Stantec

Memo

To:	Maine Department of Transportation	From:	Lori Benoit, Michael Chelminski
	Augusta, Maine		Northampton MA Office
File:	197450347	Date:	November 8, 2021

Reference: Estimated Elevation Ranges of Intertidal Habitats for Middle River / Dyke Bridge Alternatives

In support of the Dyke Bridge Replacement Project (Project) located on the Middle River in Machias, Maine, Stantec was tasked with estimating the extent of tidal wetland habitats for two previously vetted alternatives (4m and 10) for replacing existing flap gates at Dyke Bridge. Stantec reviewed existing background information and data on tidal hydrology and vegetation elevations and distribution in the following documents:

- Technical Report: Middle River Hydrologic and Alternatives Analysis, Stantec 2015 (Appendix A)
- Memo: Draft Phase 1 Hydraulic Analysis for Machias Dyke Bridge (#2246) Planning Phase Support Services, September 2, 2021, Stantec to MaineDOT (Stantec 2021) (MaineDOT Project Website)
- Data: SchoppeeMarsh_TidalRestrictionAssessment_Draft_Hydrodata.xls. Schoppee Marsh Tide Gate Removal Project hydrology, elevation, and vegetation data from BB USFWS GOMP/ DSF. (Included for Information Only with permission from Downeast Salmon Federation)

SIMULATED TIDAL STAGE STATISTICS

Stantec 2021 presents information obtained from the preliminary, unsteady-state numerical hydraulic model study for a range of potential alternatives for the Project, including simulated water surface elevations in the Middle River for Alternatives 4m and 10. Tidal statistics were generated for the two noted alternatives based on a hydraulic model simulation period of 34 days. Boundary conditions for the unsteady-state simulations included a constant inflow of 13.7 cubic feet per second representing a typical discharge of the Middle River and a time-varying water surface elevation at downstream boundary condition based on tidal stage data collected in the Machias River by MaineDOT in 2011.

Tidal stage statistics were developed based on the simulated water surface elevations in the Middle River landward (upstream) from Dyke Bridge using the National Oceanic and Atmospheric Administration online Tidal Analysis Datum Calculator tool[1]. Calculated tidal statistics are presented in Table 1.

Table 1. Estimated Tide Statistics for the Middle River for Alternatives 4m and 10

	Estimated Tide Statistics (ft, NAVD88)	
	Alt4m	**Alt10**
Mean Higher High Water	2.01	7.39
Mean High Water	1.87	6.87
Mean Tide level	-0.41	0.21
Mean Low Water	-2.68	-6.46
Mean Lower Low Water	-2.73	-6.66

[1] CO-OPS Datum Calculator (noaa.gov)

Reference: Estimated Elevation Ranges of Intertidal Habitats for Middle River / Dyke Bridge Alternatives

ESTIMATED SALTMARSH RANGES

Based on this review, Stantec estimated potential elevation ranges for three habitat types of high marsh, low marsh, and unvegetated intertidal areas, and present the estimates in Table 1 with elevations referenced to the North American Vertical Datum of 1988 (NAVD88).

Table 2: Estimated Potential Saltmarsh Habitat Ranges

	Estimated Saltmarsh Habitat Ranges (ft, NAVD88)			
	Alternative 4m		**Alternative 10**	
Estimated Habitat	Low Range	High Range	Low Range	High Range
High Marsh	1.9	2.0	6.9	7.4
Low Marsh	0.8	1.9	3.8	6.9
Unvegetated intertidal/subtidal	-	0.8	-	3.8

The attached figures depict the estimated areas of high marsh, low marsh, and unvegetated intertidal and subtidal habitats based on the elevation ranges in Table 1 using a digital terrain model developed using LiDAR data. These figures include estimated areas for the evaluated habitat types. The estimated habitat areas were developed based on the assumption that salinities in the Middle River landward from Dyke Bridge would be similar to salinities in the Machias River seaward from the bridge.

Unvegetated intertidal habitat is a distinct habitat type but here has been temporarily lumped with subtidal habitat until updated bathymetric data becomes available. Predicted elevations for saltmarsh habitats may be revised as additional information becomes available. The estimated elevations and descriptions for intertidal habitats landward of Dyke Bridge under two alternatives are based also on the following assumptions:

1) High marsh formation is predicted at elevations between mean high water (MHW) and mean higher high water (MHHW), which are areas typically inundated with salt water during only the highest tides of the month.

2) High marsh is typically dominated by saltmeadow cordgrass (*Spartina patens*). Black grass (*Juncus gerardii*) may be found at the highest elevations/upper border of the high marsh. Saltwater cordgrass (*Spartina alterniflora*) may be found in the high marsh in slight depressions on the marsh surface (high saline pannes) along with glasswort species (*Salicornia* spp.)

3) Low marsh has the potential to establish from MHW to the approximate elevation of the mean tide level (MTL). In actuality, *S. alterniflora* often is not found at elevations as low as the mean tide level (MTL). Data for the unrestricted portion of Machias River does not show low marsh close to the "Diurnal Tide Level" in the Machias River at an elevation (El.) of 0.47 ft (see "Assessment Notes" tab of Schoppee Marsh Excel file) and which Stantec assumes approximates the MTL. At the seaward side (no restriction) of the Machias River, the data gathered by DSF shows low marsh at El. 4.99 ft. Based on this data point, approximately 5 ft above the MTL appears to not be vegetated. However, this one data point for unrestricted low marsh is insufficient information to assess the overall elevation distribution of low marsh in the tidal wetland with unrestricted flows. Also, the start of downstream (presumably downstream of tide gate in unrestricted flow Machias River) low marsh is shown at

approximately EL. 3.6 ft in the Schoppee Marsh Excel file . In this case, approximately 50% of the tide range between MTL and MHHW is unvegetated. This data is consistent with previously published findings indicating that ice scour may limit the lower extent of low marsh in northern New England salt marshes (Hardwick-Witman 1986) and this may explain lack of Spartina alterniflora at or near the MTL. Therefore, the lower limit of low marsh for both alternatives 4m and 10 was roughly estimated as the MHHW el. minus 50% of the tide range between the MTL and the MHHW.

4) *S. alterniflora* is the dominant, monotypic plant species of the low marsh.

5) Unvegetated intertidal areas (encompasses habitat called “mud flat”) are expected in the range from MTL to mean lower low water. Erosion caused by ice scour of mid-range intertidal areas may limit the lower extent of vegetated intertidal areas. Increased height of tidal flooding may inhibit *S. alterniflora* growth in the intertidal region below MHW particularly in locations such as the Gulf of Maine that experiences extreme tidal ranges.

6) At individual tidal sites, variations in microtopography and flood/drainage patterns, including those due to disturbances such as culverts and tide gates that cause tidal restrictions, may alter the elevations and predicted patterns at which high marsh, low marsh, and unvegetated tidal areas are established.

7) Estimated ranges of intertidal habitats for Alternative 10 were adjusted based on field-collected data at unrestricted Machias River intertidal sites. Notably, the extreme tide heights, and duration, and ice scour may preclude low marsh/ *S. alterniflora* establishment in a significant portion of the intertidal zone below MHW.

8) Under the Alternative 4m scenario, it was assumed that high marsh may become established in a narrow elevation range that will not be flooded daily but only on the highest predicted tides each month and based on restricted flow through the culverts that will limit the higher tidal heights.

MIDDLE RIVER STAGE-AREA CURVE

A stage-area (hypsometric) curve was developed from a digital terrain model (DTM) of land adjacent to the Middle River upstream from Dyke Bridge to the vicinity of Stride Bridge. The DTM was developed using existing LiDAR and was initially compiled for development of the project hydraulic model study program.

Figure 1 depicts the stage-area curve along with the estimated High Marsh and Low Marsh habitat elevation ranges for Alternatives 4m and 10 that are presented in Table 2. Table 3 presents the stage-area data in tabular format.

The stage-area data does not include areas for elevations below Elevation 0.0 ft which are largely in the current area that is inundated during normal tidal conditions in the Middle River upstream from Dyke Bridge. The estimated saltmarsh habitat ranges presented in Table 2 and in Figure 1 indicate that areas below Elevation 0.0 would be unvegetated intertidal/subtidal habitat for Alternative 4m and that areas below Elevation 4.5 ft would be unvegetated intertidal/subtidal habitat for Alternative 10.

Reference: Estimated Elevation Ranges of Intertidal Habitats for Middle River / Dyke Bridge Alternatives

Figure 1. Stage-Area Curve

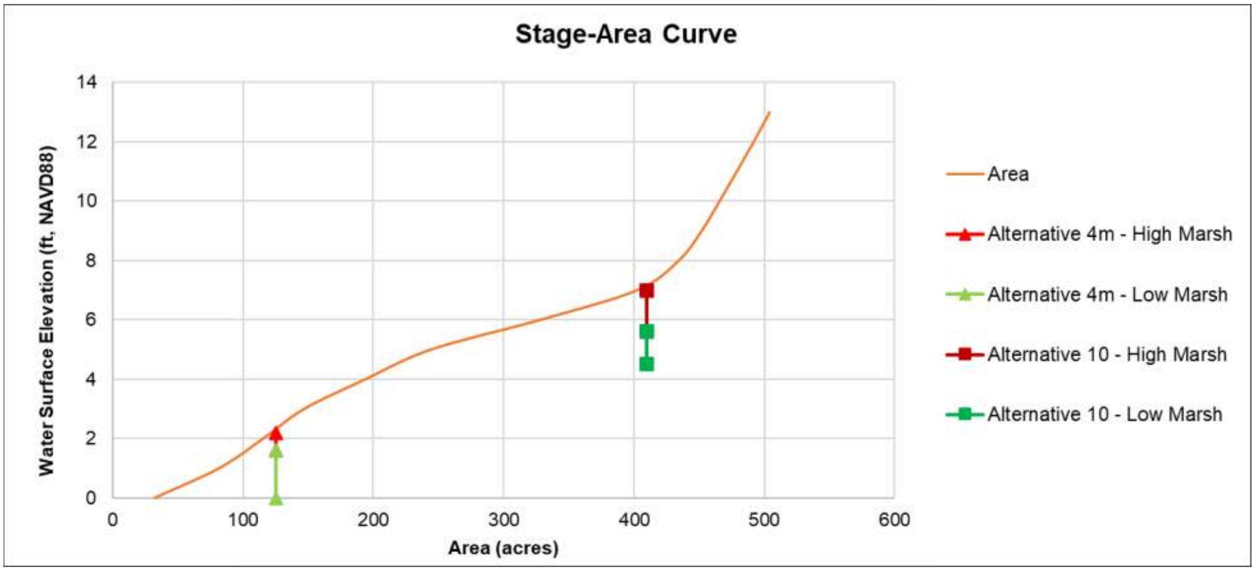

Table 3. Stage-Area Curve Data from Figure 1 for Middle River Upstream from Dyke Bridge

WSEL (ft, NAVD88)	Area (acres)
0	33
1	82
2	116
3	147
4	194
5	244
6	328
7	402
8	434
9	452
10	465
11	478
12	491
13	504

Reference: Estimated Elevation Ranges of Intertidal Habitats for Middle River / Dyke Bridge Alternatives

DATA LIMITATIONS AND CAVEATS

The methodology for collection of vegetation data by DSF is not provided. Using a series of transects from below MTL to the upland is a standard method for vegetation assessment. Identifying plants and community types on the fly in the field and taking vegetation and elevation data would not be recommended as this approach could introduce selection bias.

We are not able to determine from the DSF plant community and elevation data exactly which data applies to the Eastern Schoppee Marsh. That location has a partial tidal restriction (does not drain fully at low tide and does not reach full tidal height compared to the unrestricted Machias River) and could be skewing the data if it is grouped with the "unrestricted" data. Based on the presentation of three sets of tidal data (Machias River, Schoppee Marsh Restricted, and Schoppee Marsh Eastern), we would expect three sets of vegetation data that reflect the tidal regime in each location. However, plant community and elevation data is shown only as restricted vs. unrestricted. Are there any vegetation and elevation data specifically for the Eastern Schoppee Marsh? Of the three locations, the Eastern Schoppee Marsh may be most similar to the alternative 4m.

Elevations of vegetation community called "Low hypersaline panne – restricted" does not make sense given the elevations of the high marsh. Hypersaline pannes are embedded within the high marsh zone and are typically only a few millimeters lower in elevation than the surrounding S. patens-dominated high marsh. The elevation data for the pannes appear to be lower by a foot or more in elevation compared to the high marsh. It is possible that these areas are stunted and dying S. alterniflora areas caused by excessive duration of flooding upstream of the Schoppee tide gate.

The data assessment appears to be in the draft stage. Note comment by "WBennett" regarding the vegetation community classification: "Need to further evaluate the classification of different communities. Many irregularities exist and overlap." We suggest proceeding with caution on using and interpreting the existing data for predicting locations/areas of salt marsh habitats for the different design alternatives. We may want to discuss the data with DSF, and additional data collection may be warranted.

Please contact Stantec with questions or comments regarding the information presented in this memo.

Stantec Consulting Services Inc.

for: L K B 11/08/2021

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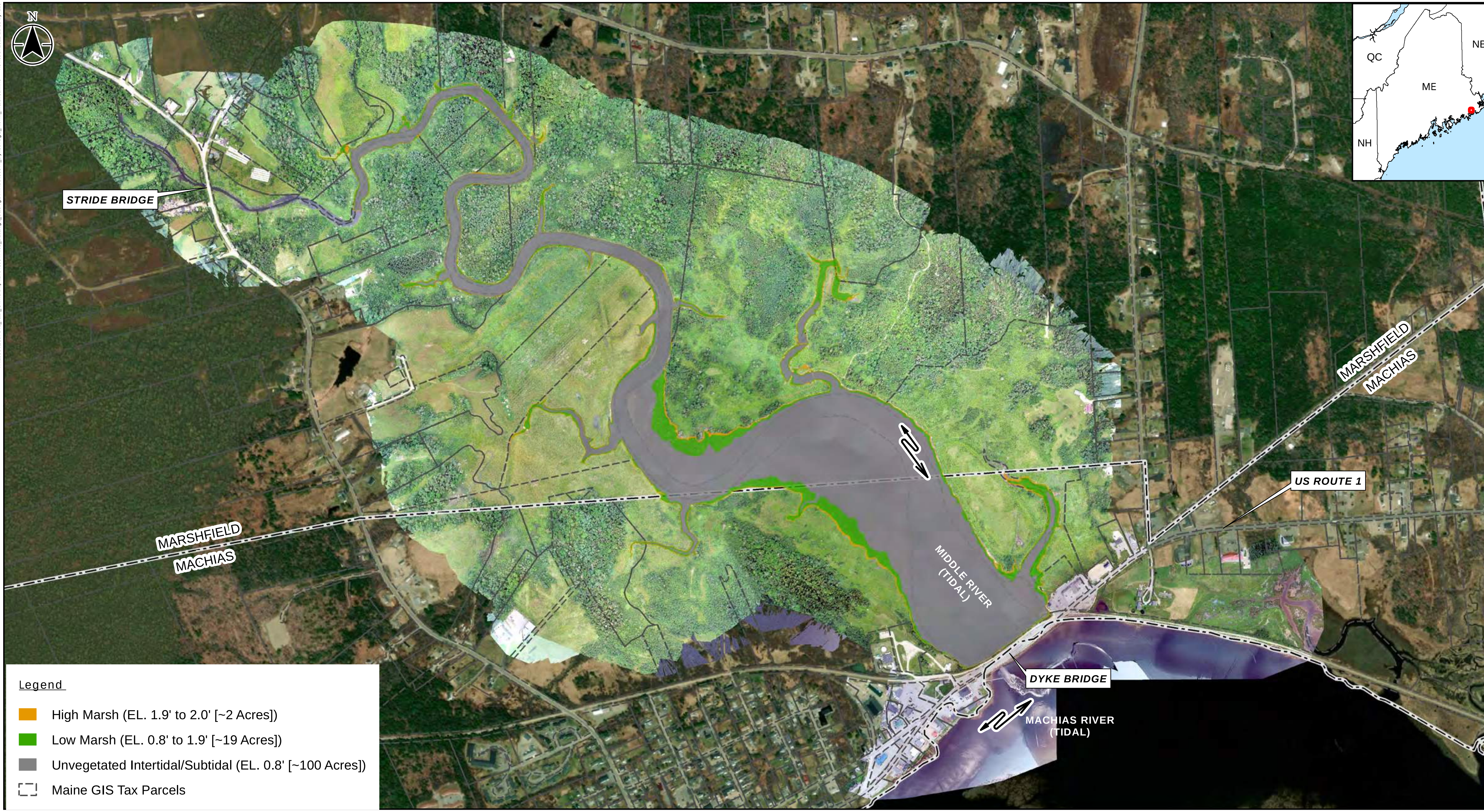
Attachment: Figure 1: Alternative 4m, Estimated Saltmarsh Habitat
Figure 2: Alternative 10, Estimated Saltmarsh Habitat

c. Tim Merritt, Stantec



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50347_DykeBridge_Alt4m_marshes.mxd

Notes

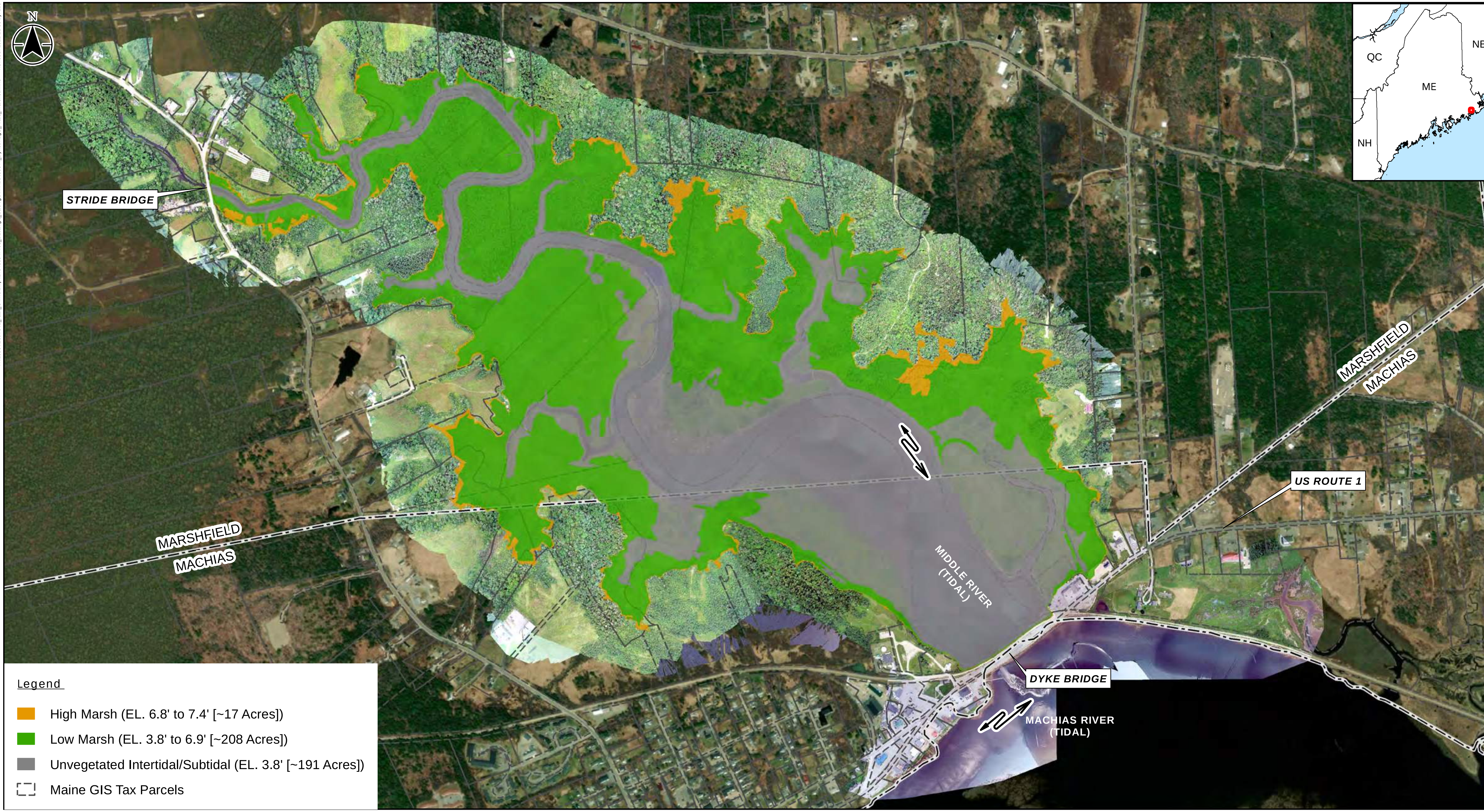
1. Approximate water surface elevations (WSEL) for proposed alternatives are based on the 2021 Phase 1 hydraulics analysis using tidal stage data collected by MaineDOT in 2011.
2. Coordinate System: NAD 1983 UTM Zone 19N FT
3. Vertical Datum: NAVD88
4. Aerial imagery in the project area was obtained by unmanned aircraft vehicle (UAV) by MaineDOT on July 20, 2021.
5. Aerial imagery surrounding the project area is provided by ArcGIS Online World Imagery Mapping Service (http://server.arcgisonline.com/arcgis/services/World_Imagery/MapServer).
6. TIN Surface information is based on survey data provided by the Maine Department of Transportation.

Client/Project
Maine DOT
Dyke Bridge
Machias, Maine

Figure No.
1

Title Alternative 4m
Estimated Saltmarsh Habitat

11/9/2021



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50347_DykeBridge_Alt10_marshes.mxd

Notes

1. Approximate water surface elevations (WSEL) for proposed alternatives are based on the 2021 Phase 1 hydraulics analysis using tidal stage data collected by MaineDOT in 2011.
2. Coordinate System: NAD 1983 UTM Zone 19N FT
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6. TIN Surface information is based on survey data provided by the Maine Department of Transportation.

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1 inch = 833 feet (At page size of 11"x17")

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Maine DOT
Dyke Bridge
Machias, Maine

Figure No.
2

Title Alternative 10
Estimated Saltmarsh Habitat

11/9/2021

APPENDIX A

2015 Hydrologic Analyses and Alternatives Evaluations

Technical Report: Middle River Hydrologic and Alternatives Analyses

Hydrologic Analyses and Alternatives Evaluations, Dyke Bridge and Stride Bridge, Middle River, Machias, Maine

Prepared for:
Maine Department of Transportation
Attn.: Nathan Howard
Bureau of Planning
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Prepared by:
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June 30, 2015

Sign-off Sheet

This document entitled Technical Report: Middle River Hydrologic and Alternatives Analyses was prepared by Stantec Consulting Services Inc. ("Stantec") for the account of the Maine Department of Transportation (the "Client"). Northstar Hydro, Inc. is a subcontractor to Stantec for this study and contributed to the preparation of this report.

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Ellen O'Brien, P.E., President, Northstar Hydro.

This report was prepared for the MaineDOT Bureau of Planning by Stantec for work as part of State W.I.N. # 016714.00, Federal W.I.N. #BR-1671(400)X, and funded through Appropriation #9095.

Stantec

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Executive Summary

The Maine Department of Transportation (MaineDOT) contracted with Stantec Consulting Services Inc. (Stantec) to perform hydrologic and hydraulic analyses to evaluate a range of bridge and/or culvert alternatives to replace the Dyke Bridge (#2246) and the Stride Bridge (#3973) over the Middle River in the vicinity of the Town of Machias, Maine. Dyke Bridge crosses the Middle River immediately landward of the confluence of the Middle River with the Machias River in the Town of Machias. Stride Bridge crosses the Middle River in the Town of Marshfield approximately 3 miles upstream from Dyke Bridge.

This study develops and evaluates a range of alternative bridge and/or culvert geometries at Dyke Bridge and Stride Bridge. The primary focus of this study is to evaluate potential replacement structures at the two bridges relative to existing conditions and potential sea-level rise. Seven general alternatives were evaluated at Dyke Bridge, and range from no-action (Alternative 1) and replacement in-kind (Alternative 2), alternative culvert systems with operable gates (e.g., self-regulating tide gates [SRTs]) as presented by Alternatives 3 and 4, to a large bridge and/or group of culverts (Alternatives 5, 6, and 7) that would provide for unhindered tidal exchange in the Middle River upstream (landward) from Dyke Bridge.

Evaluated alternatives at Stride Bridge where limited to retaining the existing culvert and replacement with a single-span bridge.

Factors that are considered in the development and evaluation of alternatives at Dyke Bridge in this report include:

1) Conveyance of tidal flow at Dyke Bridge;
2) Potential inundation of land upstream from Dyke Bridge that would result from increased tidal exchange;
3) Upstream fish passage at Dyke Bridge and impacts to upstream fish passage at Stride Bridge; and
4) The potential for evaluated alternatives to affect inundation of areas along the Middle River landward from Dyke Bridge for the evaluated sea-level rise conditions.

The primary tool for evaluation of alternatives is a numerical hydraulic model of the study reach of the Middle River from its confluence with the Machias River to Stride Bridge. The one-dimensional, unsteady-state numerical hydraulic model was developed using the U.S. Army Corps of Engineers HEC-RAS software system (HEC-RAS model). The model was developed using Lidar terrain data and bathymetric data collected by MaineDOT. Boundary condition and calibration data for the HEC-RAS model included tidal stage data and peak upland flow statistics provided by MaineDOT. The HEC-RAS model was calibrated and validated for existing conditions using tidal stage data provided by MaineDOT.

The preliminary alternative evaluation process was initiated with a review of information on SRTs, which are the basis of two of the general alternatives. Based on this review, it was determined

that SRTs (Alternative 3) and "fish-friendly" SRTs (Alternative 4) are not practical technologies for replacement of the existing culvert and flap-gates system at Dyke Bridge and are not expected to improve upstream fish passage relative to other evaluated alternatives.

Three general alternatives were evaluated to provide for unhindered tidal exchange at Dyke Bridge. Based on this review, it was determined that a single-span bridge (Alternative 6) is a feasible alternative for replacement of the existing culverts at Dyke Bridge, but that a group of large culverts (Alternative 5) or a group of culverts along with a single-span bridge (Alternative 7) are not feasible alternatives at Dyke Bridge.

The HEC-RAS model was used to evaluate a set of the evaluated alternatives at Dyke Bridge and Stride Bridge. The HEC-RAS model was used to evaluate a broad range of alternatives; this study presents information and findings for approximately 100 unsteady-state flow scenarios. Based on information obtained from the HEC-RAS model and consideration of the four factors noted previously, it was identified that feasible alternatives at Dyke Bridge include:

- Replacement in-kind (Alternative 2) without flap gates on every culvert; and
- Replacement with a single-span bridge (Alternative 6).

Multiple scenarios were evaluated for replacement in-kind (Alternative 2). These scenarios evaluated four or five box culverts with up to two free-flowing culverts (no flap gate). These scenarios would provide for landward flow through the culverts without flap gates during flood tides and are expected to substantially improve upstream fish passage while limiting inundation of land along the Middle River landward from Dyke Bridge. Depending on the selected variation of Alternative 2, including the total number of culverts and the number of culverts with and without flap gates, this alternative can limit inundation of land upstream from Dyke Bridge while substantially improving upstream fish passage. Information developed as part of this study indicates that increasing typical tidal water surface elevations upstream from Dyke Bridge by more than 2 feet (ft) would result in regular tidal inundation of substantial areas of land.

Replacement with a single-span bridge (Alternative 6) would provide for volitional upstream fish passage and would result in substantial inundation of land along the Middle River landward from Dyke Bridge. Specifically, normal tidal water surface elevations would increase by 8 to 10 ft immediately landward from Dyke Bridge. Based on the results of the HEC-RAS model evaluations, the minimum length of a single-span bridge to provide unhindered tidal flow at Dyke Bridge is 60 ft with vertical abutments and would require dredging of a channel under the bridge and upstream into the Middle River.

Based on factors that are considered in this study and the study evaluations and findings, the primary constraints associated with replacement of the existing Dyke Bridge culvert systems are 1) upstream fish passage, and 2) inundation of land upstream from Dyke Bridge. Replacement in-kind (Alternative 2) with some free-flowing culverts can provide for improved upstream fish passage while limiting flooding of landward areas. Installation of a single-span bridge can provide for free-flowing conditions at Dyke Bridge and volitional upstream fish passage, but would result in substantial inundation of land upstream from Dyke Bridge.

1.0 INTRODUCTION

The Maine Department of Transportation (MaineDOT) contracted with Stantec Consulting Services Inc. (Stantec) to perform hydrologic and hydraulic analyses to evaluate a range of bridge and/or culvert alternatives to replace the Dyke Bridge (#2246) and the Stride Bridge (#3973) over the Middle River in the vicinity of the Town of Machias, Maine. Dyke Bridge crosses the Middle River immediately landward of the confluence of the Middle River with the Machias River in the Town of Machias. Stride Bridge crosses the Middle River in the Town of Marshfield approximately 3 miles upstream from Dyke Bridge. The project location is depicted in Figure 1.

The objective of this study is to develop and evaluate a range of alternative bridge and/or culvert geometries at the two subject bridges, and the primary focus is to evaluate potential alternatives for replacement structures at the two subject bridges. The evaluation of replacement includes consideration of the existing tidal restriction associated with Dyke Bridge, which severely limits tidal flow landward from Dyke Bridge. This study evaluates a range of alternatives at Dyke Bridge and two alternatives at Stride Bridge. The evaluated alternatives at Dyke Bridge include:

- Alternative 1: No Action;
- Alternative 2 (baseline): Replacement In-Kind without restoration of tidal flow;
- Alternative 2 (variations) :Replacement In-Kind with the following variations;
    - Replacement In-Kind with partial restoration of tidal flow;
    - Replacement with partial restoration of tidal flow and provisions for fish passage;
- Alternative 3: Replacement with self-regulating tide gates (SRTs);
- Alternative 4: Replacement with “fish-friendly” SRTs;
- Alternative 5: Replacement with multiple adjacent culverts to restore tidal flow;
- Alternative 6: Replacement with a traditional span bridge; and
- Alternative 7: Replacement with a traditional span bridge with some adjacent culverts.

The evaluated alternatives at Stride Bridge include:

1. Concrete invert lining;
2. Slip-lining; and
3. Other alternatives to be determined.

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Notes
1. Coordinate System: NAD 1983 UTM Zone 19N
2. Data Sources include: USGS Imagery/Topo provided by The National Map Mapping Service (http://basemap.nationalmap.gov/arcgis/services/USGSImageryTopo).

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Prepared by ABC on 2014-00-00
Reviewed by ABC on 2015-00-00

00963_DykeBridge_LOC.mxd

Client/Project
Maine DOT
Dyke Bridge
Machias, Maine

Figure No.
1

Title
Project Location Map
7/1/2015

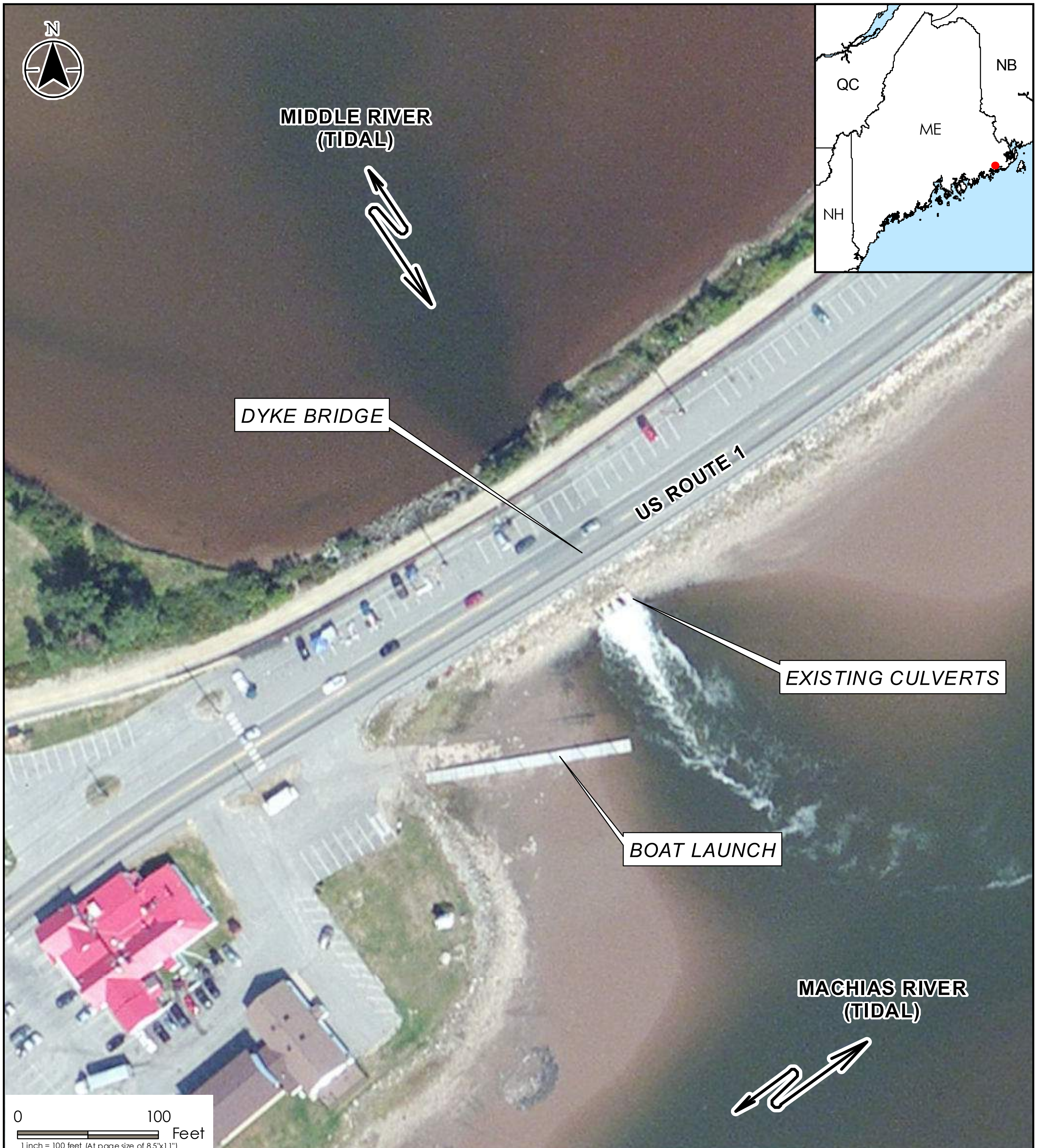
2.0 EXISTING CONDITIONS

2.1 DYKE BRIDGE

Dyke Bridge is located on U.S. Route 1 and consists of an embankment structure with four box culverts that are fitted with flap gates. The embankment has a length of over 1,000 feet (ft) and is constructed of timber cribbing with rubble and earthen fill. The four box culverts, constructed of timber and stone masonry, are approximately 80 ft long, 5 ft wide, 5 ft high, and have top-hinged flap gates installed on the seaward side of each of the four culverts. The culverts and flap gates are deteriorated. A combination of factors, including leakage through the flap gates and the causeway, result in landward flow into the Middle River during semi-diurnal flood tides. Dyke Bridge is shown in Figure 2 along with relevant adjacent features.

2.2 STRIDE BRIDGE

Stride Bridge is located on State Route 192 and consists of an earthen embankment with a 12.5-ft-diameter corrugated metal pipe culvert (CMP) with the ends coped to the roadway embankment. Stride Bridge is shown in Figure 3.



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00963_DykeBridge_Aerial.mxd

Notes
1. Coordinate System: NAD 1983 UTM Zone 19N
2. Aerial imagery provided by ArcGIS Online World Imagery Mapping Service (http://server.arcgisonline.com/arcgis/services/World_Imagery/MapServer).

Legend
Dominant Upland Flow

Client/Project
Maine DOT
Dyke Bridge
Machias, Maine

Figure No.
2

Title
Dyke Bridge Aerial
7/1/2015

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00963_StrideBridge_Aerial.mxd

Notes
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Legend

Dominant Upland Flow

Client/Project
Maine DOT
Dyke Bridge
Machias, Maine

Figure No.
3

Title
Stride Bridge Aerial
7/1/2015

2.3 HYDROLOGY

MaineDOT design guidelines recommend evaluating the following combinations of upland stream flows with selected tidal stages. The following combinations were modeled as part of this study:

a. Everyday Tides with 1.1-year river flow;

b. Everyday Tides with 50-year river flow;

c. 50-year Storm Surge with 1.1 year river flow;

d. Surge to be superimposed at mid-rising, high tide, mid-falling and low tides.

These conditions were modeled with the addition of 100-year upland flow with typical tides.

2.3.1 Upland Hydrology

Boundary condition data for upland flows in the Middle River at Stride Bridge and Dyke Bridge were provided by MaineDOT and are included as Appendix A. A summary of peak flow statistics is provided in Table 1.

Table 1: Peak Flows

Location	*Drainage Area (sq. mi.)*	***Return-Interval Event (Years)*/Peak Flow (cfs)**							
		1.1	***2***	***5***	***10***	***25***	***50***	***100***	***500***
Stride Bridge	9.41	130	265	213	522	670	787	912	1,221
Dyke Bridge	13.22	152	297	452	565	715	832	958	1,264

For model simulations of storm surge, a steady state upland flow of 152 cubic feet per second (cfs) was used to model flow in the Middle River. For model simulations combining typical tide cycles (1.1-year tide) with higher upland flows (50- and 100-year), flow hydrographs were developed for the Middle River. Hydrograph time to peak was assumed to be 12 hours and recession time was assumed to be 24 hours. Peak stream flow was assumed to occur at about 12 hours before the highest tide in the 1.1-year tide hydrograph. Hydrograph shape was assumed to be triangular. These assumptions should be evaluated for appropriateness for final evaluation and design of a selected alternative for replacement of the culverts at Dyke Bridge.

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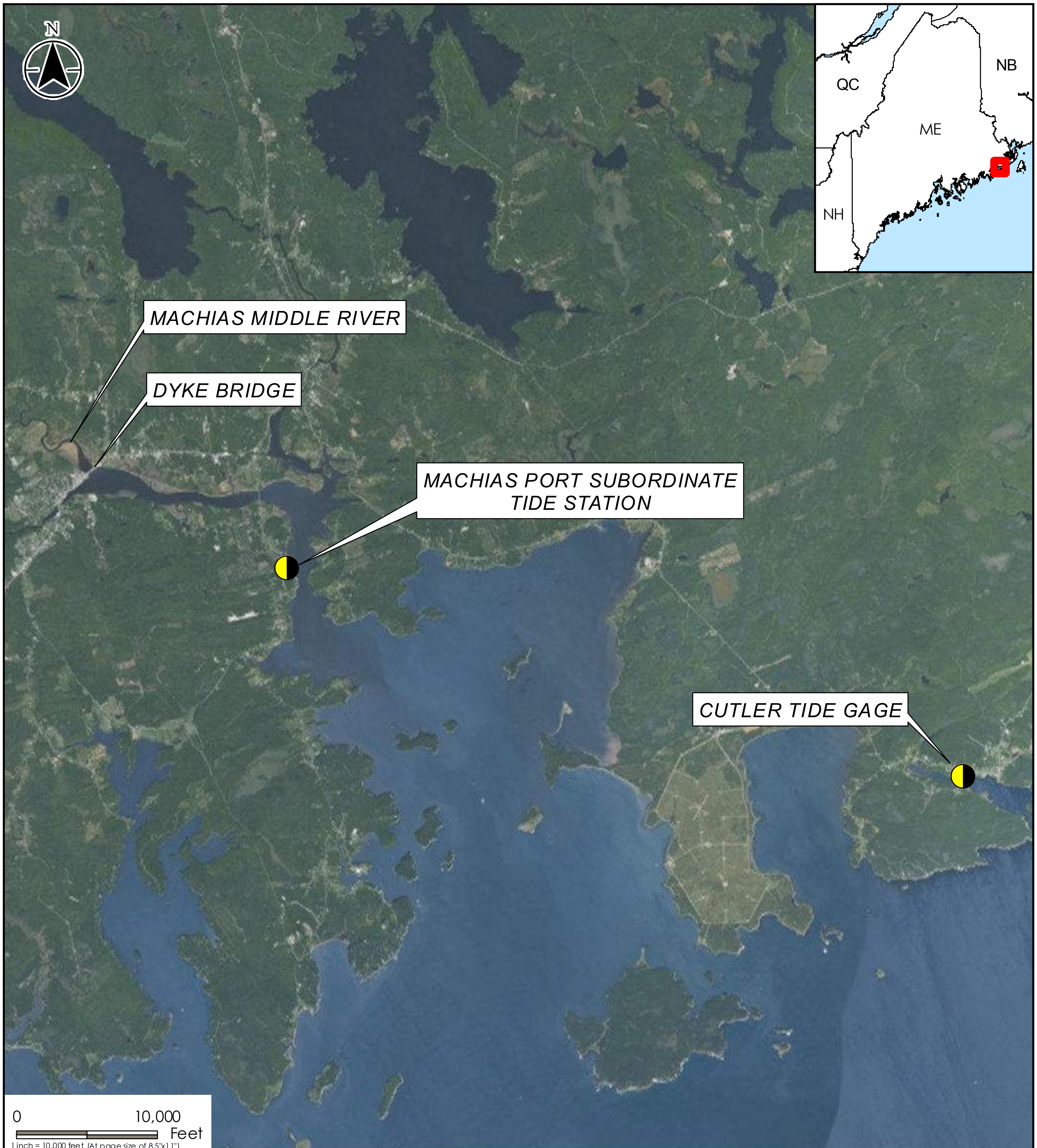

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00963_Gages.mxd

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Legend

Tide Gages

Client/Project

Maine DOT
Dyke Bridge
Machias, Maine

Figure No.

4

Title

NOAA Tide Stations

7/1/2015

2.3.2 Tidal Hydrology at Dyke Bridge

Sources of tide data used for this study include:

a. NOAA Recording tide gage data at Eastport, Cutler;

b. NOAA Predicted tide data at Subordinate Station on Machias River;

c. MaineDOT recorded data downstream of Dyke Bridge and Upstream of Dyke Bridge;

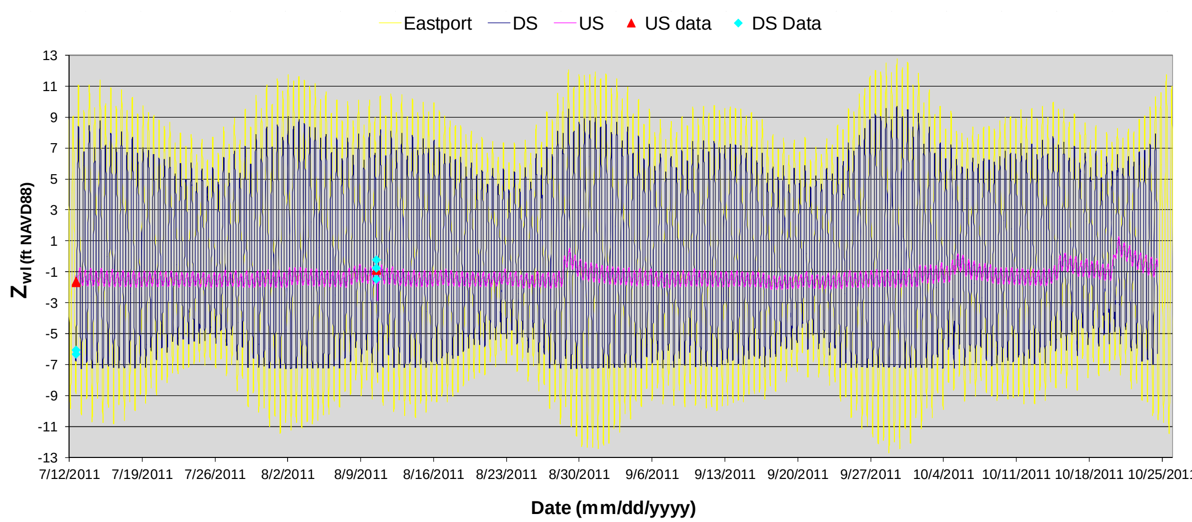
d. U.S. Army Corps of Engineers (USACE) Tidal Flood Profiles for Peak Storm Surge Elevations; and

e. MaineDOT provided guidance on calculation of surge hydrographs.

2.3.2.1 Recorded Tidal Stage Data- Project Data and NOAA Station Data

MaineDOT measured tidal stage data in the vicinity of Dyke Bridge in 2011 as part of this study. The tidal stage data were collected at two locations during the period from July 12, 2011, through October 24, 2011, using datalogging pressure transducers that recorded pressures at 5-minute intervals. The data were collected landward and seaward from Dyke Bridge in the Middle River and Machias River, respectively. These data were rectified by MaineDOT to the NAVD88 vertical datum in electronic file format and are plotted in Figure 5.

Figure 5: MaineDOT Tide Data, Downstream and Upstream of Dyke Bridge, July through October 2011



Tidal statistics were obtained for the tidal stage data collected in the Machias River seaward from Dyke Bridge by parsing-out the higher high tide, lower high tide, higher low tide, and lower low tide for the period from July 12, 2011, through October 24, 2011, using a parsing algorithm subroutine programmed in Visual Basic for Applications. Mean higher high water (MHHW) is calculated as the average of the higher high tide over each 24-hour period, and mean high water (MHW) is calculated as the average of the lower high tide over each 24-hour period. Mean low water (MLW) and mean lower low water (MLLW) area calculated as the average of the higher and lower (lowest) low tide over each 24-hour period. These site-specific calculations are compared to the predicted values of MHHW, MHW, MLW and MLLW at the Machiasport Tide Station and at the Cutler Tide Gage in Table 2, Table 3, and Table 4.

Review of Figure 5 indicates a low-end threshold for the data collected in the Machias River seaward from Dyke Bridge; this suggests that the datalogging pressure transducer was installed above the elevation of the lower low tides.

The parsed data was used to develop tidal statistics that are presented in Table 2, which includes the maximum, minimum, and average water surface elevations from the tidal stage data that was collected in the Machias River seaward from Dyke Bridge.

Table 2: Tidal Statistics from MaineDOT Data Set

Tidal Data (ft, NAVD88)						
Max.	**MHHW**	**MHW**	**Average**	**MLW**	**MLLW**	**Min.**
9.8	7.4	6.5	0.05	-6.4	-6.8	-7.5

Table 3 presents tidal statistics from National Oceanic and Atmospheric Administration tide stations at Eastport, Cutler Naval Base (Cutler), and Bar Harbor (Machias is located between Cutler and Bar Harbor along the coastline).

Table 3: Tidal Statistics from NOAA Stations

Station	Tidal Statistics (Elevation in feet)						
	MHHW	**MHW**	**NAVD88**	**MTL**	**MSL**	**MLW**	**MLLW**
Eastport	9.34’	8.86’	0’	-0.31’	-0.23’	-9.49’	-9.93’
Cutler	6.81’	6.39’	N/A	0.1’	0.0’	-6.37’	-6.75’
Bar Harbor	5.7’	5.28’	N/A	-0.1’	0.0’	-5.29’	-5.67’

Additional tidal data is available for Machias Port. This station is a subordinate tidal station, with predicted tides based on Eastport tides multiplied by 0.69.

Table 4: Tidal Statistics Predicted at Machias Port NOAA Subordinate Station

Station	Tidal Statistics (Elevations in feet)						
	MHHW	**MHW**	**NAVD88**	**MTL**	**MSL**	**MLW**	**MLLW**
Machias Port	6.45	6.11	0’	-0.21	-0.16’	-6.55	-6.85

Because the recorded data provided similar statistics to the NOAA station data at Cutler and Machiasport, the tidal data obtained by MaineDOT was used for stage boundary conditions at the downstream (seaward end) of the project for model runs where high upland flows were combined with normal tides, and where storm surge was added to typical tides.

2.3.2.2 Storm Surge Boundary Condition

A boundary condition representative of a Category 1 hurricane (approximately equivalent to a 50-year storm surge) is required for tidal bridge design and was developed for this study.

For the downstream storm surge boundary condition, an unsteady flow hydrograph representing a 50-year storm surge event was developed by combining typical tide data with predicted surge at Machias.

2.3.2.2.1 Daily Tide

Measured tide data in the Machias River immediately seaward from Dyke Bridge was obtained by MaineDOT from July 2011 through October of 2011. These data are in good agreement with predicted tide data from the referenced seaward locations, and were combined with a storm surge hydrograph to create a synthetic storm surge tide at the project site. Data from September 21 to 25, 2011 was used as a representative set of typical tide data. High tides ranged to a high of 7.3 ft and a low of -6.9 ft, and are in good agreement with the statistical MHHW and MLLW values of 7.4 ft and --6.8 ft computed for the data set (Table 2).

2.3.2.2.2 Storm Surge

The Maine coast experiences storm surge due to hurricanes and Nor'easter storms. MaineDOT recommends using a category 1 hurricane wind field to estimate a storm surge for a 50-year (2-percent annual return-interval) surge. This analysis is based on Phase III of Development of Hydraulic Computer Models to Analyze Tidal and Coastal Storm Hydraulic Conditions at Hydraulic Structures and two appendices – A: National Oceanic and Atmospheric Administration (NOAA) Predictions of Hurricane Properties and B- ADCIRC Station Results (Phase III Report). For this project, MaineDOT provided a spreadsheet for converting peak surge levels to a hurricane-type surge hydrograph.

ADCIRC predicted surge levels for Machias Bay as follows:

- 50-year surge: 2.16 ft. Hydrograph duration 15 hours
- 100-year surge: 2.79 ft. Hydrograph duration 15 hours

Section 2.1 of the Phase III Report predicts a maximum surge of 2.5 ft. This is based on a Radius of Maximum Winds of 51 nm and forward speed of 54 knots for 95% of storms in Downeast Maine. With a D value of 0.94, a resulting maximum surge level of 2.5 is calculated.

The maximum recorded surge at Cutler is 2.466 ft with a surge duration of 17 hours. The maximum recorded surge at Eastport is 2.523 ft.

2.3.2.2.3 Combined Peak Surge Plus Tide Data

The following list summarizes available information on storm tides, combined surge statistics (typical tide plus surge), and recorded high tide events at locations near the project area (Table 5).

- USACE 2012 Tidal Flood Profiles.
  - Eastport: 50-year 14.3 ft NAVD88
  - Machias Port: 50-year (Eastport multiplied by 0.69) 9.9 ft NAVD88
  - Cutler: 50-year 10.8 ft NAVD88
- FEMA Flood Insurance Study of Machias.
  - 100-year: 11.8 ft NAVD88
  - 100-year map, 1988, 12.5 ft NGVD29[1], 11.8 ft NAVD88
  - Based on outdated USACE Tidal Flood Profiles
- USACE Tidal Flood Profiles 2012 at Cutler:
  - 50-year 10.5 ft NAVD88
  - 100-year 10.8 ft NAVD88

Table 5: Recorded Highest Tides at Cutler NOAA Gage and Machias (Data from MaineDOT)

Date	Machias	Cutler
9/28/2011	9.55	9.9
9/29/2011	9.71	10.14
10/28/2011		10.7

[1] National Geodetic Vertical Datum of 1929

3.0 HEC-RAS HYDRAULIC MODEL

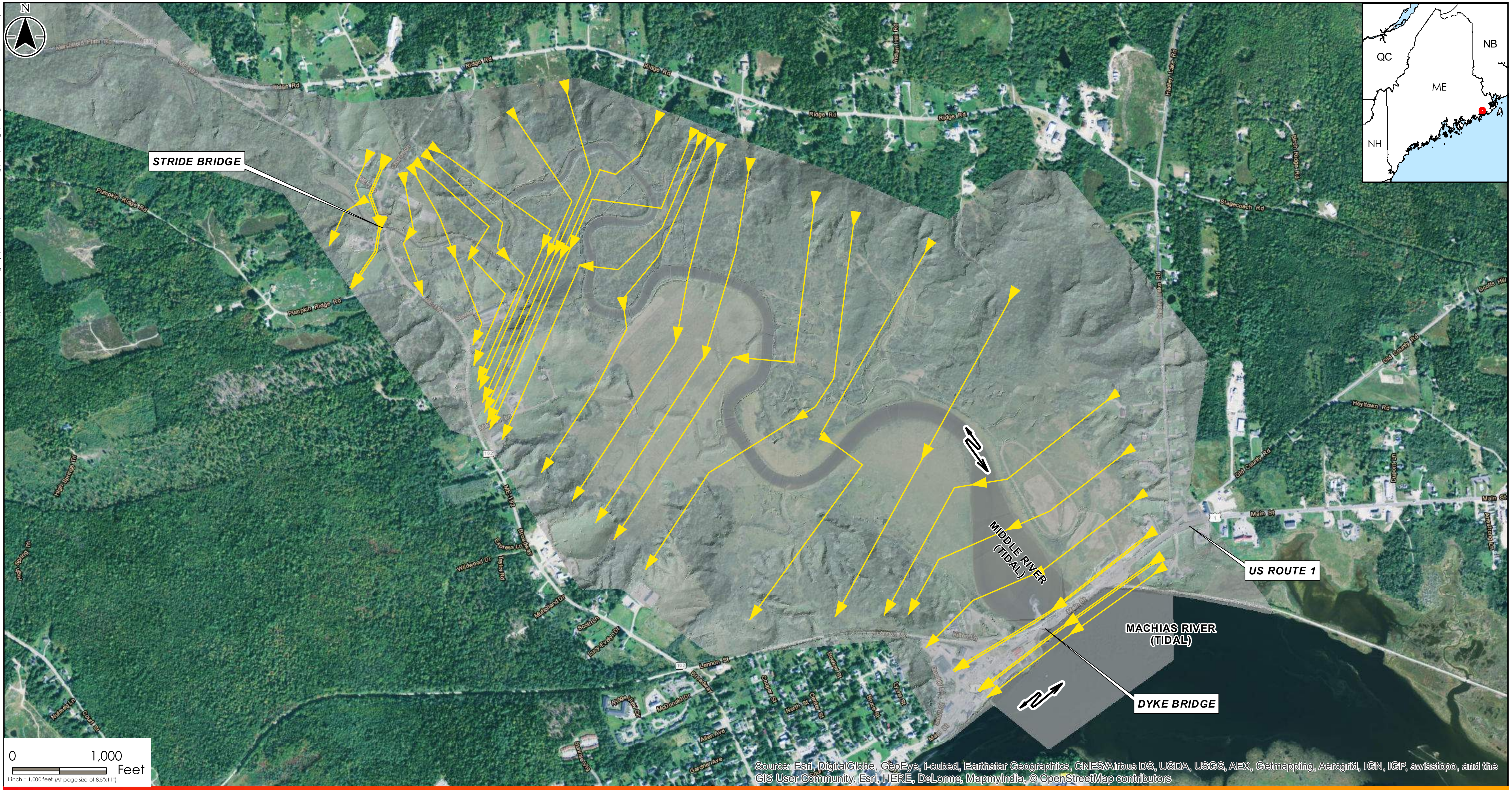
A one-dimensional, unsteady-state numerical hydraulic model was developed using the USACE HEC-RAS (versions 4.1 and 5.0 [beta]). HEC-RAS version 5.0 (beta) was used for project work beginning in April of 2015 at the suggestion of MaineDOT as this version of HEC-RAS includes automated routines for modeling flap gates. The hydraulic model was developed using information obtained from MaineDOT and other sources.

3.1 GEOMETRIC DATA

Geometric data for the revised HEC-RAS model was developed using topographic data provided by MaineDOT along with a limited number of bathymetric transects surveyed by MaineDOT. The layout of the HEC-RAS model domain is depicted in Figure 6, and Figure 7 depicts the geometric domain with color shading and the existing area that is normally wetted based on interpretation of aerial photography.

The HEC-RAS model domain was developed using the HEC-GeoRAS Geographic Information System (GIS) extension in ESRI ARC GIS software. The basis for this model was Lidar data provided by MaineDOT, which is depicted as the gray-shaded area in Figure 6. The Lidar data did not provide elevation coverage in persistently wetted areas landward (upstream) from Dyke Bridge. Bathymetric transects obtained by MaineDOT were therefore used to augment the Lidar data.

The GIS model was also used to develop an area-elevation dataset for the reach of the Middle River between Stride Bridge and Dyke Bridge. This curve is provided in Appendix B.



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Reviewed by MRC on 2015-02-23

00963_DykeBridge11x17.mxd

Legend

- Cross Sections
- Maine DOT TIN Surface
- Dominant Upland Flow

Notes

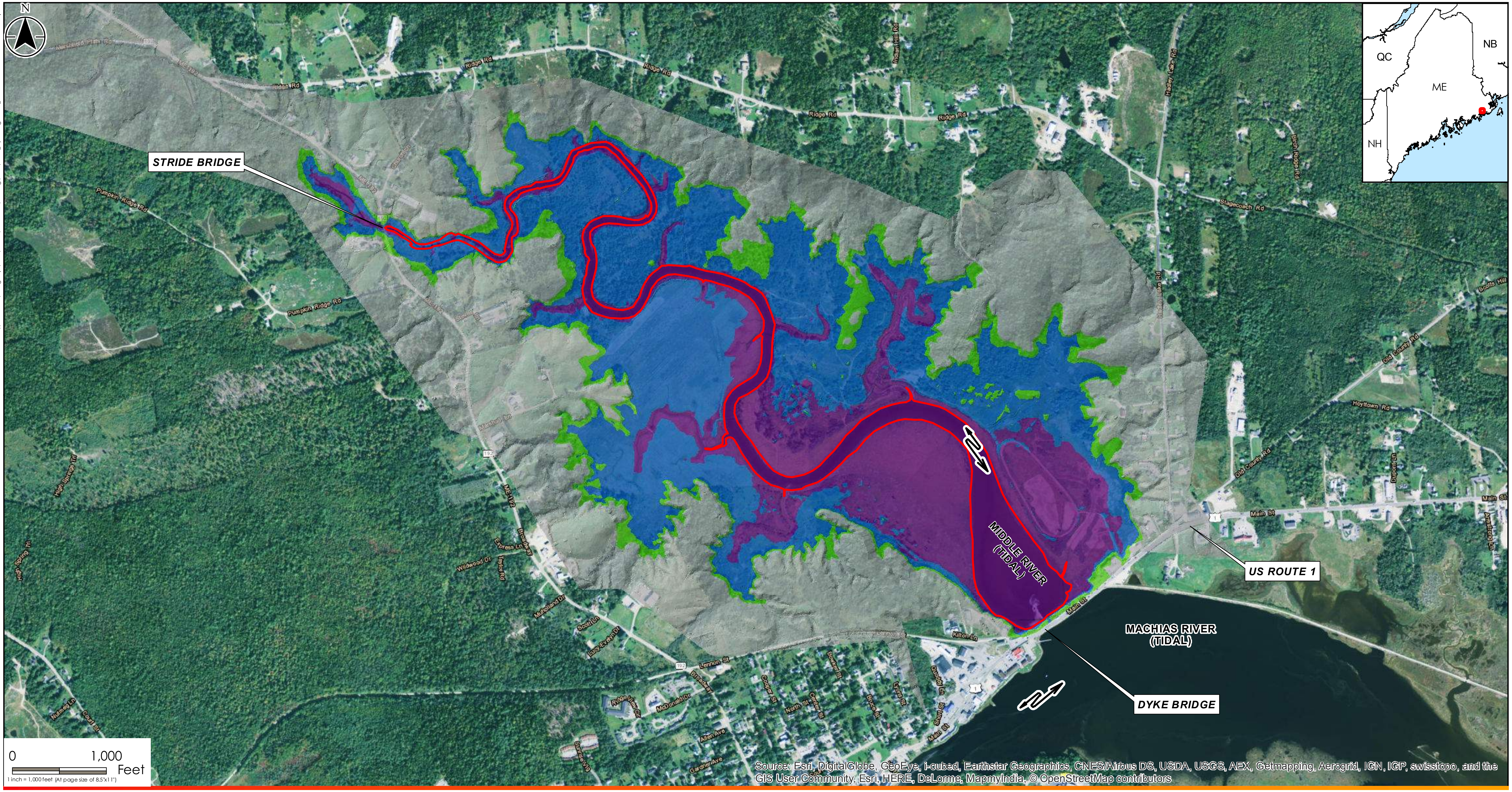
1. Coordinate System: NAD 1983 UTM Zone 19N FT
2. Aerial imagery provided by ArcGIS Online World Imagery Mapping Service (http://server.arcgisonline.com/arcgis/services/World_Imagery/MapServer).
3. TIN Surface information is based on survey data provided by the Maine Department of Transporation.

Client/Project
Maine DOT
Dyke Bridge
Machias, Maine

Figure No.
6

Title
HEC-RAS Model Domain

7/1/2015



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Reviewed by MRC on 2015-02-23

00963_DykeBridge11x17_elev.mxd

Legend

Water Surface Elevation (ft)

- < 4
- 4 - 8
- 8 - 12
- >12
- Inundated Area
- Dominant Upland Flow

Notes

1. Coordinate System: NAD 1983 UTM Zone 19N FT
2. Vertical Datum: NAVD88
3. Aerial imagery provided by ArcGIS Online World Imagery Mapping Service (http://server.arcgisonline.com/arcgis/services/World_Imagery/MapServer).
4. TIN Surface information is based on survey data provided by the Maine Department of Transporation.

Client/Project
Maine DOT
Dyke Bridge
Machias, Maine

Figure No.
7

Title
Elevation Map

7/1/2015

3.2 BOUNDARY CONDITIONS

The following combinations of upland flow and tidal stage were selected for the hydraulic model at Dyke Bridge and Stride Bridge.

- Typical tides with 1.1-year river flow, upland flow modeled as steady state flow.
- Typical tides with 50-year river return-interval flow with the riverine flow hydrograph modeled as triangular hydrograph with 12 hour time to peak.
- Typical tides with 100-year return-interval flow with the riverine flow hydrograph modeled as triangular hydrograph with 12 hour time to peak.
- 50-year storm surge with 1.1 year river flow.
- Surge to be superimposed at mid-rising, high tide, mid-falling and low tides.

3.2.1 Middle River (Upland Flow)

Riverine peak flows in the Middle River were provided by MaineDOT and are included in Table 6. For this project, and to simplify boundary conditions, only the flows predicted for Dyke Bridge were used in the model, but were used as the boundary condition at the upstream end of the model upstream from Stride Bridge. This assumption and development and use of suitable upland flow hydrographs should be incorporated into final design analyses.

Table 6: Riverine Peak Flows in Middle River

Location	1.1-Year Return-Interval (cfs)	50- Year Return-Interval (cfs)	100- Year Return-Interval (cfs)
Stride Bridge	130	787	912
Dyke Bridge	152	832	958

3.2.2 Tidal Stage

3.2.2.1 Typical Tides

Typical ("everyday") tide hydrographs are based on data recorded by MaineDOT from July 2011 to October of 2011 in the Machias River immediately seaward from Dyke Bridge. The data show a highest recorded tide elevation of 9.7 ft on September 29, 2011. At that time, the Cutler gage recorded an elevation of 10.1 ft.

Table 7: Summary of Tide Stage Information

Tide Stage/Date	Recorded at Machias (ft, NAVD88)	Cutler gage (ft, NAVD88)
MHHW	7.4	6.8
MHW	6.5	6.4
MLW	-6.5	-6.4
MLLW	-6.8	-6.8
lowest	-7.5	not applicable
9/24/2011	7.4	7.3
9/28/2011	9.55	9.9
9/29/2011	9.71	10.14
10/28/2011		10.7

3.2.2.2 Combinations of Riverine Peak Flows and Typical Tides

Riverine peak flows were combined with typical high tides as recorded in the MaineDOT data. An example of this combination is in HEC-RAS Plan No. 24, which models the existing culverts at Dyke Bridge and Stride Bridge, and imposes a 50-year peak flow hydrograph on a high tide. The 50-year return-interval hydrograph peak flow of 832 cfs passes Stride Bridge at 12:35 on 14 July, 2011. Corresponding water levels at Dyke Bridge are presented in Table 8.

Table 8: Combinations of Peak Upland Flows and Typical Tides at Dyke Bridge

Date and Time	High Water Level (ft, NAVD88)	50- Year Return-Interval Peak Flow (cfs)
July 14, 2011 at 22:25	8.4	832
July 14, 2011 at 10:35	7.0	832
July 14, 2011 at 23:05	8.8	832

Tidal and upland flow hydrographs were combined with that same timing. This combination should be reviewed for final design.

3.2.2.3 Combination of 1.1-year Riverine Peak Flow with Storm Surge Tides

For this study, the MHHW value for the MaineDOT recorded normal tide data downstream of Dyke Bridge was combined with a peak surge of 2.5 ft, with the following high and low values associated with timing of peak surge and tides. These tidal conditions were modeled with the 1.1-year return-interval peak flow (152 cfs) as the inflow (upstream) boundary condition. A precise recurrence interval has not been assigned to this surge level, but the difference between a 50-year and 100-year surge in this area is a few tenths of a foot. Based on data outlined in

Section 2.3.2.2.3, this tidal peak elevation should be reviewed for final design. The data suggests a value between 9.8 ft and 10.8 ft when the peak surge coincides with the peak high tide.

Table 9: Combinations of Upland Flow with Storm Surge Tides

Timing of Peak Surge	High Water Level (ft, NAVD88)	Low Water Level Before Peak Surge (ft, NAVD88)
Mid-Rising	8.0	-7.0
High Tide	9.8	-7.0
Mid-Falling	8.0	-7.0
Low-Tide	7.8	-7.0

4.0 MODEL BOUNDARY CONDITIONS

This section presents boundary condition scenarios requested by MaineDOT for evaluation with the study hydraulic model.

4.1 STEADY-STATE BOUNDARY CONDITIONS

Steady-state boundary conditions were modeled with specified inflow (upstream) boundary conditions and specified water surface elevations at the downstream (seaward) boundary condition. Steady-state boundary conditions are presented in Table 10.

Table 10: Steady-State Boundary Conditions

Case	Upland Runoff (Return-Interval Event)	Downstream (fixed stage)	Comments
Case 1	50-Year	MHW	-Gates assumed fully open. (4 ft height). Upstream elevation would be 9.9 ft. Upstream of Stride Bridge, the modeled elevation is 11.0 ft.
Case 2	50-Year	MLW	The applied water surface elevation for MLW is expected to result in very high calculated flow speeds for the span bridge alternatives at Dyke Bridge because the upstream channel elevation is well above the MLW elevation. Upstream of Dyke Bridge, water surface elevation would be 1.4 ft and 7.3 ft upstream of Stride Bridge.

Based on review of information, including the area-elevation curve that was developed as part of this project for the reach of the Middle River between Stride Bridge and Dyke Bridge and the HEC-RAS model results, it was determined that steady-state hydraulic analyses are of little practical utility for this study. The basis for this determination is that there is substantial hydrologic storage in the reach of the Middle River between the two project bridges relative to the volume of upland runoff hydrographs in the Middle River. This finding was validated as part of this study by 1) steady-state model simulations that depict overtopping of Dyke Bridge during moderate upland runoff flow events that predict overtopping of Dyke Bridge, and 2) unsteady-state model simulations with upland runoff hydrographs that do not result in overtopping of Dyke Bridge. The question of whether Dyke Bridge has been overtopped was discussed with MaineDOT during project meetings, and MaineDOT indicated that they are not aware of upland runoff events having resulted in overtopping of Dyke Bridge.

4.2 UNSTEADY-STATE BOUNDARY CONDITIONS

Unsteady-state boundary conditions were used for hydraulic model evaluations using the project HEC-RAS model. Unsteady-state boundary conditions are presented in Table 11. As noted in Section 4.1, trial runs using upland peak flows as a steady state input resulted in unrealistically high water surface elevations that do not account for storage along the reach of the Middle River between the two bridges. For this reason, upland flows were modeled as triangular hydrographs that were developed based on professional judgment.

Table 11: Unsteady-State Boundary Conditions

Case	Upland Runoff (Return-Interval Event)	Tidal Regime	Comments
Q1T1	1.1-Year-steady flow	Recorded Tides +9.0/-7.5	
Q50T1	50-Year-Hydrograph, peak = 824 cfs	Recorded Tides	Peak upland flow occurs at tides in range of 7.0 ft to 8.8 ft.
Q100T1	100-Year-Hydrograph = 958 cfs	Recorded Tides	Peak upland flow occurs at tides in range of 7.0 ft to 8.8 ft.
Q1T50M	1.1-Year	Category 1 Hurricane (2.5 ft peak)_ +9.8 ft /-6.9 ft	Peak of storm surge at mid-rising tide (8.0 ft)
Q1T50H	1.1-Year	Category 1 Hurricane (2.5 ft peak)	Peak of storm surge at high tide (9.8 ft)
Q1T50M	1.1-Year	Category 1 Hurricane – (2.5 ft peak)	Peak of storm surge at mid-falling tide (8.0 ft)
Q1T50L	1.1-Year	Category 1 Hurricane – (2.5 ft peak)	Peak of storm surge at low tide (7.8 ft)

4.3 SEA-LEVEL RISE SCENARIOS

Three sea-level rise (SLR) scenarios were evaluated for selected model simulations, including:

1) Current MHHW conditions;
2) Design Year (current) MHHW with Moderate (0.5 meter [1.64 ft]) SLR; and
3) Design Year (current) MHHW with High (1.0 meter [3.28 ft]) SLR.

5.0 PRELIMINARY EVALUATIONS – TYPICAL TIDES

This section presents information on the evaluation of project alternatives with typical tides and low streamflows in the Middle River as represented by tidal stage data collected by MaineDOT and a flow of 20 cfs in the Middle River, respectively.

5.1 EXISTING CONDITIONS AND REPLACEMENT IN-KIND

Hydraulic conditions at Dyke Bridge were evaluated for existing conditions (Alternative 1) and for replacement in-kind (Alternative 2). The objectives of these evaluations included:

1) Calibration and validation of the hydraulic model for existing conditions; and
2) Evaluation of replacement in-kind (i.e., with four 5 ft by 5 ft flap gates).

These evaluations were performed using tidal stage data collected by MaineDOT and an assumed normal upland flow in the Middle River of 20 cfs.

5.1.1 Alternative 1 - Existing Conditions

Existing conditions at Dyke Bridge were modeled in HEC-RAS using gates and operational rules. The use of gates and operational rules precludes modeling of culverts in combination with gates in HEC-RAS. The modeled approach therefore does not include effects of flow through culverts and gates; it solely evaluates hydraulic parameters (e.g., conveyance, losses) at the gate. This approach is analogous to flow through on overly-large culvert (i.e., losses are minimal and can be discounted) with a controlled gate at one end. This approach was used early in the project because HEC-RAS 4.1 did not include an option for modeling flap gates (Plan No. 87).

The existing Dyke Bridge culverts include four 5 ft by 5 ft wood and masonry box culverts with flap gates. Based on review of survey data provided by MaineDOT, including elevations of the culvert inverts and tidal stage data collected landward and seaward from Dyke Bridge, and preliminary model simulation, the existing culverts were modeled with heights of 4 ft and minimum gate openings of 0.35 ft. The reduced gate heights were used to address apparent blockage in the bottoms of the culverts as determined from bridge inspection reports provided by MaineDOT. The minimum gate opening was used to provide for landward flow during flood tides, which is apparent in visual observations and tidal stage data collected by MaineDOT in the Middle River landward from Dyke Bridge. The culverts and flap gates were modeled as sluice gates in HEC-RAS using operational rules programmed in the HEC-RAS unsteady-flow rules editor.

5.1.1.1 Existing Conditions Without Gate Operations

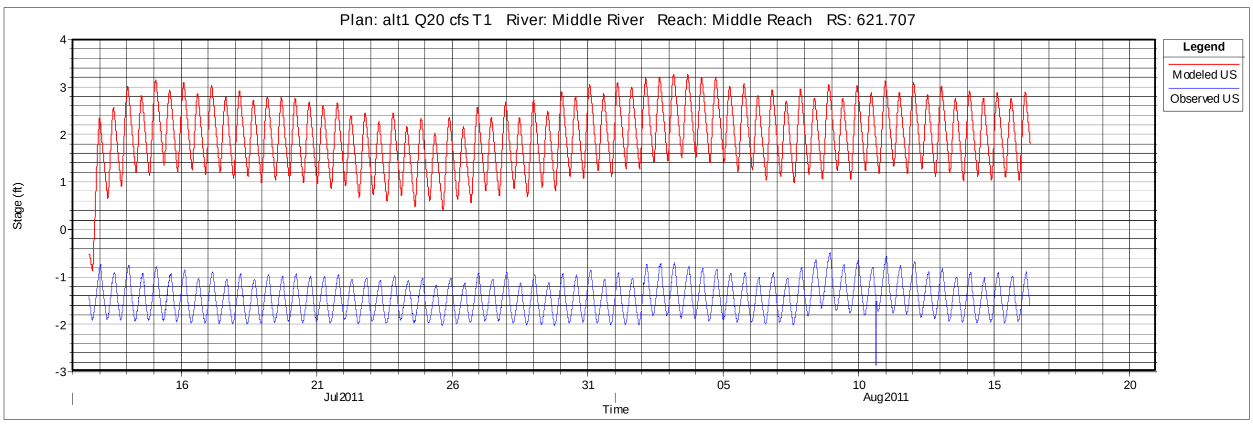
Existing conditions were initially evaluated without operational rules and the four gates set in the "open" position. Under this condition, the equilibrium water level in the landward reach of the

Middle River is simulated as the approximate average of the high and low water conditions (Plan No. 86).

This simulation reflects conditions that would result from removal or failure of the tide gates. Results of this simulation, including measured ("Observed US[2]") and simulated ("Modeled US") water surface elevations in the Middle River landward from Dyke Bridge, are depicted in Figure 8. It is apparent in this figure that removal or failure of the tide gates would increase in daily water surface elevations by up to 5 ft in the Middle River upstream from Dyke Bridge during typical tides with an upland flow in the Middle River of 20 cfs. The increase in water surface elevations by 5 ft reflects the difference between the maximum elevation of typical tides (elevation -1 ft) and the predicted maximum elevation of approximately 4 ft for typical tides.

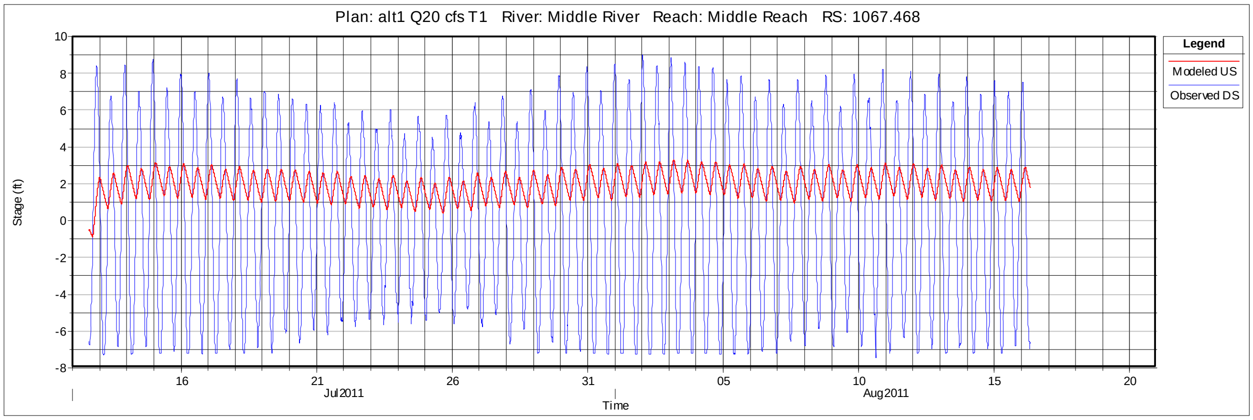
Figure 9 presents the measured tidal stage data seaward from Dyke Bridge ("Observed DS[3]") and the simulated water surface elevations landward from Dyke Bridge ("Modeled US").

Figure 8: Alternative 1 (Existing Conditions) W/O Gate Operations (Measured and Simulated Water Surface Elevation Landward from Dyke Bridge)



[2] "US" is used as an abbreviation for "upstream" (landward) from Dyke Bridge.
[3] "DS" is used as an abbreviation for "downstream" (seaward) from Dyke Bridge.

Figure 9: Alternative 1 (Existing Conditions) W/O Gate Operations (Simulated Landward and Measured Seaward Water Surface Elevations)



5.1.1.2 Existing Conditions With Gate Operations

Existing conditions were simulated using the HEC-RAS unsteady-flow rules option to reflect operation of the existing flapper gates and represents calibration of this model scenario to existing conditions (Plan No. 87). These rules were programmed as internal boundary conditions in HEC-RAS. The programmed rules were set to operate the four existing flap gates according to the same rules. The analysis for existing conditions with gate operations used a minimum gate opening of 0.35 ft to account for leakage through the existing gates and the causeway.

The rules for the existing conditions evaluation are shown in Figure 10. Figure 11 presents the simulated water surface elevations (“Modeled US”) relative to the measured stage (“Observed US”) landward from Dyke Bridge as measured by MaineDOT. The predicted water surface elevations range from approximately -2.0 ft to -0.7 ft for a period of time when data obtained by MaineDOT indicates water surface elevations of approximately -2.0 ft to -0.8 ft.

Table 12 presents invert information for the 4 existing box culverts.

Table 12: Dyke Bridge Culvert Box Inverts

Location	Culvert	DS Invert	DS (Prev)	US (Prev)
east	Culvert #1	-4.0	-0.38	-3.8
center-east	Culvert #2	-4.0	-4.2	-4.2
center-west	Culvert #3	-4.5	-4.7	-4.7
west	Culvert #4	-3.6	-4.4	-4.4
	average	***-4.1***	***-3.4***	***-4.3***

Following review of the tidal stage data collected by MaineDOT and the reported invert elevations, it is apparent that debris likely limits outflow from the landward reach of the Middle

River. To accommodate debris, the modeled invert for existing conditions was set at an elevation of -3.1 ft, which is approximately 1 ft higher than the average invert elevation of the four culverts. The culvert height was reduced to 4 ft for this analysis to accommodate the apparent partial occlusion in the culverts.

Figure 10: Existing Conditions Rules

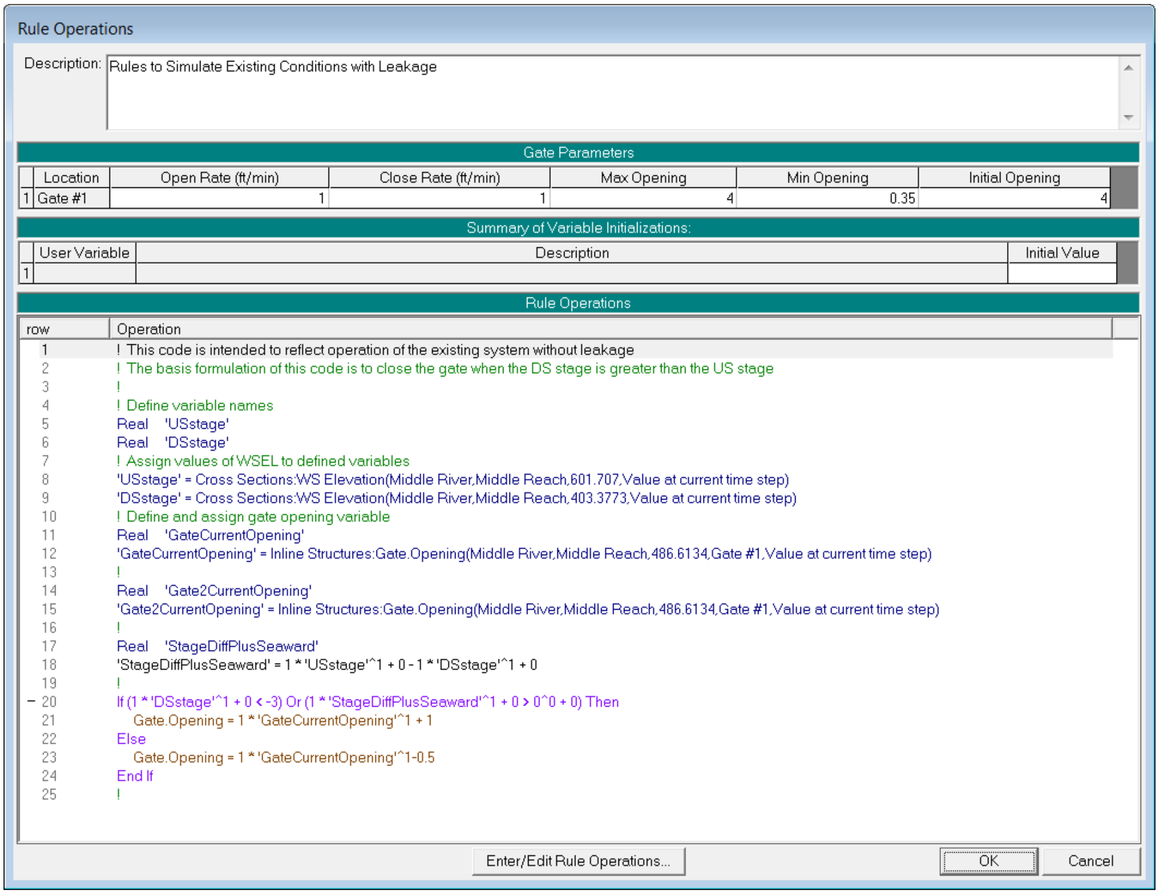
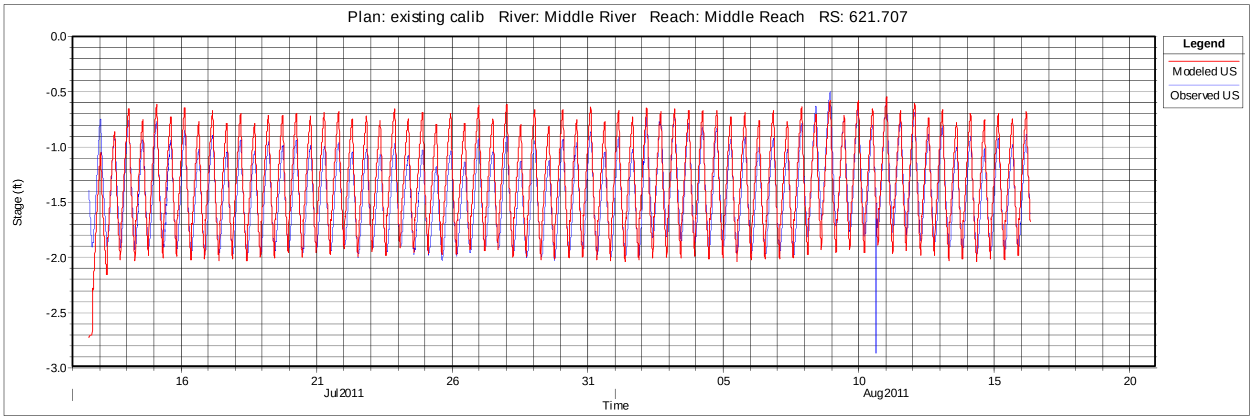


Figure 11: Alternative 1 (Existing Conditions) with Gate Operations (Simulated and Observed)



5.1.2 Alternative 2 – Replacement In-Kind

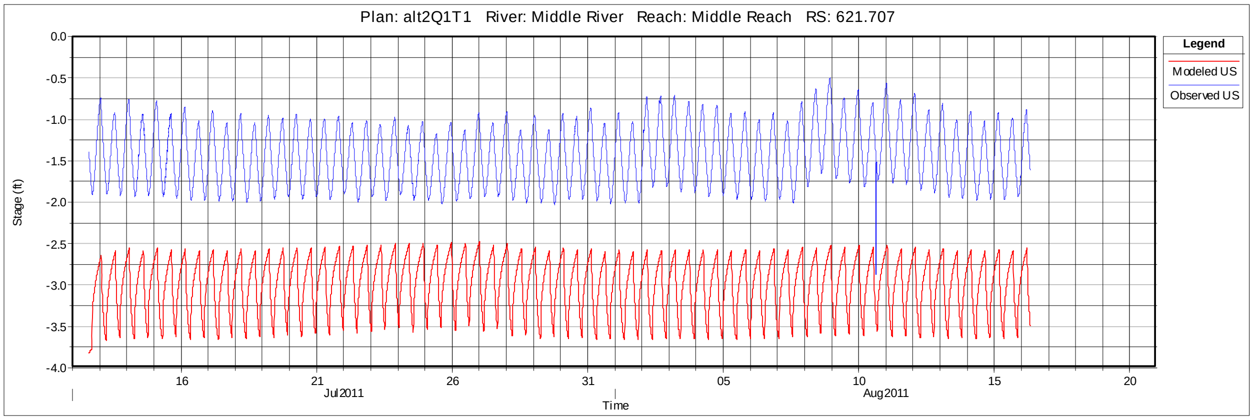
Replacement in-kind with flap gates on four culverts was evaluated along with variations of replacement in-kind that evaluated eliminating flap gates on some of the culverts.

5.1.2.1 Replacement In-Kind (Plan No. 13[4])

Alternative 2 reflects in-kind replacement of the existing culvert and gate system. The model setup for this alternative did not include a minimum gate setting to account for leakage through the gates or the causeway. A pronounced effect of this simulation results from the lack of landward tidal flow, which results in very small semi-diurnal variation in stage that results from riverine inflows into the "impoundment" when the tide gates are "closed." These conditions were simulated with upland flow of 20 cfs and typical tides represented using tidal stage data collected by MaineDOT seaward from Dyke Bridge in the Machias River.

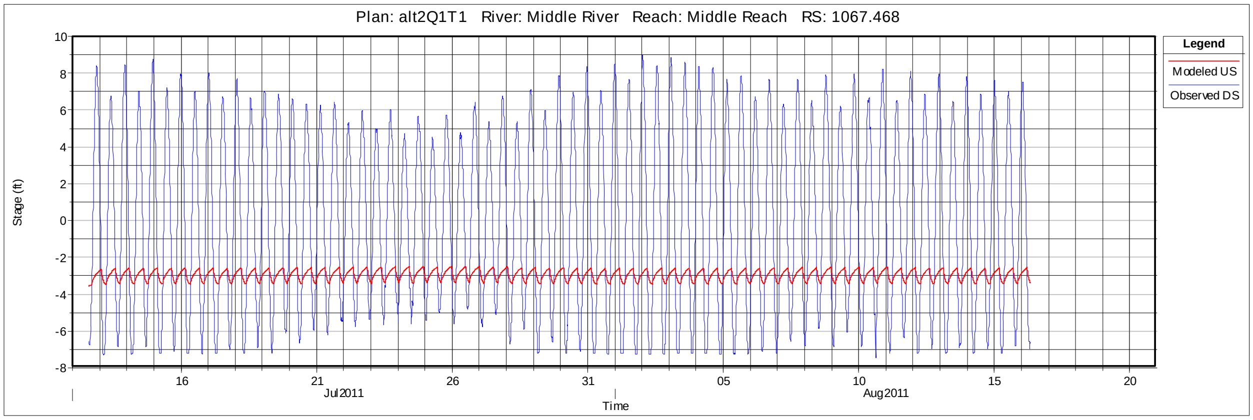
[4] This HEC-RAS model simulation was performed using Plan No. 13, which is setup to model the 1.1-year, return-interval flow with the inflow boundary condition changed from 151.6 cfs to 20 cfs for this simulation only.

Figure 12: Alternative 2 (Replacement In-Kind) (Simulated [Landward] and Observed [Landward])



Modeling of this alternative was performed using the invert elevations provided by MaineDOT with gate heights of 5 ft. For the MaineDOT recorded tide data, downstream of Dyke Bridge elevations vary from 9.0 ft to -7.5 ft. Upstream of Dyke Bridge, the simulated tidal elevations in the Middle River landward from Dyke Bridge range from -3.3 ft to -2.5 ft. The lower water surface elevations immediately landward from Dyke Bridge eliminate tidally-influenced changes in water surface elevations at Stride Bridge.

Figure 13: Alternative 2 (Replacement In-Kind) (Simulated and Observed, Landward and Seaward)



5.1.3 Replacement In-Kind With Variations for Flap Gate Operations

Replacement in-kind with variations for operations of flap gates were evaluated as a means to provide for improved upstream fish passage at Dyke Bridge. The objective of the modeled variations on Alternative 2 is to evaluate the potential to provide for landward flow at Dyke Bridge during the flood tide through culverts without gates. The modeled Alternative 2 variations include:

a. Five 5 ft x 5 ft culverts with flap gates on four of the culverts (Plan No. 82). Results of this simulation that include the observed upstream tide data are presented in Figure 14;

b. Four 5 ft x 5 ft culverts with flap gates on three of the culverts (Plan No. 83). Results of this simulation that include the observed upstream tide data are presented in Figure 15; and

c. Four 5 ft x 5 ft culverts with flap gates on two of the culverts (Plan No. 27). Results of this simulation that include the observed upstream tide data are presented in Figure 16.

Summary tables with the results of these simulations are included in Section 6.0.

The model simulation results with five box culverts with four flap gates (Figure 14) and four box culverts with three flap gates (Figure 15) are similar, and would result in maximum typical water surface elevations landward from Dyke Bridge that are approximately 1.5 ft to 2 ft higher (typical high tide elevations are approximately 0.5 ft and 1 ft, respectively) than current conditions (existing typical high tide elevation is approximately -1 ft). The low tide simulation results indicate that the alternative with five box culverts would result in low tide water surface elevations that are similar to existing conditions, whereas the simulation results with four box culverts indicate that low tide water surface elevations would be approximately 1 ft higher. The lower low tide elevations result from the increased capacity of the five culverts to discharge flow seaward during the ebb tide relative to the capacity of the single open culvert to provide for landward flow. A criteria for evaluating these alternatives is the ratio of culverts with landward conveyance and seaward conveyance, which is 0.2 for the alternative with five box culverts and four flap gates and 0.25 for the alternative with four box culverts and three flap gates.

The model simulation results with four box culverts and two flap gates (Figure 16), and has a ratio of culverts with landward conveyance and seaward conveyance of 0.5. The maximum typical high tide elevations for this alternative are approximately 3 ft higher (typical high tide elevation is approximately 2 ft) than existing conditions (existing typical high tide elevation is approximately -1 ft) and the low tide elevations are marginally higher than the maximum typical high tide elevations.

Figure 17 depicts approximate contour lines and shading associated with the maximum typical tidal water surface elevations in the Middle River landward from Dyke Bridge for these three variations of Alternative 2, including contour lines at elevations of 1 ft and 2 ft and a change in shading at an elevation of 4 ft. For reference, this figure also includes the area that is currently wetted during typical tidal conditions (approximate elevation of -1 ft). Note that the terrain data used to develop this figure (Lidar data provided by MaineDOT) did not include bathymetric data, and contour lines that extend across the channel of the Middle River are not accurate.

Figure 14: Five 5 ft x 5 ft Culverts with Flap Gates on Four Culverts (One Open)

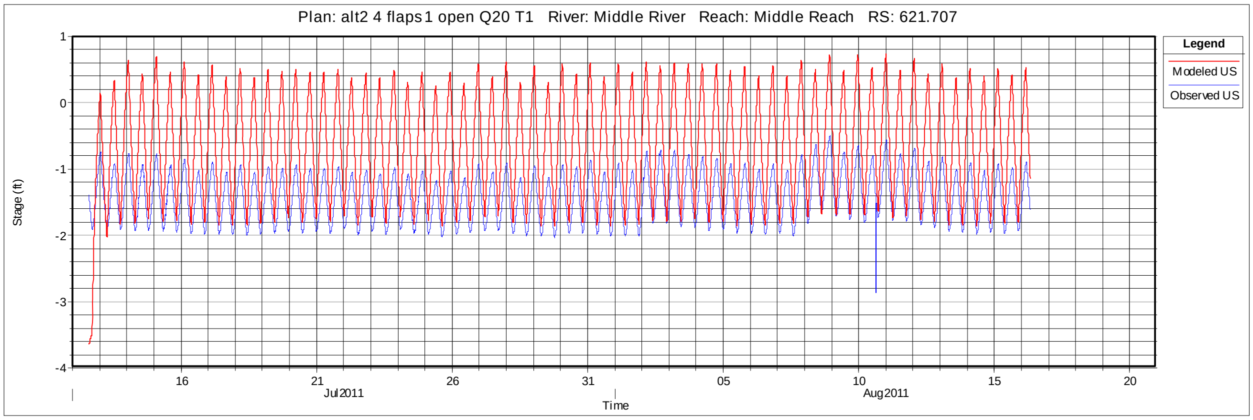


Figure 15: Four 5 ft x 5 ft Culverts with Flap Gates on Three Culverts (One Open)

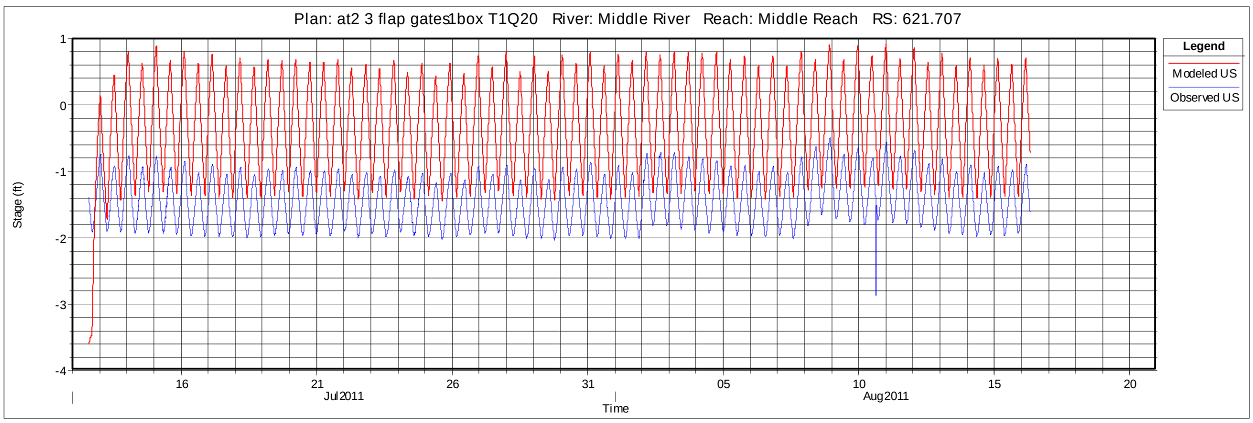
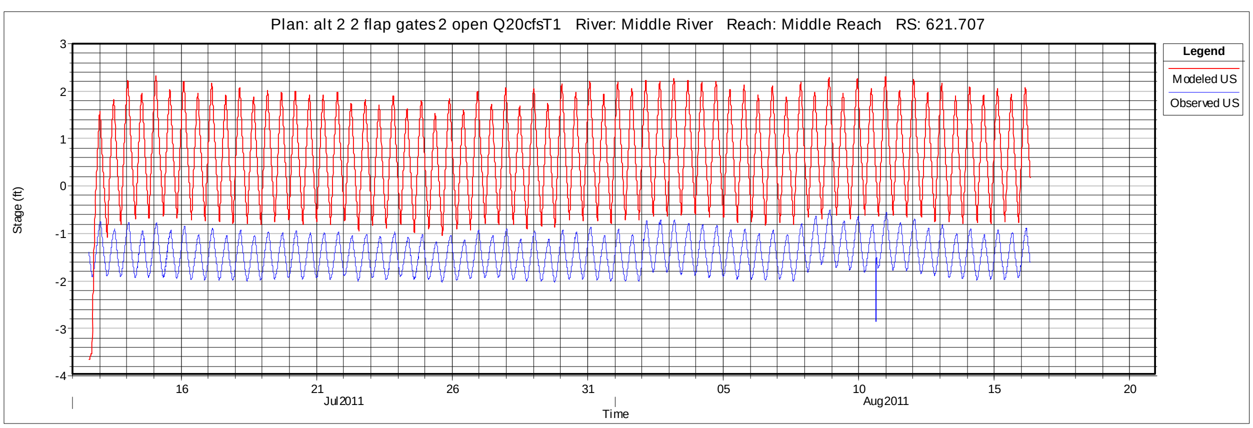
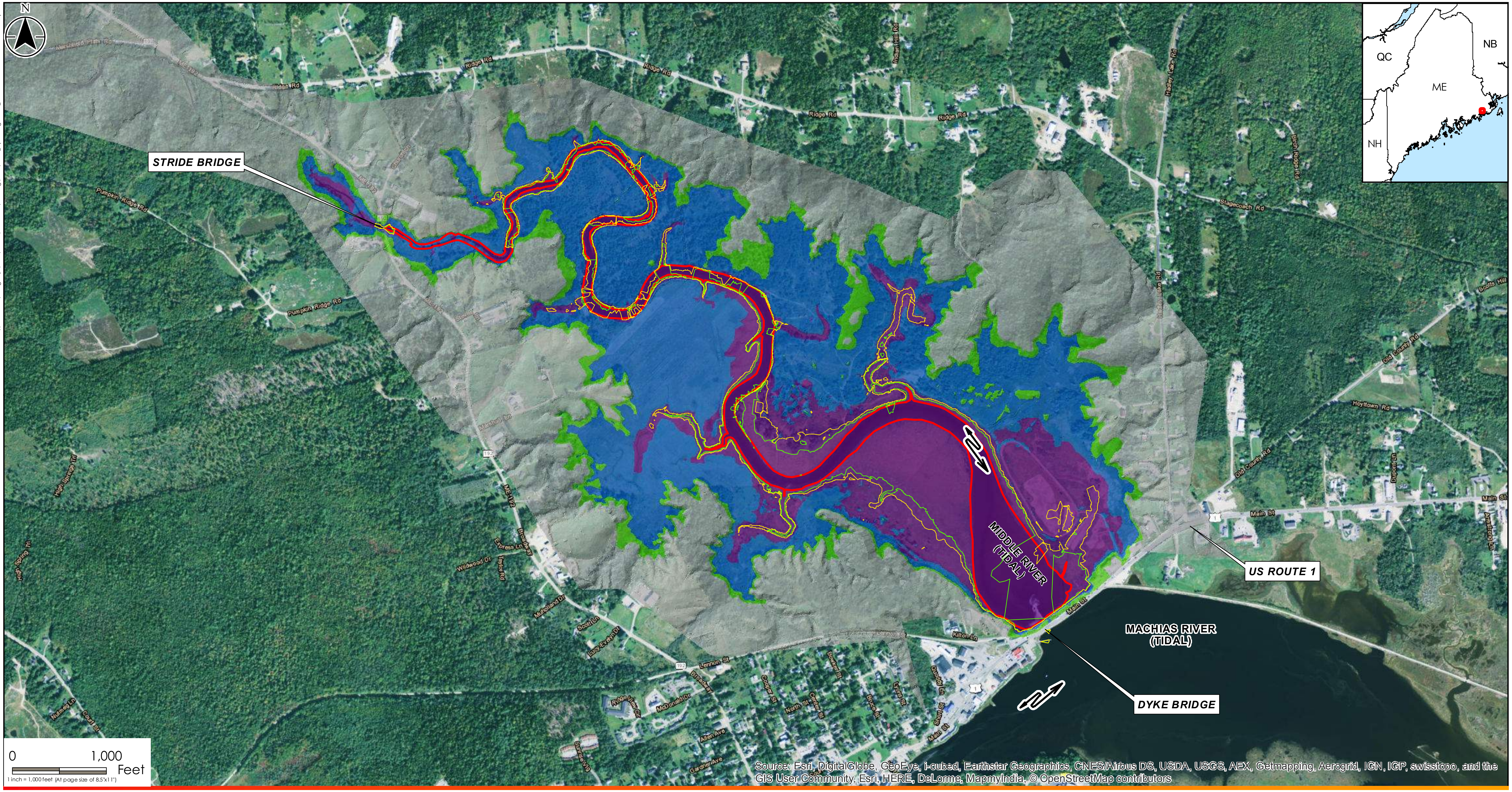


Figure 16: Four 5 ft x 5 ft Culverts with Flap Gates on Two the Culverts (Two Open)





195600963

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Prepared by EPL on 2015-02-23
Reviewed by MRC on 2015-02-23

00963_DykeBridge11x17_cont.mxd

Legend

Water Surface Elevation (ft)

- < 4
- 4 - 8
- 8 - 12
- >12
- Dominant Upland Flow
- Inundated Area
- 1' Contour
- 2' Contour

Notes

1. Coordinate System: NAD 1983 UTM Zone 19N FT
2. Vertical Datum: NAVD88
3. Aerial imagery provided by ArcGIS Online World Imagery Mapping Service (http://server.arcgisonline.com/arcgis/services/World_Imagery/MapServer).
4. TIN Surface information is based on survey data provided by the Maine Department of Transporation.

Client/Project
Maine DOT
Dyke Bridge
Machias, Maine

Figure No.
17

Title
Contour Map

7/1/2015

5.2 SELF-REGULATING TIDE GATES

This section presents information on potential alternatives with self-regulating tide gates (SRTs).

5.2.1 Alternative 3 – SRT without Fish Passage

Alternative 3 reflects SRTs without provisions for upstream fish passage. This alternative could be implemented with a single large SRT or with multiple smaller SRTs. This alternative was not evaluated with the hydraulic model following review of SRT technologies as part of this alternative (reference Appendix C).

5.2.2 Alternative 4 – SRT with Fish Passage

Alternative 4 reflects SRTs with provisions for upstream fish passage. This alternative could be implemented with a single large SRT that would be operated to allow for upstream fish passage, multiple smaller SRTs that could be operated individually or collectively to provide for upstream fish passage, or single or multiple SRTs along with an ungated (free-flowing) culvert that would be intended to provide for upstream fish passage. This alternative was not evaluated with the hydraulic model following review of SRT technologies as part of this alternative (reference Appendix C).

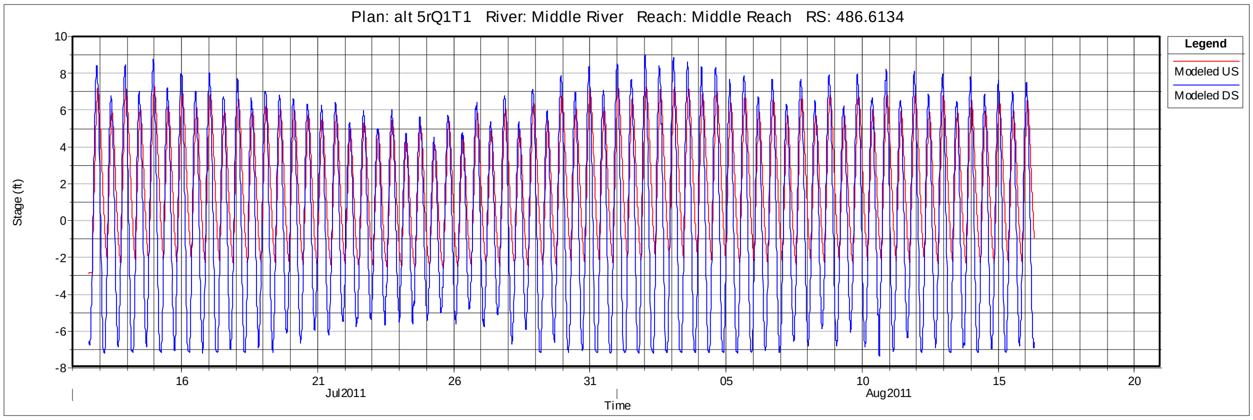
5.3 FREE-FLOWING ALTERNATIVES

This section presents alternatives that are intended to provide for restoration of tidal flow in the Middle River landward from Dyke Bridge to within 3 to 6 inches of conditions in the Machias River immediately seaward from Dyke Bridge.

5.3.1 Alternative 5 – Multiple Adjacent Culverts

Multiple geometries were evaluated for Alternative 5, which reflects multiple adjacent culverts that are intended to provide for tidal restoration. Model simulations were performed for an alternative comprised of five 12 ft (height) by 15 ft (width) box culverts with the inverts set at an elevation of -4.0 ft. Simulated water surface elevations (Figure 18) seaward ("Modeled DS") and landward ("Modeled US") from Dyke Bridge for this geometry and the 1.1-year return-interval upland flow simulations indicate that multiple adjacent culverts would not restore tidal stages to within 3 inches to 6 inches landward from Dyke Bridge. (Plan No. 17)

Figure 18: Alternative 5 – (4) 12' (h) x 15' (w) Box Culverts

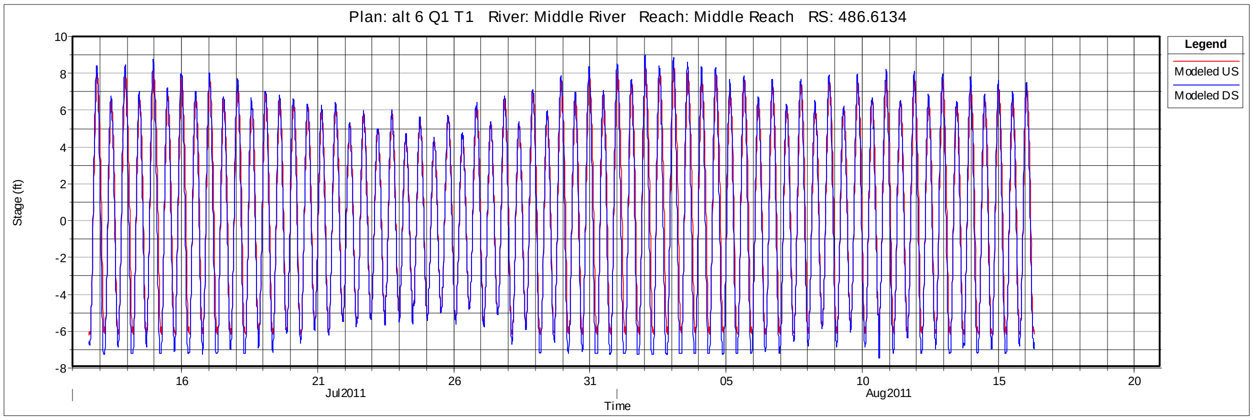


5.3.2 Alternative 6 – Span Bridge

Alternative 6 reflects a span bridge intended to provide for tidal restoration. This alternative was the first of the "free-flowing" alternatives to be evaluated as this alternative provides a means to bound the other free-flowing alternatives (Alternatives 5 and 7).

Based on the preliminary simulation results, a traditional span bridge would require a minimum span of 60 ft with vertical abutments to achieve close to the objectives of this alternative (Figure 19 - 1.1-year flow and tide is simulated in Plan No. 20 for this alternative). Based on the model results, a single-span bridge with a clear span of 60 ft would provide for landward tidal water surface elevations within 0.5 of the seaward tidal stage except during higher high tides, during which the landward tidal stage would be up to 1 ft below the seaward tidal stage.

Figure 19: Alternative 6 – 60-ft Clear Span Bridge



5.3.3 Alternative 7 – Span Bridge with Culverts

Alternative 7 as requested by MaineDOT reflects a span bridge with adjacent culverts intended to provide for tidal restoration. The suggested basis for this alternative is use of a smaller span (relative to Alternative 6) along with relief culverts in the causeway adjacent to the bridge.

An identified consideration for this alternative is whether to install the relief culvert inverts low enough to remain wetted at low tide or whether to install relief culverts that would convey flow during the peak tidal flow only.

Based on the preliminary model analyses and subsequent discussions with MaineDOT, it was determined that this alternative is not feasible relative to the single span bridge alternative (Alternative 6). This alternative was not modeled.

6.0 HYDRAULIC MODEL EVALUATION RESULTS

This section presents results of the hydraulic model evaluation performed as part of this study.

High upland flows and high tides were modeled for each bridge alternative as described in Section 5.0. Tide and flow combinations are as discussed in Sections 3.0 and 4.0.

Table 13 presents model results for existing conditions (Alternative 1). Table 14 presents model results for Alternative 2 (replacement in-kind with four 5 ft x 5 ft box culverts with flap gates) along with a variation on this alternative that is comprised of five 5 ft x 5 ft box culverts with four culverts have flap gates and one ungated, free-flowing culvert. Table 15 presents a summary of three variations on Alternative 2, including:

1) Five 5 ft x 5 ft culverts with flap gates on four culverts and one free-flow culvert;

2) Four 5 ft x 5 ft culverts with flap gates on three culverts and one free-flow culvert; and

3) Four 5 ft x 5 ft culverts with flap gates on two culverts and two free-flow culverts.

Table 16 presents model results for Alternative 5. This alternative is comprised of five 12 ft (h) x 15 ft (w) box culverts, and evaluated the potential to provide for full tidal restoration using culverts in lieu of a bridge.

Table 17 and Table 18 present model results for Alternative 6, which is represented by a 60-ft, single-span bridge, and include evaluation of higher roadway elevations as part of analyses that evaluated sea-level rise and slip-lining at Stride Bridge.

Table 19 presents a summary of results from the HEC-RAS model evaluations and result. Information on the HEC-RAS model setup, including identification of the HEC-RAS geometry, flow, and plan files, is provided in Appendix D.

Table 13: Summary of Model Results for Alternative 1 - Existing Conditions

Riverine Flow (cfs)	Tides (high/low)	Sea Level Rise (m)	Surge (ft)	Tide + Surge Downstream from Dyke Bridge (ft)	Elevations Upstream from Dyke Bridge (ft)		Peak Elevations at Stride Bridge (ft)	
					High	Low	DS	US
1.1-year	**Recorded**							
152 - steady	+9.0/-7.5	none	none	9.0/-7.5	1	-0.9	1.4	1.8
		0.5 m		10.7/-5.6	1.4	-0.6	1.7	2.1
		1m		12.3/-4.22	4.5		4.6	4.7
50-year	**Recorded**							
824 steady	+9.0/-7.5	none	none	9.0/-7.5	6.7	4.4	6.9	8.3
Hydrograph	+9.0/-7.5	none	none	9.0/-7.5	3.7	-0.1	4.6	7.3
Hydrograph		0.5 m		10.7/-5.6	4.3	-0.6	4.7	7.3
Hydrograph		1m		12.3/-4.22	5.5	-0.05	5.5	7.3
100-year	**Recorded**							
958 -steady	+9.0/-7.5	none	none	9.0/-7.5	7.6	5.4	5.4	9.4
958 hydrograph	+9.0/-7.5	.5 m		10.7/-5.6	4.2	-1	4.2	8.1
hydrograph		1 m		12.3/-4.22	4.6	-0.7	5.1	8.1
Hydrograph		1m		12.3/-4.22	5.7	-0.5	5.7	8.1
1.1year	**Spring tides**		**2.5' surge**	**Surge at High Tide**				
1.1-year	7.3/-6.9	none	2.5	9.8/-7.0	0.6	-1.1	1.1	1.7
steady		0.5 m		11.4/-5.7	1.2	-0.7	1.5	2
		1m		13.1/-5.4	5.8	-1.9	5.9	5.9
1.1-year	**Spring tides**		**Surge timing**					
1.1-year	7.3/-6.9	none	MR	8/-7	0.6	-1	1.1	1.8
steady		none	MF	8/-7	0.6	-1.1	1.1	1.8
		none	L	7.8/-7	0.6	-1	1.1	1.8

Table 14: Summary of Model Results for Alternative 2 with One Variation on Alternative 2

Riverine Flow (cfs)	Tides (ft) (high/low)	Sea Level Rise (m)	Surge (ft)	Tide + Surge Downstream from Dyke Bridge (ft)	Four 5 ft x 5 ft Box Culverts				Five 5 ft x 5 ft Box Culverts with One Open			
					Elevations Upstream from Dyke Bridge (ft)		Peak Elevations at Stride Bridge (ft)		Elevations Upstream from Dyke Bridge (ft)		Peak Elevations at Stride Bridge (ft)	
					High	Low	DS	US	High	Low	DS	US
1.1-year	**Recorded**											
152 - steady	+9.0/-7.5	none	none	9.0/-7.5	0.08	-2.3	0.8	1.6	1.8	-0.7	2	2.3
		0.5 m		10.7/-5.6	0.5	-2	1	0.7	2.4	-0.24	2.6	
		1m		12.3/-4.22	3.6	-1.2	3.6	3.7	5	0.3	5	
50-year	**Recorded**											
Hydrograph	+9.0/-7.5	none	none	9.0/-7.5	3.2	-2.2	4.3	7.3	4	-1	4.8	7.3
		0.5 m		10.7/-5.6	3.5	-2	4.5	7.3				
		1m		12.3/-4.22	4.5	-1.3	5	7.3				
100-year	**Recorded**											
hydrograph	+9.0/-7.5	none	none	9.0/-7.5	3.5	-2.3	4.7	8.1	4.3	-0.9	5.1	8.1
		0.5 m		10.7/-5.6	3.8	-2	4.9	8.1				
		1m		12.3/-4.22	4.8	-1.5	5.4	8.1				
1.1year	**Spring tides**		**2.5' surge**	**Surge at High Tide**								
152 cfs steady flow	7.3/-6.9	none	2.5	9.8/-7.0	-0.17	-2.3	0.7	1.6	1.8	-1	2	2.3
		0.5 m		11.4/-5.4	0.4	-2	1	1.7	2.5	-0.4	2.8	2.9
		1m		13.1/-3.8	5.6	-1.1	5.7	5.7	6.3	0.5	6.3	6.3
1.1-year	**Spring tides**		Surge timing									
152 cfs - steady	7.3/-6.9	none	MR	8/-7	-0.1	-2.3	0.8	1.6				
		none	MF	8/-7								
		none	L	7.8/-7								

Table 15: Summary of Model Results for Alternative 2 Variations

Alternative 2 Variations	Riverine Flow (cfs)	Tides (ft) (high/low)	Sea Level Rise (m)	Surge (ft)	Tide + Surge Downstream from Dyke Bridge (ft)	Elevations Upstream from Dyke Bridge (ft)		Peak Elevations at Stride Bridge (ft)	
						DS	US	DS	US
Five 5 ft x 5 ft box culverts with four flap gates and one open culvert Invert Elev.: -4.05 ft; Top of Road Elev.: 11 ft									
	20	9.0/-7.5	none	0	9.0/-7.5	9	0.7	0.8	0.8
	152			0		9	1.8	2	2.3
	152	7.3/-6.9	none	2.5	9.8/-7.0	9.8	1.8	2	2.3
Four 5 ft x 5 ft box culverts with three flap gates and one open culvert Invert Elev.: -4.05 ft; Top of Road Elev. 11 ft									
	20	9.0/-7.5	none	0	9.0/-7.5	9	0.9	0.9	1
	152			0		9	2.1	2.2	2.5
	152	7.3/-6.9	none	2.5	9.8/-7.0	9.8	2	2.2	2.5
Four 5 ft x 5 ft box culverts with two flap gates and two open culverts Invert Elev.: -4.05; Top of Road Elev.: 11 ft									
	20	9.0/-7.5	none	0	9.0/-7.5	9	2	2.3	2.3
	152			0		9	3.1	3.2	3.4
	152	7.3/-6.9	none	2.5	9.8/-7.0	9.8	3	3.1	3.3

Table 16: Summary of Model Results for Alternative 5 - Replacement with Five 12 ft x 15 ft Box Culverts with Top of Road at 17 ft

Riverine Flow (cfs)	Tides (ft) (high/low)	Sea Level Rise (m)	Surge (ft)	Tide + Surge Downstream from Dyke Bridge (ft)	Elevations Upstream from Dyke Bridge (ft)		Peak Elevations at Stride Bridge (ft)	
					High	Low	DS	US
1.1-year	**Recorded**							
152 - steady	+9.0/-7.5	none	none	9.0/-7.5	7.3	-2.5	7.4	7.4
		0.5 m		10.7/-5.6	8.6	-2	8.6	8.7
		1m		12.3/-4.22	10.2	-0.6	10.2	10.3
50-year	**Recorded**							
Hydrograph	+9.0/-7.5	none	none	9.0/-7.5	7.5	-2.3	7.6	8.8
		0.5 m		10.7/-5.6	8.7	-2	8.7	9.8
		1m		12.3/-4.22	10.2	-0.6	10.2	11.1
100-year	**Recorded**							
hydrograph	+9.0/-7.5	none	none	9.0/-7.5	7.5	-2.3	7.7	9.3
		0.5 m		10.7/-5.6	8.8	-1.9	8.9	10.2
		1m		12.3/-4.22	10.2	-0.6	10.3	11.5
1.1year	**Spring tides**		**2.5' surge**	**Surge at High Tide**				
152 - steady	7.3/-6.9	none	2.5	9.8/-7.0	7.5	-2.6	7.5	7.6
		0.5 m		11.4/-5.4	8.8	-1.9	8.8	8.8
		1m		13.1/-4.0	10.6	-0.6	10.6	10.6
1.1-year	**Spring tides**		Surge timing					
152 - steady	7.3/-6.9	none	Mid-Flood	8/-7	6.9	-2.5	7	7
		none	Mid-Ebb	8/-7				
		none	L	7.8/-7				

Table 17: Summary of Model Results for Alternative 6 -60 ft Span at Dyke Bridge (Low Chord at 9 ft, Top of Road at Elev. 11 ft) with Multiple Alternatives at Stride Bridge (as noted) with Top of Road at Elev. 17 ft

Riverine Flow (cfs)	Tides (ft) (high/low)	Sea Level Rise (m)	Surge (ft)	Tide + Surge Downstream from Dyke Bridge (ft)	Elevations Upstream from Dyke Bridge (ft)		Peak Elevations at Stride Bridge (ft)	
					High	Low	DS	US
1.1-year	**Recorded**							
152 - steady	+9.0/-7.5	none	none	9.0/-7.5	8.3	-6.1	8.5	8.5
		0.5 m		10.7/-5.6	9.8	-5.6	9.8	9.9
		1m		12.3/-4.22	11.2	-3.8	11.2	11.3
50-year	**Recorded**							
Hydrograph	+9.0/-7.5	none	none	9.0/-7.5	8.3	-6.1	8.3	9.5
		0.5 m		10.7/-5.6	9.8	-5.6	9.8	10.8
		1m		12.3/-4.22	11.2	-3.8	11.2	12.2
100-year	**Recorded**							
hydrograph	+9.0/-7.5	none	none	9.0/-7.5	8.4	-5.9	8.4	9.9
hydrograph		0.5 m		10.7/-5.6	9.9	-5.6	9.9	11.1
hydrograph		1m		12.3/-4.22	11.3	-3.7	11.3	12.6
1.1year	**Spring tides**		**2.5' surge**	**Surge at High Tide**				
1.1-year	7.3/-6.9	none	2.5	9.8/-7.0	8.9	-6.1	8.9	8.9
		0.5 m		11.4/-5.4	10.1	-5.3	10.1	10.2
		1 m		13.1/-3.7	11.5	-3.6	11.6	11.6
1.1-year	**Spring tides**		**Surge timing**					
1.1-year	7.3/-6.9	none	Mid-Flood	8/-7	7.7	-1.1	7.7	7.8
		0.5 m	Mid-Ebb	9.64/-5.4				
		1m	L	11.28/-3.7				

Table 18: Summary of Model Results for Alternative 6 - 60 ft Span at Dyke Bridge (Low Chord at 9 ft, Top of Road at Elev. 14.7 ft) with Multiple Alternatives at Stride Bridge (as noted) with Top of Road at Elev. 17 ft

Riverine Flow (cfs)	Stride Bridge Alternative	Tides (ft) (high/low)	Sea Level Rise (m)	Surge (ft)	Tide + Surge Downstream from Dyke Bridge (ft)	Elevations Upstream from Dyke Bridge (ft)		Peak Elevations at Stride Bridge (ft)	
						High	Low	DS	US
1.1-year		Recorded							
	no change	9/-7.5	1m	none	12.3/-4.2	11.3	-3.8	11.3	11.4
	slip lined	9/-7.5	1m		12.3/-4.2	11.3	-3.8	11.3	11.4
50-year	no change	9/-7.5	none	none	9/-7.5				
Hydrograph			0.5 m		10.7/-5.9				
			1m		12.3/-4.2	11.2	-3.8	11.3	12.2
100-year	no change	9/-7.5	none	none	9/-7.5				
Hydrograph			0.5 m		10.7/-5.9				
			1m		12.3/-4.2	11.3	-3.8	11.3	12.6
50-year	slip lined	9/-7.5	none	none	9/-7.5	8.4	-6.1	8.4	9.8
Hydrograph			0.5 m		10.7/-5.9	9.8	-5.6	9.9	11.2
			1m		12.3/-4.2	11.3	-3.7	11.4	12.7
100-year	slip lined	9/-7.5	none	none	9/-7.5	8.3	-6.1	8.4	10.3
Hydrograph			0.5 m		10.7/-5.9	9.8	-5.6	9.9	11.7
			1m		12.3/-4.2	11.3	-3.8	11.4	13.2
		Spring			Surge=2.5 ft				
1.1-year	no change	7.3/-6.9	none	2.5	9.8/-6.9	8.7	-6.1	8.8	8.8
			0.5 m		11.4/-5.3	10.1	-5.2	10.2	10.2
			1m		13.1/-3.6	11.5	-3.6	11.7	11.7
					Mid Tide Surge				
1.1-year	no change	7.3/-6.9	none	2.5	8.0/-6.9				
			0.5 m		9.6/-5.3				
			1m		11.3/-3.6				
					High tide surge				
1.1-year	slip lined	7.3/-6.9	none	2.5	9.8/-6.9	8.9	-6.2	8.8	8.8
			0.5 m		11.4/-5.3	10.1	-5.1	10.1	10.2
			1 m		13.1/-3.6	11.7	-3.6	11.7	11.7
					Mid Tide Surge				
1.1-year	slip lined	7.3/-6.9	none	2.5	8.0/-6.9				
			0.5 m		9.6/-5.3				
			1 m		11.3/-3.6				

Table 19: Summary of Model Evaluations and Results

Bridge Geometry	Top of Roadway at Dyke Bridge (ft)	Dyke Bridge Geometry	Stride Bridge Geometry	Riverine Flow (cfs)	Tides (ft) (high/low)	SLR (m)	Surge (ft)	Tide+ Surge Downstream from Dyke Bridge (ft)	Elevations Upstream from Dyke Bridge (ft)		Peak Elevations at Stride Bridge (ft)	
									High	Low	DS	US
Typical Tides, 1.1-year flow, SLR				1.1-year	Recorded			DS of Dyke BR				
1-Existing	elev 11	Existing	TR=12	152 - steady	+9.0/-7.5	none	none	+9.0/-7.5	1	-0.9	1.4	1.8
		4-4X5' boxes	inv -2.8/-2.5			0.5 m		+10.7/-5.6	1.4	-0.6	1.7	2.1
		w/ gates, inv -3.1	12.5' cmp			1m		+12.3/-4.22	4.5		4.6	4.7
2-replace	elev 11	replace ex, gates	TR=12	152 - steady	+9.0/-7.5	none	none	+9.0/-7.5	0.08	-2.3	0.8	1.6
		4-5X5 boxes,	inv -2.8/-2.5			0.5 m		+10.7/-5.6	0.5	-2	1	0.7
		inv -4.05	12.5' cmp			1m		+12.3/-4.22	3.6	-1.2	3.6	3.7
2 REV	elev 11	replace ex, gates	same	152 - steady	+9.0/-7.5	none	none	+9.0/-7.5	1.8	-0.7	2	2.4
		4 flap gates, 1 open box				0.5 m		+10.7/-5.6	2.4	-0.24	2.6	2.8
		inv -4.05				1m		+12.3/-4.22	5	0.3	5	5.1
5- 5 boxes	elev 11	5- 15HX12W' boxes	TR 17	152 - steady	+9.0/-7.5	none	none	+9.0/-7.5	7.3	-2.5	7.4	7.4
		bridge	invs -2.6/-2.5			0.5 m		+10.7/-5.6	8.6	-2	8.6	8.7
		inv = -5, n=.03	n=.015			1m		+12.3/-4.22	10.2	-0.6	10.2	10.3
6 - 60' span	elev 11	1- 60' span	TR=17	152 - steady	+9.0/-7.5	none	none	+9.0/-7.5	8.3	-6.1	8.5	8.5
		LC=9, TR=11	n=.028			0.5 m		+10.7/-5.6	9.8	-5.6	9.8	9.9
		invs -7.2/-8.0	invs -2.6/-2.5			1m		+12.3/-4.22	11.2	-3.8	11.2	11.3
Typical Tides, 50-year flow, SLR				50-year	Recorded							
1-Existing	elev 11	Existing	TR=12	824 steady	+9.0/-7.5	none	none	+9.0/-7.5	6.7	4.4	6.9	8.3
		4-4X5' boxes	inv -2.8/-2.5	Hydrograph	+9.0/-7.5	none	none	+9.0/-7.5	3.7	-0.1	4.6	7.3
		w/ gates, inv -3.1	12.5' cmp	Hydrograph		0.5 m		+10.7/-5.6	4.3	-0.6	4.7	7.3
				Hydrograph		1m		+12.3/-4.22	5.5	-0.05	5.5	7.3
2-replace	elev 11	replace ex, gates	TR=12	Hydrograph	+9.0/-7.5	none	none	+9.0/-7.5	3.2	-2.2	4.3	7.3
		4-5X5 boxes,	inv -2.8/-2.5	Hydrograph		0.5 m		+10.7/-5.6	3.5	-2	4.5	7.3
		inv -4.05	12.5' cmp	Hydrograph		1m		+12.3/-4.22	4.5	-1.3	5	7.3
2 REV	elev 11	replace ex, gates	same	Hydrograph	+9.0/-7.5	none	none	+9.0/-7.5	4	-1	4.8	7.3
		4 flap gates, 1 open box		Hydrograph		0.5 m		+10.7/-5.6				
		inv -4.05		Hydrograph		1m		+12.3/-4.22				
5- 5 boxes	elev 11	5- 15HX12W' boxes	TR 17	Hydrograph	+9.0/-7.5	none	none	+9.0/-7.5	7.5	-2.3	7.6	8.8
		bridge	invs -2.6/-2.5	Hydrograph		0.5 m		+10.7/-5.6	8.7	-2	8.7	9.8
		inv = -5, n=.03	n=.015	Hydrograph		1m		+12.3/-4.22	10.2	-0.6	10.2	11.1
6 - 60' span	elev 11	1- 60' span	TR=17	Hydrograph	+9.0/-7.5	none	none	+9.0/-7.5	8.3	-6.1	8.3	9.5
		LC=9, TR=11	n=.028	Hydrograph		0.5 m		+10.7/-5.6	9.8	-5.6	9.8	10.8
		invs -7.2/-8.0	invs -2.6/-2.5	Hydrograph		1m		+12.3/-4.22	11.2	-3.8	11.2	12.2
Typical Tides, 100-year flows, plus SLR				100-year	Recorded							
1-Existing	elev 11	Existing	TR=12	958 -steady	+9.0/-7.5	none	none	+9.0/-7.5	7.6	5.4	5.4	9.4
		4-4X5' boxes	inv -2.8/-2.5	958 hydrograph	+9.0/-7.5	.5 m		+10.7/-5.6	4.2	-1	4.2	8.1
		w/ gates, inv -3.1	12.5' cmp	Hydrograph		1 m		+12.3/-4.22	4.6	-0.7	5.1	8.1
				Hydrograph		1m		+12.3/-4.22	5.7	-0.5	5.7	8.1
2-replace	elev 11	replace ex, gates	TR=12	Hydrograph	+9.0/-7.5	none	none	+9.0/-7.5	3.5	-2.3	4.7	8.1
		4-5X5 boxes,	inv -2.8/-2.5	Hydrograph		0.5 m		+10.7/-5.6	3.8	-2	4.9	8.1
		inv -4.05	12.5' cmp	Hydrograph		1m		+12.3/-4.22	4.8	-1.5	5.4	8.1
2 REV	elev 11	replace ex, gates	same	Hydrograph	+9.0/-7.5	none	none	+9.0/-7.5	4.3	-0.9	5.1	8.1
		4 flap gates, 1 open box		Hydrograph		0.5 m		+10.7/-5.6				
		inv -4.05		Hydrograph		1m		+12.3/-4.22				
5- 5 boxes	elev 11	5- 15HX12W' boxes	TR 17	Hydrograph	+9.0/-7.5	none	none	+9.0/-7.5	7.5	-2.3	7.7	9.3
		bridge	invs -2.6/-2.5	Hydrograph		0.5 m		+10.7/-5.6	8.8	-1.9	8.9	10.2
		inv = -5, n=.03	n=.015	Hydrograph		1m		+12.3/-4.22	10.2	-0.6	10.3	11.5
6 - 60' span	elev 11	1- 60' span	TR=17	Hydrograph	+9.0/-7.5	none	none	+9.0/-7.5	8.4	-5.9	8.4	9.9
		LC=9, TR=11	n=.028	Hydrograph		0.5 m		+10.7/-5.6	9.9	-5.6	9.9	11.1
		invs -7.2/-8.0	invs -2.6/-2.5	Hydrograph		1m		+12.3/-4.22	11.3	-3.7	11.3	12.6

Table 19: Summary of Model Evaluations and Results

Bridge Geometry	Top of Roadway at Dyke Bridge (ft)	Dyke Bridge Geometry	Stride Bridge Geometry	Riverine Flow (cfs)	Tides (ft) (high/low)	SLR (m)	Surge (ft)	Tide+ Surge Downstream from Dyke Bridge (ft)	Elevations Upstream from Dyke Bridge (ft)		Peak Elevations at Stride Bridge (ft)	
									High	Low	DS	US
High Spring Tide plus Surge, 1.1-year flow, plus SLR				**1.1year**	**Spring tides**		**2.5' surge**					
1-Existing	elev 11	Existing	TR=12	1.1-year	7.3/-6.9	none	2.5	9.8/-7.0	0.6	-1.1	1.1	1.7
		4-4X5' boxes	inv -2.8/-2.5	steady		0.5 m		11.4/-5.7	1.2	-0.7	1.5	2
		w/ gates, inv -3.1	12.5' cmp			1m		13.1/-5.4	5.8	-1.9	5.9	5.9
2-replace	elev 11	replace ex, gates	TR=12	1.1-year	7.3/-6.9	none	2.5	9.8/-7.0	-0.17	-2.3	0.7	1.6
		4-5X5 boxes,	inv -2.8/-2.5			0.5 m		11.4/-5.4	0.4	-2	1	1.7
		inv -4.05	12.5' cmp			1m		13.1/-3.8	5.6	-1.1	5.7	5.7
2 REV	elev 11	replace ex, gates	same	1.1-year	7.3/-6.9	none	2.5	9.8/-7.0	1.8	-1	2	2.3
		4 flap gates, 1 open box				0.5 m		11.4/-5.4	2.5	-0.4	2.8	2.9
		inv -4.05				1m		13.1/-3.8	6.3	0.5	6.3	6.3
5- 5 boxes	elev 11	5- 15HX12W' boxes	TR 17	1.1-year	7.3/-6.9	none	2.5	9.8/-7.0	7.5	-2.6	7.5	7.6
		bridge	invs -2.6/-2.5			0.5 m		11.4/-5.4	8.8	-1.9	8.8	8.8
		inv = -5, n=.03	n=.015			1m		13.1/-4.0	10.6	-0.6	10.6	10.6
6 - 60' span	elev 11	1- 60' span	TR=17	1.1-year	7.3/-6.9	none	2.5	9.8/-7.0	8.9	-6.1	8.9	8.9
		LC=9, TR=11	n=.028			0.5 m		11.4/-5.4	10.1	-5.3	10.1	10.2
		invs -7.2/-8.0	invs -2.6/-2.5			1 m		13.1/-3.7	11.5	-3.6	11.6	11.6
1-Existing	Existing	Existing	Existing	1.1-year	7.3/-6.9	none	MR	8/-7	0.6	-1	1.1	1.8
				steady		none	MF	8/-7	0.6	-1.1	1.1	1.8
						none	L	7.8/-7	0.6	-1	1.1	1.8
2-replace	Same as Exist.	Same as Exist.	no change	1.1-year	7.3/-6.9	none	MR	8/-7	-0.1	-2.3	0.8	1.6
						none	MF	8/-7				
						none	L	7.8/-7				
5- 5 boxes	Same as Exist.	5- 15' boxes	no change	1.1-year	7.3/-6.9	none	MR	8/-7	6.9	-2.5	7	7
						none	MF	8/-7				
						none	L	7.8/-7				
6 - 60' span	Same as Exist.	1- 60' span	no change	1.1-year	7.3/-6.9	none	MR	8/-7	7.7	-1.1	7.7	7.8
						0.5 m	MF	9.64/-5.4				
						1m	L	11.28/-3.7				
Typical Tides, Flows Vary, Dyke BR and Stride BR Alternatives				**1.1-year**	**Recorded**							
6 - 60' span	**14.7'**	1- 60' span	no change	1.1-year	9/-7.5	1m	none	12.3/-4.2	11.3	-3.8	11.3	11.4
6 - 60' span	**14.7'**	1- 60' span	**slip lined**	1.1-year	9/-7.5	1m		12.3/-4.2	11.3	-3.8	11.3	11.4
6 - 60' span	**14.7'**	1- 60' span	no change	**50-year**	9/-7.5	none	none	9/-7.5				
				Hydrograph		0.5 m		10.7/-5.9				
						1m		12.3/-4.2	11.2	-3.8	11.3	12.2
6 - 60' span	**14.7'**	1- 60' span	no change	**100-year**	9/-7.5	none	none	9/-7.5				
				Hydrograph		0.5 m		10.7/-5.9				
						1m		12.3/-4.2	11.3	-3.8	11.3	12.6
6 - 60' span	**14.7'**	1- 60' span	**slip lined**	**50-year**	9/-7.5	none	none	9/-7.5	8.4	-6.1	8.4	9.8
				Hydrograph		0.5 m		10.7/-5.9	9.8	-5.6	9.9	11.2
						1m		12.3/-4.2	11.3	-3.7	11.4	12.7
6 - 60' span	**14.7'**	1- 60' span	**slip lined**	**100-year**	9/-7.5	none	none	9/-7.5	8.3	-6.1	8.4	10.3
				Hydrograph		0.5 m		10.7/-5.9	9.8	-5.6	9.9	11.7
						1m		12.3/-4.2	11.3	-3.8	11.4	13.2

Table 19: Summary of Model Evaluations, Results, and HEC-RAS Model Setup (Continued)

Bridge Geometry	Top of Roadway at Dyke Bridge (ft)	Dyke Bridge Geometry	Stride Bridge Geometry	Riverine Flow (cfs)	Tides (ft) (high/low)	SLR (m)	Surge (ft)	Tide+ Surge Downstream from Dyke Bridge (ft)	Elevations Upstream from Dyke Bridge (ft)		Peak Elevations at Stride Bridge (ft)	
									High	Low	DS	US
Storm Surge Tides, 1.1-year flows, plus SLR, Dyke/Stride options					**Spring**			**Surge=2.5'**				
6 - 60' span	**14.7'**	1- 60' span	no change	**1.1-year**	7.3/-6.9	none	2.5	9.8/-6.9	8.7	-6.1	8.8	8.8
						0.5 m		11.4/-5.3	10.1	-5.2	10.2	10.2
						1m		13.1/-3.6	11.5	-3.6	11.7	11.7
								Mid Tide Surge				
Case 6 - 60' span	**14.7'**	1- 60' span	no change	**1.1-year**	7.3/-6.9	none	2.5	8.0/-6.9				
						0.5 m		9.6/-5.3				
						1m		11.3/-3.6				
								High tide surge				
Case 6 - 60' span	**14.7'**	1- 60' span	**slip lined**	1.1-year	7.3/-6.9	none	2.5	9.8/-6.9	8.9	-6.2	8.8	8.8
						0.5 m		11.4/-5.3	10.1	-5.1	10.1	10.2
						1 m		13.1/-3.6	11.7	-3.6	11.7	11.7
								Mid Tide Surge				
Case 6 - 60' span	**14.7'**	1- 60' span	**slip lined**	1.1-year	7.3/-6.9	none	2.5	8.0/-6.9				
						0.5 m		9.6/-5.3				
						1 m		11.3/-3.6				
Calibration Model Runs				**20 cfs**	**Recorded**							
Case 1	11	Existing	TR=12		+9.0/-7.5	none	none	9.0/-7.5	-0.55	-2	-0.49	-0.41
		4-4X5' boxes	inv -2.8/-2.5									
		w/ gates, inv -3.1	12.5' cmp									
Case 1	11	Existing	TR=12		+9.0/-7.5	none	none	9.0/-7.5	3.3	3.3	3.3	0.7
		4-4X5' boxes	inv -2.8/-2.5									
		NO gates, inv -3.1	12.5' cmp									
Alt 2 Replacement in kind options												
Alt 2 4 flap gates, 1 open box		4 5X5 flap gates	TR=12	20	+9.0/-7.5	none	none	9.0/-7.5	9	0.7	0.8	0.8
	11	one open 5X5	inv -2.8/-2.5	152					9	1.8	2	2.3
		inv -4.05	12.5' cmp									
alt 2 3 flaps 1 open		3 5X5 flap gates	TR=12	20	+9.0/-7.5	none	none	9.0/-7.5	9	0.9	0.9	1
		one open 5X5	inv -2.8/-2.5	152					9	2.1	2.2	2.5
		inv -4.05	12.5' cmp									
alt 2 2 flaps 1 open		2 5X5 flap gates	TR=12	20	+9.0/-7.5	none	none	9.0/-7.5	9	2	2.3	2.3
		two open 5X5	inv -2.8/-2.5	152					9	3.1	3.2	3.4

7.0 TECHNOLOGY REVIEW: SELF-REGULATION TIDE GATES

Stantec performed a technology review of SRTs as part of this study. This review included obtaining and reviewing information on SRTs and evaluating the potential suitability of SRTs as elements of Alternative 3 and “fish-friendly” SRTs as elements of Alternative 4. The compiled SRT technology review is provided in Appendix B.

7.1 SELF-REGULATING TIDE GATES

Review of information and discussions with SRT manufacturers indicated that SRTs can be constructed in virtually any size based on site-specific needs. Scaling-up of SRT designs would necessitate appropriate care of structural elements and consideration of hydraulic performance. In addition, mechanical components of scale-up SRTs would need to be appropriately designed.

SRT costs vary between manufacturers and specific designs. A rule-of-thumb provided by a designer and manufacturer of tide gates who was contacted as part of this study is $450 per square-foot of gate area for manufacturing smaller SRTs. Application of this rule to a 4 ft by 4 ft SRT would result in a cost of $7,200. Similarly, application of this rule to a 10 ft by 10 ft SRT would result in a cost of $45,000, which appears to be low and reflect that the rule-of-thumb is not linearly scalable to larger gates. Note that these costs do not include installation of SRTs or modifications to associated culvert systems, which may include construction of additional structural elements and design features intended to prevent movement of the culvert elements when there is differential hydraulic head at closed tide gates.

Maintenance requirements for SRTs will vary based on selected designs and size; it is expected that larger SRTs will require increased maintenance. Expected primary maintenance requirements include 1) maintaining the SRT mechanical systems, and 2) debris management. Potential failure of mechanical systems can result from wear resulting from regular operation of tide gates and damage from debris, such as flotsam (e.g., logs) and ice during winter months. Based on discussions with a manufacturer of tide gates, operation of tide gates at flow speeds of greater than 5 to 6 feet-per-second (fps) during closure of the tide gates can result in damage to the tide gate systems. Based on modeled conditions for this study, it is expected that flow speeds in excess of 6 fps could be encountered during gate closure if operation of tide gates requires gate closure when the hydraulic head between the seaward and landward sides of the tide gate is greater than approximately 0.6 ft.

Evaluation of hydraulic model simulation data for Alternative 5 indicates that the hydraulic head through culverts as part of that alternative would exceed 1 ft within 1 hour after the start of the flood tide and would exceed 2 ft later during each flood tide. These conditions would result in flow speeds in the range of 8 fps and 10 fps, respectively, through a tide gate installed on the seaward face of a culvert system. Note that additional hydraulic losses through the tide gates in addition to those that were calculated for the culverts would result in increased hydraulic head and flow speeds.

Consequences of failure of SRTs are relevant to this project. Because the Dyke Bridge and associated causeway are located on a waterway with a relatively large tributary watershed and the existing tidal regime landward from the bridge is suppressed, there are potential impacts that could result from failure of SRT gate systems in the "open" or "closed" positions. Failure of tides gates in the "open" position could result in increased tidal inundation landward from Dyke Bridge (this scenario is similar to what would result if the existing flap gates failed or were removed). Failure of tide gates in the "closed" position could result in accumulation of freshwater landward from the bridge. Given the relatively large volume of available hydrologic storage between Dyke Bridge and Stride Bridge, it is expected that failure of tide gates in the "open" position and resulting tidal inundation would result in increased impacts relative to failure of tide gates in "closed" positions.

Factors related to public safety include entrainment in the tide gates (including SRTs) and/or culverts. Culverts with widths that are less than small recreational watercraft pose impingement hazards, as small boats could become impinged across the culvert inlets; installation and operation of tide gates would increase the impingement hazard by reducing opening widths. The associated hazard increases at higher flow speeds through the tide gate or culvert. An additional factor related to public safety is that larger culvert and gate systems will have capacity for increased flow and a larger area of influence that could result in entrainment of boats and swimmers. While a bridge opening could have greater capacity, the reduced potential for impingement associated with a bridge would result in a decrease in potential hazards. These concerns are relevant to this project given the proximity of the state-owned boat launch that is located immediately seaward from the existing Dyke Bridge culverts.

The potential for sea level rise should be evaluated in the context of SLRs and resiliency of the Dyke Bridge causeway to limit landward inundation. This concern is particularly relevant to overtopping of the causeway during storm events, which could result in inundation of areas that are currently "protected" by the causeway. Even short-term inundation of the landward area with salt water could have pronounced effects on existing flora and fauna, such as die-off of salt-intolerant vegetation.

7.2 "FISH-FRIENDLY" SRTS

Some manufacturers of SRTs describe "fish-friendly" SRTs; information obtained as part of the SRT technology review indicates that some SRTs may be better suited than others for fish passage, and that these may be termed "fish-friendlier" but not necessarily fish-friendly.

Site-specific constraints appear to substantially limit the use of fish-friendlier SRTs at Dyke Bridge; these constraints largely follow on the factors that are identified for typical SRTs, and include functional limitations on the operational capabilities of SRTs related to hydraulic head and flow speeds.

The primary identified constraints to installation of fish-friendly SRTs at Dyke Bridge are associated with:

1) Operation of tide gates in a high-velocity environment; and

2) Relatively high-speed flow through the culvert and tide gate system during the ebb tide.

As discussed in the preceding section, operation of SRTs in high-velocity environments can result in damage to the tide gates. The applicability of fish-friendly SRTs at Dyke Bridge to provide for improved upstream fish passage is therefore substantially constrained by the large difference in water surface elevations seaward and landward from Dyke Bridge during the flood tide.

Based on the evaluation of culverts for Alternative 5, flow speeds through the evaluated culverts during the ebb tide would largely preclude upstream movement of slower-swimming fish, such as rainbow smelt (*Osmerus mordax*). In addition, the culvert inverts would need to be set at an elevation of approximately -8 ft (4 ft lower than the existing culverts) to have the culvert and tide gate invert below low tide elevations seaward from Dyke Bridge as a baseline requirement for upstream passage low tide. An expected consequence of lower culvert inverts is lowering of the low tide pool landward of Dyke Bridge by approximately 7 ft relative to existing conditions.

8.0 FISH PASSAGE

This study includes preliminary evaluation of fish passage at Dyke Bridge and Stride Bridge, including evaluation of "fish friendly" self-regulating tide gates (Alternative 4) at Dyke Bridge. This section presents information on and an evaluation of fish passage through SRTs and general and site-specific constraints to use of SRTs technologies at Dyke Bridge.

Identified effects on fish passage are addressed separately for Dyke Bridge and Stride Bridge. While there is interaction between the two sites, including effects of tidal stage associated with the evaluated alternatives at Dyke Bridge, the number of alternatives and scenarios evaluated as part of this study did not include direct evaluation of all of the potential combinations of alternatives at Dyke Bridge and Stride Bridge that may affect upstream fish passage at both sites.

Discussion of fish passage is focused on Dyke Bridge, where existing conditions for upstream fish passage are currently marginal, and is followed by a discussion of fish passage at Stride Bridge.

8.1 DYKE BRIDGE

8.1.1 Alternative 1: No Action

The existing flap gates at Dyke Bridge are deteriorated, and leakage through the flap gates and embankment results in some landward tidal flow. Landward flow through gaps in the flap gaps and/or unseated closure is possible but is expected to be limited except for very small-bodied fish that will pass through gaps. Analysis of the tidal stage data provided by MaineDOT for the period from July 11 through October 24, 2011 indicates that the temporal during of landward and seaward flow is evenly split (i.e., 50% landward and 50% seaward) during normal tides. The HEC-RAS model analysis of existing conditions for the period from July 12, 2011 through August 12, 2011, yielded the same percentages of landward and seaward flow.

As previously noted, landward flow at Dyke Bridge during flood tide results from leakage of the flap gates and leakage through the adjacent embankment, and therefore provides for very limited upstream fish passage. Based on observed conditions at Dyke Bridge, upstream fish passage during periods of seaward flow is expected to be limited to short duration periods when the tidal stage landward from Dyke Bridge is marginally higher than the seaward stage and the seaward stage is higher than the culvert barrel outlet inverts. When the seaward stage is below the culvert barrel outlet inverts, it is expected that flow over the riprap apron seaward from the Dyke Bridge culverts prevents upstream passage for fish due to high-speed flow and a leaping barrier associated with flow over the riprap apron.

8.1.2 Stride Bridge

The existing Stride Bridge culvert is persistently backwatered and the invert (elevation -2.5 ft) is below the lowest recorded water surface elevation upstream from Dyke Bridge, and is therefore expected to provide for good upstream fish passage during lower flow conditions. During high-flow conditions, this culvert may be a short-term barrier to upstream fish passage depending on backwater conditions (e.g., water surface elevations in the downstream reach of the river) and total flow.

8.2 ALTERNATIVE 2: REPLACEMENT IN-KIND WITHOUT RESTORATION OF TIDAL FLOW

8.2.1 Dyke Bridge

In-kind replacement of the culverts and flap gates at Dyke Bridge is expected to eliminate landward flow through the culverts and therefore eliminate landward movement of fish during the flood tide or the ebb tide when water surface elevations landward from Dyke Bridge are lower than the seaward water surface elevations. It is not expected that there would be more than incidental landward passage of fish through the flap gates when flow is seaward due to high-speed flow through the gates and flow over riprap apron seaward from the culvert.

8.2.2 Stride Bridge

This alternative could reduce daily variations in flow landward from Dyke Bridge and would therefore result in lower water surface elevations at Stride Bridge. These potential changes could result in increased downstream flow speeds at Stride Bridge. Lower tailwater elevations and increased flow speeds at Stride Bridge would decrease the potential for upstream fish passage relative to existing conditions. Note that reductions in tailwater surface elevations at Stride Bridge would be persistent at low flows for this alternative because of the loss of tidal affects.

8.3 ALTERNATIVE 2: REPLACEMENT IN-KIND WITH VARIATIONS FOR FLAP GATE OPERATIONS

This modified concept for Alternative 2 includes evaluation of box culverts at Dyke Bridge with flap gates on a subset of the culverts and at least one free-flowing culvert. The objective of having a persistently-open culvert(s) is to provide for unhindered landward flow when the flood tide is higher than the elevation of the culvert invert and the water surface elevation landward from Dyke Bridge.

8.3.1 Dyke Bridge

Three variations on Alternative 2 were evaluated:

a. Five 5 ft x 5 ft culverts with flap gates on four of the culverts (Plan No. 82). Results of this simulation that include the observed upstream tide data are presented in Figure 14;

b. Four 5 ft x 5 ft culverts with flap gates on three of the culverts (Plan No. 83). Results of this simulation that include the observed upstream tide data are presented in Figure 15; and

c. Four 5 ft x 5 ft culverts with flap gates on two of the culverts (Plan No. 27). Results of this simulation that include the observed upstream tide data are presented in Figure 16.

Table 20 presents information on the three evaluated variations of Alternative 2 and, for comparison, simulation results for existing conditions.

Table 20: Evaluation of Landward and Seaward Flow

Simulation	Typical High Tide (ft NAVD88)	Seaward Flow (%)	Landward Flow (%)
Existing Conditions	-1 ft	50%	50%
Five Culverts with one free-flowing (Plan No. 82)	0.5 ft	53%	47%
Four culverts with one free-flowing (Plan No. 83)	1 ft	55%	45%
Four culverts with two free-flowing (Plan No. 27)	2 ft	55%	45%

The three evaluated Alternative 2 variations result in higher water surface elevations landward from Dyke Bridge relative to existing conditions and small (3% to 5%) decreases in the duration of landward flow relative to existing conditions. While the duration of landward flow is decreased relative to existing conditions, the Alternative 2 variations provide for landward flow through an open box culvert. Note that existing landward flow results from the deteriorated condition of the existing culverts and flap gates, and that reconstruction of the culverts would result in no landward flow. The Alternative 2 variations are therefore expected to provide for substantial improvements to upstream fish passage at Dyke Bridge relative to existing conditions and in-kind replacement of the existing culvert system.

8.3.2 Stride Bridge

The Alternative 2 variations would result in higher typical tidal elevations landward from Dyke Bridge and could result in increased depths of water at Stride Bridge, which would result in lower flow speeds through the Stride Bridge stream crossing.

8.4 ALTERNATIVE 3: REPLACEMENT WITH PARTIAL RESTORATION OF TIDAL FLOW

8.4.1 Dyke Bridge

Installation of tide gates at Dyke Bridge that would allow for higher normal tides elevations landward from the bridge would result in increased landward flow during the flood tide through the bridge and could result in some improvement to upstream fish passage. The potential to improve upstream fish passage with tide gates would be heavily influence by the type of tide gate and operational regime.

8.4.2 Stride Bridge

Potential impacts to upstream fish passage at Stride Bridge could result from partial restoration of tidal flow at Dyke Bridge. Higher tidally-affected water surface elevations at Stride Bridge would result in lower flow speeds through the existing culvert and could result in flow reversal (i.e., landward flow), which would tend to improve upstream fish passage. If a tide gate was operated to provide lower water surface elevations landward from Dyke Bridge, this condition would result in higher flow speeds and reduced potential for upstream fish passage at Stride Bridge.

Note that the geometry of the HEC-RAS model was developed without detailed bathymetric information along some of the reach of the Middle River downstream from Stride Bridge, and it is therefore uncertain whether there are natural hydraulic controls (e.g., riffles) that would limit reductions in water surface elevations at Stride Bridge if a replacement culvert at Dyke Bridge resulted in lower low tide elevations landward from Dyke Bridge.

8.5 ALTERNATIVE 4: REPLACEMENT WITH PARTIAL RESTORATION OF TIDAL FLOW AND PROVISIONS FOR FISH PASSAGE

8.5.1 Dyke Bridge

Installation of tide gates with dedicated provisions for upstream fish passage at Dyke Bridge would allow for management of typical tidal water surface elevations landward from the bridge. Depending on the operational regime of tide gates and landward flow during flood tide, this alternative could improve upstream fish passage relative to existing conditions.

8.5.2 Stride Bridge

Potential impacts to upstream fish passage at Stride Bridge could result from partial restoration of tidal flow at Dyke Bridge and would largely depend on the tidal regime landward from Dyke Bridge. Higher tidally-affected water surface elevations at Stride Bridge would result in lower flow speeds through the existing culvert and could result in flow reversal (i.e., landward flow), which would tend to improve upstream fish passage. Lower water surface elevations could also result, which would result in high flow speeds through the culvert and reduced potential for upstream fish passage.

Note that the geometry of the HEC-RAS model was developed without detailed bathymetric information along some of the reach of the Middle River downstream from Stride Bridge. It is therefore uncertain whether there are natural hydraulic controls (e.g., riffles) downstream from Stride Bridge that would limit reductions in water surface elevations downstream from Stride Bridge if a replacement culvert at Dyke Bridge resulted in lower landward low tide elevations.

8.6 ALTERNATIVES 5, 6, AND 7: FULL TIDAL RESTORATION

Full restoration of tidal flow as part of Alternatives 5, 6, and 7 would result in improved upstream fish passage at Dyke Bridge. Achieving upstream fish passage for slower-swimming fish would, however, require construction of a new, lower channel through the footprint of the existing Dyke Bridge causeway and upstream along the Middle River. The need for a new channel is based on bathymetric data collected by MaineDOT landward from Dyke Bridge, which indicates that the bottom of the existing channel higher than low tide elevations downstream (seaward) from Dyke Bridge.

8.6.1 Dyke Bridge

Full tidal restoration at Dyke Bridge would improve upstream fish passage, but the extent of improvements would be substantially affected by the bottom elevation of the channel through the bridge opening and into the upstream reach of the Middle River. Based on the hydraulic model results and observed conditions, it is expected that full tidal restoration could result in high flow speeds through a full-restoration alternative unless a lower channel is constructed (e.g., dredge) within the footprint of the existing Dyke Bridge causeway and further upstream in the Middle River.

8.6.2 Stride Bridge

Potential impacts to upstream fish passage at Stride Bridge would result from full tidal restoration of tidal flow at Dyke Bridge. Higher tidally-affected water surface elevations at Stride Bridge would result in lower flow speeds through the existing culvert and, at higher tides, flow reversal (i.e., landward flow) at Stride Bridge. Higher water surface elevation and/or flow reversal would improve upstream fish passage, but lower water surface elevations, which could also result from a larger tidal range, would result in high flow speeds through the culvert.

Note that the geometry of the HEC-RAS model was developed without detailed bathymetric information along some of the reach of the Middle River downstream from Stride Bridge, and it is therefore uncertain whether there are natural hydraulic controls (e.g., riffles) that would limit reductions in water surface elevations at Stride Bridge if a replacement structure at Dyke Bridge resulted in lower low tide elevations landward from the Dyke Bridge causeway.

9.0 STRIDE BRIDGE REPLACEMENT OPPORTUNITIES

A preliminary evaluation for replacement of Stride Bridge was developed as part of this study. This evaluation was developed based on a minimum span of 37 ft as defined by 1.2-times the bankfull width of the Middle River at Stride Bridge of 31 ft as identified by MaineDOT.

The preliminary evaluation included review of geologic map data obtained from the Maine Geological Survey to assess potential subsurface conditions (e.g., potential presence of shallow bedrock) and hydrologic information that was used as part of this study.

Three potential, single-span options were evaluated:

1) A single, 1.2-times bankfull-width span with vertical abutments and a shallow foundation;
2) A single, 1.2-times bankfull-width span with sloped abutments and a deep foundation; and
3) A single, 1.0-time bankfull-width span with sloped abutments and a deep foundation.

A summary memo that presents information on potential replacement bridge geometries at Stride Bridge is included in Appendix E.

10.0 REFERENCES

ESRI ArcMap Version 9.3.1. 1999, Arcview License

Federal Emergency Management Agency. Flood Insurance Study, Town of Machias, ME, November 18, 1988. Community Number 230140
Maine Dept. of Transportation. Bridge Design Manual. August, 2003.
U.S. Army Corps of Engineers, Hydrologic Engineering Center. HEC-RAS River Analysis System. Version 4.10. Davis, January, 2010

U. S. Dept. of the Interior, Geological Survey, with Maine Dept. of Transportation. Estimating the Magnitude and Frequency of Peak Flows for Streams in Maine for Selected Recurrence Intervals. Water Resources Investigations Report 99-4008.

U.S. Army Corps of Engineers. Updated Tidal Flood Profiles for the New England Coastline. February, 2012

Maine Office of Geographic Information. 2' contours from Lidar Data, Machias
http://www.maine.gov/megis/catalog/contours2ft_tiles.shtml

U.S. Geological Survey, Topographic Map Data. From ESRI database

NOAA, Tides and Water Levels. Eastport, Maine
http://tidesandcurrents.noaa.gov/waterlevels.html?id=8410140

NOAA, Tides and Water Levels. Bar Harbor,
http://tidesandcurrents.noaa.gov/waterlevels.html?id=8413320

NOAA, Tides and Water Levels. Cutler,
http://tidesandcurrents.noaa.gov/waterlevels.html?id=8411060

NOAA Tide Predictions. MachiasPort. Machias River.
http://tidesandcurrents.noaa.gov/noaatidepredictions/NOAATidesFacade.jsp?Stationid=8411467

USGS Gaging Station 01021500. Machias River at Whitneyville,Maine
http://waterdata.usgs.gov/me/nwis/inventory/?site_no=01021500

PHASE III for the Pooled Fund Study. Development of Hydraulic Computer Models to Analyze Tidal and Coastal Stream Hydraulic Conditions at Highway Structures. Ayres Associates and Edge and Associates. For South Caroline Dept. of Transportation. March, 2002

APPENDICES

Appendix C : SRT TECHNOLOGY REVIEW

Project Name:	Machias Causeway	**PIN:**	16714
Stream Name:	Middle River	**Town:**	Marshfield
Bridge Name:	Stride Bridge	**Bridge No.**	3973
Route No.	US 1	**USGS Quad:**	
Analysis by:	CSH	**Date:**	5/13/2014

Peak Flow Calculations by USGS Regression Equations (Hodgkins, 1999)

Enter data in blue cells only!

	km^2	mi^2	ac	*Enter data in [mi^2]*
A	24.38	9.41	6024.4	Watershed Area
W	3.05	1.18	753.7	Wetlands area (by NWI)
P_c	618573	4957554		watershed centroid (E, N; UTM 19N; meters)
County	Washington			*choose county from drop-down menu*
pptA	44.2			mean annual precipitation (inches; by look-up)
SG	0.00			sand & gravel aquifer as decimal fraction of watershed A

Worksheet prepared by:
Charles S. Hebson, PE
Environmental Office
Maine Dept. Transportation
Augusta, ME 04333-0016
207-557-1052
Charles.Hebson@maine.gov

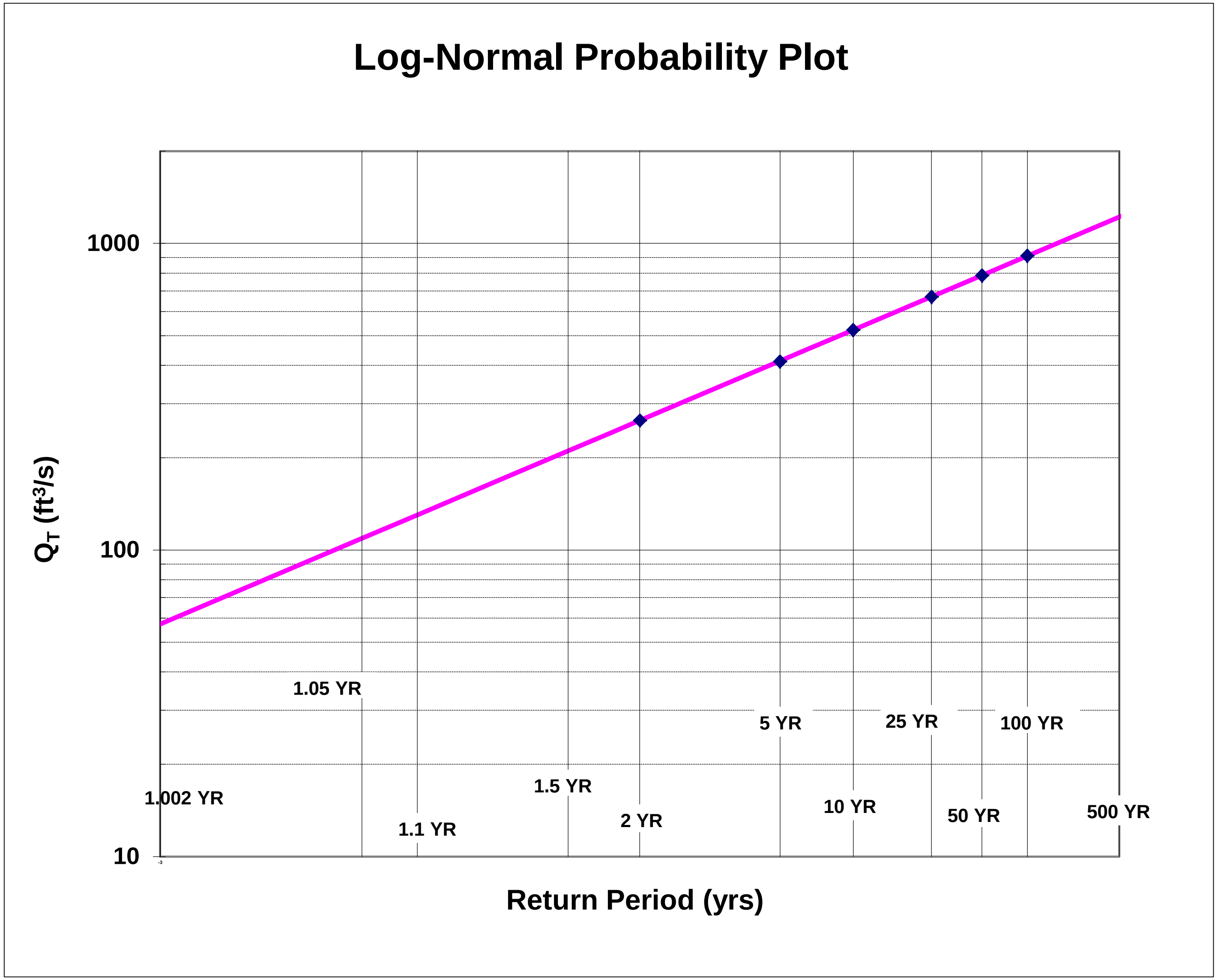
A (km^2)	24.38	**Conf Lvl**	0.67
W (%)	12.51		

Ret Pd T (yr)	Peak Flow Estimate Lower	Q_T (m^3/s)	Upper	Q_T (ft^3/s)
1.1		3.69		130.2
2	5.36	7.50	10.49	264.7
5	8.32	11.68	16.41	412.5
10	10.42	14.78	20.99	522.0
25	13.18	18.98	27.33	670.2
50	15.28	22.27	32.46	786.5
100	17.50	25.82	38.11	911.8
500	22.68	34.57	52.70	1220.6

Reference:

Hodgkins, G., 1999.
Estimating the magnitude of peak flows for streams
in Maine for selected recurrence intervals
Water-Resources Investigations Report 99-4008
US Geological Survey, Augusta, Maine

$Q_T = b \times A^a \times 10^{-wW}$



Log-Normal Probability Plot
1000
100
10
Q_T (ft³/s)
1.002 YR
1.05 YR
1.1 YR
1.5 YR
2 YR
5 YR
10 YR
25 YR
50 YR
100 YR
500 YR
Return Period (yrs)

Project Name:	Machias Causeway	**PIN:**	16714
Stream Name:	Middle River	**Town:**	Marshfield
Bridge Name:	Stride Bridge	**Bridge No.**	3973
Route No.	US 1	**USGS Quad:**	
Analysis by:	CSH	**Date:**	5/13/2014

DO NOT ENTER ANY DATA ON THIS PAGE; EVERYTHING IS CALCULATED

MAINE MONTHLY MEDIAN FLOWS BY USGS REGRESSION EQUATIONS (2004)

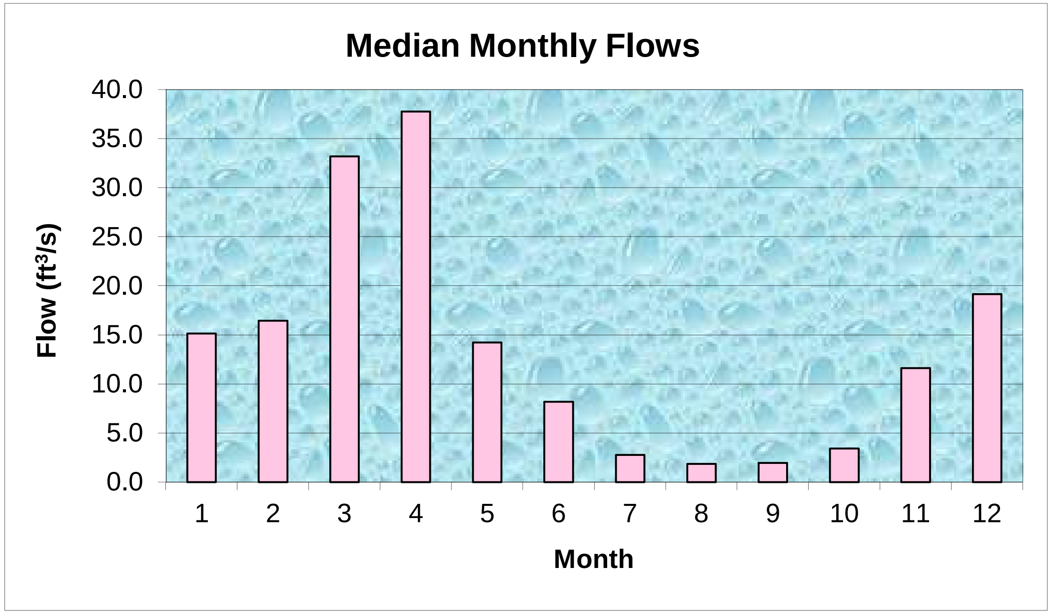
Worksheet prepared by:
Charles S. Hebson, PE
Chief Hydrologist
Maine Dept. Transportation
Augusta, ME 04333-0016
207-624-3073
Charles.Hebson@maine.gov

	Value	**Variable**	**Explanation**
	9.413	*A*	Area (mi^2)
618573	4957554	P_c	Watershed centroid (E,N; UTM; Zone 19; meters)
	31.80	*DIST*	Distance from Coastal reference line (mi)
	44.2	*pptA*	Mean Annual Precipitation (inches)
	0.00	*SG*	Sand & Gravel Aquifer (decimal fraction of watershed area)

Month	Q_{median} (ft3/s)	(m^3/s)
Jan	**15.14**	0.4290
Feb	**16.44**	0.4658
Mar	**33.19**	0.9406
Apr	**37.77**	1.0702
May	**14.22**	0.4029
Jun	**8.19**	0.2322
Jul	**2.76**	0.0782
Aug	**1.87**	0.0531
Sep	**1.96**	0.0555
Oct	**3.41**	0.0967
Nov	**11.61**	0.3289
Dec	**19.15**	0.5426

Q_{bf}	**54.6**	
ann avg	**19.1**	
ann med	**9.7**	
$Q_{1.002}$	**57.3**	
$Q_{1.01}$	76.7	
$Q_{1.05}$	109.1	

W_{bf}	24.5	estimated bankfull width
d_{bf}	1.9	
Q_{bf}	186.4	assume v = 4ft/s



Project Name:	Machias Causeway	**PIN:**	16714
Stream Name:	Middle River	**Town:**	Machias
Bridge Name:	Dyke Bridge	**Bridge No.**	2246
Route No.	US 1	**USGS Quad:**	
Analysis by:	CSH	**Date:**	11/29/2011

Peak Flow Calculations by USGS Regression Equations (Hodgkins, 1999)

Enter data in blue cells only!

	km^2	mi^2	ac	*Enter data in [mi^2]*
A	34.24	13.22	8459.9	Watershed Area
W	5.25	2.03	1297.3	Wetlands area (by NWI)
P_c	620020	4956225		watershed centroid (E, N; UTM 19N; meters)
County	Washington			*choose county from drop-down menu*
pptA	44.2			mean annual precipitation (inches; by look-up)
SG	0.00			sand & gravel aquifer as decimal fraction of watershed A

Worksheet prepared by:
Charles S. Hebson, PE
Environmental Office
Maine Dept. Transportation
Augusta, ME 04333-0016
207-557-1052
Charles.Hebson@maine.gov

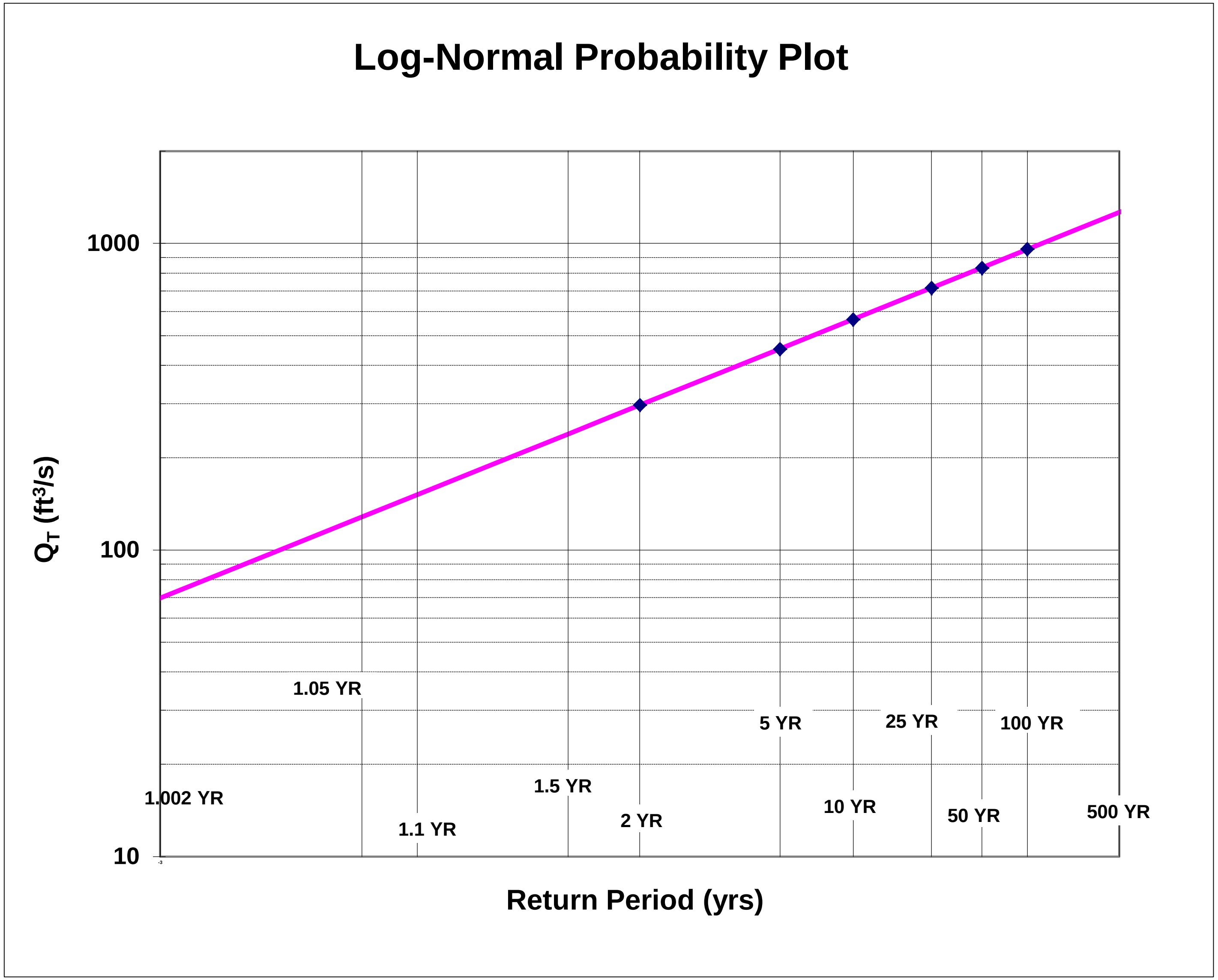
A (km^2)	34.24	**Conf Lvl**	0.67
W (%)	15.33		

Ret Pd T (yr)	**Peak Flow Estimate Lower**	**Q_T (m^3/s)**	**Upper**	**Q_T (ft^3/s)**
1.1		4.29		151.6
2	6.01	8.41	11.76	296.9
5	9.12	12.80	17.95	451.9
10	11.28	15.99	22.68	564.7
25	14.09	20.26	29.14	715.4
50	16.20	23.57	34.31	832.4
100	18.42	27.14	39.98	958.3
500	23.53	35.79	54.45	1263.9

Reference:

Hodgkins, G., 1999.
Estimating the magnitude of peak flows for streams
in Maine for selected recurrence intervals
Water-Resources Investigations Report 99-4008
US Geological Survey, Augusta, Maine

$Q_T = b \times A^a \times 10^{-wW}$


Log-Normal Probability Plot
1000
100
10
Q_T (ft³/s)
1.002 YR
1.05 YR
1.1 YR
1.5 YR
2 YR
5 YR
10 YR
25 YR
50 YR
100 YR
500 YR
Return Period (yrs)

Project Name:	Machias Causeway		**PIN:**	16714
Stream Name:	Middle River		**Town:**	Machias
Bridge Name:	Dyke Bridge		**Bridge No.**	2246
Route No.	US 1		**USGS Quad:**	
Analysis by:	CSH		**Date:**	11/29/2011

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MAINE MONTHLY MEDIAN FLOWS BY USGS REGRESSION EQUATIONS (2004)

Worksheet prepared by:
Charles S. Hebson, PE
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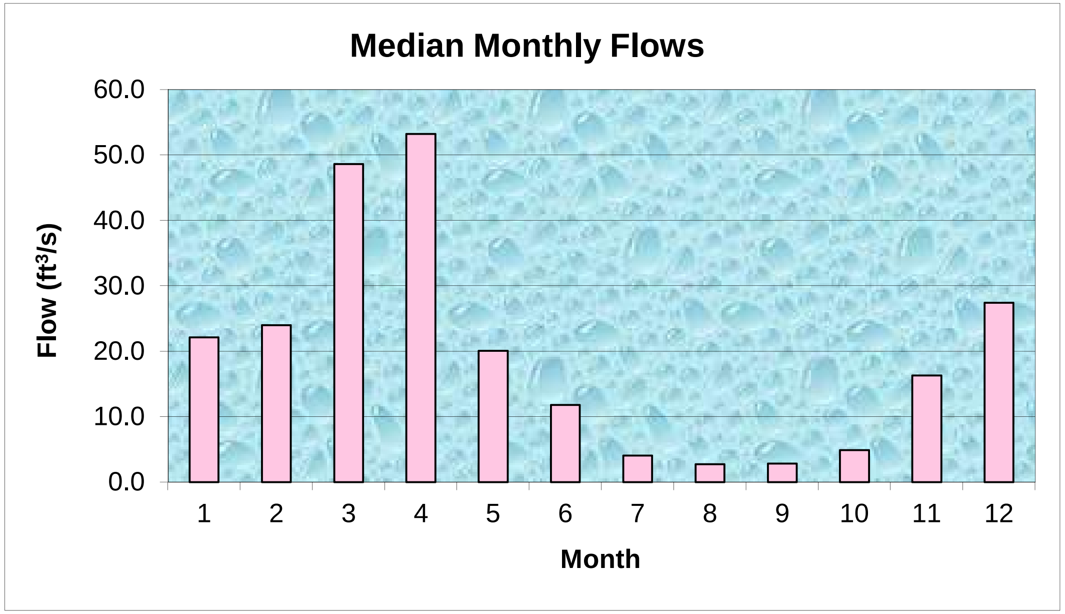
207-624-3073
Charles.Hebson@maine.gov

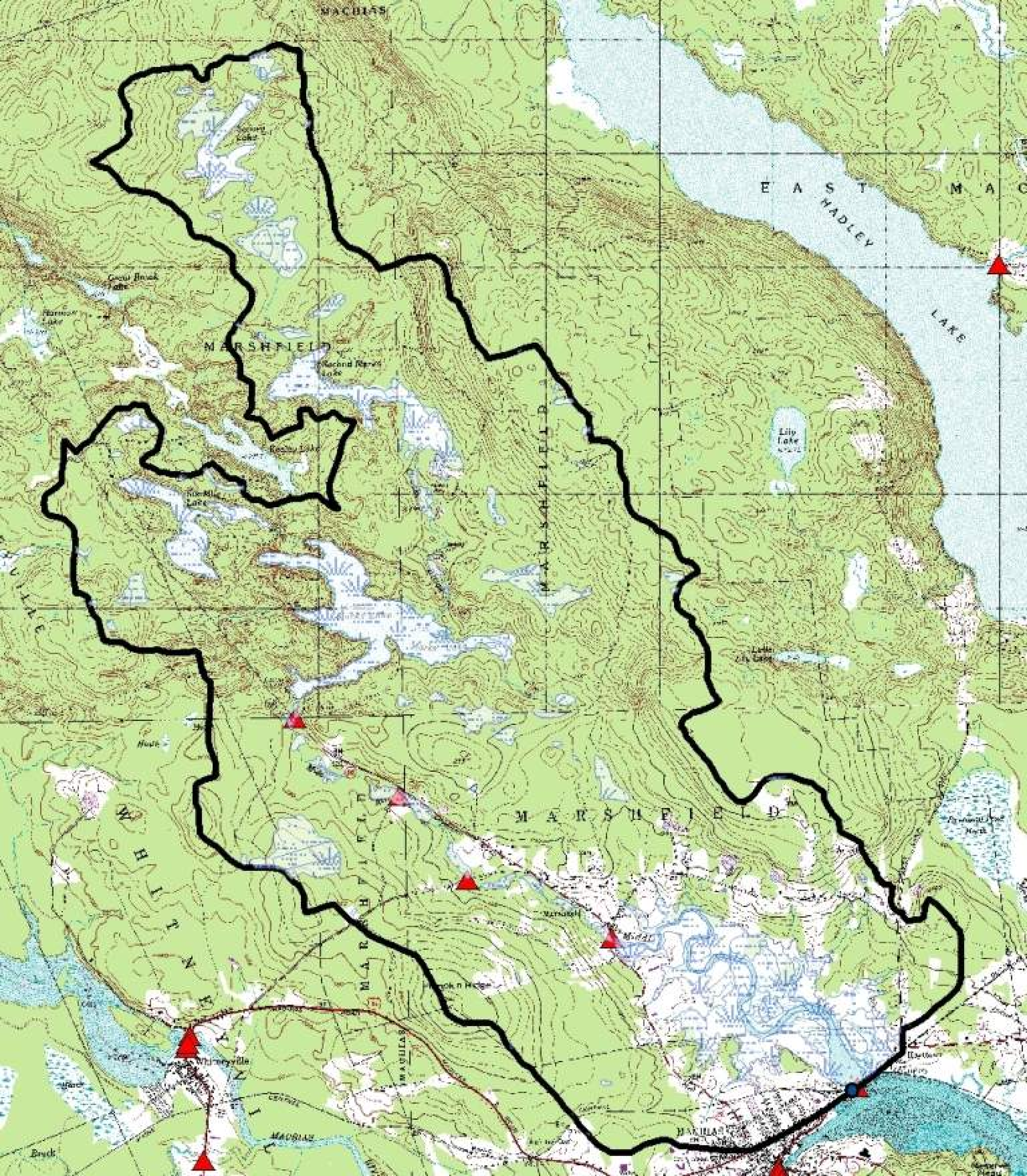
	Value	**Variable**	**Explanation**
	13.219	*A*	Area (mi^2)
620020	4956225	P_c	Watershed centroid (E,N; UTM; Zone 19; meters)
	30.65	*DIST*	Distance from Coastal reference line (mi)
	44.2	*pptA*	Mean Annual Precipitation (inches)
	0.00	*SG*	Sand & Gravel Aquifer (decimal fraction of watershed area)

Month	Q_{median} (ft3/s)	(m^3/s)
Jan	**22.14**	0.6273
Feb	**23.99**	0.6800
Mar	**48.61**	1.3775
Apr	**53.21**	1.5080
May	**20.10**	0.5696
Jun	**11.81**	0.3346
Jul	**4.08**	0.1156
Aug	**2.74**	0.0776
Sep	**2.84**	0.0805
Oct	**4.91**	0.1392
Nov	**16.32**	0.4625
Dec	**27.41**	0.7766

Q_{bf}	**78.1**
ann avg	**26.7**
ann med	**13.7**
$Q_{1.002}$	**69.7**
$Q_{1.01}$	91.8
$Q_{1.05}$	128.1

W_{bf}	29.2	estimated bankfull width
d_{bf}	2.3	
Q_{bf}	265.4	assume v = 4ft/s



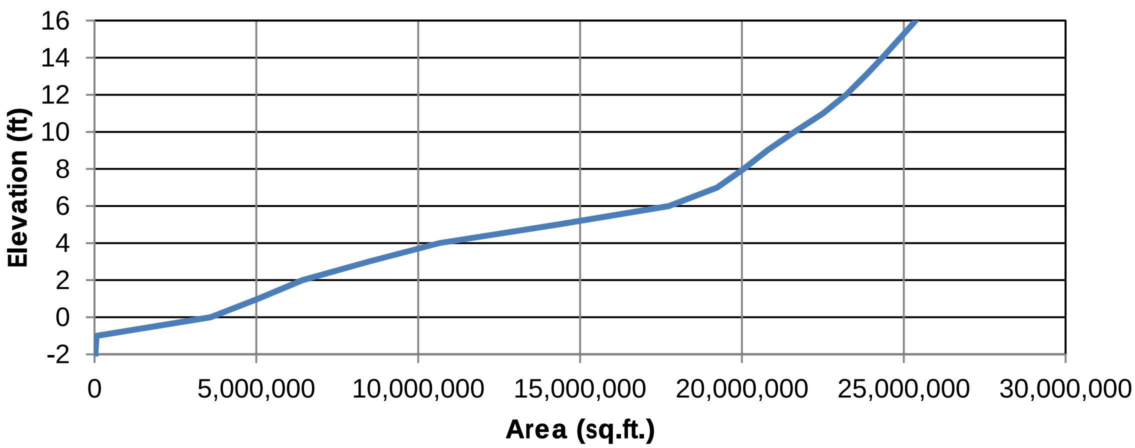


MACHIAS
EAST MAC
HADLEY
LAKE
MARSHFIELD
MARSHFIELD
MARSHFIELD
Lily Lake
WHITNEYVILLE
Whitneyville
MACHIAS

Appendix A :UPLAND HYDROLOGY

Appendix B: ELEVATION-AREA INFORMATION, MIDDLE RIVER LANDWARD FROM DYKE BRIDGE

Plot of Elevation-Area Data

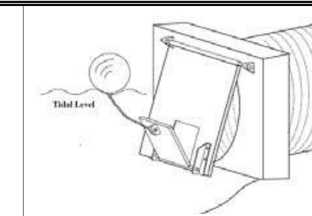
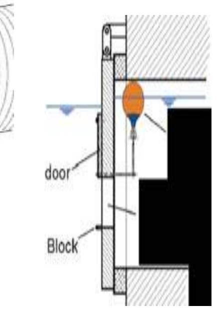
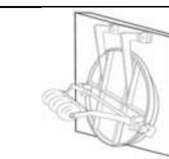
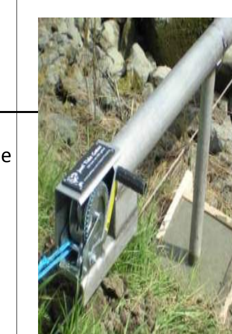


Tabular Elevation-Area Data

Elevation (ft NAVD88)	Area (sq. ft)	Area (acres)
-1	62,361	1.43
0	3,584,172	82.3
1	5,052,564	116
2	6,426,034	148
3	8,469,801	194
4	10,661,151	245
5	14,323,379	329
6	17,742,072	407
7	19,237,352	442
8	20,052,345	460
9	20,780,224	477
10	21,623,345	496
11	22,513,513	517
12	23,220,294	533
13	23,796,594	546
14	24,328,877	559
15	24,853,485	571
16	25,366,834	582

TYPE	MANUFACTURER	OPERATIONS	PASSIVE / ACTIVE	ALLOWS TIDAL FLUSHING?	ALLOWS US FISH PASSAGE?	GATE MATERIALS	PROS	CONS	NOTES	IMAGES (from manufacturers' websites)
TRADITIONAL TIDE GATES (most restrictive)										
Top-Hinged Tide Gate (THTG): cast iron and wood	Armtec (Hydro Gate), Golden Harvest, Waterman, Rodney Hunt	Round or square lid hinged at upper edge of pipe. Attached by single- or double-hinge system. Hydraulic head differential causes gate to open/close.	Passive (change in hydraulic head differential)	No (unless leaking or propped open)	Under limited range of flow conditions during ebb tide	Cast iron, wood (materials with higher restorative force)	Relatively simple, durable and reliable. Long lifespan. Efficient in preventing backflushing if sized, installed and maintained properly.	Landward impacts associated with impacts on tidal flushing, WSELs, AOP, water quality. Can trap floating debris (requiring maintenance). Conveyance reduced as weight to size ratio increases. Limited conveyance capacity and increased velocities at lower flows associated with reduced opening. THTGs expected to remain closed at least 50% of time. Heavier gates have higher restorative force resulting in 1) large hydraulic head differential required to open gate (resulting in opening only during brief period of ebb tide) and 2) increased velocity and turbulence through opening.	Traditionally, round THTGs are cast iron and rectangular THTGs are wood. Variable criteria in top-hinge flap gates include: opening size (e.g., radius), opening shape (e.g., round, rectangular), pivot radius (measured from top hinge), and duty (e.g., light/medium/heavy-duty).	
FISH-FRIENDLIER TIDE GATES (less restrictive)										
THTG: lighter materials	Golden Harvest, Nehalem Marine Manufacturing, Waterman, Rodney Hunt	Same as above.	Same as above	No (unless leaking or propped open)	Same as above	Aluminum, plastic, FRP, fiberglass (materials with lower restorative force)	Lighter materials may require significantly less hydraulic head differential to open in relation to THTGs made from traditional materials (e.g., cast iron, wood). Open for greater amount of time and with wider opening than heavier THTGs. Plastic and fiberglass gate may be less expensive than metal gates.	Lighter materials may not be as strong or durable, may include increased maintenance and repairs, are more easily damaged, and may have decreased lifespan. Landward impacts related to tidal flushing remain similar to THTGs constructed of heavier materials.		
THTG: radial	Unable to find current manufacturer.	Same as above.	Same as above	No (unless leaking or propped open)	Same as above	Spun aluminum	Lightweight and relatively inexpensive. Low restorative force.	Thin material can be vulnerable to damage from debris. Concave shape of gate may constrain passage of larger fish. Landward impacts related to tidal flushing remain similar to THTGs constructed of heavier materials.	Unable to find a current manufacturer of this style.	
THTG: flexible	Armtec (Hydro Gate), Plasti-Fab Inc.	Same as above.	Same as above	No (unless leaking or propped open)	Same as above	1"-thick neoprene cover mounted to steel frame	Quiet operations, low maintenance, low head loss, debris easily removed/flushed, no hinge pin wear points, no painting or lubrication required.	Flexible materials may be less durable. Landward impacts related to tidal flushing remain similar to THTGs constructed of heavier materials.	60" max width (per Hydro Gate).	
Duckbill	RedValve (Tideflex)	Opening is vertical slot (check valve) in stiff, yet deformable material mounted at DS end of pipe; default position of check valve is closed; deforms to open when hydraulic head differential is high enough.	Passive (change in hydraulic head differential)	No (unless leaking or propped open)	Thought to prevent US migration of some adult fish.	Flexible synthetic material	Simple, can be durable and reliable. Requires low hydraulic head differential to open valve. Can be self-cleaning (of debris). Flexible material may allow for formation of seal even around debris, allowing only minor leakage even when clogged with debris. Relative to DS flow, studies suggest performs equal to or better than THTGs.	Landward impacts associated with impacts on tidal flushing, WSELs, AOP, water quality. Small opening does not pass large debris; difficult to keep free from debris and debris removal can be difficult to remove. Potential for excessive head loss. Thought to allow downstream migration of juveniles but to prevent US migration of some adult fish.		

TYPE	MANUFACTURER	OPERATIONS	PASSIVE / ACTIVE	ALLOWS TIDAL FLUSHING?	ALLOWS US FISH PASSAGE?	GATE MATERIALS	PROS	CONS	NOTES	**IMAGES** (from manufacturers' websites)
FISH-FRIENDLIER TIDE GATES (less restrictive - *continued*)										
Motorized Slide Gate	Armtec (Hydro Gate), Waterman	Motorized vertical lift slide gate. Water levels monitored by sensors. Gate raises/lowers according to programmed parameters (e.g., water level elevations).	Active (Motorized vertical lift	Yes (depending on management)	Dependent on operations parameters	Metal	Allows for tidal flushing within desired parameters; allows for modification of parameters.	Requires electrical services at tide gate. Maintenance of motor, electrical supply and programming. Relatively complicated and expensive. Power outage can result in loss of control of gate.		
Manually Actuated Gate	Armtec (Hydro Gate), Plasti-Fab Inc., Rodney Hunt	Manually opened & closed. Approach can be applied to entire gate or to "trap door" within gate (see below).	Active (gate manually operated)	Yes (depending on management)	Dependent on operations parameters		Low cost	Requires manual operation / implementation of operational protocol.		
Side-Hinged Tide Gate (SHTG)	Armtec (Hydro Gate), Golden Harvest, Plasti-Fab Inc.	Top hinge installed closer to culvert opening than bottom hinge to create downward tilt which provides restorative force to enable gate to close at end of ebb tide.	Passive (change in hydraulic head differential)	No (unless leaking or propped open)	Under limited range of flow conditions during ebb tide	Wood, aluminum, stainless steel	Simple, can be durable and reliable, wide opening under lower flows (relative to THTGs), less likely to trap debris (compared to THTGs, duckbill style), reduced impingement hazard. Very small restorative force. Opens with smaller hydraulic head differential and stays open longer and wider than THTGs. Water velocities and turbulence through SHTGs are typically lower than through THTGs of similar size and weight. Increased opening duration and size (during ebb tide) reduces certain impacts associated with AOP, water quality and connectivity impacts relative to THTGs. Nehalem states SHTG capable of providing up to 30-40% more conveyance than THTG.	Landward impacts associated with impacts on tidal flushing, WSELs, AOP, water quality. Potential for increased wear on hinge mechanisms relative to THTGs. Support structure for gate is more difficult and costly to install. Angle of tilt must be set precisely and in such a way that it will not change over time.		 

TYPE	MANUFACTURER	OPERATIONS	PASSIVE / ACTIVE	ALLOWS TIDAL FLUSHING?	ALLOWS US FISH PASSAGE?	GATE MATERIALS	PROS	CONS	NOTES	**IMAGES** (from manufacturers' websites)
FISH FRIENDLIER GATE MODIFICATIONS (less restrictive)										
Pet Door / Trap Door (top-hinge, bottom-hinge, and side-hinge)	Nehalem Marine Manufacturing, Golden Harvest	Smaller gate placed within field of the tide gate. Smaller gate constructed to open with very low hydraulic head differential (lower than tide gate). Hinge may be mounted on top, bottom or side.	Passive (change in hydraulic head differential)	No (unless leaking or propped open); except Bottom-Hinged Trap Door which remains open for part of the flood tide.	Under limited range of flow conditions during ebb tide (and flood tide in case of bottom-hinged trap door)	Aluminum, plastic (materials with low restorative force)	Trap door requires lower hydraulic head differential to open (than tide gate on which it is mounted); may remain open for longer duration than gate; may improve flow and fish passage.	Trap door may clog with debris and may increase susceptibility of gate to debris jams.		 
Mitigator Fish Passage Device	Nehalem Marine Manufacturing	Floats mounted on gate rotate a block (cam) that props gate partially open during portion of rising tide. Can be mounted on THTG or on smaller aperture within larger gate (e.g., Pet Door).	Passive (change in hydraulic head differential)	Yes. Limited.	Under limited range of flow conditions during ebb tide and portion of flood tide.		Inexpensive and reliable.	Limited adjustability (opening limited to range of cam). Debris can foul float mount.	Size of cams determines size of opening during flood tide. Can be sized based on passage criteria of fish.	 
Permanent Hole		Permanent opening placed within field of larger tide gate. Allows for limited amount of bi-directional flow.	n/a	Yes. Limited.	Under appropriate flow conditions during ebb and flood tide.		Allows for limited tidal flushing, saltwater intrusion; may provide US and DS AOP through ebb and flood tides. May improve water quality, connectivity, AOP.	Uncontrolled opening.	Opening must be sized and located correctly to avoid/minimize high velocities and turbulence relative to fish passage criteria.	
Variable Backflow Flap Gate (VBFG)	Juel Tide Gates	Control mechanism retrofitted to SHTG or THTG. Gate closes on rising tide when "draft force" through culvert exceeds tension exerted by VBFG rigging device.	Passive (change in flow through culvert and hydraulic head differential)	Yes (within set parameters)	Under appropriate flow conditions during ebb and flood tide.		Appears to be a simple and relatively inexpensive retrofit.	Minimal information available for review (except promotional piece by the designer labeling the VBFG "ingenious").	Gate opens 80-90 degrees to headwall when WSEL at DS side of gate is ≤ WSEL at US side.	 

TYPE	MANUFACTURER	OPERATIONS	PASSIVE / ACTIVE	ALLOWS TIDAL FLUSHING?	ALLOWS US FISH PASSAGE?	GATE MATERIALS	PROS	CONS	NOTES	**IMAGES** (from manufacturers' websites)
SELF REGULATING TIDE GATES & SIMILAR (least restrictive)										
Buoyancy-Compensated THTG (SRT)	Waterman Industries, Golden Harvest	Gate is buoyant; rises with water level. Floats mounted to counterbalancing arm of gate frame are more buoyant than gate lid. Default position is open (gate floating on water). Position of floats controls WSEL "trip elevation" - WSEL at which gate closes on rising tide.	Passive (change in hydraulic head differential and WSEL)	Yes (within set parameters)	Under appropriate flow conditions during ebb and flood tides.		Relatively simple. Designed to remain open except when flood tide exceeds set elevation; allows tidal flushing within desired parameters. Relatively low maintenance. Because default position is open, may interfere least with fish passage.	Frame / floats can collect debris, affect operation and requiring maintenance. Float adjustment may be difficult and/or have limited range. During high flow events, submerged vent tubes may pass floodwater US. Gates may slam shut. Culvert may require vertical vents to prevent water hammer when gate closes. Cannot respond to FW elevs at US side (as compared to MTR [see below]).		
Muted Tidal Regulator (MTR)	Nehalem Marine Manufacturing	MTR unit mounts on US side of pipe in SHTG or THTG. Gate is closed by float located at US side of pipe. Control mechanism extends from float at US end to gate at DS end of pipe. During flood tide, gate remains open until target WSEL is reached at US side of pipe. Requires related infrastructure on both US and DS sides of pipe Closing is regulated by the WSEL at US side of the pipe - so can respond to conditions related to both tidal and FW flows/elevs.	Passive (change in WSEL at US side of pipe)	Yes (within set parameters)	Under appropriate flow conditions during ebb and flood tides.		Placement of MTR at US side of pipe allows for opening/closing of structure to respond to both landward and seaward WSELs (tidal & FW conditions); trip elevation is related to max elevation of backwater pool, not tidal elev., resulting in greater opportunity for connectivity, mixing, and passage. SHTG with MTR provides >50% more fish passage "time" relative to conventional THTG and SHTG applications (per Leo Kuntz). Kuntz states that failed SRTs are replaced with SHTG/MTR combos. Easily adjustable trip elevation.	Expensive. Includes many moving components.		  

Appendix D : SUMMARY OF HEC-RAS MODEL SETUP

Appendix D: Summary of HEC-RAS Model Setup

Bridge Geometry	Top of Roadway at Dyke Bridge (ft)	Dyke Bridge Geometry	Stride Bridge Geometry	Riverine Flow (cfs)	Tides (ft) (high/low)	SLR (m)	Surge (ft)	HEC-RAS Model Files		
								Geometry File	Flow file	Plan
Typical Tides, 1.1-year flow, SLR				**1.1-year**	**Recorded**			**Q1.1 Recorded Tides SLR varies**		
1-Existing	elev 11	Existing	TR=12	152 - steady	+9.0/-7.5	none	none	Alternative 1r rev.g21	Alternative 1 US Rules Q1p1 .u5	alt1rq1Tide1.p10
		4-4X5' boxes	inv -2.8/-2.5			0.5 m		Alternative 1r rev.g21	Alternative 1 US Rules Q1p1HSLR .u11	alt1rq1Tide1Hslr.p11
		w/ gates, inv -3.1	12.5' cmp			1m		Alternative 1r rev.g21	Alternative 1 US Rules Q1p1FSLR .u12	alt1rq1Tide1Fslr.p12
2-replace	elev 11	replace ex, gates	TR=12	152 - steady	+9.0/-7.5	none	none	Alternative 2r.g12	Alternative 2 US Rules Q1p1 .u13	Alt2 R1 Q1p13
		4-5X5 boxes,	inv -2.8/-2.5			0.5 m		Alternative 2r.g12	Alt 2 US Rules Q1p1HSLR .u14	Alt2 R1 Q1p1 HSLR.p14
		inv -4.05	12.5' cmp			1m		Alternative 2r.g12	Alt 2 US Rules Q1p1FSLR .u15	Alt2 R1 Q1p1 FSLR.p15
2 REV	elev 11	replace ex, gates	same	152 - steady	+9.0/-7.5	none	none	Alternative 2 REV 4 gates 1box.g22	.u51	alt 2 REV Q1 T1.p84
		4 flap gates, 1 open box				0.5 m		Alternative 2 REV 4 gates 1box.g22	.u53	alt 2 REV Q1 T1 HSLR.p79
		inv -4.05				1m		Alternative 2 REV 4 gates 1box.g22	.u54	alt 2 REV Q1 T1 FSLR.p85
5- 5 boxes	elev 11	5- 15HX12W' boxes	TR 17	152 - steady	+9.0/-7.5	none	none	Alternative 5r.g13	Alternatives5-6-7 Free FlowingQ1p1.u16	alt 5rQ1T1.p17
		bridge	invs -2.6/-2.5			0.5 m		Alternative 5r.g13	Alternatives5-6-7 Free FlowingQ1p1 HSLR.u1	alt5r Q1 T1 HSLR.p18
		inv = -5, n=.03	n=.015			1m		Alternative 5r.g13	Alternatives5-6-7 Free FlowingQ1p1 FSLR.u1	alt5r Q1 T1 FSLR.p19
6 - 60' span	elev 11	1- 60' span	TR=17	152 - steady	+9.0/-7.5	none	none	Alternative 6.g09	Alternatives5-6-7 Free FlowingQ1p1.u16	alt 6 Q1 T1.p20
		LC=9, TR=11	n=.028			0.5 m		Alternative 6.g09	Alternatives5-6-7 Free FlowingQ1p1 HSLR.u1	alt 6 Q1 T1 HSLR.p21
		invs -7.2/-8.0	invs -2.6/-2.5			1m		Alternative 6.g09	Alternatives5-6-7 Free FlowingQ1p1 FSLR.u1	alt 6 Q1 T1 FSLT.p22
Typical Tides, 50-year flow, SLR				**50-year**	**Recorded**			**Q50**		
1-Existing	elev 11	Existing	TR=12	824 steady	+9.0/-7.5	none	none	Alternative 1r rev.g21	Alternative 1 US rules R Q50.u9	atr1r Q50 T1.p23
		4-4X5' boxes	inv -2.8/-2.5	Hydrograph	+9.0/-7.5	none	none	Alternative 1r rev.g21	Alternative 1 US rules R Q50Hydrograph.u1	alt1r q50HYD-T1.p24
		w/ gates, inv -3.1	12.5' cmp	Hydrograph		0.5 m		Alternative 1r rev.g21	Alternative 1 US rules R Q50Hyd- HSLR.u19	alt 1r q50HYD-T1HSLR.p25
				Hydrograph		1m		Alternative 1r.g11	Alternative 1 US rules R Q50Hyd-FSLR.u20	1r q50HYD-T1FSLR.p26
2-replace	elev 11	replace ex, gates	TR=12	Hydrograph	+9.0/-7.5	none	none	Alternative 2r.g12	Alternative 2 US Rules R Q50HYD p1 .u21	Alt2 R1 Q50HYD T1.p28
		4-5X5 boxes,	inv -2.8/-2.5	Hydrograph		0.5 m		Alternative 2r.g12	Alternative 2 R q50HYD T1 HSLR.u22	alt2 q50 HYD T1 HLSR.p29
		inv -4.05	12.5' cmp	Hydrograph		1m		Alternative 2r.g12	alt2R Q50HYD T1 FSLR.u23	alt2 q50 HYD T1 FLSR.p30
2 REV	elev 11	replace ex, gates	same	Hydrograph	+9.0/-7.5	none	none	Alternative 2 REV 4 gates 1box.g22	alt 2REV T50 Q1. u55	alt 2 rev T50 Q1.p89
		4 flap gates, 1 open box		Hydrograph		0.5 m		Alternative 2 REV 4 gates 1box.g22		
		inv -4.05		Hydrograph		1m		Alternative 2 REV 4 gates 1box.g22		
5- 5 boxes	elev 11	5- 15HX12W' boxes	TR 17	Hydrograph	+9.0/-7.5	none	none	Alternative 5r.g13	Alternatives 5-6-7 Q50HYD T1.u24	alt5 Q50HYD T1.p31
		bridge	invs -2.6/-2.5	Hydrograph		0.5 m		Alternative 5r.g13	Alternatives 5-6-7 Q50HYD T1 HSLR.u25	alt5 Q50HYD T1 HSLR.p32
		inv = -5, n=.03	n=.015	Hydrograph		1m		Alternative 5r.g13	Alternatives 5-6-7 Q50HYD T1 FSLR.u26	alt5 Q50HYD T1 FSLR.p33
6 - 60' span	elev 11	1- 60' span	TR=17	Hydrograph	+9.0/-7.5	none	none	Alternative 6.g09	Alternatives 5-6-7 Q50HYD T1.u24	alt6 Q50HYD T1.p34
		LC=9, TR=11	n=.028	Hydrograph		0.5 m		Alternative 6.g09	Alternatives 5-6-7 Q50HYD T1 HSLR.u25	alt6 Q50HYD T1 HSLR.p35
		invs -7.2/-8.0	invs -2.6/-2.5	Hydrograph		1m		Alternative 6.g09	Alternatives 5-6-7 Q50HYD T1 FSLR.u26	alt6 Q50HYD T1 FSLR.p36
Typical Tides, 100-year flows, plus SLR				**100-year**	**Recorded**			**Q100**		
1-Existing	elev 11	Existing	TR=12	958 -steady	+9.0/-7.5	none	none	Alternative 1r rev.g21	Alternative 1 US rules R Q100.u27	atr1r Q100 T1.p37
		4-4X5' boxes	inv -2.8/-2.5	958 hydrograph	+9.0/-7.5	.5 m		Alternative 1r rev.g21	Alternative 1 R Q100Hyd T1.u28	alt1r q100HYD-T1.p38
		w/ gates, inv -3.1	12.5' cmp	Hydrograph		1 m		Alternative 1r rev.g21	Alternative 1 R Q100Hyd T1HSLR.u36	alt1r q100HYD-T1HSLR.p52
				Hydrograph		1m		Alternative 1r rev.g21	Alternative 1 R Q100Hyd T1FSLR.u37	alt1r q100HYD-T1FSLR.p53
2-replace	elev 11	replace ex, gates	TR=12	Hydrograph	+9.0/-7.5	none	none	Alternative 2r.g12	Alternative 2 US Rules R Q100HYD p1 .u29	Alt2 R1 Q100HYD T1.p39
		4-5X5 boxes,	inv -2.8/-2.5	Hydrograph		0.5 m		Alternative 2r.g12	lternative 2 US Rules R Q100HYD t1 HSLR .u3	Alt2 R1 Q100HYD T1 HSLR.p54
		inv -4.05	12.5' cmp	Hydrograph		1m		Alternative 2r.g12	lternative 2 US Rules R Q100HYD T1 FSLR .u3	Alt2 R1 Q100HYD T1 FSLR.p55
2 REV	elev 11	replace ex, gates	same	Hydrograph	+9.0/-7.5	none	none	Alternative 2 REV 4 gates 1box.g22	Alt 2 REV q100 T1.u56	Alt 2 REV Q100 T1. p81
		4 flap gates, 1 open box		Hydrograph		0.5 m		Alternative 2 REV 4 gates 1box.g22		
		inv -4.05		Hydrograph		1m		Alternative 2 REV 4 gates 1box.g22		
5- 5 boxes	elev 11	5- 15HX12W' boxes	TR 17	Hydrograph	+9.0/-7.5	none	none	Alternative 5r.g13	Alternatives 5-6-7 Q100HYD T1.u30	alt5 Q100HYD T1.p40
		bridge	invs -2.6/-2.5	Hydrograph		0.5 m		Alternative 5r.g13	" HSLR.u40	" HSLR.p01
		inv = -5, n=.03	n=.015	Hydrograph		1m		Alternative 5r.g13	" FSLR.u41	" FSLR.p57
6 - 60' span	elev 11	1- 60' span	TR=17	Hydrograph	+9.0/-7.5	none	none	Alternative 6.g09	Alternatives 5-6-7 Q100HYD T1.u30	alt5 Q100HYD T1 FSLR.p41
		LC=9, TR=11	n=.028	Hydrograph		0.5 m		Alternative 6.g09	"HSLR.u40	" HSLR.p58
		invs -7.2/-8.0	invs -2.6/-2.5	Hydrograph		1m		Alternative 6.g09	" FSLR.u41	" FSLR.p59

Appendix D: Summary of HEC-RAS Model Setup (Continued)

Bridge Geometry	Top of Roadway at Dyke Bridge (ft)	Dyke Bridge Geometry	Stride Bridge Geometry	Riverine Flow (cfs)	Tides (ft) (high/low)	SLR (m)	Surge (ft)	HEC-RAS Model Files		
								Geometry File	Flow file	Plan
High Spring Tide plus Surge, 1.1-year flow, plus SLR				**1.1year**	**Spring tides**		**2.5' surge**	**Q1.1 50-year SURGE at HIGH TIDE SLR varies**		
1-Existing	elev 11	Existing	TR=12	1.1-year	7.3/-6.9	none	2.5	Alternative 1r rev.g21	Alternative1_Cat50yr_Q1H.u04	Alt 1r 50Tide Q1H.p42
		4-4X5' boxes	inv -2.8/-2.5	steady		0.5 m		Alternative 1r rev.g21	" HSLR.u44	" HSLR.p88
		w/ gates, inv -3.1	12.5' cmp			1m		Alternative 1r rev.g21	" FSLR.u45	" FSLR.p78
2-replace	elev 11	replace ex, gates	TR=12	1.1-year	7.3/-6.9	none	2.5	Alternative 2r.g12	Alternatives2r_Cat50yr_Q1p1_H.u06	alt2r 50yrtide q1 surgeathigh.p43
		4-5X5 boxes,	inv -2.8/-2.5			0.5 m		Alternative 2r.g12	" HSLR.u46	" HSLR.p16
		inv -4.05	12.5' cmp			1m		Alternative 2r.g12	" FSLR.u47	" FSLR.p56
2 REV	elev 11	replace ex, gates	same	1.1-year	7.3/-6.9	none	2.5	Alternative 2 REV 4 gates 1box.g22	Alt 2 REV q1 T50.u57	alt2REV q1 T50.p90
		4 flap gates, 1 open box				0.5 m		Alternative 2 REV 4 gates 1box.g22	Alt 2 REV q1 T50 HSLR.u58	alt 2 REV q1 T50 HSLR.p91
		inv -4.05				1m		Alternative 2 REV 4 gates 1box.g22	Alt 2 REV q1 T50 FSLR.u59	alt 2 REV q1 T50 FSLR.p92
5- 5 boxes	elev 11	5- 15HX12W' boxes	TR 17	1.1-year	7.3/-6.9	none	2.5	Alternative 5r.g13	Alternatives5r_Cat50yr_Q1p1_H.u03	alt5r 50yrtide q1 surgeathigh.p44
		bridge	invs -2.6/-2.5			0.5 m		Alternative 5r.g13	" HSLR.u43	" HSLR.p03
		inv = -5, n=.03	n=.015			1m		Alternative 5r.g13	"FSLR.u42	" FSLR.p02
6 - 60' span	elev 11	1- 60' span	TR=17	1.1-year	7.3/-6.9	none	2.5	Aternative 6.g09	Alternatives6_Cat50yr_Q1p1_H.u03	alt6 50yrtide q1 surgeathigh.p45
		LC=9, TR=11	n=.028			0.5 m		Aternative 6.g09	" HSLR.u43	" HSLR.p60
		invs -7.2/-8.0	invs -2.6/-2.5			1 m		Aternative 6.g09	" FSLR.u42	" FSLR.p61
1-Existing	Existing	Existing	Existing	1.1-year	7.3/-6.9	none	MR	Alternative 1r rev.g21	alternative1_Cat50yr_Q1MF.u031	alt 1r 50Tide Q1 surgeatMFT.p46
				steady		none	MF	Alternative 1r rev.g21	alternative1_Cat50yr_Q1ME.u032	alt 1r 50Tide Q1 surgeatME.p47
						none	L	Alternative 1r rev.g21	alternative1_Cat50yr_Q1L.u033	alt 1r 50Tide Q1 surgeatL.p48
2-replace	Same as Exist.	Same as Exist.	no change	1.1-year	7.3/-6.9	none	MR	Alternative 2r.g12	Alternatives2r_Cat50yr_Q1p1_MF.u34	alt2r 50T Q1 surge at MF tide.p49
						none	MF	Alternative 2r.g12	ME	ME
						none	L	Alternative 2r.g12	L	L
5- 5 boxes	Same as Exist.	5- 15' boxes	no change	1.1-year	7.3/-6.9	none	MR	Alternative 5r.g13	Alternatives5-6-7_Cat50yr_Q1p1_MF.u34	alt5r 50T Q1 surge at MF tide.p50
						none	MF	Alternative 5r.g13	ME	ME
						none	L	Alternative 5r.g13	L	L
6 - 60' span	Same as Exist.	1- 60' span	no change	1.1-year	7.3/-6.9	none	MR	Aternative 6.g09	Alternatives5-6-7_Cat50yr_Q1p1_MF.u35	alt6 50T Q1 surge at MF tide.p51
						0.5 m	MF	Aternative 6.g09	HSLR	HSLR
						1m	L	Aternative 6.g09	FSLR	FSLR
Typical Tides, Flows Vary, Dyke BR and Stride BR Alternatives				**1.1-year**	**Recorded**			**High Causeway at Route 1 plus check slip lined Stridge Bridge Q1.1, Q50, Q100 with Recorded Tide and SLR**		
6 - 60' span	**14.7'**	1- 60' span	no change	1.1-year	9/-7.5	1m	none	Alternative 6 elev14p7.g08	Alternatives 5-6-7FreeflowingQ1p1FSLR.u18	alt6 14p7 Q1T1FSLR.p62
6 - 60' span	**14.7'**	1- 60' span	**slip lined**	1.1-year	9/-7.5	1m		Alternative 6 elev14p7 slipline stride.g18	Alternatives 5-6-7FreeflowingQ1p1FSLR.u18	alt6 14p7 SL Q1T1FSLR.p63
6 - 60' span	**14.7'**	1- 60' span	no change	**50-year**	9/-7.5	none	none	Alternative 6 elev14p7.g08	Alternatives 5-6-7 Q50 T1.u24	
				Hydrograph		0.5 m		Alternative 6 elev14p7.g08	Alternatives 5-6-7 Q50 T1 HSLR.u25	
						1m		Alternative 6 elev14p7.g08	alt 5-6-7 Q50HYD T1 FSLR.u26	alt6 14p7 Q50 T1 FSLR.p64
6 - 60' span	**14.7'**	1- 60' span	no change	**100-year**	9/-7.5	none	none	Alternative 6 elev14p7.g08	alternatives 5-6-7 100HYD T1.u30	
				Hydrograph		0.5 m		Alternative 6 elev14p7.g08	"HSLR.u40	
						1m		Alternative 6 elev14p7.g08	" FSLR.u41	alt 6 14p7 Q100 T1 FSLR.p65
6 - 60' span	**14.7'**	1- 60' span	**slip lined**	**50-year**	9/-7.5	none	none	Alternative 6 elev14p7 slipline stride.g18	Alternatives 5-6-7 Q50 T1.u24	alt 6 14p7 SL Q50 T1.p66
				Hydrograph		0.5 m		Alternative 6 elev14p7 slipline stride.g18	Alternatives 5-6-7 Q50 T1 HSLR.u25	" HSLR.p67
						1m		Alternative 6 elev14p7 slipline stride.g18	alt 5-6-7 Q50HYD T1 FSLR.u26	" FSLR.p68
6 - 60' span	**14.7'**	1- 60' span	**slip lined**	**100-year**	9/-7.5	none	none	Alternative 6 elev14p7 slipline stride.g18	alternatives 5-6-7 100HYD T1.u30	alt6 14p7 SL Q100 T1.p69
				Hydrograph		0.5 m		Alternative 6 elev14p7 slipline stride.g18	"HSLR.u40	" HSLR.p70
						1m		Alternative 6 elev14p7 slipline stride.g18	" FSLR.u41	" FSLR.p71

Appendix D: Summary of HEC-RAS Model Setup (Continued)

Bridge Geometry	Top of Roadway at Dyke Bridge (ft)	Dyke Bridge Geometry	Stride Bridge Geometry	Riverine Flow (cfs)	Tides (ft) (high/low)	SLR (m)	Surge (ft)	HEC-RAS Model Files: Geometry File	HEC-RAS Model Files: Flow file	HEC-RAS Model Files: Plan
Storm Surge Tides, 1.1-year flows, plus SLR, Dyke/Stride options					**Spring**			**High Causeway at Route 1 plus check slip lined Stridge Bridge 50-year SURGE at High Spring Tide plus SLR**		
6 - 60' span	**14.7'**	1- 60' span	no change	**1.1-year**	7.3/-6.9	none	2.5	Alternative 6 elev14p7.g08	Alternatives6_Cat50yr_Q1p1_H.u03	alt 6 14p7 Q1 T50.p72
						0.5 m		Alternative 6 elev14p7.g08	" HSLR.u43	alt 6 14p7 Q1 T50 HSLR.p73
						1m		Alternative 6 elev14p7.g08	" FSLR.u42	alt 6 14p7 Q1 T50 FSLR.p74
Case 6 - 60' span	**14.7'**	1- 60' span	no change	**1.1-year**	7.3/-6.9	none	2.5	Alternative 6 elev14p7.g08		
						0.5 m		Alternative 6 elev14p7.g08		
						1m		Alternative 6 elev14p7.g08		
Case 6 - 60' span	**14.7'**	1- 60' span	**slip lined**	1.1-year	7.3/-6.9	none	2.5	Alternative 6 elev14p7 slipline stride.g18	Alternatives6_Cat50yr_Q1p1_H.u03	alt6 14p7 SL Q1 T50H.p76
						0.5 m		Alternative 6 elev14p7 slipline stride.g18	" HSLR.u43	alt6 14p7 SL Q1 T50H HSLR.p75
						1 m		Alternative 6 elev14p7 slipline stride.g18	" FSLR.u42	alt6 14p7 SL Q1 T50H FSLR.p77
Case 6 - 60' span	**14.7'**	1- 60' span	**slip lined**	1.1-year	7.3/-6.9	none	2.5	Alternative 6 elev14p7 slipline stride.g18		
						0.5 m		Alternative 6 elev14p7 slipline stride.g18		
						1 m		Alternative 6 elev14p7 slipline stride.g18		
Calibration Model Runs				**20 cfs**	**Recorded**					
Case 1	11	Existing	TR=12		+9.0/-7.5	none	none	Alternative 1r-rev.g21	Alt 1 rules rev.u52	Alt 1r gates 20 cfs T1.p87
		4-4X5' boxes	inv -2.8/-2.5							
		w/ gates, inv -3.1	12.5' cmp							
Case 1	11	Existing	TR=12		+9.0/-7.5	none	none	Alt 1 no gates.g20	Alternative 1 no gates 20 cfs T1.u50	alt 1 q20 T1 no gates.p86
		4-4X5' boxes	inv -2.8/-2.5							
		NO gates, inv -3.1	12.5' cmp							
Alt 2 Replacement in kind options										
Alt 2 4 flap gates, 1 open box		4 5X5 flap gates	TR=12	20	+9.0/-7.5	none	none	Alternative 2 REV 4 gates 1box.g22	alternative 2 REV no rules Q20T1.u61	alt2 4 flapgates 1 open box Q20cfsT1.p82
	11	one open 5X5	inv -2.8/-2.5	152				Alternative 2 REV 4 gates 1box.g22	alternative 2 REV no rules Q1T1.u51	alt2 4 flapgates 1 open box Q1cfsT1.p80
		inv -4.05	12.5' cmp							
alt 2 3 flaps 1 open		3 5X5 flap gates	TR=12	20	+9.0/-7.5	none	none	Alternative 2 3 flap gates 1 open.g02	alternative 2 REV no rules Q20T1.u61	alt2 3 flapgates 1 open box Q20cfsT1.p04
		one open 5X5	inv -2.8/-2.5	152				Alternative 2 3 flap gates 1 open.g02	alternative 2 REV no rules Q1T1.u51	alt2 3 flapgates 1 open box Q1cfsT1.p83
		inv -4.05	12.5' cmp							
alt 2 2 flaps 1 open		2 5X5 flap gates	TR=12	20	+9.0/-7.5	none	none	alternative 2 2 flap gates 2 open.g03	alternative 2 REV no rules Q20T1.u61	alt2 2 flapgates 2 open box Q20cfsT1.p27
		two open 5X5	inv -2.8/-2.5	152					alternative 2 REV no rules Q1T1.u51	alt2 2 flapgates 2 open box Q1T1.p06

Appendix E: MEMO ON STRIDE BRIDGE REHABILITATION AND REPLACEMENT OPTIONS

Stantec

Memo

To:	Michael Chelminski	From:	Tim Merritt
	Topsham ME Office		Scarborough ME Office
File:	195600963, Task 208	Date:	January 22, 2015

Reference: MaineDOT Stride Bridge – Rehab & Replacement Options

The following is a memo describing the rehab and replacement options for the Stride Bridge for your review/use:

STRIDE BRIDGE

Stride Bridge is located on the Middle River in Marshfield, Maine, and is comprised of a corrugated metal pipe (CMP) with a diameter of 12.5 feet (ft) that is approximately 40 ft long and mitered to the upstream and downstream slopes of the roadway embankment. The upstream and downstream invert elevations[1] of the culvert are -2.58 ft and -2.48 ft, respectively.

Hydraulic Conditions In the Middle River

Hydraulic conditions at Stride Bridge are affected by upland (riverine) flow and backwater conditions that propagate upstream from the downstream reach of the Middle River, including effects associated with regulation of landward tidal flow at Dyke Bridge. Peak riverine flows in the Middle River at Stride Bridge and Dyke Bridge were provided by MaineDOT and are provided in Table 1.

Table 1: Peak Flows

	Return-Interval Event (Years)/ Peak Flow (cfs)							
Location	***1.1***	***2***	***5***	***10***	***25***	***50***	***100***	***500***
Stride Bridge	130	265	213	522	670	787	912	1,221
Dyke Bridge	152	297	452	565	715	832	958	1,264

Dyke Bridge is approximately 15,000 ft downstream (seaward) from Stride Bridge, and is comprised of a causeway with four box culverts that crosses the Middle River immediately upstream (landward[2]) from its confluence with the Machias River. Hydraulic conveyance at the Dyke Bridge is provided by four 5 ft x 5 ft box culverts with invert elevations of approximately -4 ft that have flap gates installed on the downstream (seaward) side of the culverts. The flap gates restrict landward tidal flow while allowing for downstream (seaward) flow of upland runoff from the Middle River.

[1] Elevations provided by Maine DOT and referenced to the North American Vertical Datum of 1988 (NAVD88).
[2] "Landward" and "seaward" are used in addition to "upstream" and "downstream", respectively, to reflect bi-directional flow associated with tidal conditions in the Machias River.

Reference: MaineDOT Stride Bridge – Rehab and Replacement Options

The Machias River is tidally influenced immediately seaward from Dike Bridge; and Tidal stage parameters for the Machias River were developed for this study using data collected by Maine DOT; these statistics are presented in Table 1.

Table 2: Tidal Statistics for Machias River

Tidal Data (ft, NAVD88)						
Max.	**MHHW**	**MHW**	**Average**	**MLW**	**MLLW**	**Min.**
11.7	**9.3**	**8.4**	**2.0**	**-4.5**	**-4.8**	**-5.5**

Tidal stage data collected by Maine DOT in the Middle River immediately upstream (landward) from Dyke Bridge indicates that the normal tidal range is from elevation -0.5 (normal high tide) to elevation -2.0 (normal low tide).

Backwater effects associated with the existing tide gate system at Dyke Bridge result in persistent backwater effects in the upstream reach of the Middle River and minimum water surface elevations (approximately elevation -2.0 ft) that are above the invert of the Stride Bridge culvert.

BRIDGE REHABILITATION OPTIONS

As requested by Maine DOT, the evaluated rehabilitation options for the Stride Bridge are invert lining and sliplining.

The top half of existing culvert appears to be in good condition and the bottom half is corroding so invert lining could be appropriate for this structure. There have been several MaineDOT invert lining projects in the past several years and they generally consist of a 5 to 6 inch reinforced slab cast against the lower half of the corrugated metal pipe (CMP) with shear studs welded along the sides of the pipe to transfer load from the existing CMP to the new concrete invert lining. The exposed steel portion could also be coated or painted to help prolong the life of the structure. Invert lining would maintain the structural integrity of the original design as the lower portion continues to corrode and the MaineDOT Bridge Design Guide (BDG) estimates that it would extend the life of the structure for 25 years or more. The structural capacity would need to be evaluated further for this alternative, as the current bridge rating is below current AASHTO design loads.

Sliplining would be a longer term rehabilitation option where a slightly smaller pipe would be placed inside the existing and the space between would be filled with grout. The estimated life span of a sliplining, according to the BDG would be 75 years, as it is a complete replacement with a new pipe.

The main concerns with these rehabilitation alternatives are the following:

- The existing roadway width is only 23' wide and sliplining or invert lining would not allow for any roadway widening;
- The hydraulic opening would be reduced;
- Fish passage may not be adequate.

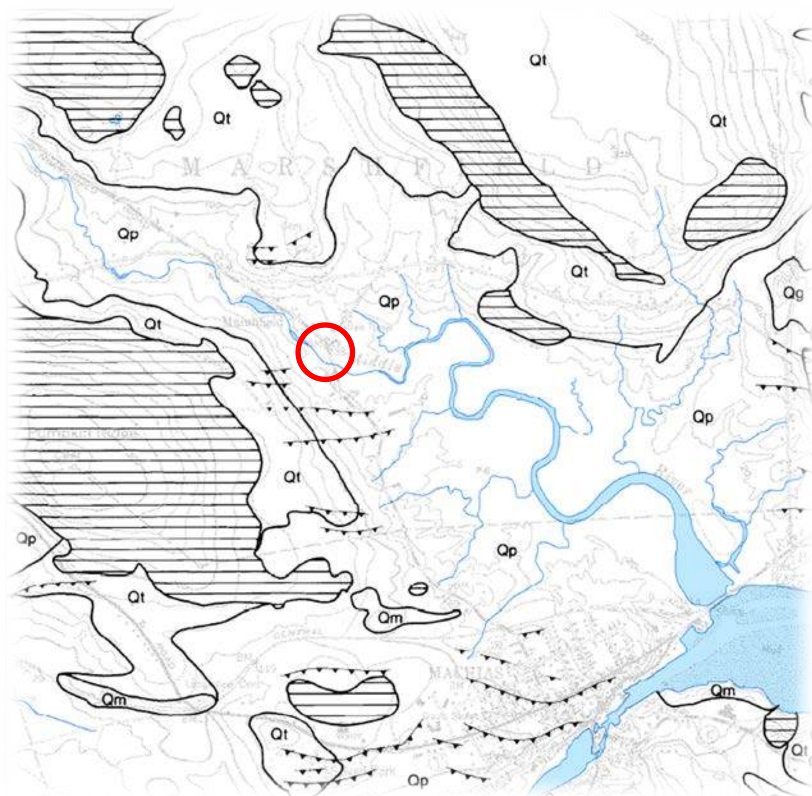
Reference: MaineDOT Stride Bridge – Rehab and Replacement Options

BRIDGE REPLACEMENT OPTIONS

Replacement bridge alternatives for the Stride Bridge will depend on the actual subsurface information at the site and depth to bedrock. If bedrock is shallow, tall cantilever abutments bearing directly on bedrock could be used with a short superstructure just long enough to provide bankfull width plus the design safety factor. If the bedrock is very deep, integral or spill-through abutments with riprap protection sloping towards the channel would likely be needed and the superstructure would be a much longer span.

The Maine Geological Survey website has surficial geology maps available of the site which show "Qp" soils at the surface with bedrock outcrops (shown hatched) nearby, see Figure 1. The "Qp" designation indicates that Stride Bridge is on a silt and clay deposit, so the longer span integral or spill-through abutment alternative is the likely alternative, however site specific borings would be required to confirm how deep this layer is.

http://www.maine.gov/dacf/mgs/pubs/online/surficial/surficial.htm



Qps / Qp	Glacial-marine deposits (Presumpscot Formation)

Silt, clay, and sand. Commonly a clayey silt, but sand is very abundant at the surface in some places. Locally fossiliferous. Map unit includes small areas of till, sand, and gravel that are not completely covered by marine sediment.

Qps: Mostly sand, but may be underlain by silt and clay. Moderate to high permeability. Fair to good drainage.

Qp : Mostly silt and clay. Low permeability. Poor drainage.

Figure 1 Clip from Maine Geological Survey's *Reconnaissance Surficial Geology of the Machias Quadrangle, Maine* by Harold Borns, Jr. 1974.

The following are conceptual bridge replacement options for two different subsurface conditions:

Reference: MaineDOT Stride Bridge – Rehab and Replacement Options

1. **Shallow Bedrock @ 1.2x Bankfull Width with Vertical Abutments**: Full-height cantilever abutments at 1.2-times bankfull width (37' face-to-face). The superstructure would likely be 21" voided slabs with a varying leveling slab up to 6", spanning 40' bearing-to-bearing, similar to Fryeburg WIN 17872.00. The structure depth at the center of road would be about 30". The low chord of the bridge should have a minimum 2' freeboard from the Q10 water surface elevation (based on MHW) including wave heights, as described in the BDG.
    a. A precast concrete arch, such as a Conspan ®, could also be used with full-height abutments, but are not recommended due to the smaller hydraulic opening.
2. **Deep Foundation @ 1.2x Bankfull Width with Sloped Abutments:** Integral or spill-through abutments with sloping riprap (1.5H:1V) protection towards the channel. If the toe of riprap is at the edge of 1.2-times bankfull width and a 2'-6" shelf is provided in front of the abutment the span would be at least 76' (73' face-to-face abutments). NEXT beams or butted box beams would be the likely beam type for spans in this range. 36" NEXT F-beams with an 8" deck and 3" wearing surface would put the structure depth around 52", accounting for cross-slope. Similar to the first alternative 2' of freeboard should be provided over the Q10, which may require a significant profile raise.
3. **Deep Foundation @ 1.0x Bankfull Width with Sloped Abutments:** Similar to alternative 2, but starting the toe of riprap at bankfull width, since the sloping riprap provides much more hydraulic opening over the full-height cantilever abutment alternative. It would drop the span to around 70' and would likely reduce the structure depth to 48", by using a 32" NEXT beam vs. 36".

Based on the available information it has been assumed that no underground utilities exist in the immediate vicinity of Stride Bridge.

STANTEC CONSULTING SERVICES INC.

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Daniel.Taylor@stantec.com

DOWNEAST SALMON FEDERATION

Schoppee Marsh Feasibility Study RFP Information

Note: The following pages are included for reference only and included with permission from The Downeast Salmon Federation. Please contact Downeast Salmon Federation directly for any questions related to the data included herein.

DOWNEAST SALMON FEDERATION

2021 Request for Proposals for Feasibility Study

The Schoppee Marsh restoration project plans to restore full tidal flows and full fish access to Schoppee Marsh, a 40-acre salt marsh at the head of Machias Bay. Tidal flows into the marsh were restricted in the early 1900s when a railroad was built between it and the bay. A single 42-inch diameter culvert with a top hinge tide gate preventing salt water from entering but allowing water to exit the marsh was built through the railroad bed. The only saltwater to enter the marsh flows from an adjoining marsh over a height of land at high tide. The volume of saltwater flowing from the adjoining marsh is not enough to fully flood Schoppee and, at lower high tides, when the top of the tide is below the height of land, no water at all gets into Schoppee. The drain culvert is unable—due to size or placement—to fully drain the marsh so that water backs up behind the railroad bed between tides.

Although some saltwater is flooding the marsh, it is effectively inaccessible to fish. None of the benefits that a salt marsh provides—food, protection from predators, spawning and rearing habitat—are available to resident or migrating fish.

A preliminary hydrological survey (done by the US Fish and Wildlife Service and the Downeast Salmon Federation (DSF)) of the marsh indicates that the marsh bed has subsided. Non-salt marsh plants have colonized some areas and large areas have reverted to mudflats and are devoid of any plant life due the impaired hydrology—unlike the adjoining marsh which, with full tidal flows, is lush with salt marsh grasses and other halophilic plants.

Work to be done: The restoration project will include the following tasks:

1. Feasibility study to determine all that needs to be done to fully restore the marsh—including the necessary volume of the tidal flow, the size of the opening required, and whether the marsh substrate needs to be raised by thin layer deposition of fill to ensure recolonization of saltmarsh vegetation.
2. Design tidal flow control structure. This is likely to be a small bridge but could also be a series of culverts. The structure must be "railroad ready," that is, able to support a railroad if the bed is reconverted to a working railroad.
3. Obtain all necessary permits and approvals.
4. Thin layer substrate deposition to raise marsh bed. Multiple depositions may be required if the marsh bed must be raised by a substantial amount.
5. Transplant spartina plugs and other salt marsh vegetation.
6. Construct tidal flow control structure.
7. Return tidal flows to marsh.
8. On-going monitoring to chart progress as salt marsh recovers.

This request for proposals (RFP) is **specifically for the completion of Task 1 and 2**, from which will come recommendations for the remaining steps, such as targeted restoration measures. We are looking for detailed proposals with potential strategies laid out. A detailed budget must be included as well. I am available to answer any questions as you develop for proposal. I have attached some of the pertinent background information in my email, including a project map, preliminary tidal cycle flow data, LiDAR elevation data, and the current location of the two drainage culverts. This project is being carried out via grant funding from the National Fish and Wildlife Foundation (NFWF) and all work must align with their guidelines, as well as those from DSF. **Please submit your proposals to the email below by Tuesday, August 17th, 2021**. Selection of a vendor will be made based upon the following criteria:

1. Experience with similar projects and a proven track record of restoration success.
2. Expertise of the project staff (hydrology, salt marsh ecology, fisheries science).
3. Proposal outlines in sufficient detail the steps to achieve restoration of the marsh.
4. Proposal includes a budget that is consistent with the project expectations.
5. Proposal includes a timeline for completion that is consistent with project expectations.

Sincerely,

Charlie Foster
Habitat Restoration Program Manager
Downeast Salmon Federation
(207) 619-3474
charlie@mainesalmonrivers.org

Restoring Schoppee Salt Marsh:
Increasing the Coastal Resilience of Machias, Maine.

Coastal Community Context

Risk to coastal community: Much of the historic downtown district of the Town of Machias, the county seat of Washington County, is located below or only slightly above the Base Flood Elevation (BFE) as established by FEMA. This area of the town is already periodically flooded during extreme high tides and/or storms. The town conducted a Waterfront Resilience Study in 2017 to investigate and define the risk of flood damage to downtown Machias due to anticipated sea-level rise (Machias 2017). The study determined that at BFE + 2 feet 12 buildings would be inundated causing an economic impact of just under $8 million. At BFE + 4 feet, 22 buildings would be inundated at a cost of almost $17 million. The town's wastewater treatment plant is already forced to pump water during high tides under current conditions and would be inundated under the BFE + 6 feet scenario. On April 9th 2020, a spring tide inundated downtown Machias and caused an overflow event at the treatment plant. The wastewater that seeped into the nearby estuary caused valuable shellfish grounds to be closed. For context, the population of Machias is about 2,300.

The study developed a conceptual engineering design for a flood protection system. Primary protection would come from a seawall; secondary protection from a living shoreline. The study recognized that hardened structures such as seawalls reflect wave energy and may exacerbate erosion, destroy intertidal habitat, and alter sediment transport patterns. The study specified the need to include living shoreline in the seawall design and to develop other living shoreline projects in Machias Bay to absorb floodwaters and storm surges. The subject of this application, 50 acres of Schoppee Marsh were cut off from saltwater tidal flow by a railroad built in 1906.

The proposed project would restore Schoppee Marsh, adding to Machias' living shoreline, protecting the historic downtown district as well as restoring salt marsh habitat and reopening the marsh to fish passage. The project is consistent with the NOAA and the State of Maine's interests in developing living shorelines to reduce coastal flooding (NOAA 2015, Maine 2017). It is also consistent with the Natural Resource Resilience Program's intent to connect conservation with resiliency actions.

Efforts to prepare community: The Downeast Salmon Federation (DSF) has laid a solid foundation on which to launch this project. DSF has engaged and has the support of the town's civic leaders and civic organizations, including the Machias Downtown Revitalization Committee, which will host several public meetings over the course of the project, the Sunrise County Economic Council, and the Washington County Council of Governments. The project has widespread support within the community and we have many offers of volunteer help.

DSF has also worked to build support for the project in the relevant state and federal agencies, including the US Fish and Wildlife Service (USFWS), which provided staff to do the initial hydrological survey of the marsh; the Maine Natural Areas Program in the Department of Agriculture, Conservation, and Forestry (DACF); the Maine Coastal Program, a division of the Maine Department of Marine Resources; the Maine Geological Survey; the Department of Environmental Protection; the Maine Department of Transportation (DOT), which owns the railroad bed; and the US Army Corps of Engineers, which will be one of the key permitting agencies.

We have also solicited and received the support of several local and regional Non-Governmental Organizations (NGOs) all of which are involved in land and habitat restoration and conservation. These include the Maine Coast Heritage Trust, The Nature Conservancy, the Downeast Fisheries Partnership, and the Sipayik Environmental Department of the Passamaquoddy Tribe.

Science teachers at all of the area schools have been briefed and invited to participate in the project with their students. Several key professors at the University of Maine at Machias (UMM), including Dr. Tora Johnson, who currently chairs the Science division at UMM and was a leader in the Waterfront Resilience Study as well as the predictive modeling for Machias flooding and Machias Bay living shoreline analyses will participate in the data collection and post-completion monitoring of the project.

Action leading up to proposed project: All preliminary work required to successfully initiate the proposed project has been completed or is in process:

- Permission has been secured from the landowner to work in the marsh and from DOT and DACF to work on the rail bed;
- An initial hydrological survey was completed by DSF with USFWS staff;
- Secondary deployment of surface water elevation data loggers is underway;
- Baseline data collection protocols have been designed and data collection has begun;
- Engineering firms have been informally consulted to determine the necessary scope and approximate cost of a feasibility study. The study will be necessary before the engineering design work can begin;
- Research to determine required project permitting has been completed;
- Outreach to the community to ensure public support for the project has been initiated and will continue throughout the project;
- Schools and summer programs have been invited to participate in the data collection and restoration work (6 have agreed);
- Several professors at the University of Maine at Machias have agreed to engage their students in research projects related to the project;
- Fundraising to support all work completed to date has been accomplished;
- Fundraising for subsequent work is in progress.

Predictive modeling or threat assessments: Predictive modeling of the threats facing Machias due to sea-level rise in coming decades was undertaken in the Waterfront Resiliency Study (Machias 2017). Based on NOAA's low, medium, high sea-level predictions for the Cutler Tidal Station at the mouth of Machias Bay, downtown Machias would suffer the flooding indicated in the following maps:

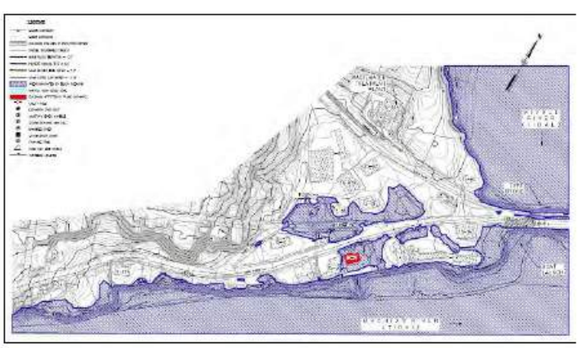


Figure 5 – Effective Base Flood Elevation;

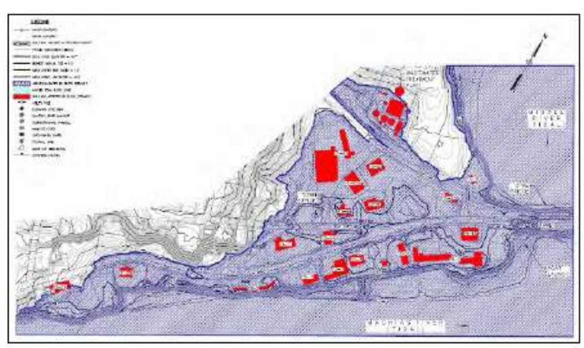
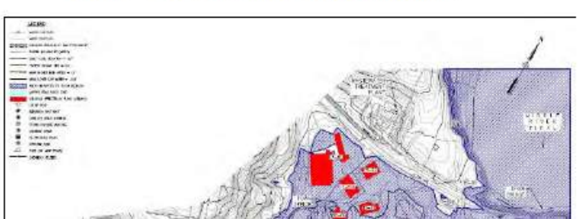


Figure 7 – Base Flood Elevation plus 4-FT



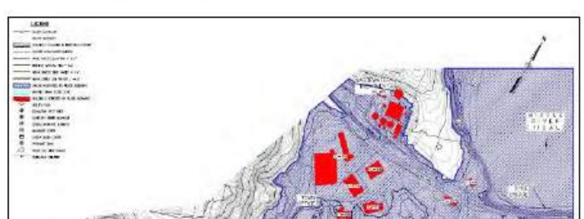


Figure 1. Predictive modeling for downtown Machias at Base Flood Elevation (BFE) plus 2, 4, and 6-foot sea-level rise (SLR) scenarios was completed by Dr. Tora Johnson at the University of Maine at Machias GIS lab. Machias currently floods during King Tide storm events as evident in Figure 5 above left. Legend: Blue is flood zone, red are structures.

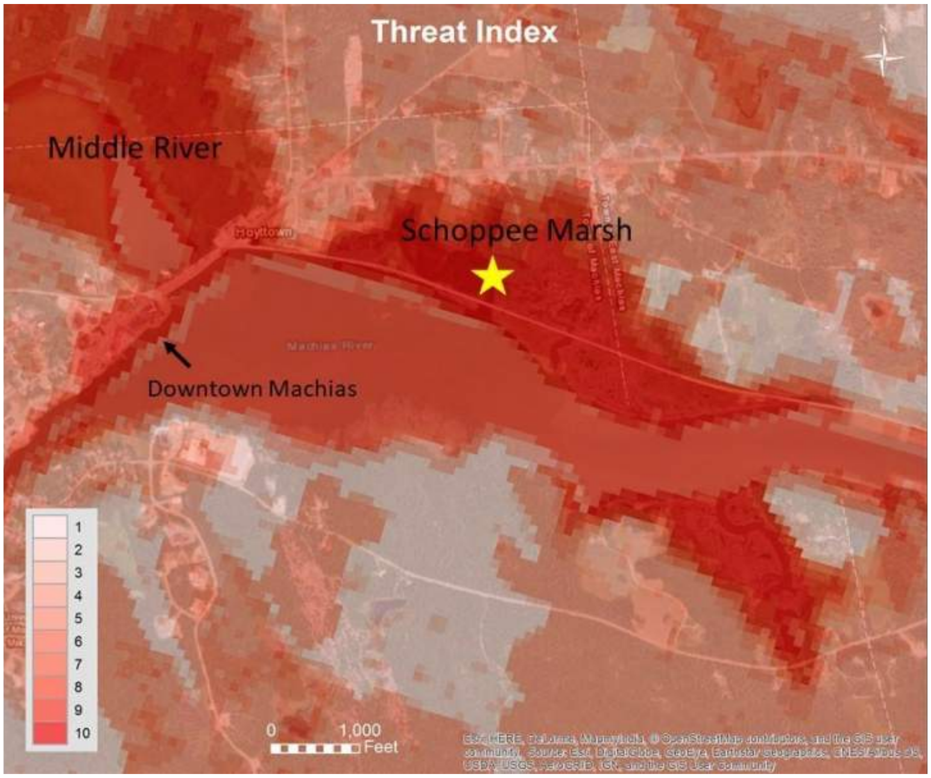


Figure 2: The NFWF Coastal Resilience Evaluation and Siting Tool (CREST) Community Threat Index ranks Downtown Machias and Schoppee Marsh at threat level #10.

Activities:

All of the activities detailed below must be successfully completed for this project to achieve its outcomes.

- **Adaptive Management Strategies:** DSF intends to use an adaptive management strategy to restore marsh surface elevation, hydrology, and vegetation. The strategy will be informed by making experimental changes, observing the results, and adopting methods that support the recolonization of halophytic vegetation. Experimental changes include: 1) Propping open the tide gate that blocks tidal flow into the western half of the mash to increase drainage and tidally deposited sediment; 2) Conducting experimental planting of *Spartina alterniflora* to help re-establish vegetation in the subsided extent of the marsh; 3) Digging shallow runnels to drain pooling water off the eastern half of the marsh surface; 4) Filling ditches with bailed marsh grass to restore marsh surface elevation and reduce erosion; 5) Pulling ditch plugs (if present) in the heavily ditched and bermed eastern half of the marsh to increase drainage and reduce erosion. The data gleaned from these experiments will inform the feasibility study and help DSF determine best practices for restoring the marsh—particularly those areas of the marsh that are denuded and significantly subsided.

  This activity will begin before the grant performance period and will be completed before construction to replace the undersized crossing or crossings begins. DSF's partners in this activity will be Bill Bennett (US Fish and Wildlife Service) and Jeremy Bell (The Nature Conservancy), who will both provide technical expertise, and UMM Professors mentoring student research projects, as well as various area schools who will help with monitoring, data collection, and physical labor. This activity is linked to the outcome of "Completed Feasibility Study" and the post-grant period outcomes of "Restoration of salt-marsh function in Schoppee Marsh" and "Healthier, more productive, and more resilient Machias Bay Estuary ecosystem."

- **Monitoring:** Pre- and post-restoration monitoring data collected by students at the University of Maine at Machias (UMM), Washington Academy, and 5-12th-grade "citizen scientists." DSF has extensive experience training and working with citizen scientists on other monitoring projects and has developed citizen science data collection protocols to ensure high-quality data. This activity is linked to the outcomes Baseline data collected and Community understanding of and support for salt marsh restoration and the post-project outcome Restoration of salt-marsh ecology.

- **Execute the feasibility study**: The feasibility study will develop a hydrodynamic model of the marsh which will provide the specifications required to design the new tidal control structure(s) that will be placed in the railroad bed. Marsh surface, structure, longitudinal profile, cross-sections and surface water elevation data will be used to evaluate 4-6 foot sea-level rise and storm surge scenarios to create a HEC-RAS model to determine the hydraulics of water flow across the marsh. The design engineers will use this model to determine the size of the tidal control structure(s). The model will also be used to determine how to most effectively restore salt marsh function while reducing risk of flooding and loss, protect public and private infrastructure and property, restore diadromous fish passage, and ensure public access.

  These activities will be completed during the performance period. DSF will contract the feasibility study to an engineering firm with expertise in salt marsh restoration. We have begun informal conversations with two firms. DSF's project manager will be partnering with Bill Bennett (US Fish and Wildlife) and Jeremy Bell (The Nature Conservancy), who both have extensive experience in salt marsh restoration. This activity is linked to the grant outcome of Completed Feasibility Study and is a required input into the Engineering Design Plans 50% Complete outcome.

- **Initiate engineering design work:** DSF will engage an engineering firm to design a tidal control structure that performs to the specifications detailed in the feasibility study.

  Fifty percent of this activity will be completed by the end of the performance period. DSF will contract with an engineering firm—we have experience with several leading engineering firms, having worked with them on other projects. This activity is linked to the outcome: Engineering Design Plans 50% Complete.
  Apply for permits: This project, in the Final Design and Permitting phase, will need multiple permits and authorizations from the Army Corps of Engineers, Maine Department of Environmental Protection, USFish and Wildlife Service, the National Historic Preservation Act and the Machias Shoreland Zoning Ordinance. DSF has excellent working relationships with the issuing state and federal agencies. We anticipate that all permits will have been applied for by the end of the grant performance period.

- **Communication:** DSF has enlisted the support of the Machias **Downtown Revitalization Committee** to help engage and inform the community about the project and the importance to the downtown of a living shoreline. Currently, DSF plans two meetings, each hosted by the Committee, at which DSF and project partners will share how the restoration project and the floodwater storage ecosystem service benefit the town. The students who have been working as "citizen scientists" will present results from the data they have collected. Further engagement will happen via the local media and on our website and Facebook pages. DSF will plan at least one event that will attract state-wide media coverage.
- **Student engagement:** DSF will work with the **Downeast Coastal Conservancy** (DCC), a local land trust, to implement the educational and community outreach portion of the project. Four schools (K-12), five professors at the **University of Maine at Machias** (UMM), and the **4H SPIN program** through the UMM Cooperative Extension will instruct their students in salt marsh biology and train them to conduct student

research projects and how to be "citizen scientists." Students, both as scientists and citizen scientists will assist in collecting baseline and monitoring data and help with various restoration projects such as transplanting *Spartina* plugs and mapping the ditches, berms, and dikes.

- **Fundraising:** DSF will be lead on raising the funds required to complete the project. We anticipate having the funds pledged or in-hand at the end of this grant's performance period so that there is no delay moving forward with the next phase of the project. The amount that DSF must raise is well within our historical performance—DSF has one to two $200,000 - $400,000 projects in process every year. This activity is linked to all four of the post-performance period outcomes.

Outcome(s):

Proposed Project Outcomes

- **Baseline data collected.** Outcome measure: All relevant baseline data has been collected. Metrics include surface water elevations, longitudinal profile and cross-sections, vegetation species and % cover, pore water salinity, fish and bird presence and absence, benthic invertebrates presence and absence. Baseline data will be compared to post-project monitoring data to measure the degree and speed of restoration.

- **Adaptive management data collected.** Outcome measure: 1) The tide gate is propped open, increasing drainage and tidally deposited sediment processes; 2) Pools are drained, ditches are filled, and ditch plugs are pulled; 3) Observations generated by adaptive management procedures will inform the feasibility study.

- **Completed Feasibility Study.** Outcome measure: The feasibility study is completed per DSF specifications. The study will provide the data and analysis we need to restore marsh hydrology, and subsequently salt marsh ecosystem functions—including how to manage water flow for storm surges, 100 and 500-year floods, future sea-level rise; and impacts to surrounding landowners and infrastructure.

- **Engineering design plans.** Outcome measure: Engineering design 50% complete.

All of the above outcomes align with the Resiliency Plan (2017) in that they further the restoration of a living shoreline that will serve to store floodwaters and contribute to the resiliency of downtown Machias in the face of SLR and increasing storm frequency and intensity.

Community Outcome

- **Community understanding of and support for salt marsh restoration.** Outcome measure: 400 students, teachers, and community members participate in community meetings, trainings, data collection, or active restoration work. This amounts to more than 15% of the town's population.

Project Outcomes (Beyond Performance Period)

- **Greater resilience to sea-level rise and coastal flooding in Machias.** Outcome measure: 50 acres of restored living shoreline. This outcome fully aligns with the recommendation of the Resiliency Report (2017).

- **Hydrological function restored to Schoppee Marsh.** Outcome measure: Fully functioning tidal exchange. Tidal inundation period and frequency measured by HOBO Onset Data Loggers U20L.

- **Restoration of salt-marsh ecology:** Outcome measure: Halophytic vegetation, and typical salt marsh fish and birds have recolonized the marsh. Recolonization will be measured by ongoing post-project monitoring and compared to pre-restoration baseline data.

- o **Healthier, more productive, and more resilient Machias Bay Estuary ecosystem.** Outcome measure: The estuary is large and its health and resiliency are dependent on so many variables that it will not be possible to accurately measure this outcome.
- o **Community support for living shore restoration.** DSF intends to use the restoration of Schoppee Marsh to educate the community about the value of salt marshes so that the residents of Machias become more supportive of restoring additional salt marsh ecosystems.

Annual Milestones

Milestone	Completion Date
First community meeting detailing the project	Spring 2020
Marsh revegetated by transplanting salt marsh plants	Spring 2020
Baseline data collected (2018-2020)	Summer 2020
Fundraising for Phase II	Summer 2020
Feasibility study completed	Fall 2020
Second community meeting explaining project	Spring 2021
Engineering design completed	Fall 2021
Control structure completed and operational	Summer 2022
Tidal flows return (volume determined by feasibility study)	2022-2025?
Community celebration	Fall 2022
Post-project monitoring (5 years)	2027

Tracking Metrics:

Monitor Progress

The following four metrics are those DSF intends to achieve during the NFWF Coastal Resilience grant performance period.

Resilience – Outreach/Education/Technical Assistance - # gov't entities participating

DSF has engaged the US Fish and Wildlife Service (USFWS); the Maine Natural Area Program and the Maine Division of Parks and Public Lands, both divisions of the Department of Agriculture, Conservation, and Forestry (DACF); the Maine Coastal Program, a division of the Maine Department of Marine Resources; the Maine Geological Survey; the Department of Environmental Protection; the Maine Department of Transportation (DOT), which owns the railroad bed; and the US Army Corps of Engineers. DSF will engage 8 agencies or divisions of agencies. This metric will be tracked by a simple count; there are no challenges anticipated.

Resilience -- Outreach/Education/Technical Assistance - # people reached

DSF will have at least two public meetings (hosted by the Machias Downtown Revitalization Committee) to brief the community about the Schoppee restoration project. Students at UMM and those working as our project "citizen scientists" will present what they have learned. DSF will organize in the community to ensure a good turnout. We anticipate reaching directly 150. We will track this metric by having both a sign-in sheet at the public meetings and doing a headcount by staff during the meeting. Tracking this metric will be relatively easy, with a minor challenge in ensuring people sign the sign-in sheets.

Resilience - Restoration planning/design/permitting - # E&D plans developed

At the conclusion of this grant's performance period, DSF intends to have 50% of the engineering design completed for a tidal control structure that will restore the tides to Schoppee Marsh. Progress will be monitored by frequent meetings and project reports from the engineering contractor. Although the engineering firm that will do the designs has not yet been selected, DSF and our partners have worked with many of the engineering firms in the state and we are confident both of their high level of competence and our ability to work productively with them.

Resilience – Volunteer participation - # of volunteer hours

Volunteers are a critical component of this project. DSF anticipates 500 volunteer hours; volunteer time will be tracked using sign-in/sign-out sheets that DSF staff will manage.

Project Team

Dwayne Shaw is DSF's Executive Director and will be responsible for overall management of the project. Shaw has guided development of fisheries and land conservation programs since 1989. Shaw has served on numerous fisheries-related boards and advisory committees, including the Maine Sea Grant Public Advisory Committee and the Federal Recovery Team for Endangered Atlantic Salmon.

Charlie Foster is the Habitat Restoration Project Manager for the Downeast Salmon Federation. He has over 12 years of experience as a scientist and environmental project manager with expertise in estuarine ecology, habitat restoration, and infrastructure projects. He has managed environmental projects with budgets exceeding $2M, including the restoration of a tidal passage along the Texas coast in 2014.

Jacob van de Sande has been a Land Protection Project Manager for Maine Coast Heritage Trust since 2014. In that capacity, he manages complex land purchases and restoration projects.

Jeremy M. Bell is the River and Coastal Restoration Director for The Nature Conservancy in Maine. He has nearly 20 years' experience as a restoration ecologist and project manager and is the strategy lead for coastal resiliency as well as river and coastal restoration for TNC in Maine.

Kyle Winslow is trained in Conservation Biology and has focused most of his work on restoring the endangered Atlantic salmon. He worked for the Axiom Education and Training Center offering STEM (Science, Technology, Engineering, and Math) educational activities to area youth.

Bill Bennett is a Fish and Wildlife Biologist with the USFWS Gulf of Maine Coastal Program. Bennett provides technical assistance with hydrogeomorphic assessments and development of restoration designs

The mission of the **Downeast Salmon Federation** is to conserve wild Atlantic salmon and its habitat, restore a viable sports fishery and protect other important river, scenic, recreational and ecological resources in eastern Maine. DSF has a thirty-eight-year history removing dams, replacing barriers to fish passage, restoring habitat, and returning diadromous fish to watersheds where they have long been extinct.

Other

Transferability: The restoration of Schoppee Marsh will be the first large salt marsh restoration project in eastern Maine. It will also be the first restoration of a natural area in order to provide protection from floods, storm surges, and sea-level rise. As the first such project, it provides us with a distinct and valuable opportunity: To educate and engage the general public in the possibility and importance of using natural systems to protect manmade infrastructure. An example of the need to introduce such thinking is the "Washington County Hazard Mitigation Plan," which was submitted to FEMA's Pre-Disaster Mitigation Program in January 2019. This plan lists hundreds of needed infrastructure changes, but not one use of a natural system for hazard mitigation.

In designing this project, DSF has put considerable emphasis on community outreach and education—specifically to develop the community and political support for future projects. The Natural Resource Resilience Program evaluates proposed projects, in part, on their transferability. DSF asserts that political and community support is critical to transferability. To further support the transferability of the lessons learned at Schoppee, DSF intends to work with local contractors to develop in-region expertise in salt marsh restoration and living shoreline construction. Finally, DSF will hold a post-project debrief with all key partners (including local, state, and federal agencies) to evaluate the project to ensure that the lessons learned are incorporated into future projects.

Sustainability: DSF will transfer the tidal control structures to the State of Maine at project completion.

Photographs

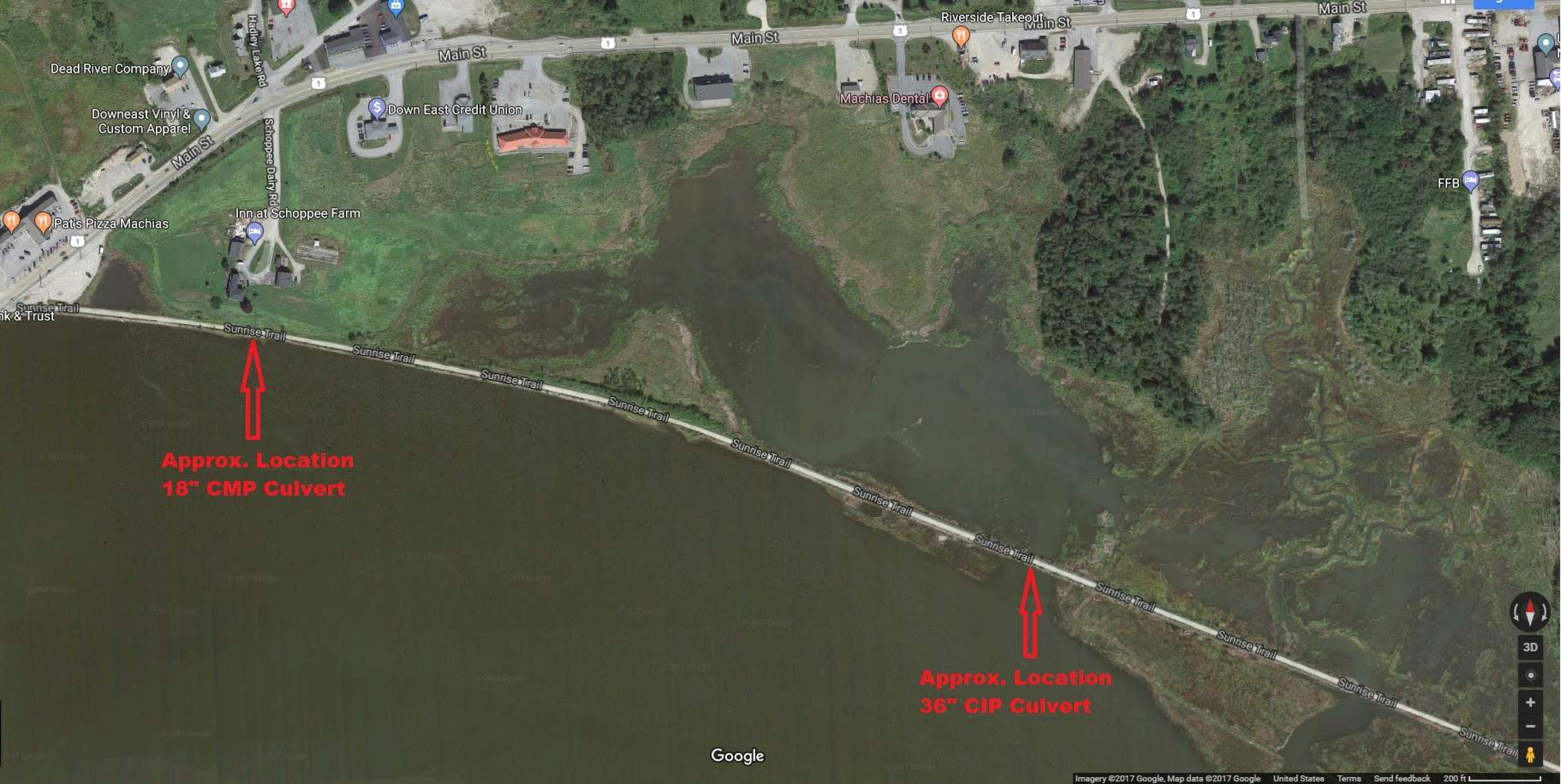
Figure 1: Restricted Tidal Flow. Looking west on the Sunrise Trail. Machias River is on the left and Schoppee Marsh on the right side of the trail. Credit Russell Heath, Downeast Salmon Federation.
Figure 2: Pannes. The brown area has subsided approximately one foot according to a LIDAR survey, and exhibits typical panne characteristics such as sparse cover of common glasswort (*Salicornia depressa)*, algal mats, and cracked mud due to impaired hydrology. Credit Russell Heath, Downeast Salmon Federation.
Figure 3: Tide Gate. The tide gate preventing saltwater entry into the western half of Schoppee Marsh. Even if the gate were removed, the culvert would not be large enough to ensure adequate saltwater inundation of the marsh. Credit Shri Verrill, Downeast Salmon Federation.

Literature Cited

Machias, Maine, Baker Design Consultants, Ransom Consulting Engineers and Scientists, and West Falls Surveying, 2017. Waterfront Resilience Study. 81pp. https://www.wccog.net/assets/MachiasResilience/17-59%20Machias%20Downtown%20Resilience%20Rprt1.30.19.pdf

Maine Coastal Program, Department of Agriculture, Conservation, and Forestry, 2017. Increasing resilience and reducing risk through successful application of nature based coastal infrastructure practices in New England: The Maine Approach. https://www.maine.gov/dacf/mgs/explore/marine/living-shorelines/workshop_slovinsky_maine_living_shorelines.pdf

National Oceanic and Atmospheric Administration, 2015. Guidance for Considering the Use of Living Shorelines. 36pp. https://www.habitatblueprint.noaa.gov/wp-content/uploads/2018/01/NOAA-Guidance-for-Considering-the-Use-of-Living-Shorelines_2015.pdf



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