Stantec

Memo

To:	MaineDOT	From:	Michael Chelminski. P.E. Gordon E. Clark
File:	179450347	Date:	September 16, 2021

Reference: Phase 1 Hydraulic Analysis for Machias Dyke Bridge (#2246) Planning Phase Support Services

This memo was prepared by Stantec Consulting Services Inc. (Stantec) under contract to the Maine Department of Transportation (MaineDOT) for Planning Phase Support Services as part of the Dyke Bridge Replacement Project (Project) located on the Middle River in Machias, Maine. MaineDOT is pursuing replacement of the existing infrastructure at Dyke Bridge due to its poor condition with the objectives to provide adequate drainage from upland floods without overtopping the Route 1 roadway, provide adequate freeboard during tidal flood events, and accommodate fish passage to the extent practicable.

As part of this scope of services for the Project, Stantec performed a hydraulic analysis (Hydraulic Study) to assess hydraulic conditions associated with the primary replacement alternatives for the Dyke Bridge culvert. This memo documents the methodology and results of the hydraulic modeling for the primary replacement alternatives as part of the Hydraulic Study in support of the ongoing planning phase of the Project (2020-2021 Planning Study).

Appendix A contains the unsteady-state stage hydrograph simulation results from the hydraulic model. Appendix B contains a figure that depicts mapped water surface elevations[1] (WSELs) along the Middle River upstream (landward) from Dyke Bridge for the primary alternatives.

This memo includes revisions to Alternative 10 (single-span bridge alternative) relative to previous versions of this memo and references apparent changes in the normal tidal WSELs in the Middle River upstream from Dyke Bridge. Changes to Alternative 10 include 1) increasing the span of the bridge from 100 feet (ft) to 120 ft, 2) changes to the spill-through abutment geometries, and 3) raising the bottom of channel elevation under the bridge. Observations during Project studies in 2021 identified that the normal tidal WSELs in the Middle River landward from Dyke Bridge may have risen relative to information obtained by MaineDOT in 2011. In August 2021, MaineDOT installed equipment to collect additional tidal stage data in the Middle River upstream from Dyke Bridge and in the Machias River downstream (seaward) from the bridge.

BACKGROUND

Dyke Bridge (#2246) caries Route 1 over the Middle River in the Town of Machias. Route 1 is a highway corridor priority 2, has an estimated daily traffic volume of 9,250 vehicles per day, and is functionally classified as a minor arterial roadway. The existing structure at Dyke Bridge is a four-cell, timber culvert supported by timber cribbing with rubble and earthen fill. A buried concrete slab that was previously installed as a remedial repair is located over the culvert. The four box culverts are approximately 130 ft long, 6 ft wide, and 5.5 ft high, and have top-hinged flap-gates installed on the seaward side of each of the four culverts. The culvert array is skewed 90 degrees to the roadway that carries two-way vehicular traffic via two 12 foot (ft) +/- lanes with 8 ft +/- shoulders on a bituminous wearing surface. Dyke Bridge needs improvement due to large spalls, heavy scaling, wide cracks, loss of and rotted timber members, and the need for urgent and unscheduled

[1] Elevations are referenced to the North American Vertical Datum of 1988 (NAVD88).

repairs. The primary purpose and need for the Project are addressing the structure's condition and the safety of the traveling public along with preserving the adjacent Calais Branch Rail Corridor.

While the existing structure restricts tidal flow, the culvert is adequate to drain upland floods without overtopping the bridge or the adjacent approach embankments. There is no apparent flood history associated with the conveyance of the existing culvert or a need to increase the hydraulic opening. However, freeboard may be inadequate to prevent overtopping of the roadway during the 100-year tidal flood event. The proposed structure configuration and opening are being driven by the need to improve the upstream fish passage while mitigating potential landward flooding during the normal daily riverine and tidal conditions. Sea level rise accommodation involves consideration of the Maine Climate Council guidance and coordination with the adjacent Town of Machias sea wall project, which may involve a phased approach. These elements represent some of the secondary purpose and needs for the Project.

Previous work for the Project has included a 2015 tidal hydraulic and alternatives analyses study prepared by Stantec for MaineDOT (2015 Study), which then progressed to a 2019 preliminary design effort by Stantec for MaineDOT that included additional hydraulic analysis of selected potential replacement alternatives (2019 PDR Study). Due to regulatory agency concerns regarding fish passage, including Atlantic salmon (*Salmo salar*) that are listed under the Endangered Species Act and associated regulatory agency opposition to a replacement-in-kind alternative, competing concerns for landward flooding impacts on historic property, and adjacent sea level rise mitigation and boat launch projects by the Town of Machias, MaineDOT decided to transition the Project back to MaineDOT Planning as the 2020-2021 Planning Study.

The proposed hydraulic studies for this phase of the Project are focused on evaluating a set of potential alternatives relative to regulatory agency request for improved upstream fish passage and potential analysis and channel design needs for replacement of the existing culverts with a bridge structure. The 2015 Study and 2019 PDR Study used varying approaches for modeling of the existing and proposed conditions using the then current version of the U.S. Army Corps of Engineers Hydrologic Engineering Center River Analysis System (HEC-RAS) software (e.g., HEC-RAS v5.0.0 to HEC-RAS v5.0.5). Modeling of the existing culverts with flap-gates for the 2015 Study required use of atypical methods (i.e., HEC-RAS "Rules"). The current version of HEC-RAS (i.e., HEC-RAS v5.0.7) includes integrated "tide-gate" routines for culverts. Therefore, it was proposed that for the Project the hydraulic models would use the most current non-beta version of HEC-RAS. This approach allows for better comparison and standardization of the evaluated alternatives relative to existing conditions.

The Project Hydraulic Study includes a two-phased hydraulic analysis approach. The first phase of the Hydraulic Study generally includes:

1. Unsteady-state modeling of conditions with normal tide data as represented by tidal stage data collected by MaineDOT in 2011 with the 50th percentile (median) flow in the Middle River; and
2. Steady-state modeling of the 100-year peak flow in the Middle River with mean high water (MHW) and mean low water (MLW) downstream boundary conditions.

Item (1) above is intended to reflect typical conditions and be suitable for evaluation of upstream (landward) fish passage at Dyke Bridge and identification of land that would be regularly inundated along the Middle River landward from Dyke Bridge. Item (2) above is intended as a check on the peak WSELs as represented by the Federal Emergency Management Agency (FEMA) Base Flood Elevation (BFE). In addition, the first phase of the Hydraulic Study includes unsteady-state flow analysis of a 1.1- and 10-year riverine flow condition for the bridge replacement alternative only (Alternative 10). This memo documents the **first phase** of the Hydraulic Study as part of the Project.

For the first phase of the Hydraulic Study, a group of primary alternatives was selected to assess 1) potential improvements to upstream fish passage at Dyke Bridge and 2) changes in normal tidal WSELs landward from Dyke Bridge. The hydraulic analyses evaluated the potential for improved fish passage and impacts to land adjacent to the landward impoundment along the Middle River under normal tidal conditions and typical riverine flows. Data obtained from the first phase of the Hydraulic Study will help determine and inform the duration of advective landward fish passage relative to existing conditions and areas of land that would be inundated if normal tidal exchange results in higher typical WSELs.

The hydraulic analyses in the first phase of the Hydraulic Study includes 1) existing conditions and 2) five primary alternatives. The five primary alternatives were identified as representative of the range of potential alternatives that were previously identified in early Project phases. Stantec developed the 2020-2021 Alternatives Matrix (Matrix), which provides a comprehensive overview of replacement alternatives for the Project. This matrix is not included in this document but is referenced in this memo. The existing conditions and primary alternatives are summarized below.

1. Existing Conditions: The primary objective for revising the past modeling for this alternative is to provide opportunity for calibration of the HEC-RAS model using the newly available integrated "tide gate" routines. Existing conditions is included in the hydraulic analysis effort for calibration and relative comparison of the evaluated alternatives.

2. Replacement in Kind (Alternative 1 in the Matrix): This alternative is based on replacement of the existing culvert system with four 5 ft by 5 ft box culverts with flap-gates that prevent landward ("upstream") flow. This alternative was modeled as part of the Middle River Hydrologic and Alternatives Analysis (2015 Study and 2019 PDR Study). This alternative is being evaluated as the baseline alternative at Dyke Bridge for comparison with the other evaluated alternatives. MaineDOT proposed this as the recommended alternative in 2019, but Stantec understands that it is no longer considered to be a viable recommended alternative because it does not provide opportunities for upstream fish passage based on the assumption that new, non-leaking flap-gates would be installed as part of this alternative. Note that Alternative 6 in the Matrix (slip-lining of the four existing culverts with new flap gates and installation of two culverts with flap-gates to maintain the existing conveyance capacity) would be designed to have similar hydraulic performance (e.g., design flow capacity) to this replacement in kind alternative and it is therefore expected that information obtained from hydraulic analysis of Alternative 1 would inform the general performance of Alternative 6 identified in the Matrix.

3. Alternative 4 in the Matrix: This alternative includes replacement with five box culverts with dimensions that are similar to the existing culverts (e.g., 5 ft by 5 ft) with flap-gates on four of the culverts and unrestricted, bidirectional flow in the fifth culvert. The objective of having a culvert without a flap-gate is to allow some landward flow and associated opportunities for upstream fish passage. Upstream fish passage would be provided by advection (i.e., fish would move with landward flow during the flood tide). This alternative assumes that the culvert inverts are at a common elevation but that this elevation may be below the invert of the existing culverts. The objective of modeling this alternative for the Hydraulic Study is to provide a consistent baseline for comparison with the other evaluated alternatives. This alternative is hydraulicly similar to Alternatives 2 to 4 and the initial culvert phase of Alternative 8 in the Matrix.

4. Alternative 4 in the Matrix with Modifications: This alternative was not in the 2020 Alternatives Matrix but includes replacement with three box culverts with large internal dimensions to address minimum fish passage dimensions for addressing expressed regulatory agency concerns. This alternative includes three 10 ft by 10 ft culverts with flap-gates on two of the culverts and unrestricted, bidirectional flow in the third culvert. The objective of having a culvert without a flap-gate is to allow some landward flow and associated opportunities for upstream fish passage. Upstream fish passage would be provided by advection (i.e., fish would move with landward flow during the flood tide). This alternative assumes that the culvert inverts are at elevation -6.05 ft (2 ft below the existing culvert outlet inverts). This alternative has been further refined as noted in the hydraulic modeling section (Methodology/Geometry Data section of this memo) below and has been added to the refined Matrix.

5. Alternative 9 in the Matrix: This alternative includes replacement of the existing culvert system with four 5 ft by 5 ft box culverts without flap-gates to provide unrestricted landward flow through the culverts. Hydraulic analysis of this alternative is intended to provide information on impacts associated with an ungated culvert system. Note that the hydraulic conveyance capacity of this alternative is similar to that of Alternative 7 in the Matrix (slip-lining of the four existing culverts and installation of two without flap-gates to maintain the existing conveyance capacity). It is therefore expected that information obtained from hydraulic analysis of Alternative 9 would inform the general performance of Alternative 7 in the Matrix. This alternative is also hydraulically similar to an alternative that included the use of fewer larger culverts (e.g., two 10 ft by 5 ft box culverts).

6. Alternative 10 in the Matrix: This alternative includes replacement of the existing culvert system with a bridge with a span of 75 ft to 125 ft. Information obtained from hydraulic model analysis of this alternative would be used along with other information to quantitatively identify potential scour in the landward embayment due to substantial restoration of tidal exchange. This would also provide a scour baseline to qualitatively assess scour potential for the other larger bridge alternatives. This alternative would substantially provide volitional fish passage and could be used as a comparison relative to the other evaluated alternatives, including evaluating whether seaward flows during the ebb tide may be too high for some target fish species (e.g., rainbow smelt) to migrate upstream through the bridge under normal tidal conditions. From a hydraulic perspective, this alternative is intended to be representative of Alternatives 10 to 12 and their variations, as well as the future bridge phase of Alternative 8, as presented in the Matrix. It will provide a baseline indication of how much additional landward flooding will occur under normal daily conditions with a bridge option, as the other bridge options would only be worse on this metric.

METHODOLOGY

Hydraulic modeling simulations of existing conditions and the primary alternatives were performed by modifying the numerical, hydraulic model that Stantec developed previously for this Project as described in the 2015 Study and 2019 PDR Study. As previously noted, the first phase of the Hydraulic Study included evaluations with steady- and unsteady-state flow regimes. The following sections document the development of the hydraulic model, including the geometric data, boundary conditions, flow regimes, and model scenarios.

HYDRAULIC MODEL

A one-dimensional, steady- and unsteady-state numerical hydraulic model (Model) was developed using HEC-RAS (v. 5.0.7) as part of the Hydraulic Study. The 2015 Study and 2019 PDR Study used earlier versions of HEC-RAS; however, the analyses reported in this memo used the current, non-beta version of HEC-RAS, which includes integration of automated flap-gate routines on culvert structures.

One shortcoming of the integrated flap-gate routines is the inability to assign individual culverts flap-gates within a group of culverts in an inline structure. The flap-gate routines can either be assigned to none of the culverts or all the culverts. Several of the primary alternatives evaluated as part of the Study include bidirectional flow (i.e., no flap-gate(s)) on one or more culvert barrels with flap-gates on the remaining culvert barrels. To apply the flap-gate routines in the Model, a “dummy reach” was developed that represented a cloned parallel reach that extends approximately 500 ft upstream and 200 ft downstream of Dyke Bridge. Additional details related to this geometry modification are documented in the Geometry Section below.

GEOMETRY DATA

Geometric data for the Model was developed using topographic data provided by MaineDOT along with a limited number of bathymetric transects surveyed by MaineDOT. Minor modifications to these transects were incorporated in the Model to increase the numerical stability during unsteady-state simulations of low-flow conditions. A “dummy-reach” (Dummy Reach) was inserted to connect upstream and downstream of Dyke Bridge (bifurcated geometry). This created two parallel reaches, which provided the ability to model the bidirectional flow culverts while still using the integrated culvert flap-gate routines. See Figure 1 for a schematic overview of the Model geometry with the parallel reaches at Dyke Bridge. Note that the flap-gate routines in HEC-RAS are based on relative WSEL differences upstream and downstream of the culvert and do not account for other factors (e.g., the weight of the water column at the location of a submerged flap gate).

The cross-sectional geometry in the parallel reaches were cloned and are identical between the two parallel reaches. Blocked obstructions were defined between corresponding similar cross-sections in the cloned parallel reaches to be symmetrical, which allowed for maintaining similar hydraulic storage during unsteady-state simulation. For example, the cross-sectional flow storage between cross-sections at Station (Sta.) 601 and 621 in the Dummy Reach (Parallel Reach 1) and Middle Reach 2 (Parallel Reach 2) is approximately equal to the cross-sectional flow storage between these stations in a single thread channel model used as part of the 2015 Study and the 2019 PDR Study. Alternative 10 evaluated as part of the first phase of the Hydraulic Study is a single thread channel model and is therefore similar to the single thread channel model used as part of the 2015 Study and the 2019 PDR Study (see the description in the Alternative 10 Section below).

The following sections document the geometric data for the Model, representing a total of six different geometries that correspond to the existing condition geometry and the five primary alternative geometries. For information related to the development of the geometric data for the Model used in the rest of the domain, refer to Section 3.0 of the Stantec 2015 Report.

Reference: **Phase 1 Hydraulic Analysis for Machias Dyke Bridge (#2246) Planning Phase Support Services**

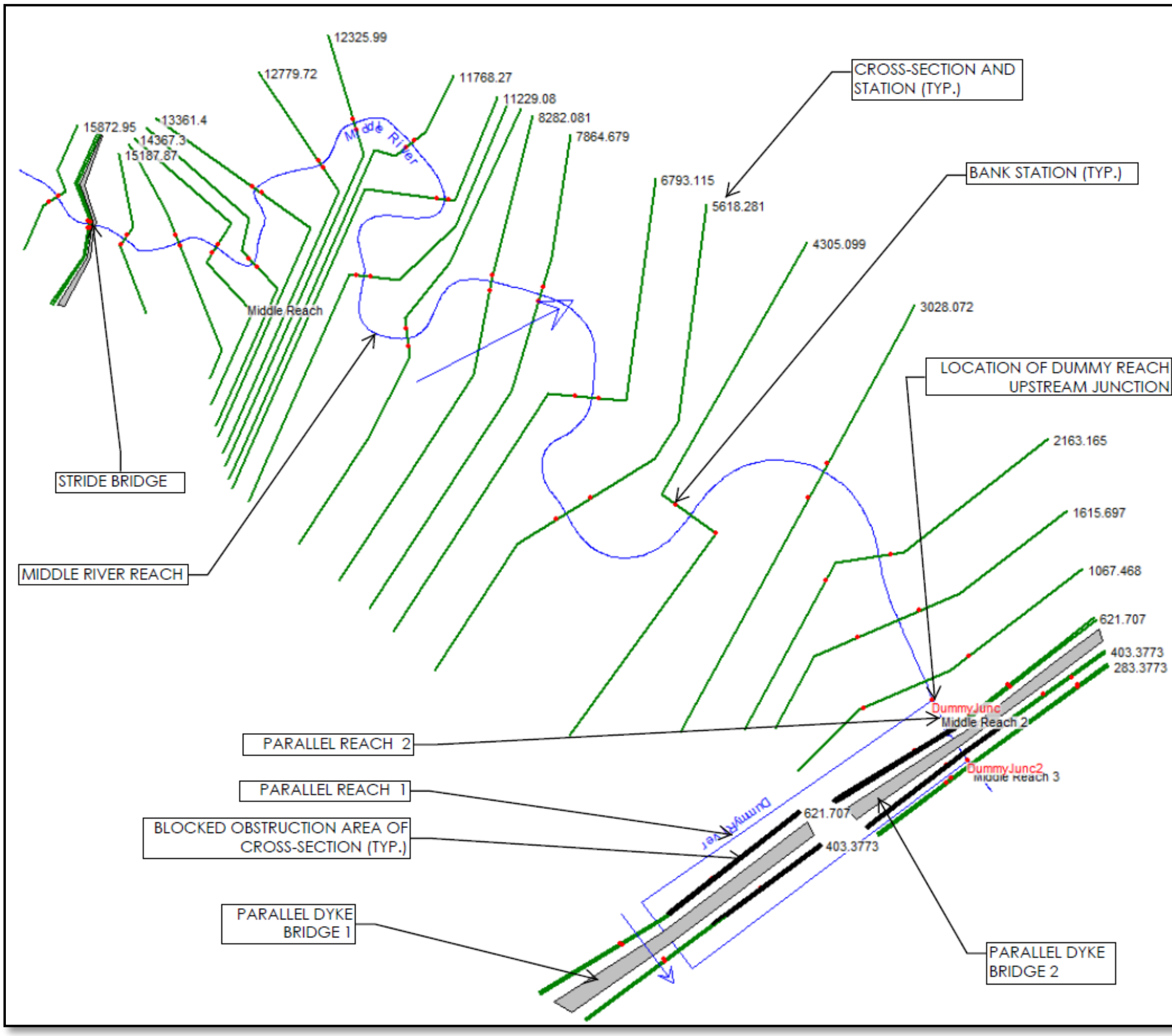


Figure 1. Overview of the general geometric schematic of the Model with the parallel reaches parametrized

Existing

The existing conditions geometry ("ex"[2]) is based on the bifurcated geometry approach that includes the cloned reach. The bifurcated geometry approach was used primarily to facilitate model calibration and for consistency of approaches across the Model simulations, since the primary alternatives also were based on the bifurcated geometry approach. The roadway embankment is modeled as two inline structures, one on each parallel reach, with one box culvert fitted with a flap-gate on Parallel Reach 1 and three box culverts fitted with flap-gates on Parallel Reach 2. The four box culverts have top-hinged flap-gates installed on the seaward side of each of the four culverts. The existing culverts and flap-gates are deteriorated, which results in partial blockage of the culverts and leakage. The integrated flap-gate routines in HEC-RAS do not allow for leakage. To accommodate leakage, a 0.35 ft high by 12 ft wide opening with the invert at -4.1 ft was used in the Model with no flap-gate for the duration of the simulation. The geometry of this "leakage opening" was determined based on an iterative calibration process comparing the simulation data to the observed data.

The existing conditions culverts were modeled with heights of 4 ft and widths of 5 ft, with the inverts of the culverts at elevation -3.1 ft. Culvert invert selection was based on review of survey data provided by MaineDOT, including elevations of the culvert inverts. The reduced culvert heights and invert elevations were used to address apparent blockages in the bottoms of the culverts (e.g., stone, debris) as determined from bridge inspection reports provided by MaineDOT and result in the Model's culvert inverts being approximately one foot higher than the average surveyed invert elevations of -4.05 ft. The existing culverts were modeled as 130 ft long with an entrance loss coefficient of 0.5 and an exit loss coefficient of 1. Manning's n values in the culvert were set at 0.018 to represent some of the debris and additional roughness within the culverts due to their existing condition. The culverts were modeled using the FHWA Chart #16 (corrugated metal box culvert) and Scale #1 (90 degree headwall), which was determined to be most representative of existing conditions.

Alternative 1

The Alternative 1 (replacement-in-kind) geometry ("alt01") is based on the bifurcated geometry approach. The roadway embankment is modeled as two inline structures, one on each parallel reach, with one box culvert fitted with a flap-gate on Parallel Reach 1 and three box culverts fitted with flap-gates on Parallel Reach 2. Alternative 1 culverts were modeled with heights of 5 ft and widths of 5 ft, with the inverts of the culverts at elevation -4.05 ft. The Manning's n for the culverts were assumed to be the same for the top and bottom at 0.012. A 130 ft culvert length was used with an entrance loss coefficient of 0.5 and an exit loss coefficient of 1. The culverts were modeled using the FHWA Chart #10 Scale #1 approach corresponding to 90 degree headwall with inlet edges chamfered three-quarters of an inch.

Alternative 4

The Alternative 4 geometry ("alt04") is based on the bifurcated geometry approach. The roadway embankment is modeled as two inline structures, one on each parallel reach, with one box culvert (no flap-gates) on Parallel Reach 1 and four box culverts fitted with flap-gates on Parallel Reach 2. Alternative 4 culverts, both with and without flap-gates, were modeled with heights of 5 ft and widths of 5 ft, with the inverts of the culverts at elevation -6.05 ft. The Manning's n for the culverts were assumed to be the same for the top and bottom at 0.012. A 130 ft culvert length was used with an entrance loss coefficient of 0.5 and an exit loss

[2] Abbreviations in quotes are provided for clarity as they are combined in the HEC-RAS Plan file names that are depicted on graphics in this memo.

coefficient of 1. The culverts were modeled using the FHWA Chart #10 Scale #1 approach corresponding to 90 degree headwall with inlet edges chamfered three-quarters of an inch.

Alternative 4 Modified

The Alternative 4 modified geometry (“alt04m”) is based on the bifurcated geometry approach. The roadway embankment is modeled as two inline structures, one on each parallel reach, with one box culvert (no flap-gates) on Parallel Reach 1 and two box culverts fitted with flap-gates on Parallel Reach 2. The Alternative 4 Modified culvert on Parallel Reach 1 was modeled with a height of 5 ft, width of 10 ft, and the invert of the culvert at elevation -6.05 ft. Alternative 4 Modified culverts on Parallel Reach 2 were modeled with heights of 5 ft, widths of 10 ft, and the inverts at -4.05 ft. Note that this is a refinement from the culvert geometry indicated earlier in this memo (Background Section). Based on preliminary analysis results and discussion with MaineDOT on March 29, 2021, it was decided that the box culvert heights should be reduced from 10 ft to 5 ft to better match the overall opening to hydraulic conveyance needs (i.e., reduce landward flows during flood tides) and reduce landward water surface levels. The open culvert invert was lowered with the intent of further improving fish passage for a wider range of tidal flows and the 10ft width was maintained to address fish injury concerns. The Manning’s n for the culverts were assumed to be the same for the top and bottom at 0.012. A 130 ft culvert length was used with an entrance loss coefficient of 0.5 and an exit loss coefficient of 1. The culverts were modeled using the FHWA Chart #10 Scale #1 approach corresponding to 90 degree headwall with inlet edges chamfered three-quarters of an inch.

Alternative 9

The Alternative 9 geometry (“alt09”) is based on the bifurcated geometry approach. The roadway embankment is modeled as two inline structures, one on each parallel reach, with two box culverts on Parallel Reach 1 and two box culverts on Parallel Reach 2. The four culverts were modeled without flap-gates, heights of 5 ft, widths of 5 ft, and the inverts at -4.05 ft. The Manning’s n for the culverts were assigned as 0.012 for the top and bottom at. A 130 ft culvert length was used with an entrance loss coefficient of 0.5 and an exit loss coefficient of 1. The culverts were modeled using the FHWA Chart #10 Scale #1 approach corresponding to 90 degree headwall with inlet edges chamfered three-quarters of an inch.

Alternative 10

The Alternative 10 geometry (“alt10m2_20210812”) is the only geometry in the first phase of the Hydraulic Study that uses a single thread channel instead of the bifurcated geometry approach. The roadway embankment is modeled as a bridge structure with a deck/roadway. The Alternative 10 bridge was modeled with bridge span of 120 ft and a clear span of 116.5 ft and a low-chord elevation of 13.1 ft. Sloping, spill-through type abutments were defined at slopes of 1.75 horizontal to 1 vertical (1.75H:1V) and 2-ft-wide benches at elevations of 10.42 ft to provide access along each abutment adjacent to both bridge abutments. The channel elevation was set at -8.5 ft. The preliminary bridge low-chord elevation was selected to match the Town of Machias’ Phase 1 sea level rise protection plans to be above the highest astronomical tide (HAT) elevation of 9.8 ft and the FEMA BFE of 10.7 ft plus a freeboard allowance for at least 1.5 ft of sea level rise. This results in a roadway grade raise of approximately 7 ft in the bridge area. Modeling of this alternative included changes to some of the HEC-RAS cross sections in the Middle River upstream (landward) from Dyke Bridge to have a lower and more defined channel. These geometric changes were made to improve the numerical stability of the unsteady-state HEC-RAS model and reflect expected erosion of sediment in the Middle River if a bridge were installed at Dyke Bridge. The bridge was modeled using the Energy (Standard

Step) approach in the bridge routines. Ineffective areas were defined within the upstream and downstream cross-sections adjacent to the bridge at an approximately one-to-one aspect ratio.

BOUNDARY CONDITIONS

Boundary conditions for the Model included both steady- and unsteady-state regimes, which are documented in the following sections.

Steady-State Boundary Conditions

The upstream[3] boundary conditions for steady-state simulations included the 100-year peak flow. Peak flows were calculated and provided by MaineDOT and are referenced in the Stantec 2015 Study. Peak flows for steady-state boundary conditions at Dyke Bridge and Stride Bridge[4] used in the Model are presented in Table 1. The steady-state upstream flows were input to the Model at locations landward of Stride Bridge and Dyke Bridge. Under steady-state conditions, these upstream, inland flows are simulated as a constant flow value (e.g., not a hydrograph) with no attenuation due to potential storage in the Model domain.

Table 1. Drainage areas and peak upland flows for upstream steady-state boundary conditions at Dyke Bridge and Stride Bridge

Location	Drainage Area (sq. mi.)	100-Year Return-Interval Event Peak Flow (cfs)
		100
Stride Bridge	9.41	912
Dyke Bridge	13.22	958

Note that the use of the bifurcated geometry approach resulted in the need to split flow between the two parallel reaches just upstream of Dyke Bridge. The initial conditions flows at the upstream junction were divided equally in half for the steady-state modeling and then recombined at the junction downstream of Dyke Bridge. Flow splits at the Model junctions were then calculated by the HEC-RAS model.

The downstream boundary conditions for the steady-state flow simulations were set at the downstream (seaward) limit of the Model assuming constant values of 6.1 ft for MHW and -6.6 ft for MLW. The MHW and MLW tidal values were based on predicted tides at the Machiasport tide station (National Oceanic and Atmospheric Administration [NOAA] Station # 8411467) as described in the 2015 Study. Predicted tides at this station are based on the Eastport, Maine recording tide gage, adjusted for height (multiply by 0.61) and time (add 1 minute for high, subtract 9 minutes for low). Table 2 presents tidal statistics developed from data collected by MaineDOT in the Machias River seaward from Dyke Bridge in 2011 and provides a comparison to the values predicted at the Machiasport tide station (see Section 2.3.2 in the 2015 Study to reference how these tidal statistics were developed). In addition, Table 3 presents tidal statistics from other adjacent NOAA

---

[3] “Upstream” and “downstream” are used in this report to describe the HEC-RAS model boundary conditions for consistency with boundary condition references in the HEC-RAS documentation. For reference, upstream generally refers to the landward direction and downstream generally refers to seaward direction.
[4] Stride Bridge is located landward from Dyke Bridge and is included in the project HEC-RAS model that was developed for a previous study of Dyke Bridge. Alternatives at Stride Bridge were not evaluated as part of the Hydraulic Study.

tide stations at Eastport, Cutler Naval Base (Cutler), and Bar Harbor (Machias is located between Cutler and Bar Harbor along the coastline). Reference tidal datums for the Machias River seaward from Dyke Bridge based on the Machiasport tide station and NAVD88 are summarized in Table 4.

Table 2. Tidal Statistics from 2011 MaineDOT Data Set (see the 2015 Study for details).

Tidal Data (ft, NAVD88)						
Max.	MHHW[a]	MHW[b]	Average	MLW[c]	MLLW[d]	Min.
9.8	7.4	6.5	0.05	-6.4	-6.8	-7.5

Table 3. Tidal Statistics from NOAA Stations

Station	Tidal Statistics (Elevation in ft)						
	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

Table 4. Tidal Statistics Predicted at Machiasport NOAA Subordinate Station

Station	Tidal Statistics (Elevations reference to ft NAVD88)						
	MHHW	MHW	NAVD88	MTL	MSL	MLW	MLLW
Machiasport	6.45	6.11	0.0	-0.21	-0.16	-6.55	-6.85

[a] "Mean Higher High Water"
[b] "Mean High Water"
[c] "Mean Low Water"
[d] "Mean Lower Low Water"

Unsteady-State Boundary Conditions

The upstream boundary conditions for the unsteady-state simulations included peak flow values for the annual median flow (50% flow duration annual exceedance), 1-year peak flow (note the 1.1-year or the peak flow with an annual exceedance of 0.91 [91%] was used as representative of the 1-year peak flow), and the 10-year peak flow (i.e., annual exceedance probability of 0.1 [10%]). Upstream boundary conditions are summarized in Table 5 below.

Table 5. Peak upland flows for upstream unsteady-state boundary conditions

Location	Return-Interval Event (Years) / Peak Flow (cfs)		
	50% Median Flow	1.1	10
Upstream Model Boundary	13.7	152	565

Note that while the annual median flow upstream inflow unsteady-state boundary condition was used across all of the alternatives, only Alternative 10 was modeled with the 1.1- and 10-year peak flows during the first phase of the Hydraulic Study and as documented in this report. Reporting on these flows for a reduced list of preferred alternatives will be included in the second phase of the Hydraulic Study.

Downstream boundary conditions used in the unsteady-state simulations was a normal tidal stage hydrograph based on a selected set of MaineDOT recorded data used as “normal tide” boundary conditions. MaineDOT collected tidal stage data at the Project site from mid-July to later October 2011 that were used as the downstream boundary condition representing typical tidal conditions. The tidal stage data were collected at two locations using datalogging pressure transducers that recorded pressure at 5-minute intervals at locations landward and seaward from Dyke Bridge in the Middle River and Machias River, respectively, and post-processed by MaineDOT to develop tidal stage and elevation data. A subset of these data (July 12 to August 17, 2011) was selected for the first phase of the Hydraulic Study that represents a range of tide levels typical of this location with high-tide elevations ranging from 4.5 to 9.0 ft and low-tide elevations ranging from -4.7 to -7.2 ft. The data subset of the seaward datalogger tide values were used for the downstream boundary condition of the unsteady-state flow model as representing typical, normal tides. For additional detail on this tidal dataset, refer to the Stantec 2015 Study.

CALIBRATION

Tidal stage data collected landward and seaward from Dyke Bridge provided an opportunity for calibration of the Model. The bidirectional “leakage gate” included allows 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. Coefficients and gate sizes within the inline gate editor in HEC-RAS were modified until a satisfactory calibration was achieved that accounted for leakage based on visual comparison of observed and simulated upstream WSELs. Leakage is accounted for in the existing conditions geometry through use of a gate opening with a height of 0.35 ft, a width of 12 ft, and an invert at -4.1 ft.

Figure 2 presents the simulation results of the final calibrated existing conditions model compared to the observed landward data. Stantec reviewed U.S. Geological Survey (USGS) stream gages in the vicinity of the Project area and identified that higher WSELs in the observed upstream stage hydrographs in Figure 2 appear to coincide with peaks in WSELs at the USGS gages. Stantec expects that these peaks are the result of precipitation and subsequent runoff and higher flows that are not reflected in the Model upstream boundary conditions for the unsteady-state simulations.

Reference: Phase 1 Hydraulic Analysis for Machias Dyke Bridge (#2246) Planning Phase Support Services

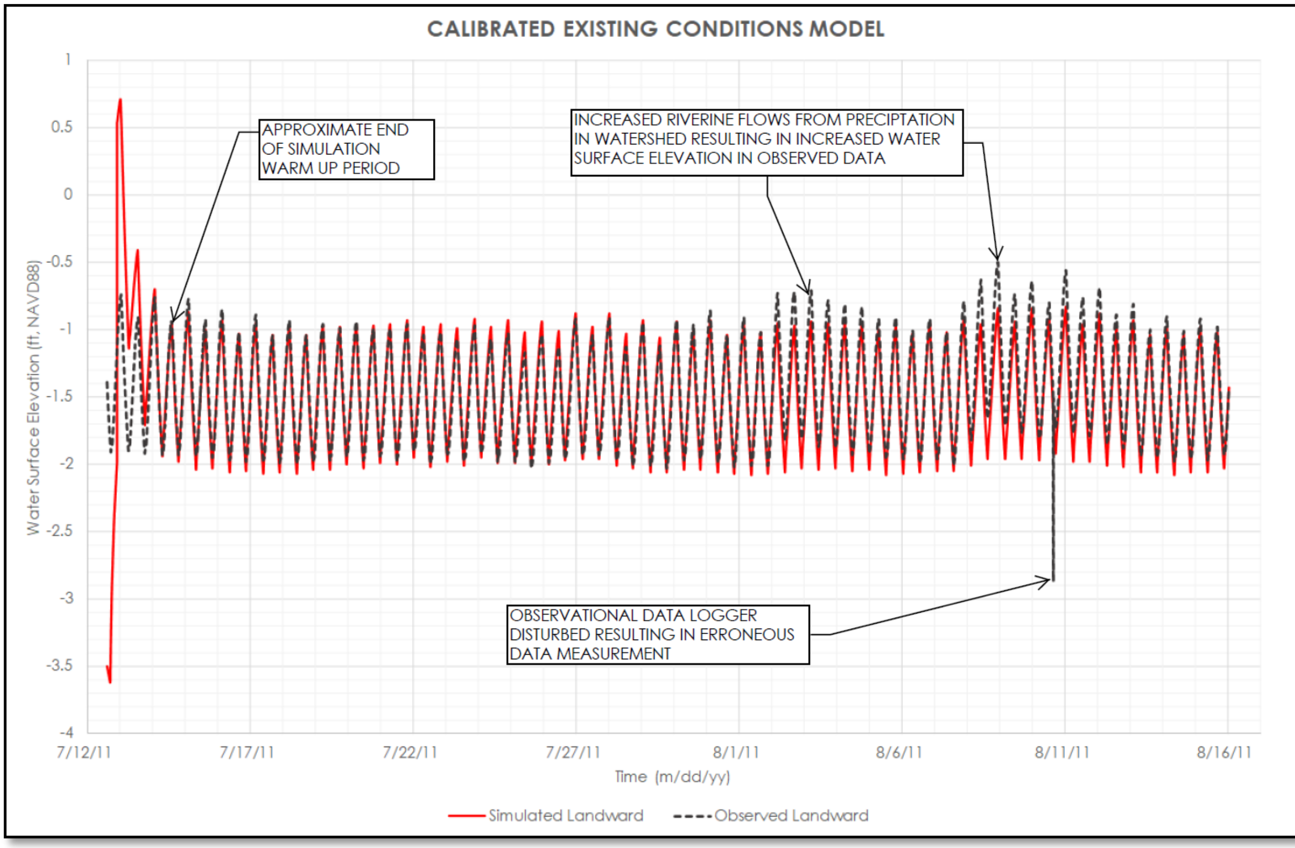


Figure 2. Final calibrated existing conditions simulation results compared to observed data

MODEL SCENARIOS

Model efforts as part of the first phase of the Hydraulic Study included 20 independent simulations (model scenarios) that consisted of unique geometries and boundary conditions combined together in HEC-RAS Plan files. These simulations included 12 steady-state and 8 unsteady-state scenarios. Table 6 presents a summary of the model scenarios used as part of the first phase of the Study and presented in this report including the plan name, geometry name, flow name, and HEC-RAS file names.

Reference: **Phase 1 Hydraulic Analysis for Machias Dyke Bridge (#2246) Planning Phase Support Services**

Table 6. Summary of unique model scenarios performed as part the first phase of the Study

Simulation No.	ScenarioID	Plan Name	Plan File	Geometry Name	Geometry File	Flow Name	Flow File
1	ex_ss_q100_mlw	ex_ss_mlw	2021_machias_phs1.p01	ex	2021_machias_phs1.g01	ss_mlw	2021_machias_phs1.f01
2	ex_ss_q100_mhw	ex_ss_mhw	2021_machias_phs1.p02	ex	2021_machias_phs1.g01	ss_mhw	2021_machias_phs1.f02
3	ex_us_fd50per_normtide	ex_us_fd50per_normtide	2021_machias_phs1.p03	ex	2021_machias_phs1.g01	us_fd50per_normtide	2021_machias_phs1.u01
4	alt01_ss_q100_mlw	alt01_ss_mlw	2021_machias_phs1.p04	alt01	2021_machias_phs1.g02	ss_mlw	2021_machias_phs1.f01
5	alt01_ss_q100_mhw	alt01_ss_mhw	2021_machias_phs1.p05	alt01	2021_machias_phs1.g02	ss_mhw	2021_machias_phs1.f02
6	alt01_us_fd50per_normtide	alt01_us_fd50per_normtide	2021_machias_phs1.p06	alt01	2021_machias_phs1.g02	us_fd50per_normtide	2021_machias_phs1.u01
7	alt04_ss_q100_mlw	alt04_ss_mhw	2021_machias_phs1.p07	alt04	2021_machias_phs1.g03	ss_mhw	2021_machias_phs1.f01
8	alt04_ss_q100_mhw	alt04_ss_mhw	2021_machias_phs1.p08	alt04	2021_machias_phs1.g03	ss_mhw	2021_machias_phs1.f02
9	alt04_us_fd50per_normtide	alt04_us_fd50per_normtide	2021_machias_phs1.p09	alt04	2021_machias_phs1.g03	us_fd50per_normtide	2021_machias_phs1.u01
10	alt04m_ss_q100_mlw	alt04m_ss_mhw	2021_machias_phs1.p10	alt04m	2021_machias_phs1.g04	ss_mhw	2021_machias_phs1.f01
11	alt04m_ss_q100_mhw	alt04m_ss_mhw	2021_machias_phs1.p11	alt04m	2021_machias_phs1.g04	ss_mhw	2021_machias_phs1.f02
12	alt04m_us_fd50per_normtide	alt04m_us_fd50per_normtide	2021_machias_phs1.p12	alt04m	2021_machias_phs1.g04	us_fd50per_normtide	2021_machias_phs1.u01
13	alt09_ss_q100_mlw	alt09_ss_mhw	2021_machias_phs1.p13	alt09	2021_machias_phs1.g05	ss_mhw	2021_machias_phs1.f01
14	alt09_ss_q100_mhw	alt09_ss_mhw	2021_machias_phs1.p14	alt09	2021_machias_phs1.g05	ss_mhw	2021_machias_phs1.f02
15	alt09_us_fd50per_normtide	alt09_us_fd50per_normtide	2021_machias_phs1.p15	alt09	2021_machias_phs1.g05	us_fd50per_normtide	2021_machias_phs1.u01
16	alt10m2_ss_q100_mlw	alt10m2_ss_mhw	2021_machias_phs1.p25	alt10m2_20210812	2021_machias_phs1.g08	ss_mhw	2021_machias_phs1.f01
17	alt10m2_ss_q100_mhw	alt10m2_ss_mhw	2021_machias_phs1.p26	alt10m2_20210812	2021_machias_phs1.g08	ss_mhw	2021_machias_phs1.f02
18	alt10m2_us_fd50per_normtide	alt10_us_fd50per_normtide	2021_machias_phs1.p22	alt10m2_20210812	2021_machias_phs1.g08	us_fd50per_normtide	2021_machias_phs1.u01
19	alt10m2_us_q001_normtide	alt10m2_us_q001_normtide	2021_machias_phs1.p23	alt10m2_20210812	2021_machias_phs1.g08	us_q001_normtide	2021_machias_phs1.u02
20	alt10m2_us_q010_normtide	alt10m2_us_q010_normtide	2021_machias_phs1.p24	alt10m2_20210812	2021_machias_phs1.g08	us_q010_normtide	2021_machias_phs1.u03

RESULTS

The following sections summarize the hydraulic Model simulation results for the steady- and unsteady-state scenarios.

STEADY STATE

A total of 12 steady-state simulations were performed as part of the Study. Table 7 below presents a summary of results from the steady-state Model simulations. The results are presented based on the WSELs upstream (US) and downstream (DS) of Dyke Bridge.

Table 7. Summary of maximum steady-state WSELs upstream (US) and downstream (DS) from Dyke Bridge

Alternative	Q100 with MLW		Q100 with MHW	
	US WSEL (ft)	DS WSEL (ft)	US WSEL (ft)	DS WSEL (ft)
Existing Conditions	5.1	-6.6	10.2	6.1
Alternative 1	3.4	-6.6	8.7	6.1
Alternative 4	0.1	-6.6	7.8	6.1
Alternative 4m	0.8	-6.6	7.3	6.1
Alternative 9	3.4	-6.6	8.7	6.1
Alternative 10	-6.5	-6.5	6.1	6.1

For the steady-state simulations with the downstream MLW boundary condition, the highest upstream WSEL was for the Existing Conditions alternative. This result is consistent with the reduced conveyance through the existing culverts due to accumulated debris. Alternative 1 and Alternative 9, which have the same culvert geometry and subsequent seaward hydraulic capacities, had the highest upstream WSEL of 3.4 ft compared to the other alternatives, which is approximately 1.7 ft lower than the WSELs for the Existing Conditions alternative (5.1 ft). Alternative 4 had a lower upstream WSEL compared to Alternative 4m due to the lower culvert inverts in Alternative 4. The lowest upstream WSEL from the alternatives was Alternative 10, which is approximately equal to the elevation of the downstream MLW boundary condition. Note that Alternative 10 assumes that existing sediment landward from Dyke Bridge would be dredged as part of or eroded as a result of this alternative.

For the steady-state simulations with the downstream MHW boundary condition, the highest upstream WSEL was for the Existing Conditions alternative. This result is consistent with the reduced conveyance due to accumulated debris in the existing culverts. Similar to the MLW simulation results, Alternative 1 and Alternative 9 have similar upstream WSELs due to having the same culvert geometry and subsequent seaward hydraulic capacities. Alternative 4 and Alternative 4m have lower upstream WSELs compared to Alternative 1 and Alternative 9 due to the increased hydraulic capacity of these alternatives. Alternative 4m has a slightly reduced upstream WSEL compared to Alternative 4 due to the slightly greater hydraulic capacity of the three 5-ft by 10-ft box culverts compared to the five 5-ft by 5-ft box culverts. Alternative 10, which represents a 116.5 ft bridge clear span geometry, had the lowest upstream WSEL and the upstream WSEL was the same as the downstream boundary condition suggesting that the bridge is able to convey the full 100-year flow with no backwatering upstream from Dyke Bridge.

UNSTEADY STATE

Eight unsteady-state simulations were performed as part of the Study. Appendix A contains figures representing the stage hydrograph output. The observed MaineDOT stage data landward of Dyke Bridge was included in the flow stage hydrographs to compare differences between the existing and proposed scenarios under normal flow conditions. Note that with the exception of the 1.1- and 10-year peak flows used as riverine conditions evaluated in Alternative 10, the riverine flows across the simulations were the median 50% stream flow.

Maximum upstream and downstream WSELs and the total change between these values were calculated for each of the alternatives. In addition, the percentage of time flow was being conveyed landward (i.e., flows moving from the sea (downstream) towards land (upstream)) at Dyke Bridge were calculated based on the simulation results. The maximum WSELs in the Middle River for normal tidal and median flow riverine flow conditions from the first phase of the Hydraulic Study simulations are reported in Table 8 below, along with the upstream WSEL range and percentage of time over the simulation for landward flow. The maximum WSELs in the Middle River for normal tidal and the 1.1- and 10-year riverine flow conditions based on the Hydraulic Study simulations are reported in Table 9. For discussion related to this section, see the Discussion Section below.

Table 8. Summary of maximum upstream WSELs for normal tidal and median riverine flow conditions, approximate total range of WSELs, and percentage of time estimated that landward flows are greater than seaward flows

Alternative	Max US WSEL (ft)	Min US WSEL (ft)	US WSEL Range (ft)	Percentage of Time for Landward Flows
Existing Conditions	-0.8	-2.1	1.3	58%
Alternative 1	-2.5	-3.4	0.9	0%
Alternative 4	0.8	-4.8	5.6	59%
Alternative 4m	2.3	-3.0	5.3	52%
Alternative 9	4.1	-0.5	4.6	41%
Alternative 10	8.6	-7.0	15.6	41%

Table 9. Summary of maximum upstream WSELs for normal tidal and the 1.1- and 10-year storm flow riverine conditions and approximate total range of WSELs for Alternative 10

Alternative	Max US WSEL (ft)	Min US WSEL (ft)	US WSEL Range (ft)
Alternative 10 (1.1-Year Peak Flow)	8.6	-7.0	15.6
Alternative 10 (10-Year Peak Flow)	8.7	-5.5	14.2

INUNDATED LAND FOR NORMAL TIDAL AND RIVER FLOW CONDITIONS

This section summarizes areas of inundated land upstream from Dyke Bridge for the six evaluated alternatives based on 1) a WSEL-area relationship (stage-area curve) and 2) the unsteady-state simulation results for the maximum WSELs during normal tidal and riverine flow conditions from the first phase of the Hydraulic Study simulations presented in Table 8. Reference Appendix B for a figure that depicts WSEL contours associated with the Study alternatives in the area adjacent to the Middle River upstream from Dyke Bridge.

The stage-area curve was developed using the existing terrain model that was compiled for the HEC-RAS Model and is depicted in Figure 3. Note that Figure 3 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. Detailed bathymetric data was not available for this area and this stage-area curve is intended for use in evaluating inundation areas associated with WSELs that are higher than the current normal tidal and riverine flow conditions. Table 10 presents the stage-area curve data developed for the Middle River upstream from Dyke Bridge in tabular format.

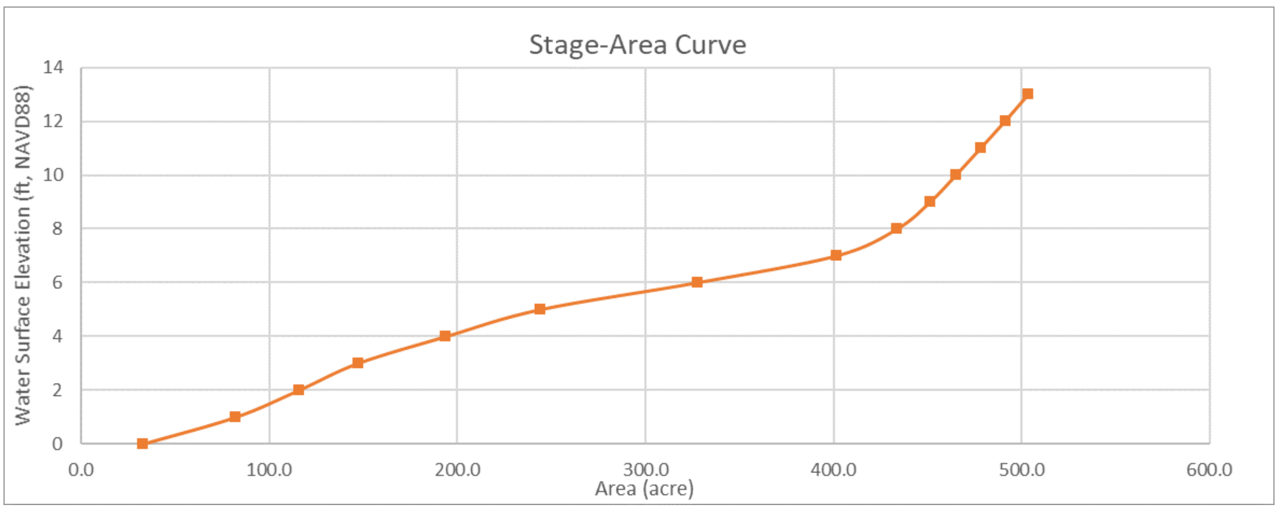


Figure 3. Stage-Area Curve for Middle River Upstream from Dyke Bridge

Reference: **Phase 1 Hydraulic Analysis for Machias Dyke Bridge (#2246) Planning Phase Support Services**

Table 10. Stage-Area Curve Data from Figure 3 for Middle River Upstream from Dyke Bridge

WSEL (ft, NAVD88)	Area (acre)
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

Table 11 presents the maximum upstream WSELs for normal tidal and riverine flow conditions based on the information presented in Table 8. The “Increased Inundation Area” in Table 11 reflects estimated inundated areas in the Middle River with normal tidal and riverine flow conditions upstream from Dyke Bridge above elevation 0.0 ft and exclusive of the existing, regularly inundated area (~33 acres). Table 11 depicts an inundation range based on 1) tidal stage data in the Middle River collected by MaineDOT in 2011 and 2) preliminary observations by Stantec and aerial photographs collected by MaineDOT using a drone in 2021 that indicate that the normal tidal WSELs have increased the regularly inundated area in the Middle River by approximately 45 acres. The lower value in the “Increased Inundation Area” range represents the estimated current (2021) condition and the higher value reflects the 2011 tidal stage data.

Table 11. Inundated areas and increased inundated areas for maximum upstream WSELs for normal tidal and riverine flow conditions

Alternative	Max US WSEL (ft)	Inundation Area (acres)	Increased Inundation Area (acres)
Existing Conditions	-0.7	<33 acres	n/a
Alternative 1	-2.5	<33 acres	n/a
Alternative 4	0.8	73	0 - 40
Alternative 4m	2.3	125	47 - 92
Alternative 9	4.1	201	123 - 168
Alternative 10	8.6	445	367 - 412

DISCUSSION

This section presents discussion of the hydraulic model simulation results for the first phase of the Hydraulic Study as part of the Project. As presented in Table 8 and depicted in the stage hydrographs presented in Appendix A, WSELs in the Middle River upstream from Dyke Bridge for median riverine flows in the Middle River and normal tidal conditions in the Machias River varied for the evaluated alternatives. In addition to evaluating the median riverine flow, this first phase of the Hydraulic Study evaluated the 1.1- and 10-year peak flows in the Middle River for Alternative 10 (bridge alternative) consistent with MaineDOT's guidance for evaluating bridges. Additional hydraulic studies will be performed, including analyses of peak flows, as part of the second phase of the Hydraulic Study.

Alternative 1 represents conditions in which the upstream maximum and minimum WSELs for the typical tidal conditions are -2.5 ft and -3.4 ft, respectively, and are the lowest compared to the other evaluated alternatives. Figure A-1 depicts the simulated and existing WSELs in the Middle River landward from Dyke Bridge for Alternative 1 with the median riverine flow and normal tidal stage boundary conditions. This is due to the increased hydraulic capacity compared to existing conditions, which had less hydraulic capacity due to blockage, and flap-gates with no leakage. The Existing Conditions alternative had the second lowest upstream WSEL (-0.7 ft). Without any leakage or bidirectional flow, the normal tide and riverine conditions maximum WSEL landward of Dyke Bridge is anticipated to be approximately 1.8 ft lower compared to existing conditions under Alternative 1. Similarly, the normal tide and riverine conditions minimum WSEL landward of Dyke Bridge is anticipated to be approximately 1.3 ft lower compared to existing conditions under Alternative 1 due to the increased hydraulic capacity of the culverts without any debris blockage and the resulting capacity to discharge flow from the Middle River to the Machias River seaward at Dyke Bridge.

Alternative 10 represents the conditions for which the upstream maximum WSEL is the highest (8.6 ft), the upstream minimum WSEL is the lowest (-7.0 ft), and the upstream water surface range is the greatest (15.6 ft) compared to the other model simulations. This is due to the large hydraulic capacity of the bridge and the ability for this alternative structure to provide a full tidal exchange with minimal losses through the bridge opening. Figure A-5 depicts the simulated and existing WSELs in the Middle River landward from Dyke Bridge for Alternative 10 with the median riverine flow and normal tidal stage boundary conditions.

Alternatives 4, 4m, and 9 represent hydraulic conditions that are in between the Existing Conditions alternative and Alternative 10 simulation results. Figures A-2, A-3, and A-4 depict the simulated and existing WSELs in the Middle River landward from Dyke Bridge for Alternative 4, 4M, and 9, respectively, with the median riverine flow and normal tidal stage boundary conditions. Alternative 4 and Alternative 4m represent conditions that include a combination of bidirectional flow culverts with other culverts that have flap-gates. The benefit of these alternatives is that landward fish passage could be accommodated during flood tides through the bidirectional flow culvert. However, the flows would be attenuated enough as to not result in the full tidal exchange that would significantly raise landward WSELs. The maximum upstream WSEL during normal tide and riverine flow conditions is approximately 1.5 ft lower under Alternative 4 compared to Alternative 4m, which is the result from the additional hydraulic capacity of the larger bidirectional flow culvert in Alternative 4m providing additional landward flow during flood tides. However, Alternative 4 results in an overall lower minimum upstream WSEL compared to Alternative 4m, which is likely the result of the lower inverts of the culverts with flap-gates in Alternative 4 allowing for additional drainage seaward, although both alternatives are relatively similar.

Alternative 9 provides an increased opportunity for landward flow during flood tides since the four 5-ft by 5-ft culverts do not have any flap gates. The only alternative that provides more landward flow during the flood-cycle tidal exchange is Alternative 10. Although the hydraulic capacity of Alternative 9 during seaward flows is the same as Alternative 1, the minimum upstream WSEL is about 2.9 ft greater due to the increased landward tidal exchange under Alternative 9. With the exception of Alternative 10, Alternative 9 results in the highest WSELs landward of Dyke Bridge for both flood and ebb tidal cycles with a maximum upstream WSEL of 4.1 ft and a minimum upstream WSEL of -0.5 ft.

The upstream WSEL ranges varied across the alternatives evaluated. The upstream WSEL ranges are presented in Table 8 and are proportional to the amplitude of the rise and fall limbs of the stage hydrographs presented in Appendix B. For example, Alternative 10 had the greatest upstream WSEL range of 15.6 ft, which corresponds to also having the largest amplitude in the stage hydrograph in Figure A-5. Similarly, Alternative 1 had the smallest upstream WSEL range compared to the other alternatives and had the smallest amplitude in the stage hydrograph in Figure A-1. Alternatives that provided increased drainage from landward to seaward during ebb tides and also provided increased opportunity for landward flow during flood tides generally resulted in greater upstream WSEL ranges relative to their maximum and minimum simulated upstream WSEL values. For example, with the exception of Alternative 10, Alternatives 4 and 4m provided the greatest range of upstream WSEL elevations and therefore increased tidal exchange.

Table 8 presents the percentage of time over the simulation period for landward flow for existing conditions and the evaluated alternatives. This information is provided as an indicator of potential landward fish passage by advection (i.e., movement of fish in the direction of flow) for comparison with existing conditions and amongst the evaluated alternatives. The time-of-landward flow statistic does not address potential quality of upstream fish passage conditions. For example, this statistic does not differentiate between flow through irregular, and potentially narrow, gaps in the existing flap gates versus the open culverts that were modeled as part of Alternatives 4, 4m, and 9. More detailed evaluation of fish passage would require identification of specific fish passage criteria (e.g., minimum depths of water) and evaluation of hydraulic conditions at each timestep in the unsteady-state hydraulic model.

Of the evaluated alternatives, Alternatives 4 and 4m provide the greatest percentage of time in which landward flows (flows conveyed downstream to upstream during flood tides) are greater than percentage of time of seaward flows (flows conveyed upstream to downstream during ebb tides). Alternative 4 reflects the highest percentage of time in which landward flows are greater than seaward due to the generally lower maximum upstream WSELs compared to the other alternatives. Since the landward WSELs are generally less for Alternative 4, this results in a greater percentage of time during which the downstream seaward WSELs are greater than the upstream landward WSELs, and therefore a greater amount of time in which the bidirectional flow culvert is conveying flow landward. For the opposite reason, Alterative 9 results in the lowest percentage of time of landward flows compared to seaward out of the alternatives simulated with bidirectional flow. Note that Alternative 1 (replacement-in-kind) with fully functional flap-gates do not result in any landward flow.

In general, the Alternative 10 maximum and minimum upstream WSELs across the median 50% flow and the 1.1- and 10-year peak flows were generally the same with very small simulated differences (reference Figures A-5, A-6, and A-7 in Appendix A). The only notable apparent changes between these scenarios are the slight increases in the upstream minimum WSELs during the ebb tide for increasing flows. However, the changes are relatively minimal. Further refinement of the bathymetry upstream in the model anticipated in the second phase of the Hydraulic Study may affect these results, since the ebb tide results in low flow conditions in the upstream channel of Middle River.

Based on the results of the steady-state simulation results, none of the primary alternatives evaluated as part of the first phase of the Hydraulic Study appear to increase the existing base-flood elevation (BFE) as defined by the Federal Emergency Management Agency (FEMA). FEMA reports the BFE at the area of Dyke Bridge as 11 ft. The existing conditions modeled under similar hydraulic conditions with the 100-year riverine flow and the mean high water downstream boundary condition results in a WSEL of approximately 10.2 ft. Primary alternatives evaluated as part of the first phase of the Hydraulic Study produced WSELs that were lower than both the FEMA BFE of 11 ft and the existing conditions simulated WSEL of 10.2 ft. Therefore, no increase in the BFE is anticipated to occur for the evaluated primary alternatives.

Simulation results from primary alternatives analyzed as part of the first phase of the Hydraulic Study provide some insight related to potential changes on hydraulic conditions, for both fish passage and hydraulic capacity, at Stride Bridge located upstream from Dyke Bridge on the Middle River. In general, alternatives that provide increased landward tidal exchange during flood ties and increase the maximum upstream WSELs also result in increased tailwater elevations at Stride Bridge. Under normal tidal and median flow riverine conditions, flow appears to be moving landward at Stride Bridge as well, which would likely provide increased opportunities for landward fish passage by advection. In addition, higher tailwater conditions at Stride Bridge would result in lower flow speeds through the culvert, which would also provide additional opportunity for fish passage. With respect to hydraulic capacity, for the alternative that resulted in the greatest upstream WSEL (Alternative 10 with 10-year peak flow riverine condition), the culvert at Stride Bridge is only flowing partially-full, suggesting that the culvert still likely has adequate hydraulic capacity. Additional quantitative evaluation of Stride Bridge is recommended to further these initial conclusions (e.g., evaluate whether freeboard is still adequate during the design hydraulic conditions).

Based on the simulation results for the first phase of the Hydraulic Study, the bridge geometry in Alternative 10 with a clear span of 116.5 ft between the bridge abutments provides conditions that substantially result in full tidal exchange with minimal (i.e., less than 0.2 ft) head losses through the bridge opening. This is due to the relatively large hydraulic capacity of the bridge compared to the other modeled alternatives. Although the 116.5 ft clear span bridge geometry still represents a hydraulic constriction at this location and accelerates flow through the opening, results from this first phase of hydraulic analysis suggest that a larger bridge opening would not provide significantly greater reductions in head losses across the bridge and therefore would also likely not result in significant additional hydraulic benefits for volitional fish passage.

It is anticipated that Alternative 10 would result in the greatest changes to the morphology of the upstream channel of the Middle River in the vicinity of Dyke Bridge due to the larger opening compared to the other alternatives. A more natural, and larger flux of sediment is expected compared to the culvert alternatives due to the increased tidal exchange and flow capacity through the bridge structure. Over time, a quasi-steady dynamic equilibrium of sediment flux landward and seaward is expected as the channel of the Middle River adjusts, and it is likely that the river may align with the historic channel bed through this process if the bridge is located adjacent to the historic channel.

SUMMARY

Following here is a bulleted summary of findings from the initial phase of the Hydraulic Study.

1. Alternative 1 does not provide upstream fish passage opportunities and therefore may not meet Project goals and objectives.

2. Alternatives 4, 4m, 9, and 10 will result in higher WSELs upstream from Dyke Bridge during normal tidal and riverine flow conditions relative to existing conditions.

3. No increases in the FEMA BFE are anticipated for the evaluated primary alternatives that were modeled as part of Phase 1 of the Hydraulic Study.

4. Alternative 4 and Alternative 4m have similar hydraulic characteristics. Alternative 4 results in lower maximum upstream WSELs compared to Alternative 4m. Alternative 4m may provide safer fish passage due to the increased size of the structure.

5. With the exception of Alternative 10, Alternative 4 and Alternative 4m appear to represent the alternatives with the greatest tidal exchange as represented by the amplitude of their stage hydrographs as well as the increased range of upstream maximum and minimum WSELs compared to the other alternatives.

6. Alternative 4 and Alternative 4m result in the greatest percentage of time in which landward flows are greater than seaward flows, which will promote advectional fish passage.

7. Alternatives 4, 4m, and 9 pose public safety risks associated with boat impingement. Additional design considerations may be required.

8. Alternative 10 has volitional, unrestricted fish passage, since the full tidal exchange is occurring at Dyke Bridge. However, the increased upstream WSELs may be an issue for property owners along the upstream reach of the Middle River. Alternative 10 also represents an alternative that would result in least likelihood of safety concerns from boat impingement, but may still pose a low headroom safety risk to boats at higher tides.

9. Based on the 2011 tide data collected by MaineDOT, Alternative 10 would result in regular inundation of approximately 412 acres of land that is not currently inundated on a regular basis. This is compared to 40 and 92 acres for Alternatives 4 and 4m, respectively.

10. Bridge alternatives that provide a clear span greater than Alternative 10 (116.5 ft) are not necessary to achieve volitional fish passage and restore full tidal exchange landward of the Dyke Bridge.

11. Alternative 10 would result in development of a larger channel morphology through this reach of the Middle River due to the larger span compared to the other culvert alternatives. Transport of sediment is expected to be greater under this alternative.

12. Primary alternatives evaluated that increase the upstream WSELs during normal tidal and median flow riverine conditions (i.e., Alternative 4, Alternative 4m, Alternative 9, Alternative 10) would likely result in increased fish passage opportunities at Stride Bridge, either by upstream passage through advection during flood tides, or by increasing the tailwater elevation at Stride Bridge, which would lower the velocities through the culvert barrel thereby facilitating passage.

13. Additional quantitative evaluations of the hydraulic conditions at Stride Bridge are recommended to assess if hydraulic design criteria (e.g., freeboard) are adequate when coupled with the hydraulic changes to the Middle River reach from the replacement alternatives proposed at Dyke Bridge.

14. Following on observations and information obtained during Project field studies in the summer of 2021, MaineDOT installed datalogging pressure transducers in the Middle River upstream from Dyke Bridge and in the Machias River downstream from the bridge in August 2021 to collect updated tidal stage data.
15. The second phase of the Hydraulic Study will evaluate a broader range of high-flow conditions, including peak riverine flows in the Middle River, tidal storm surge events in the Machias River, and sea-level rise, and will provide information to evaluate potential changes to flood elevations in the Middle River landward from Dyke Bridge.

Reference: **Phase 1 Hydraulic Analysis for Machias Dyke Bridge (#2246) Planning Phase Support Services**

APPENDIX A – UNSTEADY-STATE STAGE HYDROGRAPHS

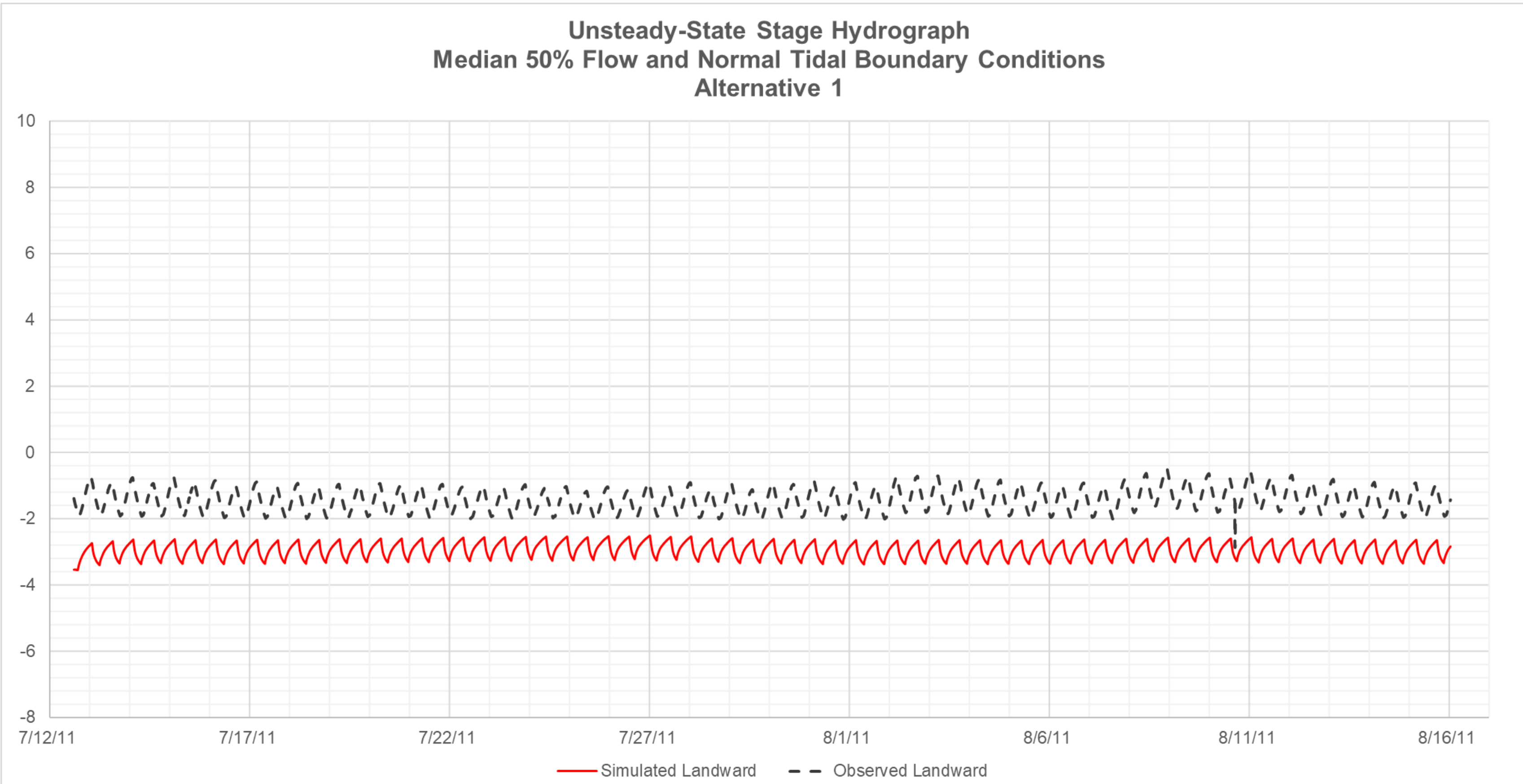


Figure A - 1. Unsteady-state stage hydrography simulation results for Alternative 1 for the median riverine flow upstream boundary condition and the normal tidal stage downstream boundary condition

Reference: **Phase 1 Hydraulic Analysis for Machias Dyke Bridge (#2246) Planning Phase Support Services**

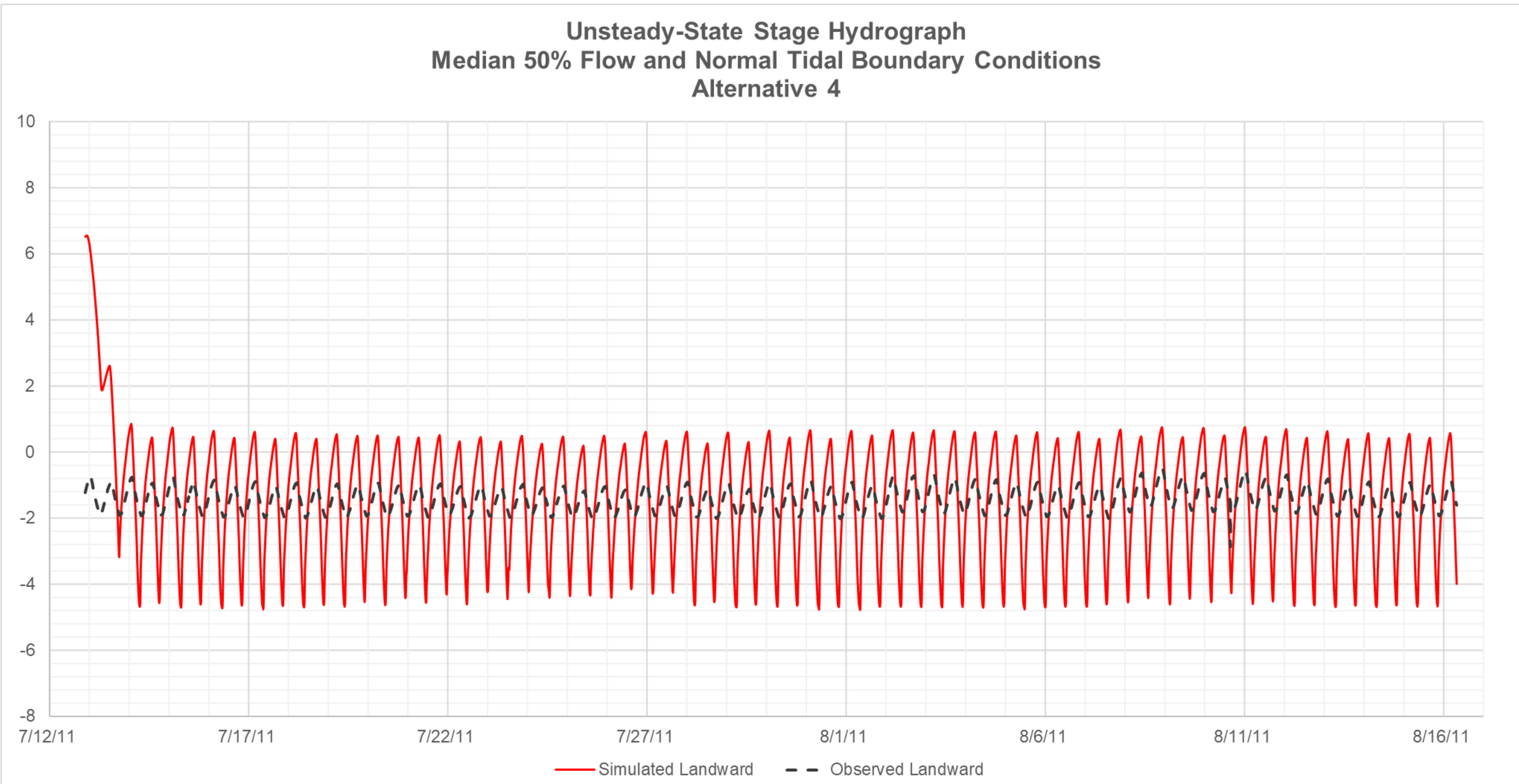


Figure A - 2. Unsteady-state stage hydrography simulation results for Alternative 4 for the median riverine flow upstream boundary condition and the normal tidal stage downstream boundary condition

Reference: **Phase 1 Hydraulic Analysis for Machias Dyke Bridge (#2246) Planning Phase Support Services**

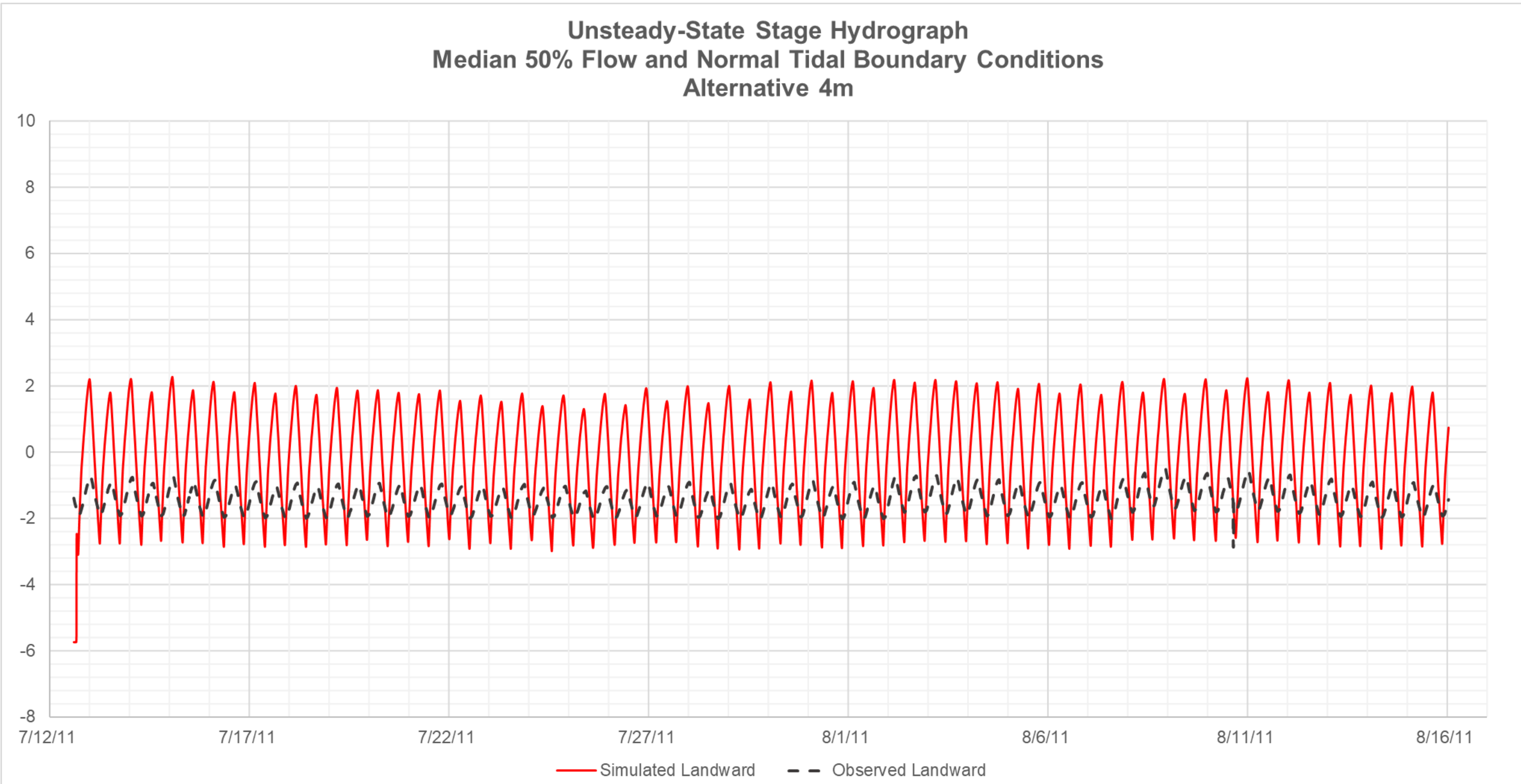


Figure A - 3. Unsteady-state stage hydrography simulation results for Alternative 4m for the median riverine flow upstream boundary condition and the normal tidal stage downstream boundary condition

Reference: **Phase 1 Hydraulic Analysis for Machias Dyke Bridge (#2246) Planning Phase Support Services**

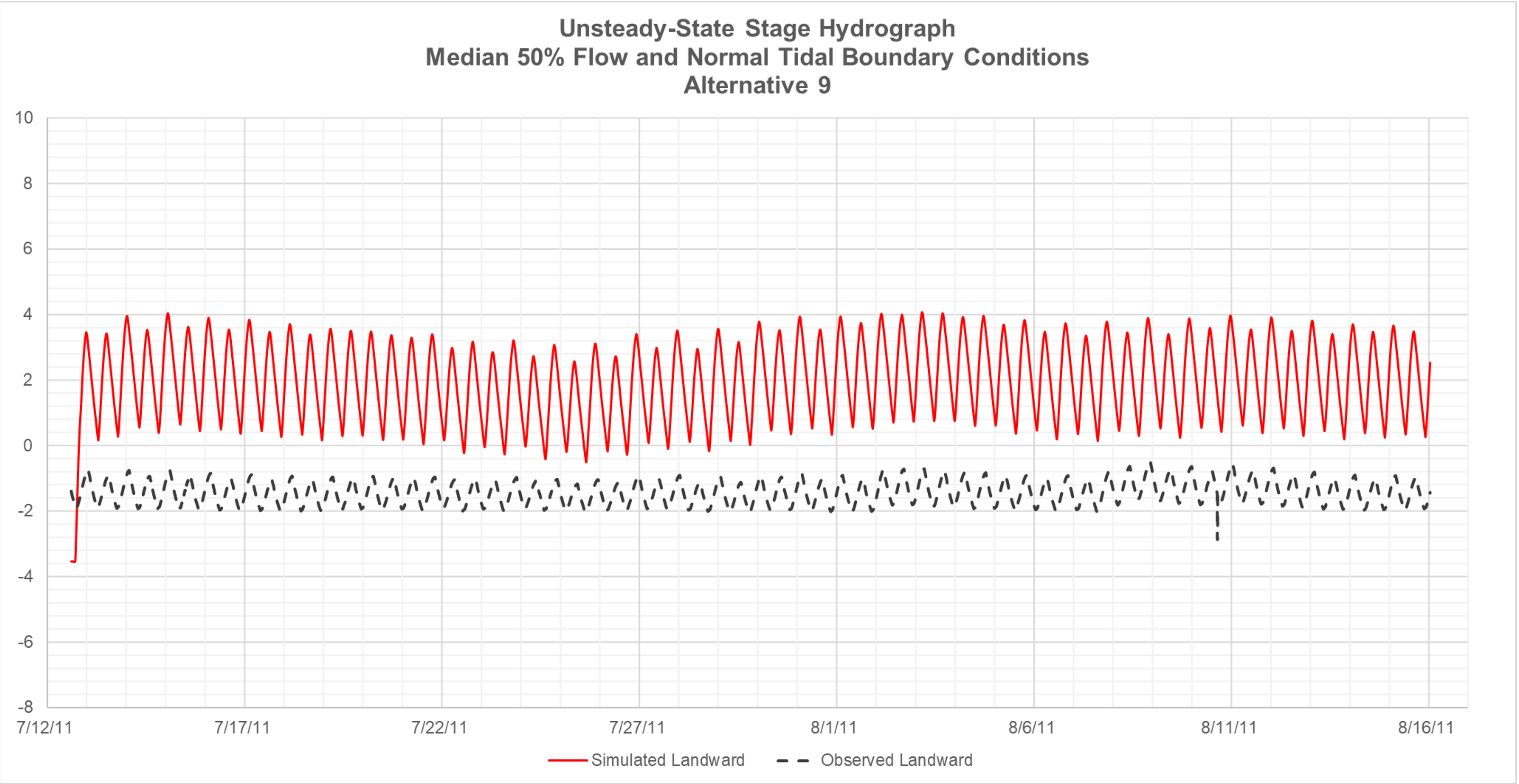


Figure A - 4. Unsteady-state stage hydrography simulation results for Alternative 9 for the median riverine flow upstream boundary condition and the normal tidal stage downstream boundary condition

Reference: **Phase 1 Hydraulic Analysis for Machias Dyke Bridge (#2246) Planning Phase Support Services**

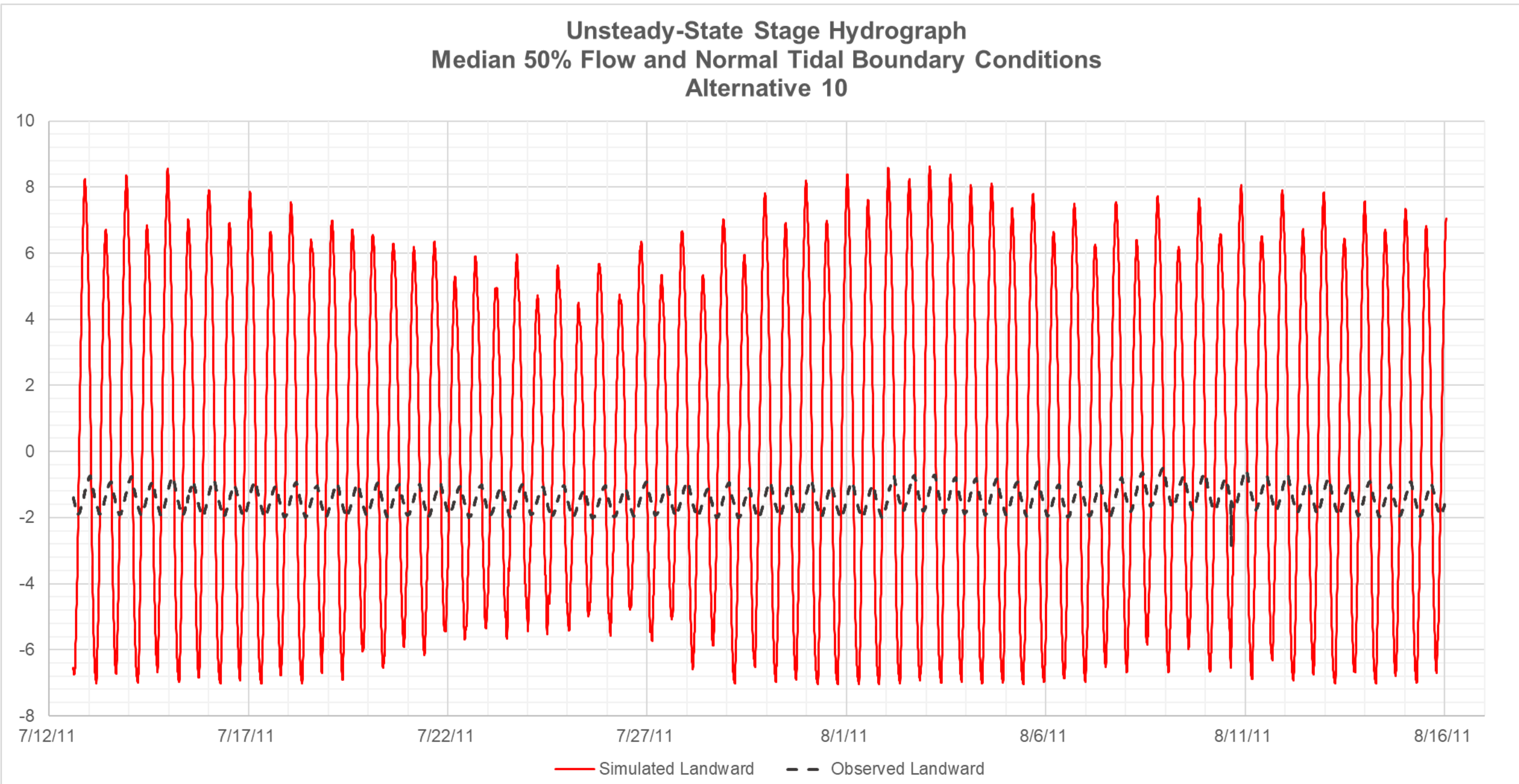


Figure A - 5. Unsteady-state stage hydrography simulation results for Alternative 10 for the median riverine flow upstream boundary condition and the normal tidal stage downstream boundary condition

Reference: **Phase 1 Hydraulic Analysis for Machias Dyke Bridge (#2246) Planning Phase Support Services**

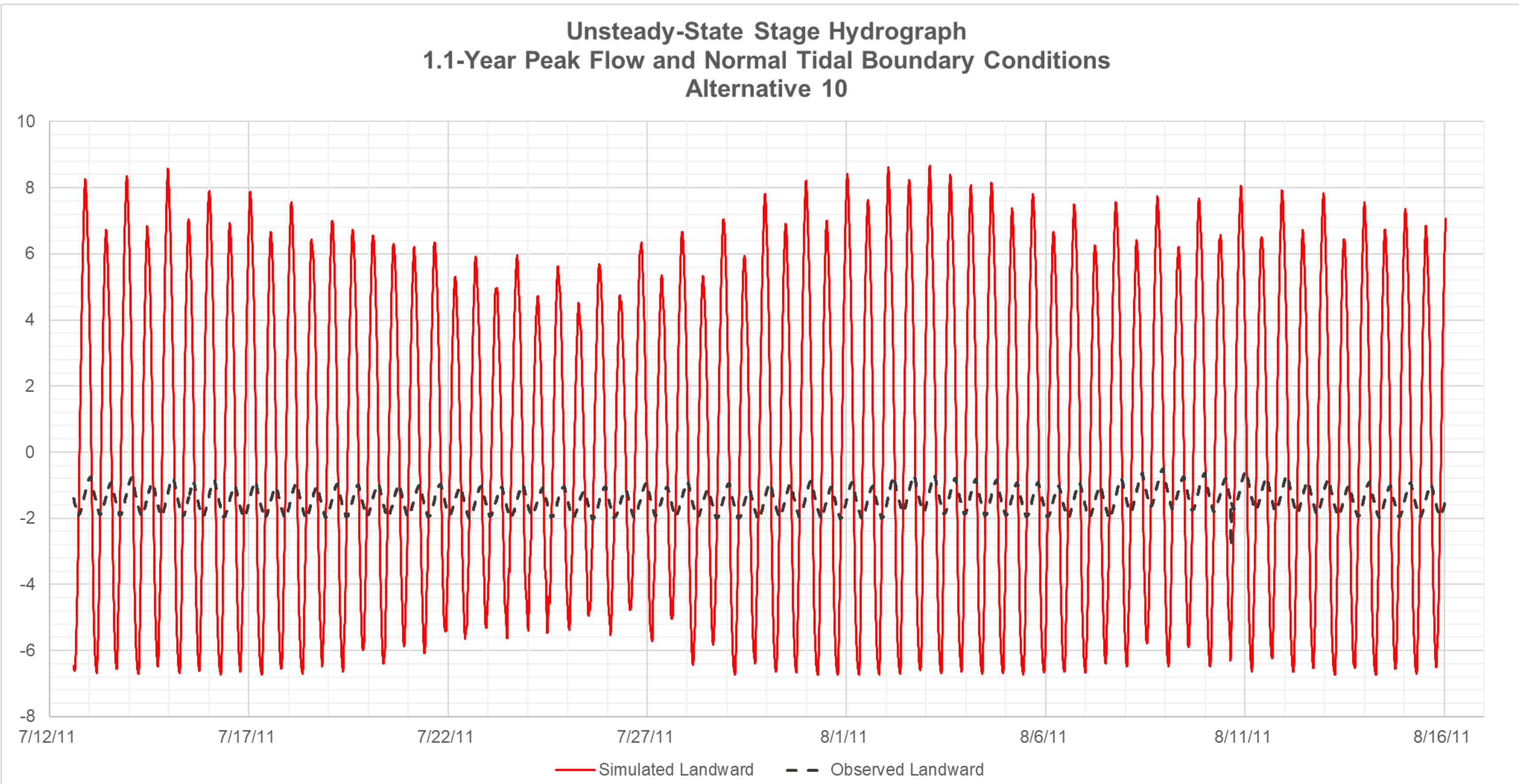


Figure A - 6. Unsteady-state stage hydrography simulation results for Alternative 10 for the 1.1-year peak flow riverine flow upstream boundary condition and the normal tidal stage downstream boundary condition

Reference: **Phase 1 Hydraulic Analysis for Machias Dyke Bridge (#2246) Planning Phase Support Services**

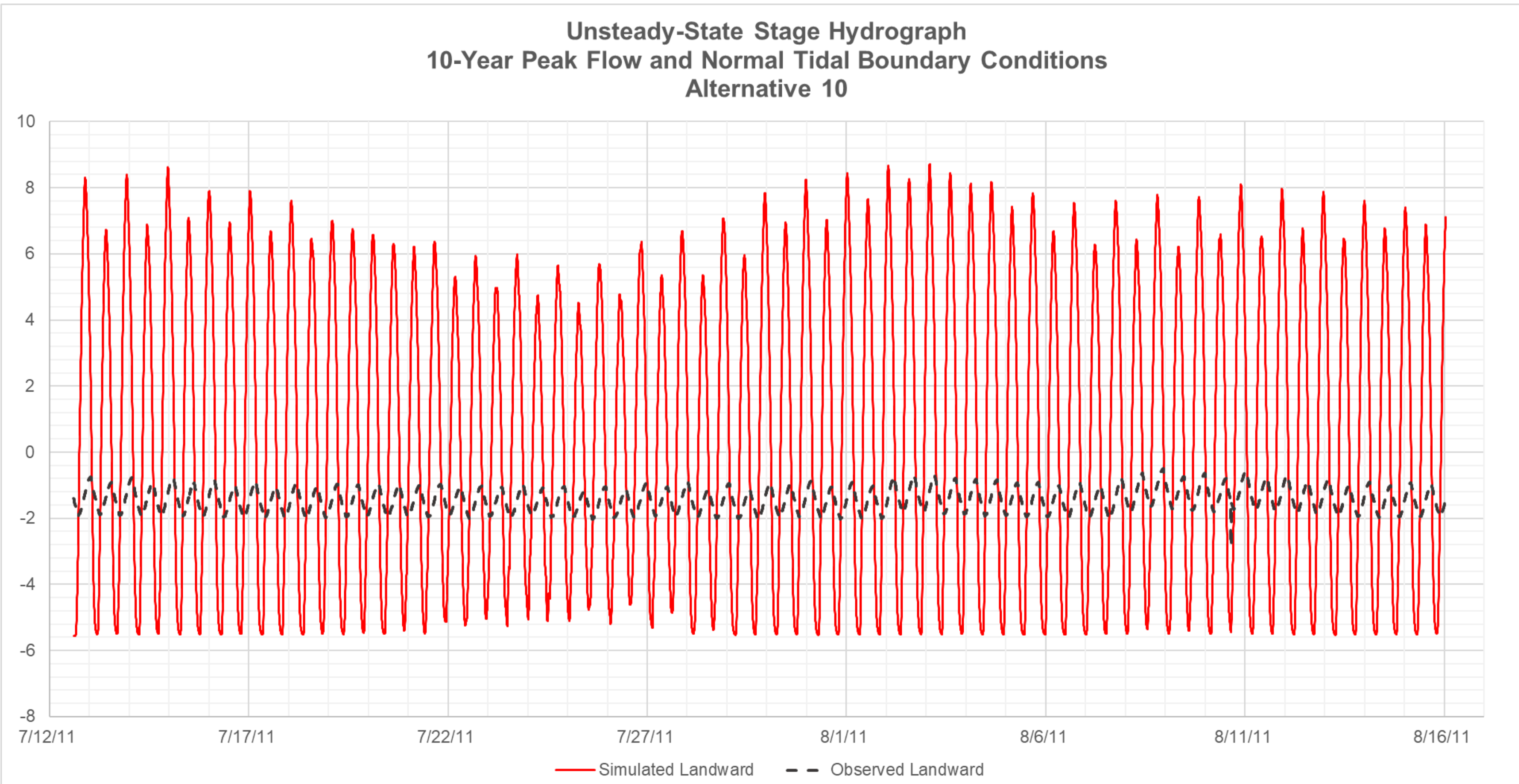
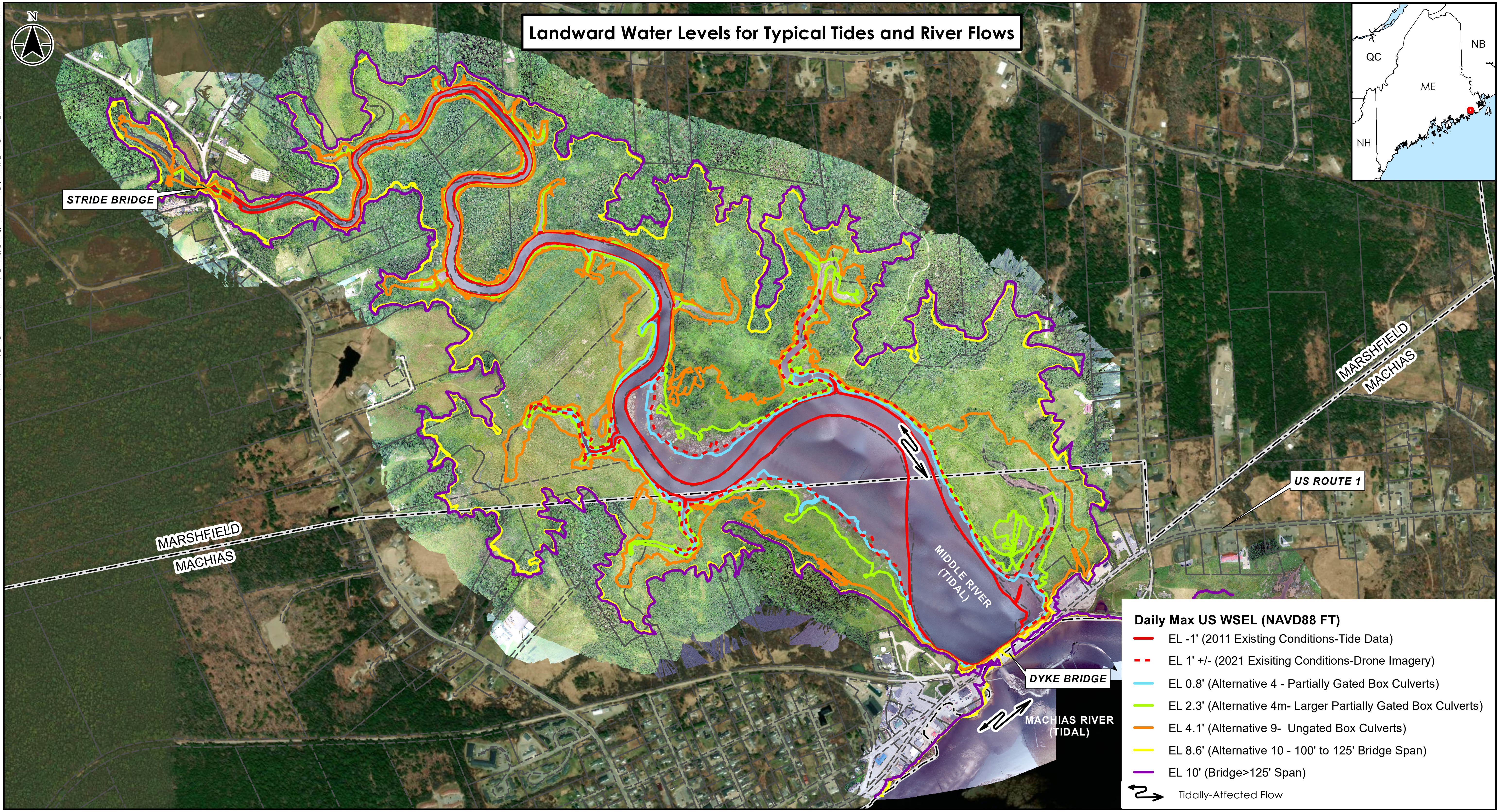


Figure A - 7. Unsteady-state stage hydrography simulation results for Alternative 10 for the 10-year peak flow riverine upstream boundary condition and the normal tidal stage downstream boundary condition

Reference: Phase 1 Hydraulic Analysis for Machias Dyke Bridge (#2246) Planning Phase Support Services

APPENDIX B – MAPPED WATER SURFACE ELEVATIONS ALONG MIDDLE RIVER UPSTREAM FROM DYKE BRIDGE FOR PRIMARY ALTERNATIVES



179450347

Stantec

30 Park Drive
Topsham, ME USA 04086
Phone (207) 729-1199

Prepared by EPL on 2021-08-09
Reviewed by MRC on 2021-08-09

50347_DykeBridge_11x17_Alt-Cont_hydraulics.mxd

Notes

1. Existing conditions are based on 2011 tidal stage data and 2021 drone imagery collected by MaineDOT. **Collection of 2021 tidal stage data is pending and will affect existing condition mapping.**
2. 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.
3. Coordinate System: NAD 1983 UTM Zone 19N FT
4. Vertical Datum: NAVD88
5. Aerial imagery in the project area was obtained by unmanned aircraft vehicle (UAV) by MaineDOT on July 20, 2021.
6. Aerial imagery surrounding the project area is provided by ArcGIS Online World Imagery Mapping Service (http://server.arcgisonline.com/arcgis/services/World_Imagery/MapServer).
7. TIN Surface information is based on survey data provided by the Maine Department of Transportation.

Legend

Maine GIS Tax Parcels

0 800 Feet
1 inch = 833 feet (At page size of 11"x17")

Client/Project
Maine DOT
Dyke Bridge
Machias, Maine

Figure No.
B-1

Title Landward Water Levels for Typical Tides and River Flows

9/16/2021