.20-0.30	0.20-0.30

e. West Branch Restoration Analysis.

The intent of modeling the West Branch was to evaluate the nine primary alternatives presented in Section 3.0 and the correlating tidal exchange to restore the salt marsh, without adversely affecting adjacent properties, roadways, or infrastructure.

i. Alternative A, Alternative B & Alternative C. Alternative A represents a 'no action' alternative, therefore, changes in either tidal or freshwater flow under this scenario is considered null. The model simulated Alternative B and alternative C, which include six box culverts of 5ft x 2.5ft and 5ft x 5ft, respectively, with neither alternative including flap gates. Alternative B culverts equal a 75 square foot opening that is equivalent to

half the existing six culverts and the Alternative C culverts equal a 150 square foot opening – the existing configuration. Additionally, Alternative B included no upstream culvert improvements while Alternative C included improvements at both Point Street and Water Street from 4-ft diameter to 5-ft diameter culverts to increase tidal exchange into the marshes upstream of these roadways. Increasing the culverts to 5-ft does not require the roadways to be raised.

The spring MHW reached at both Addison Road and Water Street is only 5.2 ft NAVD and 6.1 ft NAVD for Alternative B and Alternative C, respectively, while the spring MHW at Point Street is only 4.7 ft NAVD and 5.1 ft NAVD, respectively. These spring tide elevations are considerably lower than the spring tide elevation of Pleasant River (7.5 ft NAVD) and the marsh elevations adjacent to the channel. Therefore, a total 132 acres and 260 acres, respectively, would be restored under these scenarios out of the potential 470 acres.

Stormwater runoff hydrographs evaluated in Section 2.c and presented in Table 5 were simulated in the HEC-RAS model during spring tide conditions. Stormwater runoff increases the peak water surface elevation in the marsh but does not impact either Addison Road or Water Street. Increased water elevations at Point Street would encroach on the top of road surface during a spring tide/10-yr rain event and potentially overtop the roadway by 12-inches during a spring tide/100-yr rain event. Local observations indicate the roadway at Point Street currently experiences annual overtopping from stormwater particularly during saturated snowmelt conditions due to overgrown channel and flat gradient causing backwater effects. Therefore channel improvements in combination with an enlarged culvert may alleviate stormwater flooding in this area.

Tide hydrographs representing the 2-yr, 10-yr and 100-yr tide events were simulated in HEC-RAS to compute the expected peak water surface elevation in the marsh. Both Alternative B and Alternative C indicate increases in water elevation, although significantly lower than the correlating peak tide predicted in the Pleasant River downstream of Ridge Road. This is due to the 75 square foot and 150 square foot opening restriction at Ridge Road. Impacts to upstream roadways include no encroachment at Addison Road, encroachment at Water Street during the 10-yr flood and overtopping at Point Street of 0.6-ft to 1.6-ft during the 10yr to 100-yr tide events.

ii. Alternative D, Alternative E & Alternative F. Each of these alternatives includes replacing the existing Ridge Road causeway's six 5ft x 5ft culverts with a 150-ft open span bridge. Alternative D includes no upstream culvert improvements while Alternative E includes culvert improvements at Addison Road, Point Street and Water Street to increase tidal exchange into the marshes upstream of these roadways. Alternative F includes a culvert improvements at Addison Road only and a flap gate at Water Street to restrict tidal flow exchange upstream of Water Street into the Point Street swamps but will allow stormwater draining upstream of Water Street to discharge to the West Branch during periods of low tide. It is important to note, that stormwater will discharge through the flap gate when the tide begins to recede.

Increasing the Ridge Road opening to a 150-foot open bridge increases the tidal exchange to the West Branch marsh and significantly with the spring high water at Addison Road increasing to 1.5-1.8 feet greater than Alternative B and 0.6-0.9 feet greater than Alternative C. Similarly at Water Street, spring high water increases by 0.7-1.0 feet and 1.7-2.0 feet. The Point Street spring tide elevations increase by only 0.6 feet with the existing culvert size at Water Street (Alternative D) but increase by 2.2 feet when the Water Street Culvert is increased to a 12'x5' box (Alternative E). Alternative F includes a flap gate at the Water Street Culvert; therefore, tidal exchange is not introduced upstream of this point under this scenario. A total acres restored were computed as 349 acres, 385 acres and 314 acres, respectively, out of the potential 470 acres. It is interesting to note that the flap gate at Water Street reduces the total acres restores; however, Alternative F does include a respectable increase in total acres restored over Alternatives B and C. This is due to the increased volume of tidal flow entering the 150-foot bridge distributing across the West Branch flood plain.

The stormwater analysis evaluated in conjunction with a spring tide condition for Alternatives D, E and F determined no impact to the top of roadway at either Addison Road or Water Street, as also determined in Alternatives B and C. However, the increased volume of tidal flow entering the West Branch during these alternatives with the 12ft x 12ft box culvert at Water Street and Point Street significantly increases the flood

elevations at Point Street. Flooding at Point Street could be in excess of nearly 1-foot during a 2-yr frequency rain event coupled with peak spring tide.

Tide hydrographs representing the 2-yr, 10-yr and 100-yr tide events were simulated in HEC-RAS to compute the expected peak water surface elevation in the marsh for Alternatives D, E and F. Impacts to upstream roadways include encroachment at Addison Road during a 100-yr tide only, encroachment at Water Street during the 10-yr, 50-yr flood and 100-yr tides, and significant inundation at Point Street during each of these tide events.

iii. Alternative G, Alternative H & Alternative I. These alternatives include replacing the existing Ridge Road causeway with six 5ft x 5ft culverts with a 45ft x 12ft (or equivalent) culvert and include similar upstream culvert scenarios as Alternatives D, E and F. Alternative G includes no upstream culvert improvements while Alternative H includes culvert improvements at Addison Road, Point Street and Water Street to increase tidal exchange into the marshes upstream of these roadways. Alternative I includes a culvert improvements at Addison Road only and a flap gate at Water Street to restrict tidal flow exchange upstream of Water Street into the Point Street swamps but will allow stormwater draining upstream of Water Street to discharge to the West Branch during periods of low tide. As was noted for Alternative F, the stormwater will discharge through the flap gate when the tide begins to recede.

Increasing the Ridge Road opening to a 45ft x 12ft box culvert (or equivalent – realistic culvert dimensions will be determined during cost estimation) computed nearly identical spring tide elevations as Alternatives D, E and F with the 150-ft open bridge at each of the roadway crossings, Addison Road, Water Street and Point Street. The astronomical high water elevations for the 45ft x 12ft culvert alternatives were only 0.1-0.2 ft below those achieved in 150-ft open bridge alternatives. Total acres restored were computed as 346 acres, 377 acres and 309 acres, which was very similar to the total acres restored in Alternatives D, E and F. Again, the acres restored are reduced due to the flap gate at Water Street however some of this restricted tidal flow is distributed across the West Branch floodplain.

As expected, water elevations computed for both the stormwater analysis and tidal analysis were very similar to those computed in Alternatives D, E and F. This is due to the similar flow volume entering the marsh for the 150-ft span open bridge and 45ft x 12ft culvert opening as well as identical upstream culvert scenarios. The greatest impacts are seen at Point Street due to the low lying roadway and adjacent floodplain.

f. Channel Velocities and Sedimentation.

According to the American Society of Civil Engineers publication, Sedimentation Engineering, published in 1977, the critical water velocity for a median grain size of 0.4mm ranges between 0.45 feet per second (fps) and 0.84 fps with 0.82 fps being the critical velocity, indicating a small amount of movement, or sedimentation will occur. The critical water velocity represents the point at which the grain is suspended.

The velocities of the existing channel, computed by the model, ranged between 0.26 fps and 1.64 fps during the mean high spring water tide cycle and 0.46 fps and 1.79 fps during the 1-yr storm event. The model computed lower velocities for the 100-yr storm event because the WSE will inundate the channel and marsh. The velocity will be determined at critical locations for the alternatives that remain after the first round of feasibility selection. These velocities will be used to size rip-rap and potentially model scour/erosion/sedimentation for the selected alternative(s).

g. Sea Level Rise.

Sea level rise (SLR) was evaluated to predict the sea level change (SLC) at the West Branch and how this may impact the study area. The SLR analysis was conducted as directed in the USACE guidance, EC 1165-2-212, dated 1 October 2011. This EC requires a multiple scenario approach for three sea level rise scenarios, with each being considered equally plausible. These curves are; the historic rate of SLC at the project area, an intermediate SLC curve (modified NRC Curve I), and a high SLC curve (modified NRC Curve III). Formulation of the NRC curves from a defined starting date, and for localized su subsidence was also provided in the EC which allows from SLC to be calculated for specific project time frames and for specific geographic areas. This is critical since

SLC along the coast varies due to local subsidence, uplift, water body movement, etc. The three scenarios proposed by the NRC result in global eustatic sea-level rise values, by the year 2100, of 0.5 meters, 1.0 meters, and 1.5 meters. Adjusting the equation to include the historic Global mean sea level (GMSL) change rate of 1.7 mm/year and the start date of 1992 (which corresponds to the midpoint of the current National Tidal Datum Epoch of 1983-2001), results in updated values represented as the constant, b, in the SLC equation.

Using the SLC equation below, which is equation (3) from the EC, and a spreadsheet provided by the USACE ERDC, Figure 1 was developed for Bar Harbor, Maine. Bar Harbor was used since it is the closest NOAA station to the project site and includes historic SLC information required for this analysis.

$$E(t2) - E(t1) = 0.0017(t2-t1) + b(t22-t12)$$

Where:
t1 = is the time between the project's construction date and 1992
t2 = is the time between a future date at which one wants an estimate for sea level rise and 1992
b = 2.71 E-5 for modified NRC Curve I (low, 0.5 meter rise)
b = 7.00 E-5 for modified NRC Curve II (intermediate, 1.0 meter rise)
b = 1.13 E-4 for modified NRC Curve III (high, 1.5 meter rise)

As can be seen in both Figures 1 and 2, the historical rate (0.2 meter curve) would result in a rise of only 0.27 feet (0.04 meter) or 3.2 inches over the first 50 years. However, the level of SLR increases for each of the NRC curves as specified for use in the EC. As shown in Figure 1, the low curve (0.5 meter curve) predicts a rise of 0.4 feet (0.12 meter) or 4.8 inches, the intermediate curve a rise of 0.6 feet (0.18 meter) or 7.2 inches, and the high curve a rise of 0.81 feet (0.32 meter)or 9.7 inches.

4.0 SUMMARY

A final decision has not yet been made. The alternatives are going through cost estimation and additional, more detailed modeling, will be done on those that appear financially feasible, constructable and socially and environmentally acceptable. Additional modeling might include a sensitivity analysis of the bridge modeling approach and scour analysis, particularly for piers. Sedimentation/erosion analysis is also being considered, depending on the selected plan. Other factors will undoubtedly affect the final decision as well, and this report will be expanded.

5.0 REFERENCES

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